Space Frequency
Coordination Group

HANDBOOK

of the

SPACE FREQUENCY

COORDINATION GROUP

SFCG

Year: 2014

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(1) The effective date is the date of the most recent version of the document.

INTRODUCTION TO THE SPACE FREQUENCY COORDINATION GROUP (SFCG)

SFCG purpose and objective

The SFCG was established in order to provide a less formal and more flexible environment, as compared to the official organs of the International Telecommunications Union (ITU) (i.e, Radiocommunication Bureau (RB); Radio Communication Study Groups (SG) of the Radiocommunication Bureau), for the solution of frequency management problems encountered by member space agencies. The Terms of Reference and other aspects of SFCG organization and procedures may be found in Section II of the Handbook.

The SFCG is concerned with the effective use and management of those radio frequency bands that are allocated by the Radio Regulations of the ITU to the space research, space operations, Earth exploration-satellite, and meteorological-satellite services. The Group will also concern itself with feeder links and data relay satellites operated in connection with these services, radionavigation satellites (as far as these are used for spacecraft orbit determination) and with satellite-borne radio astronomy (including radar astronomy). Within the formal framework of the Radio Regulations, there is the need and opportunity for international informal agreement among participating space agencies concerning assignment of specific frequencies, and related technical issues.

The principal result of SFCG meetings is the adoption of resolutions and recommendations which express technical and administrative agreements. These agreements may be used by space agencies to make best use of allocated bands and to avoid interference.

The effectiveness of SFCG recommendations depends upon voluntary acceptance and use by member agencies. There is no formal process by which agencies formally agree to accept and be bound by SFCG recommendations.

Agency representatives that participate in SFCG meetings are generally expected to be able to speak for their agencies in an informed way and to be able to influence compliance with SFCG recommendations.

SFCG membership

Admission of new members is governed by Resolution A3-1 (most recent version). A listing of SFCG members and observers may be found at the end of this handbook.

INTRODUCTION TO THE SFCG HANDBOOK

Purpose of the SFCG Handbook

The purpose of this handbook is to provide the reader with all current Resolutions and Recommendations which describe agreements between agencies that participate in the Space Frequency Coordination Group (SFCG). In addition, the handbook provides background material concerning the formation, history, and methods of the SFCG, a description of the document numbering system and related definitions, and archival data concerning past SFCG action and documentation.

Organisation of the handbook

The handbook is divided into six sections. Section 6 contains archival matter and is of limited interest to most readers; a copy may be requested from the SFCG Secretariat.

Each document in the handbook is identified by a title, date, and an indication of the number of pages. No attempt is made to serially number all pages in the handbook.

Resolutions and Recommendations are additionally identified by a number, according to a system explained in *Classification and Numbering of SFCG Output Documents,* found in section I of the handbook.

CLASSIFICATION AND NUMBERING OF SFCG RECOMMENDATIONS AND RESOLUTIONS

1. Introduction

SFCG Recommendations and Resolutions are classified by:

type of document;

category of subject matter;

the meeting at which the document was originally adopted;

the number of the document as one of the series adopted by that meeting; and

the number of subsequent revisions.

The elements of this classification are embodied in the document number. For example,

RES SFCG A3-5R3

- R3 — the revision number
- 5 — the fifth output document of the third meeting
- 3 — the third SFCG meeting
- A — category (may be "A" or blank; see § 2.1 and 2.2.)
- RES — type of document

2. Description of document classification

2.1 Type of document.

A **Resolution** is an expression of action, intended action, or policy that applies to SFCG members themselves, that is, within the Group. There are two types of resolutions: **Adminstrative**, and **Technical**. Administrative resolutions are indicated by the addition of a category letter "A" to the document number, e.g., RES SFCG A2-2R1. See §2.2 below.

A **Recommendation** is an expression of an action, intended action, or policy that is to be pursued by members within their agencies or with respect to other bodies, that is, outside of the Group.

2.2 Category of subject matter.

There are two categories of subject matter:

- ☐ administrative, concerning the internal operation of the SFCG; these documents are identified by the letter "A" in the document number
- ☐ all other matters that affect member agencies and the radio services of interest to SFCG.

2.3 Meeting at which document was originally adopted.

SFCG meetings are serially numbered. A list of meetings may be found in Section VI of the Handbook.

2.4 The number in the series adopted by a particular meeting.

At a particular meeting, adopted documents in each category are sequentially numbered, beginning with 1.

2.5 Revision number.

Each time an existing document is substantially revised (more than an editorial change), a revision number is assigned. The original document carries no revision number; the first revision is Revision 1. Revision numbers are added to the original document number, which does not change. The date of the current revision is the date of the document, found at the bottom of each page in the document.

SFCG RESOLUTIONS, RECOMMENDATIONS and REPORTS

The following Recommendations and Resolutions were adopted by SFCG. The list includes all SFCG Resolutions and Recommendations that are in force. Resolutions, Recommendations and Reports not found in the list are void and have only historical interest.

I. ADMINISTRATIVE RESOLUTIONS

RES SFCG A2-1R5	Date and Place of SFCG Meetings	15 July 2010
RES SFCG A2-2R1	Language of the SFCG	16 May 1988
RES SFCG A2-3R9	SFCG Documentation	15 July 2010
RES SFCG A3-1R3	Admission of New SFCG Members	30 September 2006
RES SFCG A6-1R2	Terms of Reference of the Space Frequency Coordination Group	16 November 2000
RES SFCG A8-1R1	Intersessional Working Groups	25 September 2003
RES SFCG A8-4R3	Action Items	15 July 2010
RES SFCG A10-1R1	Waivers to SFCG Recommendations	24 April 1991
RES SFCG A11-1R2	Adoption and Revision of SFCG Recommendations	17 September 1998
RES SFCG A12-1R3	Establishment of Procedures for Inter-agency Frequency Coordination	23 September 2008
RES SFCG A12-3R2	SFCG Silver Pin Award for Meritorious Service	23 September 2004

RES SFCG A14-1R2	Rights and Obligations of Member Agencies Relevant to Composition of their Delegations at SFCG Meetings	15 September 1999
RES SFCG A14-2R2	Working Methods of Intersessional Working Groups	25 September 2003
RES SFCG A19-1R7	SFCG Meeting Input Documents	20 June 2012
RES SFCG A21-1R2	Assistance in the Assignment of Frequencies to Deep Space Missions (Category B)	3 July 2013
RES SFCG A21-2R4	SFCG Satellite Database Update Information	15 June 2011
RES SFCG A23-1R1	SFCG Member Emeritus	23 September 2004
RES SFCG A24-1	Assistance in the Assignment of Frequencies to Active Remote Sensing Missions in the Mars Region	23 September 2004
RES SFCG A24-2	SFCG Member Recognition	30 September 2006
RES SFCG A26-1R3	Lunar and Martian Interoperability and Spectrum Coordination	3 July 2013
RES SFCG A30-1	Assistance in the Assignment of CDMA Codes to Data Relay Satellite Missions in the 2 GHz Bands (2025-2110 MHz and 2200-2290 MHz)	15 July 2010
RES SFCG A30-2	SFCG Website	15 July 2010
RES SFCG A32-1	Inter-Member Cooperation in Resolving Interference to EESS (passive) and EESS (active) Operations	20 June 2012
RES SFCG A34-1	SFCG Observers	11 June 2014

II. TECHNICAL RESOLUTIONS

RES SFCG 5-9R1	Protection of Frequency Bands Allocated to Passive Sensing and Radio Astronomy	4 October 2001
RES SFCG 5-10R1	Interference to Data Collection Systems Operating in the 401-403 MHz Frequency Band Allocated to the Meteorological Satellite Service and the Earth Exploration-Satellite Service	17 September 1998
RES SFCG 14-1R2	Use of the Inter-Satellite Service (ISS) 23 GHz Band	20 October 2005
RES SFCG 14-3R1	Microwave Powered High Altitude Relay Platforms	15 December 1995
RES SFCG 15-2R4	Suitable Allocations for Radio Astronomy Observations in Space	4 October 2001
RES SFCG 15-5R2	Wind Profiler Radar Systems in the Bands near 1000 MHz	17 September 1998
RES SFCG 16-1R3	Sharing between Data Relay Satellite and Proximity Link Communication Systems and High Population Density Point-to-Multipoint Fixed Systems in the Vicinity of 26 GHz	4 October 2001
RES SFCG 17-1R2	Protection of Space Science Services from Terrestrial Service Systems in the Bands 2025-2110 MHz and 2200-2290 MHz	23 September 2004
RES SFCG 18-5	SFCG Software Guidelines	17 September 1998
RES SFCG 19-1	Efficient Use of Spectrum in the 25.5-27 GHz and 37-38 GHz Bands	15 September 1999
RES SFCG 19-6R1	EESS Active Sensing Requirements Above 100 GHz	16 November 2000
RES SFCG 19-7R4	Use of the 7750-7850 MHz Band by non-GSO Meteorological Satellites	11 June 2014
RES SFCG 20-2R3	Optical Communications	3 July 2013
RES SFCG 20-3	Protection of RNSS in the 1559-1610 MHz Band	16 November 2000

RES SFCG 21-2R4	Requirements, Performance, and Protection Criteria for EESS (Passive) Sensors	3 July 2013
RES SFCG 21-3R3	Protection of EESS (Active and Passive) Sensors from Ultra Wideband Device and Short Range Device Emissions	11 June 2014
RES SFCG 23-2R1	Use of Synthetic Aperture Radars in the Band 5250-5570 MHz	3 July 2013
RES SFCG 23-3	Use of the Allocation for EESS (active) in the Band 432-438 MHz	25 September 2003
RES SFCG 23-5	Protection of Future Radio Astronomy Observatories in the Shielded Zone of the Moon	25 September 2003
RES SFCG 24-1R1	Interference Mitigation Techniques for Future Systems Planning to Operate in the 2200-2290 MHz Band	30 September 2007
RES SFCG 24-2	Use of the Allocation for EESS (Active) in the Band 94-94.1 GHz	23 September 2004
RES SFCG 27-1	Interference Mitigation Techniques for Future Systems Planning to Operate in the 2025-2110 MHz Band.	30 September 2007
RES SFCG 29-1	Passive Bands of Interest Above 275 GHz	18 June 2009
RES SFCG 30-1	DCS in the Band 401-403 MHz	15 July 2010
RES SFCG 32-1R2	SFCG Objectives for World Radiocommunication Conferences	11 June 2014

III. RECOMMENDATIONS

REC SFCG 4-3R3	Utilization of 2 GHz Bands for Space Operation	17 September 1998
REC SFCG 5-1R5	Use of the 8450-8500 MHz Band for Space Research, Category A	17 September 1998
REC SFCG 6-1R5	Interference from Space-to-Space Links Between Non-Geostationary Satellites to Other Space Systems in the 2025 - 2110 and 2200 - 2290 MHz Bands	20 October 2005
REC SFCG 6-2R1	Transponder Turnaround Frequency Ratios for Space Research, Category A	1 September 1989
REC SFCG 7-1R5	Transponder Turnaround Frequency Ratios and Radio Frequency Channel Plans for Space Research, Category B	30 September 2007
REC SFCG 11-1R4	Use of the Band 1670 - 1710 MHz for Meteorological Satellite Services	11 June 2014
REC SFCG 12-2	Use of the 14.0 - 15.35 GHz and 16.6 - 17.1 GHz Bands for Space Research, Category A	25 September 1997
REC SFCG 12-4R3	Methods for Reduction of Potential Interference between Systems in the Space Science Services in Densely Occupied Bands	16 October 2002
REC SFCG 12-5R1	Limitations on Earth - Space Link Power Levels	15 December 1995
REC SFCG 13-3R3	Data Relay Satellite Channel Plans for the 23 and 26 GHz Bands	15 June 2011
REC SFCG 14-1R1	Protection of Deep-Space Earth Stations from Line of Sight Interference in the Bands 2290 - 2300 MHz, 8400 - 8450 MHz, and 31.8 - 32.3 GHz	20 October 2005
REC SFCG 14-2R5	Use of the 37 - 38 GHz Space Research Service Allocation	23 September 2004
REC SFCG 14-3R9	Use of the 8025 - 8400 MHz Band by Earth Exploration Satellites	11 June 2014

REC SFCG 15-1R3	Use of the 400.15 - 401 MHz Space Research Allocation for Proximity Links	3 July 2013
REC SFCG 15-2R4	Use of the Band 25.25 - 27.5 GHz for Inter-Satellite (Data Relay Satellite and Proximity Links)	16 October 2002
REC SFCG 18-1	Use of the bands 31.3–31.8 GHz and 36-37 GHz for EESS passive sensing	15 September 1999
REC SFCG 18-2	Minimum Earth Station G/T Requirements for Reception of Non-Geostationary EESS in the 8025-8400 MHz Bands	15 September 1999
REC SFCG 21-1	Spectrum Considerations for Formation Flying Systems	4 October 2001
REC SFCG 21-2R3	Efficient Spectrum Utilisation for Space Science Services on Space-to-Earth Links; Category A	20 June 2012
REC SFCG 21-3R1	Use of Sub-Carriers for Space Science Services on Space-to-Earth Links; Category A	16 October 2002
REC SFCG 22-1R1	Frequency Assignment Guidelines for Communications in the Mars Region	25 September 2003
REC SFCG 23-1R1	Efficient Spectrum Utilization for Space Research Service, Deep Space (Category B) in the Space-to-Earth Link	11 June 2014
REC SFCG 23-2	Assignment of Differential One-Way Ranging Tone Frequencies for Category B Missions	25 September 2003
REC SFCG 24-1R1	Frequency Assignment Guidelines for Active Remote Sensing in the Mars Region	18 June 2009
REC SFCG 27-1R1	Efficient Spectrum Utilisation for Space Research Service, Deep Space (Category B), in the 31.8-32.3 GHz Space-to-Earth Link	15 June 2011
REC SFCG 29-1	Efficient Sharing of the 25.5-27 GHz Band between EESS(s-E) and SRS (s-E)	18 June 2009

REC SFCG 29-2	Frequency assignment guidelines for active remote sensing in the Lunar region	18 June 2009
REC SFCG 29-3	Emergency Communications for Manned Space Flight	18 June 2009
REC SFCG 30-1	Use of Differential One Way Ranging Tones in the 8400-8450 MHz Band for Category B SRS Missions	15 July 2010
REC SFCG 30-2	Efficient Use of the 25.5-27 GHz Frequency Band by Future Earth Exploration-Satellite Systems and Space Research Satellite Systems	15 July 2010
REC SFCG 32-1	Methodology for the Computation of Aggregate Interference from the High Density Fixed Service (HDFS) to a Deep-Space Earth Station in 37-38 GHz Band	20 June 2012
REC SFCG 32-2	Communication Frequency Allocations and Sharing in the Lunar Region	3 July 2013
REC SFCG 32-3	Protection Criteria for GSO Space Research Satellites in the 7190-7235 MHz Band	20 June 2012
REC SFCG 33-1R1	Protection of Space Research Links in the 8 400 – 8 450 MHz and 8 450 – 8 500 MHz Bands from Unwanted Emission of EESS (Active) Systems Operating around 9.6 GHz	11 June 2014

IV. REPORTS

REPORT SFCG 29-1R1	Guidelines for Interference Risk Assessment between Earth Observation Satellites in the Band 8025-8400 MHz	20 June 2012
REPORT SFCG 30-1	Spectrum Requirements for Planned SRS Uplinks in the Band 22.55 – 23.15 GHz	15 July 2010
REPORT SFCG 31-1	Out-of-Band (OOB) Emission Measurement Data for Active Sensors in EESS (active)	15 June 2011
REPORT SFCG 32-1R2	Passive Sensor Filter Characteristics	11 June 2014
REPORT SFCG 32-2R1	Sharing between RNSS and EESS (active) in the Band 1215-1300 MHz	3 July 2013
REPORT SFCG 33-1	Assessment of techniques to mitigate interference potential from EESS (active) into ARNS systems in the 1215-1300 MHz band	3 July 2013
REPORT SFCG 33-2	Typical technical and operating characteristics for space borne radar sounder systems using the 40-50 MHz band	3 July 2013
REPORT SFCG 34-1	Worst Case Interference Levels From Mainlobe-To-Mainlobe Antenna Coupling of Systems Operating in the Radiolocation Service into Active Sensor Receivers Operating in the Earth Exploration-Satellite (Active) in the 35.5-36.0 GHz Band	11 June 2014
REPORT SFCG 34-2	Global RFI Survey on Earth Exploration-Satellite Service L-Band Sensors (Active and Passive)	11 June 2014

SPACE FREQUENCY COORDINATION GROUP

(S F C G)

Administrative Resolutions

Resolution SFCG A2-1R5

DATE AND PLACE OF SFCG MEETINGS

The SFCG,

CONSIDERING

a) that each SFCG meeting will be held at the invitation of one of its members in a location convenient to the host;

b) that travel costs in connection with SFCG meetings should be kept within reasonable limits to facilitate attendance by as many members as possible;

RESOLVES

1. that venues for SFCG meetings be selected in such a way as to facilitate equitable access for all Members and Observers, while at the same time attempting to keep travel cost within reasonable limits;

2. that the dates of SFCG meetings should be convenient to the host and should avoid other known spectrum management meetings as much as practicable.

Resolution SFCG A2-2R1

LANGUAGE OF THE SFCG

The SFCG,

CONSIDERING

a) that the use of more than one language in the conduct of its meetings and in its documentation would unduly complicate matters;

b) that the use of more than one language would result in considerable cost, particularly to the hosts of SFCG meetings,

RESOLVES

1. that English will be the official language for the conduct of its meetings and its documentation;

2. that members wishing to avail themselves of translation services. either at meetings or for documentation, are free to do so at their own expense.

Resolution SFCG A2-3R9

SFCG DOCUMENTATION

The SFCG,

CONSIDERING

a) that a concise record is required to reflect the deliberations and decisions of the Group;

b) that an organized procedure for input and output documentation will increase the efficient conduct of meetings;

c) that it is nevertheless desirable to minimize documentation formality in order to maintain the flexibility of the Group's proceedings;

d) that it may be necessary to formally transmit information to other entities;

RESOLVES

1. that SFCG input documents will be submitted in the form of:
   - discussion documents (including liaison statements from outside entities)
   - information documents
   - coordination documents

2. that discussion documents are to be provided as background for formal discussion and decision-making by the Group, but will not be formally approved by the meeting (see also the most recent version of SFCG RES A19-1);

3. that information documents are to be provided for the use of SFCG members in the conduct of their work and will be noted in the record of the meeting, but will neither be discussed formally nor approved by the meeting (see also the most recent version of SFCG RES A19-1);

4. that coordination documents are to be provided by SFCG Member Agencies on their future mission plans for the purpose of exchanging mission information to facilitate informal coordinations with other Member Agencies (see also the most recent version of RES SFCG A19-1);

5. that new or revised Resolutions and Recommendations which are proposed for SFCG approval will be submitted as part of discussion documents;

6. that SFCG output documents will generally be written in the form of:

   - Administrative Resolutions, governing the functioning and operation of the SFCG;
   - Resolutions, for actions to be taken within SFCG;
   - Recommendations, for action proposed by SFCG to be taken by member agencies or other outside bodies;
   - Liaison statements for formal transmission of information to other entities;
   - Action Items, to describe needed work and to assign responsibility for the conduct of that work in the interval between SFCG meetings (see the most recent version of RES SFCG A8-4).
   - Reports, based on outputs from Action Items, for providing detailed information on issues of concern to the SFCG;
   - Decisions, for documenting the results of deliberations, e.g. on requests for waivers to SFCG Recommendations, (see the most recent version of RES SFCG A10-1), or on other issues, which would not warrant the formulation of a RES A, RES or REC;

7. that Recommendations and Resolutions will be published on the SFCG Website* and will be reviewed at SFCG meetings in accordance with the provisions of the most recent version of RES SFCG A11-1;

8. that Reports based on output documentation from SFCG Action Items will be published on the SFCG Website*;

9. that the text of new Decisions and Liaison Statements will be published in the minutes of the meeting at which they were adopted, as well as a list of earlier Decisions and Liaison Statements that have been reviewed and remain in force;

10. that Action Items will be published in the minutes of the meeting at which they were adopted, and will be reviewed be the subsequent meeting for further disposition

11. that the minutes and Action Items for each SFCG meeting will be posted on the SFCG Website* solely for the use of SFCG members.

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* URL: www.sfcgonline.org

Resolution SFCG A3-1R3

ADMISSION OF NEW SFCG MEMBERS

The SFCG,

CONSIDERING

that other space agencies may wish to join SFCG;

RESOLVES

1. that any national or international space agency which is interested in the cooperative development of recommendations for frequency management matters in the support of those services in Resolution SFCG A6-1R2, or applications thereof, may become a member of SFCG;

   – by submitting a request for membership to the Executive Secretary, with subsequent approval by the Group, or

   – by accepting an invitation from the SFCG, via its Executive Secretary, or

   – by participating in an SFCG meeting as a guest of an existing member, requesting membership at that meeting, and receiving the agreement of the meeting participants.

2. that membership takes effect from the closure of the SFCG meeting at which it was granted.

Resolution SFCG A6-1R2

TERMS OF REFERENCE OF THE SPACE FREQUENCY COORDINATION GROUP (SFCG)

The SFCG,

NOTING

i) the letter of the Director General of the European Space Agency (ESA) of 16 January, 1980 in which he proposed the creation of SFCG and accepted that ESA provide the permanent Secretariat;

ii) the importance of periodically updating its Terms of Reference;

CONSIDERING

a) that the Group has successfully conducted annual meetings since 1980;

b) that the Terms of Reference are updated periodically to maintain current relevance;

RESOLVES

To establish the following Terms of Reference:

SFCG provides a forum for multilateral discussion and coordination of spectrum matters of mutual interest concerning, in particular, the following space radiocommunication services, as defined in the ITU Radio Regulations:

Space research
Space operations
Earth exploration-satellite
Meteorological-satellite

Inter-satellite
Radionavigation-satellite
Radio astronomy and radar astronomy, to the extent that they are relevant to spacecraft missions,

The agreed upon results of SFCG work will be expressed in the form of Resolutions, Recommendations, Reports, or whatever form may be appropriate for the case. SFCG members will attempt to ensure that findings of SFCG are taken into account by their agencies.

SFCG will:

- facilitate early understanding of present and future plans for space systems and services and of other systems affecting these;

- identify problem areas and coordination needs, and study potential solutions associated therewith;

- identify issues and policy matters relating to the future orderly use of the frequency bands allocated to respective space radiocommunication services;

- suggest courses of action to be taken by SFCG member agencies with regard to current and future frequency needs of the space radiocommunications services identified above~~,~~

- identify those matters for which member agencies should facilitate contributions to regional bodies (e.g., APT, CEPT, CITEL), ITU-R Study Groups; or to encourage their administrations to make proposals to ITU WRCs;

- closely cooperate in the area of frequency management with other space agencies as well as with commercial or research users of frequency bands allocated to the services identified above;

- consider any other items of technical, operational, or administrative nature which affect the interests of the Group; and

- maintain strong ties with other international bodies with related objectives.

DECIDES

to accept ESA's offer to provide the permanent Secretariat of the SFCG.

Resolution SFCG A8-1R1

INTERSESSIONAL WORKING GROUPS

The SFCG,

CONSIDERING

a) that the agenda for a given meeting may contain one or more very complex issues of an urgent nature;

b) that there is a need to restrict the duration of each meeting in order to minimize the financial burden on hosts as well as attending member agencies;

c) that, consequently, there is an occasional, exceptional need for concentrated effort requiring interaction of members during the period between meetings (the intersessional period);

RECOGNIZING

that it is preferable, whenever practicable, to consider issues within the annual SFCG meetings;

RESOLVES

1. to create, exceptionally, Intersessional Working Groups (IWGs), working between meetings, to deal with major issues of a- longer term nature (more than the period between two consecutive SFCG meetings) that cannot feasibly be completed through the annual SFCG meeting process;

2. to name each IWG in a manner which identifies its area of interest and to provide, by means of a Resolution, the terms of reference of each such group;

3. to assign tasks to each IWG by means of questions and/or action items to be accomplished during the intersessional period;

4. to appoint a chairman or coordinator for each IWG;

5. to consider the work accomplished during the intersessional period, and to assign further tasks if necessary, at a subsequent SFCG meeting.

Resolution SFCG A8-4R3

ACTION ITEMS

The SFCG,

CONSIDERING

a) that a decision taken by SFCG sometimes requires subsequent action by one or more members:

b) that the effective and timely accomplishment of this action is assisted by a specific description of the task(s), identification of a responsible individual, and establishment of a suitable timetable;

c) that a method of documenting, reviewing, reporting, and completing or terminating each action is helpful, and

d) that such actions are commonly referred to as Action Items, the action called for should be conducted between two meetings;

e) that a timely response to the action items is vital to the progress of work in the SFCG;

RESOLVES

1. to establish Action Items when appropriate to work specific to the SFCG;

2. to record the establishment of Action Items by means of serial-numbered SFCG documents called Action Items;

3. to include in each Action Item document a description of the action to be taken, the timetable for work to be done, and the name of the responsible individual who is charged with the accomplishment of the Action Item;

4. that final disposition of action items should include needed proposals for subsequent Resolutions, Recommendations, Reports, or other actions;

5. that each Action Item will be reviewed at the SFCG meeting following the meeting at which it was established

Resolution SFCG A10-1R1

WAIVERS TO SFCG RECOMMENDATIONS

The SFCG,

CONSIDERING

a) that its Recommendations are aimed at harmonizing and optimizing the use of frequency bands allocated to space radiocommunication services of concern to it;

b) that waivers to these Recommendations may weaken or jeopardize this goal;

c) that there may, however, exist exceptional circumstances under which a member agency may need to request a waiver to the application of a particular Recommendation;

RESOLVES

1. that request for waivers to the application of SFCG Recommendations shall be limited to exceptional circumstances;

2. that requests for waivers shall be submitted to member agencies for their consideration, accompanied by a comprehensive technical note explaining the rationale for the request;

3. that, when a decision is not required before the next SFCG meeting, such waiver may be granted by agreement of member agencies attending the meeting,

   or,

   when a decision is required before the next SFCG meeting, the requesting agency will propose a decision date, and the waiver will be granted if no objection to the proposed decision date or waiver is received by the SFCG secretariat from any member agency on or before the decision date;

4. that the SFCG may impose technical and/or operational constraints as a prerequisite for granting the waiver.

5. that the SFCG will document the result of its deliberations on a request for a waiver in the form of a Decision. This Decision will be annexed to the minutes of the meeting at which the deliberations took place, or, if they were carried out by correspondence, to the minutes of the subsequent SFCG meeting. Decisions will not be included in the SFCG Handbook.

Resolution SFCG A11-1R2

ADOPTION AND REVISION OF SFCG RECOMMENDATIONS

The SFCG,

CONSIDERING

a) that SFCG recommendations are the authoritative expression of agreements between SFCG members;

b) that these recommendations are also referred to and acted upon by agencies not belonging to SFCG;

c) that premature adoption and publication of SFCG recommendations can result in the need for subsequent revision;

d) that frequent revision of recommendations can reduce their effectiveness and the credibility of action by SFCG;

e) that the urgency of adopting a new recommendation should not preclude refinement of the of the text to be finally adopted and published;

RESOLVES

1. that a draft new recommendation which is submitted to an SFCG meeting for consideration, together with its supporting rationale (cf Resolution SFCG A2-3R1), may be adopted by attending member agencies;
2. that the initial adoption of a draft new recommendation shall be on a provisional basis;
3. that each provisional recommendation shall be re-examined at the next SFCG meeting for final adoption or, based on inputs in accordance with ‘resolves 2' of Resolution SFCG A8-3R1, for other action;
4. that provisional recommendations shall be included in the Handbook of the SFCG, clearly identified as provisional;
5. that member agencies may, with suitable care, refer to and make use of provisional recommendations prior to their final adoption;

6. that a proposed revision of an existing recommendation, or a provisional recommendation, shall be submitted together with supporting rationale (cf Resolution SFCG A2-3R1) within the time limits set by RESOLVES 2 of Resolution SFCG A8-3R1, and may be adopted by attending member agencies without further review;

7. that only Recommendations for which modification proposals in accordance with resolves 6 above were received, shall be reviewed at SFCG meetings. [1]

[1] Amendments consequential to ITU-R action, such as WRCs or Study Group decisions, may be introduced without supporting rationale.

Resolution SFCG A12-1R3

ESTABLISHMENT OF PROCEDURES FOR INTER-AGENCY FREQUENCY COORDINATION

The SFCG,

CONSIDERING

a) that the increasing congestion of frequency bands allocated to the space science services calls for an efficient coordination procedure to facilitate individual frequency assignments and to reduce the potential for mutual interference;

b) that the coordination procedure contained in Article **9** of the ITU Radio Regulations does not always provide the desirable flexibility to facilitate inter-agency coordination of frequency assignments;

c) that member agencies could make use of the methods contained in the annex to this Resolution to coordinate frequency utilization which may not be readily applicable in Article 9 of the Radio Regulations;

d) that some member agencies, for many years, have used with great success inter-agency procedures to facilitate coordination of frequency assignments;

e) that the principles underlying these procedures have found to be effective and may also prove useful in inter-agency coordination of frequency assignments among member agencies in general;

f) that inter-agency coordination based on a format common to member agencies will ease the application of the procedural methods;

g) that nevertheless the provisions of Article **9** of the Radio Regulations provides the formal coordination mechanism to be used between administrations when applicable;

RESOLVES

1. that those member agencies wishing to undertake inter-agency frequency coordination with other member agencies give due consideration to the use of the procedures contained in the annexed *SFCG Manual of Procedures for Inter-Agency Frequency Coordination* as a template for development of bilateral and/or multilateral agreements;

2. that member agencies involved in coordination utilize the SFCG database and provide updated information, if appropriate;

3. that pre-coordination of a system may begin before that system is entered in the SFCG database;

4. that a member agency will consider a final coordination request from another agency when that agency has entered necessary technical data in the SFCG database for coordination to proceed based on that technical data.[1]

1 This information will include orbit type, altitude, inclination, eccentricity, and if sun-synchronous, sun angle, all earth stations' latitudes and longitudes, all carriers' frequencies, bandwidth, transmit power, power spectral density, transmit antenna gain, and system point of contact name and email.

SFCG MANUAL OF PROCEDURES FOR

INTER-AGENCY FREQUENCY COORDINATION

(Annex to RES SFCG A12-1R2 of 20 October, 2005)

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Annex 1: Flow Diagram of Advance Planning Phase

1. PURPOSE

Member Agencies of the SFCG share certain radio frequency bands allocated to space services of common interest to these Agencies. As a consequence of this, it is essential that advance planning and post-launch operational coordination be carried out by these Agencies with a view to minimize radio spectrum interference between their missions.

This manual defines a method and execution of Inter-Agency frequency coordination that may be considered among consenting SFCG member agencies.

2. SCOPE

This Manual defines coordination activities associated with the use by SFCG Member Agencies of the relevant frequency bands allocated to Earth-to- Space, Space-to-Earth or Space-to-Space radio-communications in the Radio Regulations of the International Telecommunications Union (ITU), supplemented by SFCG Recommendations, where applicable.

These activities will basically consist of advance planning and operational coordination with respect to the use of relevant frequency bands by SFCG member agency missions and earth stations or by programs in which these Agencies participate. Consideration will also be given to other frequency bands when unwanted emissions are likely to occur.

3. PROCEDURAL APPROACH

3.1 Advance Planning Phase

The discovery of radio interference between active space missions or a potential interference condition in a finalized mission design may result in burdensome emergency solutions involving costly engineering changes and/or constraints on mission operations and objectives.

The initiation of advance planning of frequency use at the very early stages of a mission design is motivated by recognition of the following facts:

- The mutual coordination of frequency use is, by its very nature, rather time-consuming.

- The implementation of design modification that may be required in the course of the coordination procedure becomes increasingly more difficult as the project advances through its design and qualification stages.

Consequently, even very preliminary information made available during the early phases of mission design can be most helpful in identifying potential areas where frequency conflicts may occur. This can lead to joint remedial action by the Agencies concerned to affect minimum cost and inconvenience to the Projects concerned.

3.1.1 Description of Responsibilities

In order to carry out advance planning of frequency utilization during the preparation for, and conducting of, multiple simultaneous flight missions, the Agencies will assume the following responsibilities:

A. Identify, at the earliest possible stage of system design development, space missions susceptible to interference from, or likely to cause interference to the other Agency's space operations.

B. At the earliest possible stage, provide to the other Agency information about proposed use of frequencies in, or adjacent to, the space service frequency bands.

C. In the event that a potentially serious conflict is identified, the Agency discovering the conflict will identify areas which can facilitate coordination between the Agencies and notify the other Agency of relevant information

Resolution of interference cases, following the conclusion of advance planning phase specified in paragraph 3.1.3, will, at the same time, meet the technical information requirements of the official frequency coordination procedures (when applicable) set forth in the appropriate sections of Article 9 of the ITU Radio Regulations.

Consequently, the activities carried out between the Agencies during the advance planning phase will greatly facilitate - and thereby shorten - the official coordination in accordance with Article 9, Section II of the ITU Radio Regulations (when applicable). It can, however, not replace the formal (administrative) exchange of information required by said provision between the Radio Regulatory Authorities, responsible for the notification of the respective satellites.

3.1.2 Interfaces

The interfaces in the Agencies, for the activities carried out in the advance planning phase are listed in Table 3.1.

TABLE 3.1

INTERFACES FOR THE ADVANCE PLANNING PHASE

Agency:

Network:

Name of Contact:

Function:

Address:

Phone:

Fax:

Telex:

3.1.3 Advance Planning Procedure

The following procedure defines the framework within which the advance planning of frequency use will be carried out. The procedure for advance planning of frequency use is also outlined in a flow diagram (Annex 1, Figure 3.1). Deadlines for completion of the various tasks are indicated as a guideline. However, personnel with authority to conduct the indicated tasks are invited to make every effort to reduce the overall duration of the procedure.

Step 1: Initial Announcement of Intended Use of Frequency Bands

Objective: Initiation of procedure for advance planning phase

Responsibility: Agency A (announcing Agency)

The preliminary exchange of mission information prior to, or during the mission definition phases should take place at the earliest possible time even though some of the required information may be tentative or incomplete. Tentative or incomplete information should be clearly identified in the preliminary exchange of information.

Agencies will exchange, as soon as available and if possible, at least three (3) years prior to the scheduled launch date, summary-type information on mission design, mission objectives, trajectory/orbit data, scheduled launch time, mission lifetime[2]. Frequency information should include the allocated frequency bands that will be used, the planned centre frequencies, and occupied bandwidths. To expedite the coordination procedure, alternative frequency bands should be included whenever possible.

Step 2: Preliminary Assessment of Potential Interference

Objective: Request for identification of interference potentials

Responsibility: Agency B

2 The data set for preliminary examination of potential interference is described in Section 6.1.

Upon receipt of the preliminary coordination data forwarded by the announcing Agency (Agency A), the recipient Agency (Agency B) will promptly (preferably within one week) acknowledge receipt and proceed to examine the material with regard to interference which is likely to be caused to, or by, its missions and/or the services rendered by its networks(s) in operation.

Within approximately one month from the acknowledged date of receipt of the coordination data, the recipient Agency should notify the announcing Agency of its preliminary assessment on interference potentials. If a preliminary assessment is not possible, the recipient Agency should indicate the reasons and suggest remedies that would allow assessment to proceed. The announcing Agency will acknowledge receipt (preferably within one week) of this preliminary assessment of interference potentials and provide a response to the other Agency within a period of 1 month regarding the preliminary assessment .

Within the framework of pre-flight planning and mission analysis, the information exchanged may include, but not be limited to, the following:

- Provision of relevant trajectory/orbit and telecommunication link specifications for those missions which have been identified as susceptible to interference from, or to be sources of interference to, space operations of the other Agency. This information will consist as a minimum of that required in Appendix 4 of the Radio Regulations.
- Analysis and prediction of the extent of Interference to the discovering Agency's space operations.
- Performance of simulations and/or ground tests, if required and feasible, to determine the susceptibility to interference conditions of the mission operations system.
- Definition of critical operational phases for those missions which have been identified as being susceptible to interference.
- Development, jointly with the other Agency, of criteria for temporarily turning off telecommunications links, or other measures for avoiding interference.

Step 3: <u>Detailed Examination of Potential Interference (if required)</u>

Objective: Joint in-depth investigation of potential interference

Responsibility: Agencies A and B

The Detailed Examination is to be performed simultaneously by the Agencies concerned for all missions identified as having interference potential. Since this work requires additional resources and support from numerous internal organizations, the following procedure will be followed:

A. If more than two missions (i.e. one "mission pair") are involved in an interference

case, it may be advisable to develop a cross-reference matrix containing the Agency A and B mission pairs which are identified in Step 2 as having interference potentials. It is left to the mutual decision of the agencies involved to develop such a matrix.

B. The matrix should identify those missions requiring priority analysis together with the completion dates.

C. After priorities for the Detailed Examination have been mutually established, a detailed analysis of the high priority mission pair will be initiated by the agency that suspects interference will be experienced from the other agencies transmitters. For example, if Agency B suspects potential interference from signals radiated by the proposed transmitters of Agency A, Agency B will perform the Detailed Examination of the interference potential. Agency B will request the baseline information contained in Data Set Specifications for Advance Planning of Frequency Use as outlined in Section 6 of this document. This information will be provided by the suspected interferer Agency.

The Data Set will be furnished by Agency A within approximately one month and Agency B should complete the detailed examination within a period of two months. The result of this examination will be forwarded to Agency A for concurrence of the findings. This concurrence should be provided within one month after the receipt of the Detailed Examination.

The anticipated rate and duration of potential interference occurrences should be estimated for the period between the scheduled launch of the new mission to the end of its normal mission lifetime. However, in order to accommodate possible launch delays and/or extensions of the mission lifetime, the end date of the normal mission lifetime should be appropriately extended for the purpose of interference avoidance planning.

Step 4: Joint Analysis and/or Test/Simulations (if required)

Objective: Joint attempt to identify solution(s) of interference problem

Responsibility: Agencies A and B

In case Agency B, in Step 3, had not succeeded in resolving the interference problem, but regards as beneficial joint analysis and/or tests/simulations with A, it shall inform the latter within two weeks of its intent to initiate Step 4. This announcement shall, if possible, already include a technical outline for the proposed joint analysis and/or test/simulations program.

Step 5: Initiation of Remedial Action (if required)

Objective: Implementation of solutions to interference problems

Responsibility: Agency A and/or B

If the results of Step 4 have established the existence of unacceptable interference,

the Agencies will jointly determine whether there are feasible engineering or procedural solutions for solving or reducing the problem. Any mutually acceptable engineering solution(s) will be implemented immediately. In the absence of engineering solutions, the Agencies concerned will determine whether post launch operational procedures can be adequately coordinated or modified to alleviate the interference problem.

If adequate post-launch operations coordination can alleviate the interference problem the Agencies concerned will apply the general operations coordination procedures, called up in 3.2.3. They will jointly develop mission- specific operations coordination procedures, to be implemented for post-launch operations. The responsibility for the development and implementation of these operations-related activities rests with the offices identified in Table 3.2. The offices identified in Table 3.1 will be kept informed on the progress made in the development of the mission-specific operations procedures.

3.2 Post-Launch Operations Phase

3.2.1 Description of Activities

In all cases in which Step 5 of the advance planning procedure (paragraph 3.1.3) resolves the interference problem through the implementation of mission-specific coordinated operations procedures, the responsible Agency Operations Offices identified in Table 3.2 shall:

- Establish general operations coordination procedures for the satellites networks concerned, as required.

- Establish mission-specific operations procedures with the framework of the general operations coordination procedures as required.

- Schedule mission operations support so as to minimize disruptive RFI.

- Coordinate the resolution of immediate operations problems as necessary.

- Notify its Agency Frequency Manager of major interference cases, the circumstances involved, the action taken, and whether any additional action is required.

3.2.2 Interfaces

The Agency interfaces for the execution of post-launch operations coordination are listed in Table 3.2.

3.2.3 Operations Coordination Procedure

General operations coordination procedures by which Agencies concerned exchange operational information for the resolution of possible and/or actual Radio Frequency

Interference (RFI) problems will be developed, as required, by the offices identified in Table 3.2.

The general operations coordination procedures may be complemented by mission-specific operations procedures, if required.

General and mission-specific operations coordination procedures do not form part of this Manual.

TABLE 3.2

INTERFACES FOR POST-LAUNCH OPERATIONS COORDINATION

Agency:

Network:

Name of Contact:

Function:

Address:

Phone:

Fax:

Telex:

4. PRIORITY GUIDELINES

These priority guidelines apply in the case of interference, actual or potential, involving space missions of SFCG Member Agencies. They are meant as a tool for the treatment of interference cases in the framework of the mission specific operations coordination procedure described in 3.2.3.

Priority 1 (Critical) – Interference events that jeopardize humans actively engaged in space mission activity.

Priority 2 (Critical) – Interference events that jeopardize spacecraft safety, especially during time of a declared spacecraft emergency.

Priority 3 (Critical) – Interference events that jeopardize the successful completion of the mission objectives, i.e., objectives that are time-critical and can neither be revoked nor re-scheduled.

Priority 4 (Semi-Critical) – Interference events that could jeopardize scheduled time-critical mission objectives having limited opportunities for re-scheduling.

Priority 5 (Routine) – Interference events that jeopardize mandatory mission

objectives with subsequent opportunities for re-scheduling.

5. EXTENSION AND CANCELLATION OF FREQUENCY ASSIGNMENT

The Agencies concerned will inform each other, at the earliest possible date of any:

- Intended extension of the use of a frequency band beyond the previously scheduled termination,

- Predicted or unscheduled cancellation of a frequency assignment.

This information, which is vital to the orderly execution of advance planning phase and the conscientious management of the limited frequency resources, shall be forwarded between the offices identified in Table 3.1, Paragraph 3.1.2. It will also be duly reflected in the SFCG Satellite Data Base entries for the spacecraft concerned.

6. DATA SET SPECIFICATION FOR ADVANCE PLANNING OF FREQUENCY USE

The specification of the required Earth-to-Space, Space-to-Earth and Space-to-Space radio link data set necessary to establish radio spectrum interference potentials are listed in this section.

6.1 Data Set for Preliminary Examination of Potential Interference (3.1.3 Step 2)

The data set for the preliminary examination of potential interference shall be supplied using the format of the SFCG Satellite Data Base.

6.2 Data Set for Detailed Examination of Potential Interference

This data set shall be an expanded version of the one described in 6.1. Its contents shall be defined by the offices defined in Table 3.1 on a case by case basis.

7. REVISION AND AMENDMENT CONTROL

The SFCG Procedures Manual for Inter-Agency Frequency Coordination shall be subject to additions, deletions and amendments, as the need arises, by agreement among SFCG Members. The authority for revisions will rest with the SFCG.

The execution of the revision will rest with the Executive Secretary of the SFCG.

8. APPLICABLE DOCUMENTS

- ITU/Radio Regulations (current)

- Final Acts of most recent WRC
- Radio Regulations Board: Rules of Procedure
- Preface to Radiocommunication Bureau International Frequency Information Circular (Space Services) (BR IFIC) (http://www.itu.int/ITU-R/space/preface/index.html)
- SFCG Resolutions and Recommendations

Annex 1

Flow Diagram of Advance Planning Phase

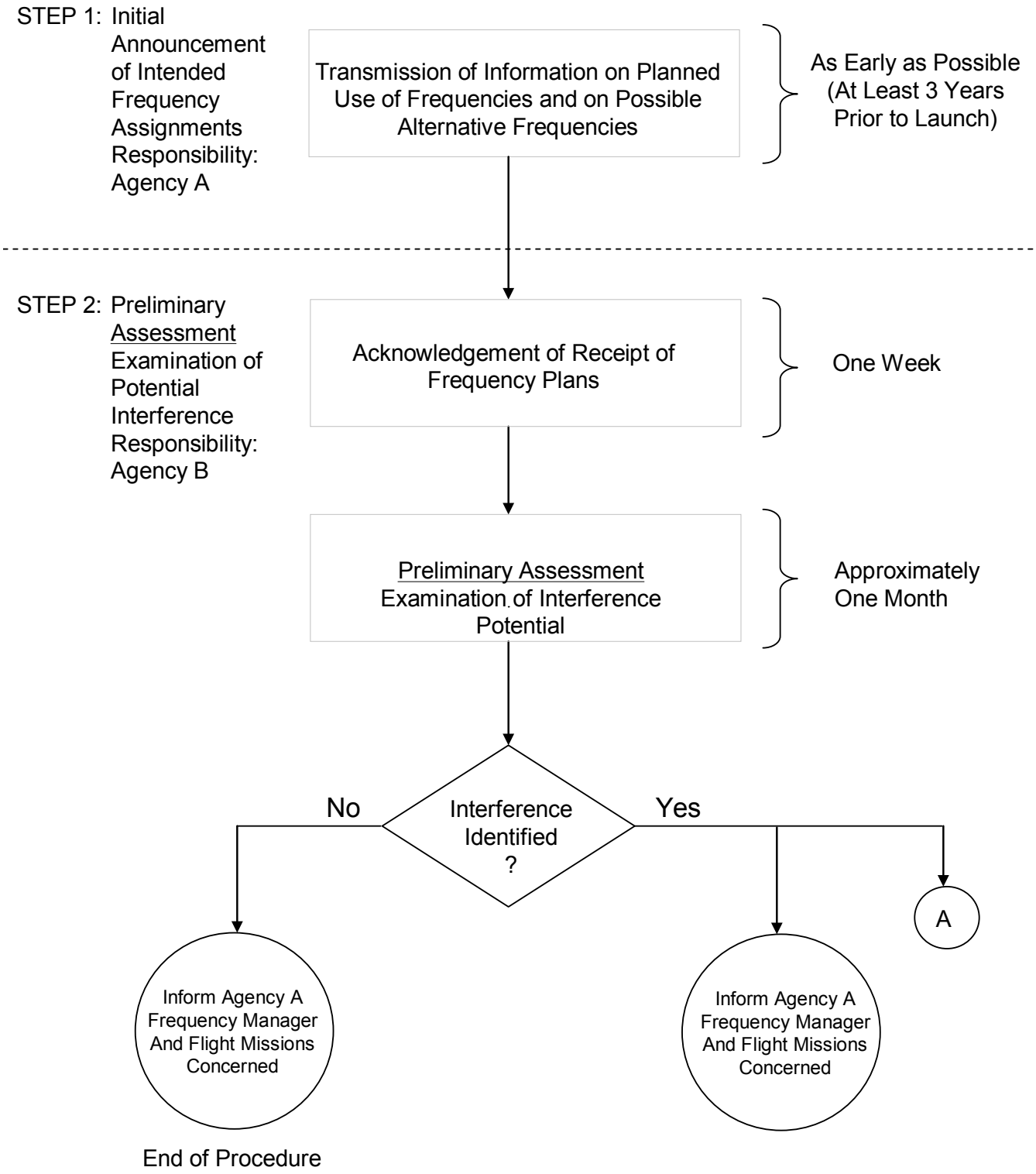


Figure 3.1 Advance Planning Phase

Flow Diagram (Sheet 1 of 4)

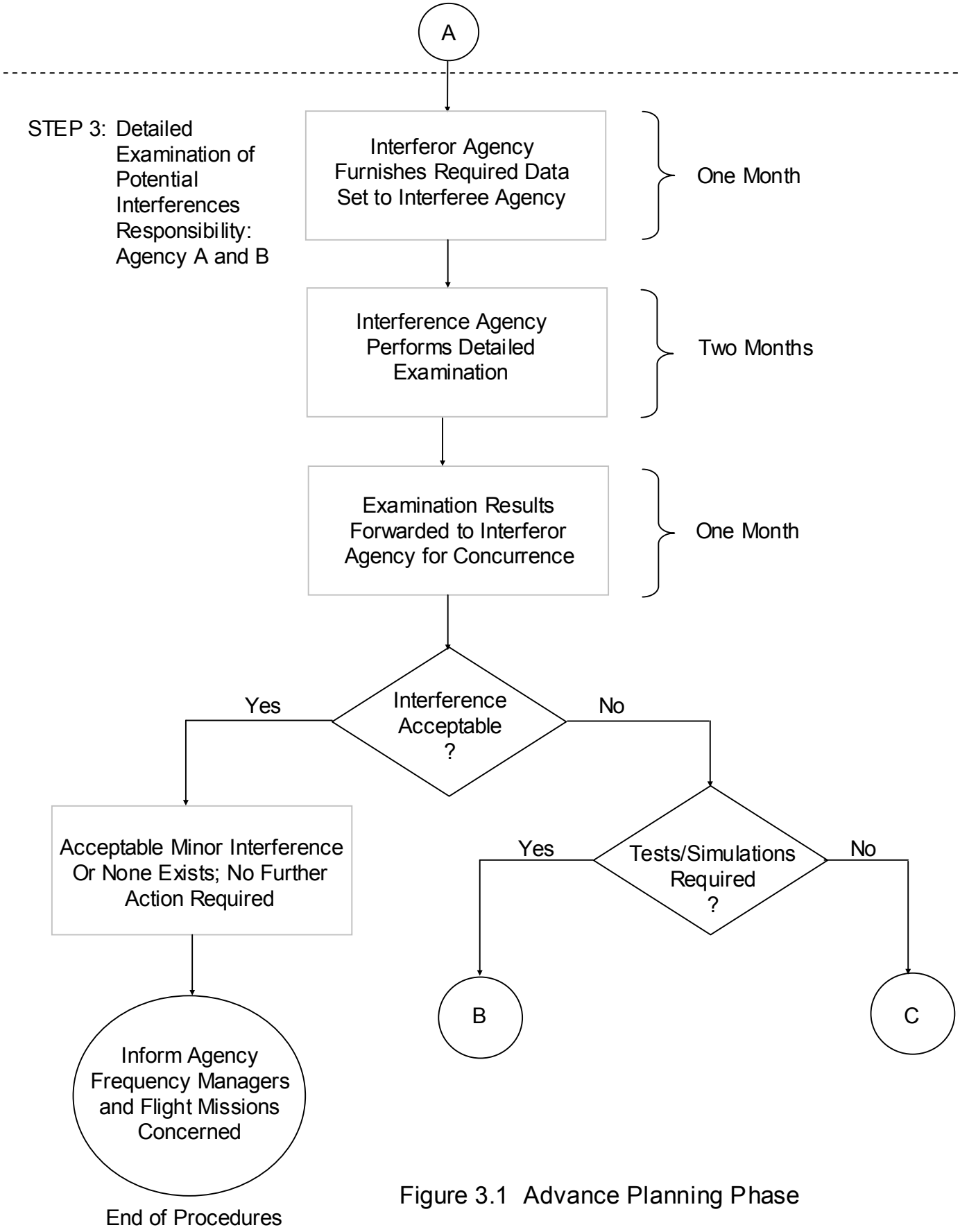


Figure 3.1 Advance Planning Phase Flow Diagram (Sheet 2 of 4)

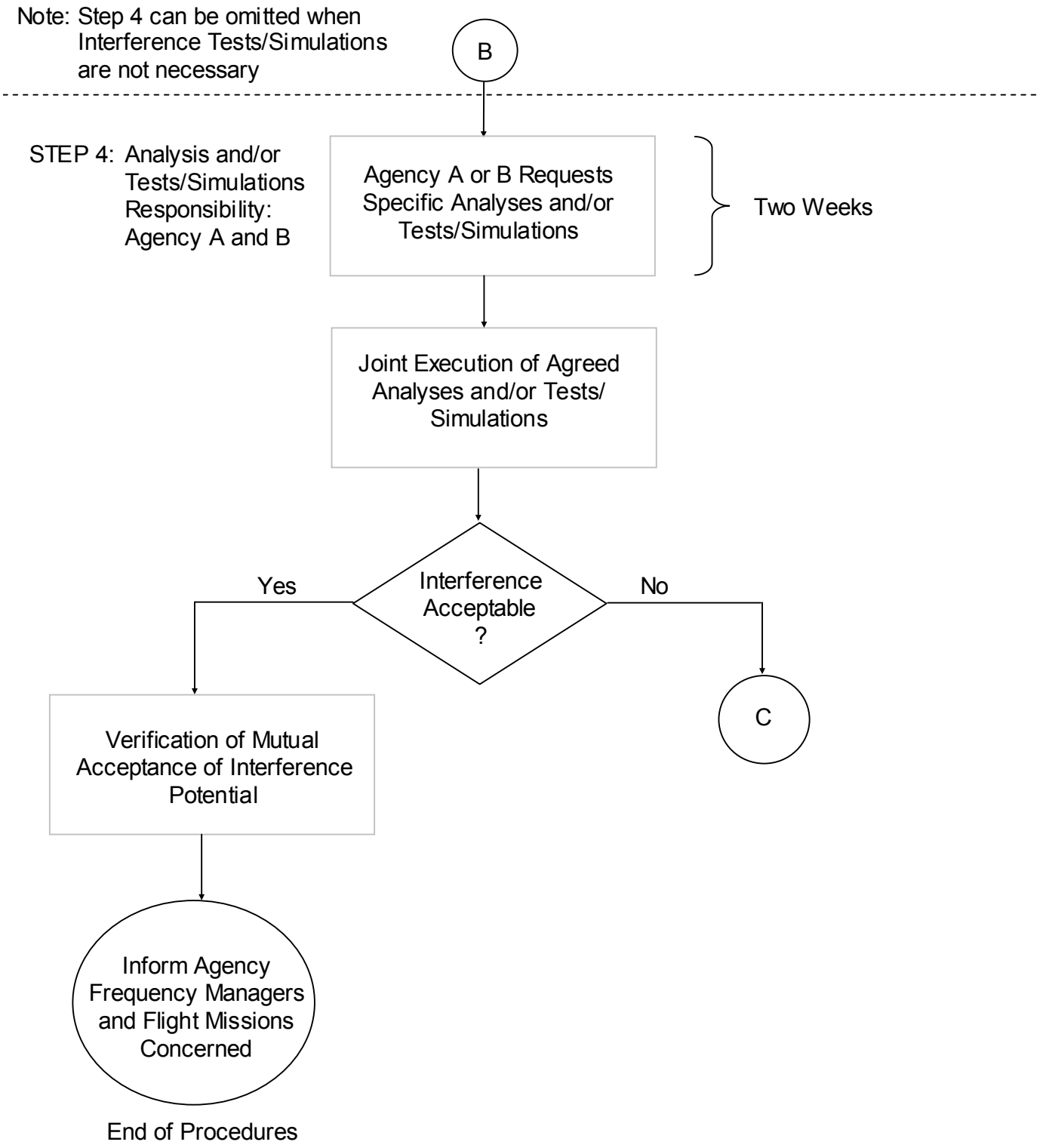


Figure 3.1 Advance Planning Phase

Flow Diagram (Sheet 3 of 4)

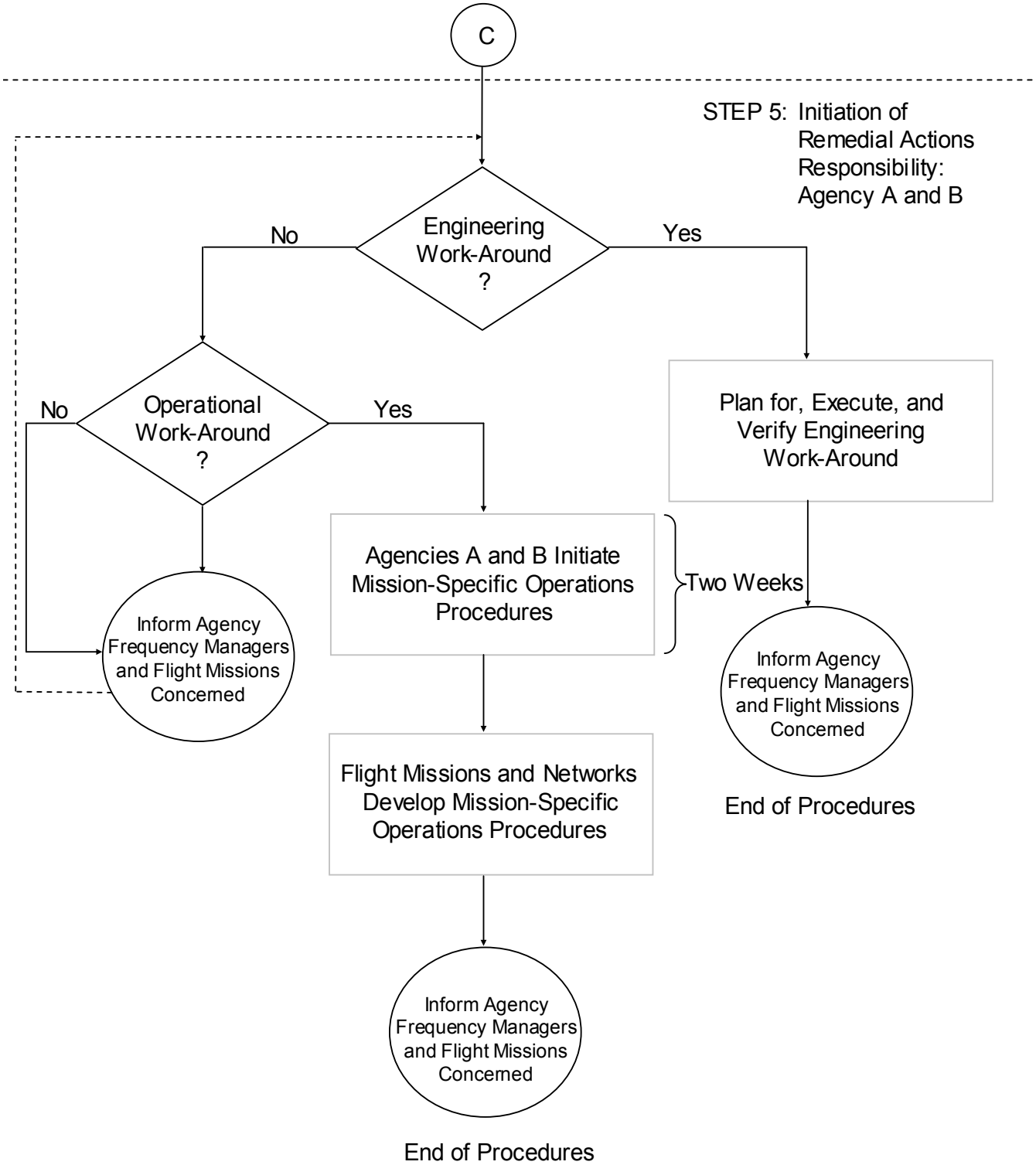


Figure 3.1 Advance Planning Phase

Flow Diagram (Sheet 4 of 4)

Resolution SFCG A12-3R2

SFCG SILVER PIN AWARD FOR MERITORIOUS SERVICE

The SFCG,

CONSIDERING

a) the desire of the SFCG to reward meritorious service with a symbolic recognition;

b) the symbolism of the metallic element silver as a durable, hard-wearing material;

ACKNOWLEDGING

the generous gift from NASA of a number of Space Frequency Coordination Group lapel pins in silver finish;

RESOLVES

1. that at each of its annual meetings, one Silver Pin Award may be awarded to the nominee who is judged to have provided meritorious service to the group;

2. that each Silver Pin Award Holder may make, in writing with the appropriate supporting reasons, one nomination for this award for consideration at the annual meeting;

3. that such nominations shall be submitted to the Executive Secretary no later than three weeks prior to the meeting at which they are to be considered;

4. that the Executive Secretary shall prepare from the nominations received, a ballot listing the name and supporting rationale concerning each nominee;

5. that the selection of the person who shall receive the award from among the nominees shall be made by open ballot conducted among the existing cadre of Silver Pin holders attending the current meeting;

6. that a record of all holders of this award will be kept in the SFCG Handbook.

Resolution SFCG A14-1R2

RIGHTS AND OBLIGATIONS OF MEMBER AGENCIES RELEVANT TO COMPOSITION OF THEIR DELEGATIONS AT SFCG MEETINGS

The SFCG,

CONSIDERING

a) that the composition of delegations at SFCG meetings has generally been comprised of representatives of space agencies, with fundamental interest in space science services;

b) that space agencies generally maintain centres of technical and operational excellence from which expertise in current space science requirements and technologies may be drawn;

c) that in the past, space agencies occasionally have invited competent experts from other disciplines;

d) that a broader interpretation of the composition of delegations will be essential due to dynamic changes in the telecommunications environment;

RECOGNIZING

a) that much of the success of the SFCG has been based on the collegial interactions of experts from the member agencies' centres of excellence, in establishing common positions for the worldwide use of space science frequency allocations;

b) that annual SFCG meetings are held at the invitation of an SFCG member agency and that the financial burden on the host agency as well as on the SFCG Secretariat must be kept within reasonable limits;

RESOLVES

1. to encourage members to consider, when composing their delegations, the inclusion of current technological and operational expertise in appropriate fields;
2. to request heads of delegation to inform the SFCG Secretariat, in due time prior to the registration deadline for an annual SFCG meeting, of the names of non-member agency staff planning to attend the meeting (this does not apply to staff figuring in the

official SFCG Members and Observers List);

INVITES

member agencies to exercise their rights in determining the composition of their delegations to SFCG meetings, in order to fulfil their obligations towards enhancing the performance and status of the SFCG as a competent and informal group,

FURTHER INVITES

member agencies to take into consideration Recognizing b) above when determining the size of their delegation.

Resolution SFCG A14-2R2

WORKING METHODS OF INTERSESSIONAL WORKING GROUPS

The SFCG,

CONSIDERING

a) that Intersessional Working Groups (IWGs) may have the exceptional need to meet in person in order to review the current status of work in progress, to exchange new ideas, and to plan for future work actions;

b) that travel to separately scheduled meetings for this purpose can be an expensive, and in some cases unacceptable burden on the participants;

c) that the annual meetings of the SFCG itself provide the commonality of location and date that brings together the participants in these IWGs;

d) that normally the work of an IWG can be accomplished by correspondence;

RESOLVES

1. that IWGs accomplish their work predominantly by electronic means;

2. that IWG members make use of the SFCG Web site to facilitate document exchange and discussion as appropriate throughout the intersessional period;

3. that IWG chairpersons report the status of the IWG's work to the annual SFCG meeting;

4. that the SFCG Secretariat provide a brief period of meeting time for each Intersessional Working Group for organizing its work plan as needed, in connection with the annual SFCG meeting;

5. that in-person IWG meetings outside the annual SFCG meeting periods should be limited to exceptional circumstances.

6. that the final output of a IWG will be in the form of a report suitable for publication as appropriate by SFCG.

Resolution SFCG A19-1R7

SFCG MEETING INPUT DOCUMENTS

The SFCG,

CONSIDERING

a) that a major purpose of SFCG meetings is to promote the open discussion and resolution of spectrum management issues among representatives of international space agencies;

b) that discussion and resolution of issues requires an understanding of agency' requirements and positions and this is best accomplished by the exchanging of Discussion Documents, described in Resolution SFCG A2-3, in advance of the meeting;

c) that initiating inter-agency coordination requires the submission of Coordination Documents, with similar characteristics of Discussion Documents, described in Resolution SFCG A2-3;

d) that SFCG meetings are generally held once each year and the amount of time available for discussing and resolving each issue is necessarily limited;

e) that delegates to an SFCG meeting must have sufficient time to read, understand, and prepare their responses to positions advocated in Discussion and Coordination Documents;

f) that another major purpose of SFCG meetings is to provide for the efficient dissemination of information among agencies on matters related to use of the RF spectrum;

g) that such exchange of information can be accomplished efficiently with Information Documents, described in Resolution SFCG A2-3, setting forth agency plans or providing other relevant information;

h) that the SFCG Web Site provides the most efficient electronic means of distributing documentation to all members;

i) that it is impractical to distribute documents by any other means,

RESOLVES

1. that agencies prepare and submit Discussion Documents only on matters in which they have a material interest;

2. that Discussion Documents shall have all of the characteristics listed in Table 1;

3. that agencies prepare and submit Coordination Documents on the satellite missions for which they require SFCG coordination to be initiated in accordance with the most recent version of Resolution SFCG A12-1;

4. that papers not possessing all of the characteristics found in Table 1 with exception of Coordination Documents shall be designated as Information Documents;

5. that electronic distribution via the SFCG Web Site is the prescribed method for distributing SFCG documents;

6. that all input documents use the standard format given in the ANNEX;

7. that agencies shall inform the SFCG Executive Secretary and Secretariat of the title and request a number for their documents well in advance of their submission to the SFCG Web Coordinator;

8. that Discussion Documents to be placed on the SFCG Web Site shall be transmitted to the SFCG Web Coordinator electronically, at least three (3) weeks prior to the first day of an SFCG meeting;

9. that Coordination Documents to be placed on the SFCG Web Site shall be transmitted to the SFCG Web Coordinator electronically, at least two (2) weeks prior to the first day of an SFCG meeting;

10. that Information Documents to be placed on the SFCG Web Site shall be transmitted to the SFCG Web Coordinator electronically, at least one (1) week prior to the first day of an SFCG meeting;

11. that all documents to be placed on the SFCG Web Site shall be transmitted to the SFCG Web Coordinator electronically, using any of the formats contained in Table 2, unless such document contains a new or revised recommendation or resolution, for which only an MS Word file format is acceptable;

12. that Information Documents received by the SFCG Web Coordinator after the deadline be posted to the SFCG Web Site at the convenience of the Web Coordinator;

13. that the time limits set forth above do not apply to documents outside the control of the SFCG, such as documents originating within the ITU, CEPT, CITEL, APT.

NOTES

that the SFCG Web Coordinator has agreed to use his *best efforts* to place documents received in a proper electronic format on the SFCG Web Site within two (2) days of receipt.

Table 1: Attributes Required to be Designated a Discussion Document

ATTRIBUTE	DEFINITION
Relevancy	Must relate to a matter acceptable for discussion at the SFCG meeting to which it is submitted.
Action Specific	Must request a specific action or modification of existing policy, or provide data needed for an action or policy.
Justification	Must fully justify (technically or administratively) the specific action requested.

Table 2: Acceptable Formats and Application Programs for SFCG Documents

FORMAT / APPLICATION	DESCRIPTION
PDF	Portable Document Format (Adobe Acrobat Reader)
MS Word, Powerpoint or Excel	Microsoft Office software components

ANNEX to RES SFCG A19-1R6

SFCG-XX **SFXX-NN/D**
DD-DD Month, YYYY
City, State or Province, Country

MEMBER AGENCY OR ORGANIZATION

DOCUMENT TITLE IN 14 PT TIMES NEW ROMAN
(SFCG Agenda Item or Action Item reference, if applicable)

Abstract

This is a short one paragraph abstract of the purpose, objective and conclusions presented in the input document. This text should be in 12 pt Times New Roman font or equivalent. The document header text including document number should be in 12 pt Time New Roman Bold. The Member Agency or Organization should be in 14 pt Times New Roman Bold and Underlined. The Document TITLE should be in 14 pt Times New Roman Bold. The body text of the document should be in a common 12 pt font.

Resolution SFCG A21-1R2

ASSISTANCE IN THE ASSIGNMENT OF FREQUENCIES TO DEEP SPACE MISSIONS (CATEGORY B)

The SFCG,

CONSIDERING

a) that the proper assignment of frequencies to deep space probes (Category B missions) is essential to mission success;

b) that this assignment process demands the appropriate software tools, significant expertise, and a complete knowledge of the existing and planned assignments to Category B missions, as well as their technical parameters, trajectories, mission timeframes, and planned events;

c) that frequency selection by one agency for all deep space missions would minimize the potential need for operational coordination;

d) that NASA/JPL has carried out successfully for many decades the task of frequency assignment to NASA and some other space agencies' deep space missions;

e) that up-to-date information on launch and end of mission dates, spacecraft trajectories, operational modes of the telecommunication links, and relevant link parameters, including the measurements of unwanted emissions such as spurious signals, is vital in conducting frequency channel selection studies and interference analyses;

RECOGNISING

the offer by NASA/JPL to assist SFCG Member Agencies, at their request, with frequency assignment tasks for Category B missions;

RESOLVES

to accept the offer by NASA/JPL, and

ENCOURAGES

SFCG Member Agencies planning deep space missions to take advantage of the assistance offered by NASA/JPL and to provide current technical, operational and mission information, including measurements of unwanted emissions such as spurious signals when available, and timely updates to facilitate frequency channel selection studies and interference analysis.

Resolution SFCG A21-2R4

SFCG SATELLITE DATABASE (SSDB) UPDATE INFORMATION

The SFCG,

CONSIDERING

a) that it is important that SFCG maintain an up-to-date satellite database for frequency planning and RFI analysis;

b) that SFCG member spacecraft utilize radio and non-radio frequency electromagnetic spectra for communication, TT&C and sensing;

c) that data from non-SFCG member spacecraft containing ITU registered frequencies are of interest;

d) that the integrity of the SSDB, i.e., its completeness and the accuracy of its data, is of utmost importance to render it a tool that can be reliably used by SFCG members for making new assignments;

e) that frequency assignments based on a lack of information can result in costly redesign or in severe operational constraints on the satellite project concerned;

f) that in accordance with the latest version of RES SFCG A12-1 final coordination request can be considered initiated only when the requesting agency has entered the necessary technical data in the SFCG database;

RESOLVES

1. that member agencies update the database information on their spacecraft projects as soon as it becomes available;

2. that member agencies identify to the SFCG database account administrator all people who will serve as agency contacts and who will be granted access privileges to the SFCG database;

3. that member agencies supply current data on national non-SFCG member spacecraft in the bands used by SFCG members whenever possible;

4. that the information is incorporated into the SFCG database as soon as any information becomes available, even if incomplete;

5. that the information to be supplied is in accordance with the parameters listed in the SFCG satellite database;

6. that instructions on the use of the SFCG database are provided both on the SFCG website (https://sfcgonline.org/) and on the SFCG database (http://cnts.gsfc.nasa.gov/sfcg/);

7. to encourage its Member Agencies to use the procedure annexed to the latest version of RES SFCG A12-1 for solving their inter-agency frequency coordination cases.

Resolution SFCG A23-1R1

SFCG MEMBER EMERITUS

The SFCG

CONSIDERING:

1. that there may be mutual benefit in encouraging former long-term SFCG participants to maintain an association with successor participants,

2. that value is seen in enabling retired long-term SFCG participants to retain a social cohesion with a view to voluntarily continuing an association with other current and retired SFCG participants,

RECOGNIZING:

that the value of service by some members, in terms of years of participation and quality of contributions, enhances the value of the work of the SFCG as a whole,

RESOLVES:

1. that Member Emeritus status be awarded to those SFCG participants retired from frequency management who, during their active service within SFCG, have participated in at least 12 meetings,

2. that Members Emeritus be entitled to:

   a. have access to the restricted areas of the SFCG website (except the SFCG SSDB),

   b. have their contact details listed on the SFCG website if they so desire, in order to encourage voluntary association with other current and former SFCG participants,

   c. participate in the Annual Dinner, as invited guests subject to compliance with the RSVP deadlines published by the host member,

   d. inclusion in the distribution of correspondence related to forthcoming meeting arrangements and other correspondence deemed appropriate by the Executive Secretary to provide a means of enabling Members Emeritus to maintain a currency of plans and activities.

Resolution SFCG A24-1

ASSISTANCE IN THE ASSIGNMENT OF FREQUENCIES TO ACTIVE REMOTE SENSING MISSIONS IN THE MARS REGION

The SFCG,

CONSIDERING

a) that the proper assignment of frequencies to active remote sensing missions in the Mars Region is essential to mission success;

b) that the proper assignment of telecommunication frequencies to deep space probes (Category B missions) is also essential to mission success;

c) that this telecommunication frequency assignment process demands the appropriate software tools, significant expertise, and a complete knowledge of the existing and planned assignments to Category B missions, as well as their technical parameters, trajectories, mission timeframes, and planned events;

d) that NASA/JPL has carried out successfully for many decades the task of telecommunication frequency assignment to NASA and some other space agencies' deep space missions;

e) that concurrent active remote sensors and a regional communication network in the Mars region may result in incompatible operations;

f) that the compatibility assessment process between active remote sensing frequencies and telecommunication frequencies in the Mars region benefits from the expertise available at NASA/JPL.

RECOGNISING

the offer by NASA/JPL to assist SFCG Member Agencies, at their request, with frequency assignment tasks for active remote sensing missions in the Mars Region;

RESOLVES

to accept the offer by NASA/JPL, and

ENCOURAGES

SFCG Member Agencies planning active remote sensing missions in the Mars Region to take advantage of the assistance offered by NASA/JPL and to provide current technical, operational and mission information and timely updates to facilitate frequency coordination and interference analysis;

Resolution SFCG A24-2

SFCG MEMBER RECOGNITION

The SFCG

CONSIDERING:

1. the success of the SFCG has, to a great extent, been due to the contributions and hard work of its dedicated membership;

2. the continued strength and longevity of the SFCG is reliant on the ongoing dedication and participation of its loyal membership;

3. the value of consistent contribution to SFCG over a period of years warrants the issuance of recognition commensurate with the level of participation.

RECOGNIZING:

the issuance of an appropriate award will not only serve as acknowledgement of service to SFCG, but may also encourage further ongoing participation in support of the SFCG.

RESOLVES:

1. that after participation in two consecutive meetings, members so qualifying be awarded the SFCG Pin (gold);

2. that after participation in twelve or more SFCG meetings, such members will qualify for recognition, on retirement from frequency management, as a Member Emeritus in accordance with the terms of Resolution SFCG A23-1;

3. that special recognition for meritorious service to the SFCG by specific individuals be provided through the awarding of a Silver Pin in accordance with Resolution SFCG A12-3R1.

Resolution SFCG A26-1R3

LUNAR AND MARTIAN INTEROPERABILITY AND SPECTRUM COORDINATION

The SFCG,

CONSIDERING

a) that its member agencies facilitate early understanding of present and future plans for space systems and services and of other systems affecting these;

b) that the following member agencies are envisaging or planning missions to the Moon or Mars or both (Lunar/Martian missions):

CNES (France)
CNSA (China)
DLR (Germany)
ESA (Europe)
ISRO (India)
JAXA (Japan)
NASA (USA)
RFSA (Russia)

c) that other, as yet unidentified, space agency members of SFCG may undertake plans to operate space missions in the vicinity of the Moon or Mars or both at a future date;

d) that because spacecraft will be clustered about or on these two bodies (Moon or Mars or both), several spacecraft will lie simultaneously within the beamwidth of an Earth station's antenna;

e) that Lunar and Martian communications relay satellites and surface elements from multiple member agencies are likely to be in simultaneous operation either jointly or independently;

f) that since spacecraft can be independently controlled by those member space agencies, it is likely that a multiplicity of spacecraft may be emitting simultaneously, and unless these emissions are carefully controlled and spectrum usage is coordinated, interference events are virtually certain;

g) that existing operations of non-lunar/Martian missions, ground-based or space-based, may be adversely affected by, or may adversely affect, the operations of lunar/Martian missions;

h) that it is essential for the identified SFCG member agencies to:

- identify spectrum requirements as envisioned by SFCG member agencies and operational usage plans;
- evaluate whether the existing spectrum allocations are adequate;

i) that an inter-governmental Lunar/Mars mission spectrum agreement was signed in 2006 between SFCG member agencies involved in such programs at this time;

CONSIDERING FURTHER

that ground network interoperability should be a top priority not only to reduce costs during periods of network overloads, but also to facilitate back-up during emergencies.

RECOGNIZING

1) that interoperability is paramount to the success, individually and collectively, of such an extensive set of exploratory space missions;

2) that the Interagency Operations Advisory Group (IOAG) was created in 1999 to facilitate interoperability among international Space Agencies' earth stations;

3) that the Terms of Reference of the IOAG include providing a forum for identifying common needs across multiple agencies for coordinating space communications policy, high level procedures, technical interfaces, and other matters related to interoperability and space communications;

4) that, the IOAG is the preferred mechanism to address interoperability and provide configuration management and maintenance of the Lunar/Mars Mission Models;

5) that, the SFCG is the preferred mechanism to provide configuration management for the spectrum use plans for missions to the Moon and to Mars (to include analyzing updated mission requirements in order to assess the adequacy of the spectrum plan in meeting the mission requirements) and to take responsibility for spectrum coordination of specific missions to the Moon and Mars.

NOTING

1. that, due to the long time span (several decades) over which Lunar and Martian missions will be conducted, an enduring organizational mechanism is needed to facilitate the agreed SFCG responsibilities;

RESOLVES

1. that the SFCG undertake future Spectrum Coordination among Lunar missions and among Mars missions, while the IOAG continues to handle matters of interoperability for those missions;

2. that if new spectrum is needed to satisfy the envisioned spectrum requirements, the SFCG should develop a plan for obtaining new allocations;

3. that a Lunar/Martian Spectrum Group (LMSG) be created with Terms of Reference as shown in the Annex to this Resolution;

4. that LMSG Members shall be those chosen to represent member agencies having envisioned or established plans for lunar/Martian missions;

5. that meetings of the LMSG take place as needed to interface with and to support the requirements of the IOAG, taking advantage of opportunities such as the annual SFCG meeting;

6. that an Observer from IOAG is encouraged to participate in meetings of the SFCG;

7. that an SFCG member participate as an Observer in IOAG meetings.

8. that Mrs C. Sham (NASA) is the chairman of the LMSG and the other member agencies points of contact are:

CNSA	Tan Wei
DLR	Ralf Ewald
ESA	Enrico Vassallo
ISRO	Manohar Sonnada
JAXA	Takashi Hamasaki
RFSA	Mikhail Vasiliev
CNES	Vincent Meens
NASA	Farzin Manshadi

ANNEX

Lunar/Martian Spectrum Group (LMSG)

Terms of Reference

1. Enable and conduct spectrum pre-coordination to ensure interference free operations for Lunar and Martian missions, including in-situ links

2. Develop, validate, and maintain the following spectrum products based upon the new Lunar/Mars communications services requirements:

    a. Lunar/Mars Spectrum Plans addressing the following functions :
        (1) Telemetry
        (2) Telecommand
        (3) Tracking
        (4) Science data return
        (5) In-situ links
        (6) Cross-links
        (7) Navigation
        (8) Remote sensing (including differential VLBI);

    b. Assessments of individual mission data rate/ bandwidth requirements,

3. Manage configuration for the Lunar/Mars Spectrum Plans and maintain these plans as current on the SFCG website.

4. Develop coordination methods for use among affected SFCG member agencies.

5. Develop and provide a mechanism for seeking regular periodic updates of the requirements of all space agencies with plans for Lunar and/or Martian robotic and/or human exploration missions.

6. Provide a report on the work of the LMSG to the SFCG at its annual meeting.

Resolution SFCG A30-1

ASSISTANCE IN THE ASSIGNMENT OF CDMA CODES TO DATA RELAY SATELLITE MISSIONS IN THE 2 GHZ BANDS (2025-2110 MHz AND 2200-2290 MHz)

The SFCG,

CONSIDERING

a) that the proper assignment of CDMA codes to Data Relay Satellite (DRS) missions in the 2 GHz bands is essential to mission success;

b) that CCSDS has developed a new set of CDMA codes for 2 GHz DRS users, which is based on, but different from, the current Space Network Interoperability Panel (SNIP) code set;

c) that this assignment process demands the appropriate software tools, significant expertise, and a complete knowledge of the existing and planned assignments to DRS missions, as well as their technical parameters, trajectories, mission timeframes, and planned events;

d) that NASA/GSFC has carried out successfully for many decades the task of CDMA code assignment to NASA and some other space agencies' DRS missions;

e) that up-to-date information on launch and end of mission dates, spacecraft orbits, operational modes of the telecommunication links, and relevant link parameters is vital in conducting CDMA code selection studies;

RECOGNISING

the offer by NASA/GSFC to assist SFCG Member Agencies, at their request, with the assignment from the new set of CDMA codes for DRS missions;

RESOLVES

to accept the offer by NASA/GSFC; and

ENCOURAGES

SFCG Member Agencies planning DRS missions to take advantage of the assistance offered by NASA/GSFC. Member Agencies can provide current relevant technical, operational and mission information and timely updates to facilitate CDMA code selection studies by filling out the "CDMA Code Request Form" available on the SFCG website at www.sfcgonline.org/Resources. The sample form is contained in Annex.

SPACE FREQUENCY COORDINATION GROUP

CDMA Code Request Form

To: cdma-request@listserv.gsfc.nasa.gov

From: Name: _____

Address: _____

Telephone: _____ Fax: _____

E-Mail: _____ Agency: _____

Spacecraft Information

Name: _____

Launch Date: _____

Estimated EOL Date _____

Coherent or non-coherent return link _____

Desired Number of CDMA Codes _____

_____

_____

Frequencies for each Code: _____

_____

_____

Date: _____

To be Completed by NASA/GSFC Spectrum Management office Only (Initials _____)

Assigned CDMA Codes:	

Resolution SFCG A30-2

SFCG WEBSITE

The SFCG

CONSIDERING:

1. the success of the SFCG is dependent upon the contributions of its members to each meeting;

2. that there is great value in maintaining SFCG documentation on a website dedicated to the work and objectives of the SFCG organization;

3. that such a website is the most efficient means for members to collaborate and exchange information related to the mission of the SFCG.

RECOGNIZING:

that NASA has graciously offered to host the SFCG Website and maintain this site for the benefit of all SFCG members

RESOLVES:

1. that the website domain sfcgonline.org be maintained for the url of the SFCG Website;

2. that a duly appointed SFCG Web Coordinator manage the website for the SFCG membership;

3. that the SFCG Web Coordinator be responsible for posting input document to the SFCG Website in accordance with the most recent version of Resolution SFCG A19-1;

4. that the SFCG Web Coordinator, in cooperation with the SFCG Executive Secretary, post all output documents, including meeting minutes, Action Items, Resolutions, Recommendations, Reports and Decisions to the SFCG Website within a reasonable time period after the completion of each SFCG meeting;

5. that access to documents internal to the workings of the SFCG such as meeting input documents, meeting minutes (including provisional recommendations) and Action Items be restricted to SFCG members.

Resolution SFCG A32-1

INTER-MEMBER COOPERATION IN RESOLVING INTERFERENCE TO EESS (PASSIVE) AND EESS (ACTIVE) OPERATIONS

The SFCG,

CONSIDERING

a) that primary allocations have been made to various active radiocommunication services in bands adjacent, nearby, or within bands allocated to the Earth exploration-satellite service (EESS) (passive) and EESS (active);

b) that emissions, either necessary or unwanted, originating from transmitters operating within the borders of the administration of one SFCG member may cause unacceptable interference to an EESS (passive) or EESS (active) mission operated by another SFCG member;

c) that the necessary or unwanted emissions referred to in b) may not be in accordance with the ITU Radio Regulations and ITU-R Recommendations;

d) that the enforcement of the ITU Radio Regulations requires that the affected administration notify the administration from where the interference, described in CONSIDERING b) and c), originates and request that the matter be investigated and resolved;

e) that some administrations act upon reports of interference only when having been notified of such by the ITU, while some other administrations will act upon reports of interference received directly from other administrations without involvement of the ITU;

f) that the processes for initiating enforcement, investigation, and resolution of interference varies between administrations;

g) that upon receipt of a report of interference, an administration will usually require that the impacted party provide its receiver characteristics;

h) that, when possible, all available information pertaining to the characteristics and location of the interference source should be provided;

i) that SFCG members are typically knowledgeable regarding the processes, described in d), within their own administrations, however, these same members are typically not knowledgeable about the implementation of these processes in other administrations;

NOTING

a) that a major purpose of SFCG meetings is to promote the open discussion and resolution of spectrum management issues among representatives of SFCG member agencies;

b) the data generated by EESS (active) and EESS (passive) missions is of benefit to all administrations including those where the emissions described in CONSIDERING b) and c), originate;

c) that the experience of an SFCG member from the administration where emissions, described in CONSIDERING b) and c), originate would facilitate the efforts of the affected SFCG member endeavoring to address these emissions in the manner described in CONSIDERING d);

RESOLVES

1. that SFCG Members experiencing unacceptable interference to either their active or passive sensors operations from emissions originating from another SFCG Member's administration may contact the Delegation Coordinator of that SFCG Member, as identified by the on-line SFCG membership list, for assistance;
2. that once contacted, the SFCG Member contacted will assist, to the extent possible, in addressing the problem within their own administration.

Resolution SFCG A34-1

SFCG OBSERVERS

The SFCG

CONSIDERING:

1. that the success of the SFCG has been enhanced by the contributions and advice of various observers who are not eligible to become SFCG Members;

2. that such observers have been informally participating in the SFCG for many years;

3. that observers may provide specific/time sensitive expertise;

RECOGNIZING:

that the ITU-R/SG7, CCSDS, CEOS, CGMS, EUMETNET, IEEE GRSS, IOAG, IUCAF, WMO, and ITWG TOVS/ATOVS are already identified as SFCG Observers in the SFCG Handbook ,

RESOLVES:

1. that SFCG Observers may attend and participate in discussions at SFCG meetings;

2. that SFCG Observers may provide technical information to the SFCG in their respective areas of expertise in the form of documents for information, discussion or coordination for consideration by SFCG Members;

3. that SFCG Observers may contribute to the development of output documents that may be considered for approval by SFCG Members;

4. that SFCG Observers may comment on output documents proposed by SFCG Members, but the final decision on these documents is taken by SFCG Members only;

5. that the SFCG may invite additional SFCG Observers with the approval of the SFCG Members.

6. That the SFCG may review the list of Observers as appropriate;

SPACE FREQUENCY COORDINATION GROUP

(S F C G)

Technical Resolutions

Resolution SFCG 5-9R1

PROTECTION OF FREQUENCY BANDS ALLOCATED TO PASSIVE SENSING AND RADIO ASTRONOMY

The SFCG,

CONSIDERING

a) that certain frequency bands are restricted to use by the passive services, and that no emissions are permitted in these bands;

b) that it has happened at least once that a space research mission has involved emissions in one of these restricted bands;

c) that some planned space research missions intend to transmit in these restricted bands;

d) that in other bands the passive services share with other space and terrestrial services;

e) that radio astronomy is conducted terrestrially or in space and is especially susceptible to interference on account of the high sensitivity of the receiving equipment;

f) that emissions from artificial satellites can be especially harmful to radio astronomy because they may be in or near the main beam of the receiving antenna, and that therefore no frequency allocations have been made, which are shared between the RAS and space services in the space-to-Earth direction;

g) that there may be exceptional circumstances in which emissions from space in bands shared between radio astronomy and active services may be justified for technical or other reasons;

RESOLVES

1. that member agencies adopt a general policy of not conducting missions involving emissions from space in those bands allocated to the radio astronomy, space research (passive) and Earth exploration-satellite (passive) services;

2. that member agencies inform the IUCAF of proposals being considered for space projects involving emissions in bands also allocated for passive use, including details suitable for publication in regular bulletins of concerned scientific organizations;

3. that the scientific community be encouraged to submit relevant comments regarding the proposed emissions before frequency assignments are finalized;

4. that member agencies refrain from conducting missions that involve emissions in the bands restricted to the passive services.

Resolution SFCG 5-10R1

INTERFERENCE TO DATA COLLECTION SYSTEMS OPERATING IN THE 401-403 MHz FREQUENCY BAND ALLOCATED TO THE METEOROLOGICAL-SATELLITE SERVICEAND THE EARTH EXPLORATION-SATELLITE SERVICE

The SFCG,

CONSIDERING

a) that the current use of data collection systems is substantial and will grow considerably in the future;

b) that all member agencies that operate data collection systems have reported interference in the 401-403 MHz band;

c) that such interference is usually one of two types:

- interference due to spurious emissions, which affects a single channel or a group of channels;
- high power interference which affects the complete band and thus all channels;

d) that such interference has already disrupted the operation of data collection services and at times rendered the systems totally unusable;

e) that the interference could be due to other services allocated in the band such as meteorological aids and/or fixed/mobile terrestrial services;

f) that some interference could be due to systems in other services, such as radiolocation devices, not allocated in the band;

g) the need to enable reliable, interference-free, operation of data collection systems;

h) the need to further identify interfering sources;

RESOLVES

1. that concerned member agencies continue monitoring of interference, and exchange information on the nature and technical characteristics of the observed interference;

2. that member agencies report to the ITU Radiocommunications Bureau (Space Services Department), via their respective administrations, cases of interference from sources not authorized to use the band.

Resolution SFCG 14-1R2

USE OF THE INTER-SATELLITE SERVICE (ISS) 23 GHZ BAND

The SFCG,

CONSIDERING

a) that the SFCG agreed to support members proposed use of the 22.55-23.55 GHz and 25.25-27.5 GHz bands for Data Relay Satellite (DRS) forward and return link operations, respectively, by data relay satellites;

b) that Recommendation ITU-R SA.1019 recommends the use of the 22.55 - 23.55 GHz and 25.25 - 27.5 GHz band for forward and return links of data relay satellites;

c) that the 23.12 - 23.55 GHz band segment has been identified by Space Network Interoperability Panel (SNIP) for inter-satellite service (ISS) links from geostationary DRS satellites to low orbiting user satellites giving due consideration to the radio astronomy allocations at 22.81-22.86 GHz and 23.07-23.12 GHz;

d) that, although limited studies of the ISS links of one mobile-satellite service (LEO) (MSS(LEO)) system as currently operated indicate that this system may be compatible with certain planned DRS operations in the 23.12-23.55 GHz band, other MSS(LEO) systems may represent significant interference problems for the planned DRS's;

e) that the 24.45 - 24.75 GHz, 32.3 - 33 GHz and 59 - 71 GHz bands are also allocated for ISS;

f) that assignments to inter-satellite links between GSO and NGSO are not subject to the ITU coordination procedures under Section II of Article **9** of the RR,

RESOLVES

1. that SFCG members urge their administrations to avoid using the band 22.55 - 23.55 GHz for ISS links other than for DRS systems, and only when necessary, to use the 22.55 - 22.81 GHz portion of this band for ISS links for non-DRS systems, thus ensuring compatibility between DRS systems, non-DRS systems and radio astronomy operations.

2. that SFCG members urge their administration to contribute to sharing studies between DRS networks and systems of other services operating in the bands 22.55-23.55 GHz and 25.25-27.5 GHz.

Resolution SFCG 14-3R1

MICROWAVE POWERED HIGH ALTITUDE RELAY PLATFORMS

The SFCG,

CONSIDERING

a) that microwave powered high altitude radio platforms are proposed to operate at altitudes up to 20 km;

b) that these platforms, which will be powered by the transmission of electro-magnetic energy from the surface of the Earth, require very high levels of power from the ground (greater than 500 kW) to propel and operate the aircraft and associated electronic equipment;

c) that the system operators are contemplating such power transmission in bands allocated to the radiolocation service and industrial, scientific and medical (ISM), which may be an inappropriate use of that service as presently defined;

d) that the radiated beam of power (EIRP greater than135 dBW) required to operate the platform may produce power density levels at orbital altitudes sufficient to cause physical damage to space-based active and passive sensors and other radio equipment, even when operating in frequency bands removed from the fundamental power transmission frequency;

e) that the radiated beam of power has the potential to cause high levels of out-of-band and harmonic emissions from intermodulation products resulting from the non-linear characteristics of the platform rectifying antenna (rectenna) used to convert RF energy to direct current energy to operate the platform;

f) that the platforms are intended to support terrestrial radio services over a wide area (greater than 750,000 km^2);

g) that such radio services may provide benefits in certain areas of low-to-medium density population distribution, but not without significant potential for harmful interference to existing terrestrial and space radio systems.

RESOLVES

1. that member agencies urge their respective administrations to take into account the following considerations during the licensing process for microwave powered high altitude relay platform systems:

   1.1 interference to other radio services resulting from intermodulation products generated by the high power densities interacting with the non-linear characteristics of the RECTENNA;

   1.2 interference and potential damage to avionics equipment on board aircraft that fly through or near the high power beam;

   1.3 interference and potential damage to telecommunication equipment on satellites that traverse the high power beam;

   1.4 potential physical damage to active and passive sensors on low orbiting satellites which traverse the high power beam;

   1.5 the propriety of using allocations to the radiolocation service, as currently defined, for the purpose of transferring power to the aircraft.

Resolution SFCG 15-2R4

SUITABLE ALLOCATIONS FOR RADIO ASTRONOMY OBSERVATIONS IN SPACE

The SFCG,

CONSIDERING

a) that radio astronomy observations can be conducted with terrestrial and space-based stations individually or in combination;

b) that space-based radio astronomy currently includes cosmic microwave background observations, very low-frequency, millimetre and sub-millimetre observations, which are either not accessible from ground-based observatories or need to use bandwidths far in excess of existing allocations;

c) that space-based radio astronomy also includes space very long baseline interferometry (VLBI) observations which intend to use practically all bands allocated to the radio astronomy service;

d) that protection criteria for space-based radio astronomy, which would take into account the specific characteristics of space-based observatories, have not yet been developed;

RESOLVES

1. that its member agencies recognize that space-based radio astronomy observations may be conducted in bands allocated to the radio astronomy service and/or to the space research service (passive);

2. that the protection criteria given in Recommendation ITU-R RA.769-1 shall be considered as giving basic protection to space-based radio astronomy stations that use the radio astronomy service frequency bands.

Resolution SFCG 15-5R2

WIND PROFILER RADAR SYSTEMS IN THE BANDS NEAR 1000 MHz

The SFCG,

CONSIDERING

a) that three bands have been identified as possible candidates for use by wind profiler radars: 904 - 928 MHz, 1270 - 1295 MHz, 1300 - 1375 MHz;

b) that the frequency band 1215-1300 MHz is allocated on a primary basis to the Earth exploration-satellite (active) and space research (active) services with some limitation expressed in RR No. **5.332**;

c) that the frequency band 1215-1300 MHz is allocated on a primary basis to the radiolocation service;

d) that Resolution 217 (WRC-97) resolves to urge administrations to implement wind profiler radars as radiolocation service systems in the bands 904-928 MHz in Region 2 only, 1270-1295 MHz and 1300-1375 MHz, having due regard to the potential for incompatibility with other services;

e) that some studies have been completed which have shown that as few as twenty wind profiler radars operating in random locations throughout the United States and Canada would cause unacceptable degradation in the performance of active spaceborne sensors operating in this band;

f) that wind profiler radars are planned in significant numbers (approximately 150 in the US/Canada);

g) that other studies have come to different conclusions about the compatibility of the two systems;

RESOLVES

that member agencies should inform their respective administrations that in making assignments to wind profiler radars in the band 1270-1295 MHz, they should consider that the remote sensing by active sensors in the band 1215-1300 MHz could experience some limitations. Member agencies shall promote the use of either of the other 2 bands indicated in CONSIDERING a) and d).

Resolution SFCG 16-1R3

SHARING BETWEEN DATA RELAY SATELLITE AND PROXIMITY LINK COMMUNICATION SYSTEMS AND HIGH POPULATION DENSITY POINT-TO-MULTIPOINT FIXED SYSTEMS IN THE VICINITY OF 26 GHz

The SFCG,

CONSIDERING

a) that a number of Administrations are considering the introduction of high population density point-to-multipoint systems in the band 25.25-27.5 GHz, currently allocated to, inter alia, the inter-satellite service;

b) that SFCG members are concerned with the potential for interference to inter-satellite service systems, including data relay satellite and proximity link operations, which may result from the introduction of high population density point-to-multipoint fixed systems at frequencies around 26 GHz;

c) that these point-to-multipoint systems are characterised by dense concentration in urban areas producing high aggregate EIRP levels toward satellite receivers which may be in low Earth orbit or in geostationary orbit;

d) that studies indicate that high population density point-to-multipoint systems may cause unacceptable interference to satellite receivers at elevation angles as high as 50° in several cases;

e) that because of economic considerations, high population density point-to-multipoint systems will probably need to be licensed based on coordination using methods different from existing procedures,

RECOGNIZING

that the ITU-R has developed Recommendation ITU-R F.1509 imposing e.i.r.p. density limits upon hub stations of high population density point-to-multipoint systems,

FURTHER RECOGNIZING

that subscriber stations in point-to-multipoint FS networks are governed by the provisions of Recommendation ITU-R F.1249,

RESOLVES

that space agencies study what practical procedures need to be developed to protect the space systems from unacceptable interference, taking into account:

- the aggregate EIRP from low and high population density point-to-multipoint fixed system transmitters at angles above the horizon;

- that the limits on point-to-multipoint FS networks in Recommendations ITU-R F.1509 and F.1249 were derived based upon compromise estimates of the future deployment densities for such FS networks.

Resolution SFCG 17-1R2

PROTECTION OF SPACE SCIENCE SERVICES FROM TERRESTRIAL SERVICE SYSTEMS IN THE BANDS 2025-2110 MHz AND 2200-2290 MHz

The SFCG,

CONSIDERING

a) that WARC-92 allocated the bands 2025-2110 MHz and 2200-2290 MHz to the space research, Earth exploration-satellite and space operation services (collectively, the space science services), on a co-primary basis with existing allocations to the fixed and mobile services;

b) that these international allocations were made in recognition of the critical reliance of space science systems on access to these bands, and the substantial capital investment in the ground-based and space-based infrastructure by the space agencies of countries representing between them more than 80% of the world's population;

c) that RR No. **5.391** and Recommendation ITU-R SA.1154 stipulates the provisions required to protect space science services from the emissions of mobile service systems in this frequency range, indicates that sharing with certain low density mobile systems is feasible, and states that high population density mobile systems (such as PCS, GMCS, IMT-2000) cannot share these bands with space science systems;

d) that at WARC-92 sharing between the fixed service and the space science services was considered feasible based on long term successful experience with existing systems and their corresponding density within the shared bands;

e) that large numbers of fixed service systems have been displaced into these 2 GHz bands to accommodate new fixed wireless access and personal communication systems in the same or adjacent bands;

f) that ITU-R has drawn up channelization plans in Recommendation ITU-R F.1098 which encompass the 2025-2110 MHz and 2200-2290 MHz bands;

g) that the investment in compatible fixed and mobile service systems in these bands in both developed and developing countries is significant;

h) that Recommendations ITU-R F.1247, F.1248, SA.1273, SA.1274, and SA.1275 stipulate the conditions necessary to ensure a stable long-term sharing environment between space science service systems and fixed service systems operating in these frequency bands;

i) that equipment for fixed wireless access systems is being produced and planned foroperation, which is not in compliance with the limits specified in Recommendation ITU-R F.1247

RECOGNIZING:

1) that all member space agencies of the SFCG rely heavily upon the availability of the 2025-2110 MHz and 2200-2290 MHz bands to conduct their Category A missions, including manned and unmanned missions, fundamental scientific research, observing both the Earth and space environments, and making an expanding contribution to the knowledge base of ecological conditions;

2) that the worldwide capital investment of public funds in the ground-based and space-based elements of the communication networks, the launch, tracking, telemetry, command and control facilities, necessary to support both manned and unmanned endeavours in space is in excess of US $ 70 billion, and is irreversibly dependent on access to these 2 GHz bands;

3) that many administrations are, *inter alia*, implementing revenue-producing methods of apportioning the frequency spectrum;

4) that deliberate, controlled de-orbiting of large mass spacecraft can best be executed relying on communications systems using frequency bands near 2 GHz which provide all-weather, reliable communications characteristics;

RESOLVES

1. that member agencies make their respective administrations aware of the difficulties in sharing with proposed terrestrial system implementations, which may vary from country to country, in the bands 2025-2110 MHz and 2200-2290 MHz;

2. that member agencies urge their respective administrations to take into account:

   a) the significant capital investment in both space science and compatible terrestrial service systems in the 2 GHz bands,

   b) the public safety aspects of the space agencies' responsibility which can be satisfied only through access to these bands.

3. that member agencies urge their administrations to avoid production, certification and operation of equipment not in compliance with the limits specified in Recommendation ITU-R F.1247.

4. that member agencies urge their respective administrations to take all these factors into account in balancing the public interest when trying to identify viable blocks of spectrum as revenue-producing allocations

Resolution SFCG 18-5

SFCG SOFTWARE GUIDELINES

The SFCG,

CONSIDERING

a) that a standard operating and programming environment for SFCG software packages will significantly enhance user friendliness and shorten the time to become familiar with the programs;

b) that proper documentation is essential to install, run, and understand the SFCG software packages with a minimum of effort;

c) that quick access to and easy maintenance of the SFCG software packages is desirable in order to make modifications or provide latest updates to programs and data bases with minimum effort;

d) that help utilities and menu driven input/output sections contribute significantly to the user friendliness of a program;

e) that data exchange between various SFCG software programmes should be compatible in order to make optimum use of available information;

RECOGNIZING

that computer viruses can prevail through attached files of e-mail and software distributed on other media,

RESOLVES

1. that member agencies ensure that software developed for distribution to other member agencies:

   1.1 is designed to run on well established and commonly used PC platforms, operating systems and applications;

   1.2 is supported by accompanying documentation related to its installation and

usage, including a description of its basic structure and any underlying mathematical models or simulation methods used;

1.3 is not encumbered with special licensing or cost implications to the users;

1.4 includes menu-driven input/output sections and on-screen help facilities;

1.5 includes the ability to review and edit inputs prior to programme execution;

1.6 provides that data used or generated by a programme be available in standard ASCII format in order that it is accessible by other programmes;

2. that member agencies screen data and files for computer viruses before distribution or after receipt and that it is incumbent on all SFCG members to immediately alert the originator of infected files and other SFCG members in order that appropriate urgent corrective action is taken.

Resolution SFCG 19-1

EFFICIENT USE OF SPECTRUM IN THE 25.5 – 27 GHZ AND 37-38 GHZ BANDS

The SFCG,

CONSIDERING

a) that it is essential to recognize the need to migrate high symbol rate space science missions to higher frequency bands;

b) that the band 25.5 – 27 GHz is allocated inter alia to the Earth exploration-satellite service (EESS) and is planned for increasing use for near Earth high data rate applications for direct space-to-Earth links;

c) that the band 37 – 38 GHz is allocated inter alia to the space research service and is planned for increasing use for Category A and Category B (including highly elliptical orbit high data rate applications) for direct space-to-Earth links;

d) that various candidate modulation techniques are currently under investigation and some of these techniques may substantially reduce bandwidth requirements;

e) that in accordance with Article **3.3** of the Radio Regulations which calls for both technical and economically justifiable measures for reducing unwanted emissions;

f) that in accordance with Article **3.9** of the Radio Regulations, "the bandwidth of emissions also be such as to ensure the most efficient utilization of the spectrum; in general, this requires that the bandwidth of emissions be kept at the lowest values which the state of the technique and the nature of the service permit",

RESOLVES

that member agencies use bandwidth efficient modulation techniques whenever practicable for high data rate space-to-Earth applications in the 25.5 – 27 GHz band and the 37 – 38 GHz band.

Resolution SFCG 19-6R1

EESS ACTIVE SENSING REQUIREMENTS ABOVE 100 GHz

The SFCG,

CONSIDERING

a) that active sensors operating in the Earth exploration-satellite service (EESS) are an increasingly important tool for many scientific and operational applications;

b) that new technology for such sensors is becoming available and will allow them to operate at frequencies above 100 GHz;

c) that WRC-2000 has allocated the band 130-134 GHz to EESS (active) with RR No. **5.562E** indicated that this allocation is limited to the band 133.5-134 GHz;

d) that WRC-2000 has allocated the band 237.9-238 GHz to EESS (active) and SRS (active) for spaceborne cloud radars only through RR No. **5.563B**;

e) that the use of a 500 MHz band by EESS(active) in the 133.5-134 GHz range will allow the operation of radar altimeters with a high horizontal and vertical resolution required to measure the thickness of snow and ice over land;

f) that the use of a band of 100 MHz by EESS(active) and SRS (active) in the 237.9-238 GHz range will allow the operation of cloud radars aimed at complementing the measurements made in the range 94-94.1 GHz by detecting thinner and higher-altitude clouds, characterized by a reflectivity of –40 dBZ;

g) that Resolution 731 (WRC-2000) indicates in its *resolves* that a future competent conference should consider the results of ITU-R studies with a view to revising the Radio Regulations, as appropriate, in order to accommodate the emerging requirements of active services, taking into account the requirements of the passive services, in bands above 71 GHz;

h) that studies at lower frequencies have demonstrated that EESS(active) can, in general, share with the radiolocation service,

RESOLVES

1. that member agencies urge their respective administration to give due consideration to the possibility of proposing new allocations to EESS(active) and SRS (active) under *resolves* of Resolution 731 (WRC-2000) as indicated in *considering* g);

2. that these allocations should preferably be proposed in bands where the sharing constraints are minimal.

Resolution SFCG 19-7R4

USE OF THE 7750-7900 MHz BAND BY NON-GEOSTATIONARY METEOROLOGICAL SATELLITES

The SFCG,

CONSIDERING

a) that sensors onboard meteorological satellites (MetSats) are an important tool for monitoring the Earth and its environment;

b) that such sensors are becoming more complex with resulting increased data rates;

c) that the ITU Radio Regulations allocate the band 7750-7900 MHz to MetSats in non-geostationary orbits on a primary basis with PFD limits as listed in Table 21-4 of the RR;

d) that MetSat operators are using the band to transmit vital meteorological and environmental data to a number of ground stations, including direct read-out user stations and main stations (Central Data Acquisition Stations (CDA));

e) that spectrum requirements of individual missions range between 30 and 150 MHz, thus limiting the possibility of segmentation as a means of interference avoidance;

f) that only conscientious frequency management of the 7750-7900 MHz band will satisfy the future requirements of numerous MetSat operators;

RESOLVES

1. that space agencies planning and operating MetSats develop procedures for efficient use of the 7750-7900 MHz band that allow interference-free reception of vital meteorological and environmental data;

2. that MetSat operators implement interference mitigation techniques to maximize the potential for sharing among MetSats systems using this band;

3. that in case of interference from MetSats operating direct readout downlinks to MetSats operating data dump downlinks, MetSats operating direct readout downlinks implement operational procedures to reduce this interference to an acceptable level. In the extreme this could include switching-off the direct broadcast transmissions while within the reception area of CDA stations during stored mission data dumps;

4. that space agencies planning MetSats in this band maximize the potential for sharing among MetSat operators by: a) coordinating frequency selection with other MetSat operators early in the system design process; b) employing techniques such as pulse-shaping and higher-order modulation to minimize the occupied bandwidth; and c) selecting a centre frequency to maximize the contiguous bandwidth available for other users.

Resolution SFCG 20-2R3

OPTICAL COMMUNICATIONS

The SFCG,

CONSIDERING

a) that optical communication has been demonstrated on Earth-to-space, space-to-Earth and space-to-space paths;

b) that further optical communication technology demonstrations and operational missions are currently planned by several SFCG member agencies;

c) that optical communication is being considered for space communication in near-earth and deep space environments;

d) that the optical spectrum is of use to scientific and industrial purposes other than communication;

e) that the Radio Regulations currently do not include definitions or nomenclature with respect to free space optical communication links;

f) that Resolution **118** (Marrakesh, 2002) of the Plenipotentiary Conference resolves that WRCs can include in agendas for future conferences, items relevant to spectrum regulation of frequencies above 3 000 GHz and take any appropriate measures, including revision of the relevant parts of the Radio Regulations;

RESOLVES

1. that SFCG member agencies that are developing or are considering the use of optical communication systems are encouraged to contribute to further SFCG studies;

2. that the SFCG, through IUCAF, bring to the attention of the International Astronomical Union (IAU) the proliferation of space-based optical communication technology.

Resolution SFCG 20-3

PROTECTION OF RNSS IN THE 1 559-1 610 MHZ BAND

The SFCG,

CONSIDERING

a) that as a result of WRC-2000, a new radionavigation-satellite service (RNSS) allocation for operation in the space-to-space direction has been created in the band;

b) that spaceborne receivers are routinely deployed which operate in this band;

c) that mobile-satellite service (MSS) GSO systems are being deployed in the adjacent 1 525-1 559 MHz band having high EIRP and may cause harmful interference to terrestrial RNSS systems operating in this band;

d) that RNSS terrestrial (safety-of-life) systems defined by Recommendation ITU-R M.1477 are critical;

e) that protecting terrestrial RNSS service (safety-of-life) will also protect low earth orbiting satellite systems;

f) that measurement of MSS out-of-band spectral power flux density (SPFD) may be feasible and may be used to better determine the level of interference to RNSS systems,

RECOGNIZING

1) that all practical means should be taken to protect RNSS (space-to-Earth) in view of its safety-of-life applications;

2) that similarly, all practical means should be taken to protect RNSS space-to-space service for current and future spaceborne receivers operating in this service,

RESOLVES

1. to encourage SFCG member agencies to make entities responsible for aeronautical safety of life operations in their administrations aware of the possible harmful

interference from these MSS GSO systems in anticipation that this will encourage appropriate steps be taken to protect RNSS from this interference;

2. to bring this matter to the attention of the International Civil Aviation Organization (ICAO);

3. to encourage measurements and studies of MSS interference to better understand the possible degradation to RNSS systems.

Resolution SFCG 21-2R4

REQUIREMENTS, PERFORMANCE, AND PROTECTION CRITERIA FOR EESS (PASSIVE) SENSORS

The SFCG,

CONSIDERING

a) that due to the continuous technological and scientific development, the requirements, performance and protection criteria for Earth exploration-satellite service (EESS) (passive) sensors must be periodically reviewed;

b) that the basic parameters related to requirements, performance and protection criteria for EESS (passive) sensors are contained in Recommendations ITU-R RS.515 and RS.2017;

c) that any revision to these Recommendations requires a consensus and a coherent approach in the parameters definition across all the passive bands;

d) that three main categories of passive sensors can be identified for the use of these bands:

1. 3-dimensional vertical atmosphere sounders requiring very high data reliability and medium resolution over multiple channels,
2. imaging radiometers requiring high data reliability, medium resolution, integration over relatively large bandwidth single channels,
3. atmospheric limb sounders requiring medium data reliability at very high resolution over many small bandwidth channels.

e) that any performance requirement has to be based on known scientific requirements for the measurement; the data resolution and availability levels must therefore be scientifically meaningful with respect to the applications for which they are used (e.g. forecasting, surface observations and climate monitoring);

f) that the implementation and orbiting of instruments capable of achieving the performance requirements should be met within a 10-year timeframe;

g) that the resulting values in these Recommendations will not be applied retro-actively;

RESOLVES

1. that the values given in Table 1 represent the requirements and performance criteria and can be used to derive appropriate protection criteria for spaceborne passive sensors;

2. that Member Agencies submit to the SFCG contributions to update the values contained in Table 1, with a view to future updating of the ITU-R Recommendations listed in CONSIDERING b).

TABLE 1

Requirements and Performance criteria for satellite passive remote sensing

Frequency Band[6] (GHz)	Total BW required (MHz)	Reference BW (MHz)	Measurement(s)	Required ΔT_e (K)	Data availability (%)[3]	Scan Mode (N, C, L)[4]
1.370-1.400s, 1.400-1.427P	100	27	Vegetation biomass, soil moisture, snow morphology, sea ice thickness; salinity	0.05	99.9	N, C
2.640-2.655s, 2.655-2.690s, 2.690-2.700P	45	10	Vegetation biomass, soil, moisture, snow morphology; salinity	0.1	99.9	N
4.200-4.400s, 4.950-4.990s	200	200	Soil moisture, sea surface temperature	0.3/0.05*	99.9	N, C
6.425-7.250	200	200	Soil moisture, sea ice thickness, sea surface temperature	0.3/0.05*	99.9	N, C
10.60-10.68p, 10.68-10.70P	100	100	Snow and ice morphology, precipitation over oceans, sea surface temperture	1.0/0.1*	99.9	N, C
15.200-15.350s, 15.350-15.400P	200	50	Rain, background channel[7] for 22 GHz water vapor	0.1	99.9	N, C
18.600-18.800p	200	200	Precipitation, Background channel[7] for 22 GHz water vapor	1.0/0.1*	95/99.9*	N, C
21.200-21.400p	200	100	Integrated vapor content	0.2/0.05*	99/99.9*	N
22.210-22.500p	300	100	Integrated vapor content	0.4/0.05*	99/99.9*	N
23.600-24.000P	400	200	Integrated vapor content	0.05	99.99	N, C
31.30-31.50P, 31.50-31.80p	500	200	Water vapor, snow and sea ice morphology; amospheric window channel	0.2/0.05*	99.99	N, C
36.000-37.000p	1 000	100	Rain, snow, lake and sea ice morphology, oil slicks; light rain over oceans	1.0/0.1*	99.9	N, C
50.200-50.400P	200	200	Surface emissions necessary for accurate temp profiles from 52.6-59.3 GHz	0.05	99.99	N, C
52.60-54.25P, 54.25-59.30p	6 700[1]	100	Temperature profiles, cloud liquid water, snow and lake ice morphology, oil slicks	0.3/0.05*	99.99	N, C
86.00-92.00P	6 000	100	Surface emissions for temperature profiles from 115.25-122.25 GHz; cloud liquid water, snow and ice morphology, oil slicks	0.05	99.99	N, C
100.0-102.0P	2 000	10	NO and O_3, precipitation	0.005	99	L
109.5-111.8P	2 000	10	Temperature, O_3, CO_2, NO	0.005	99	L
114.25-116.00P	1 750	10	Temperature, O_3, CO_2, NO	0.005	99	L

Frequency Band[6] (GHz)	Total BW required (MHz)	Reference BW (MHz)	Measurement(s)	Required ΔT_e (K)	Data availability (%)[3]	Scan Mode (N, C, L)[4]
115.25-116.00P 116.00-122.25p	7000[1]	200/10[5]	Temperature profiles; cloud liquid water, precipitation	0.05/0.005[5]	99.99/99[5]	N, L
148.5-151.5P	3 000	500/10[5]	NO, Window Channel for 183 GHz	0.1/0.005[5]	99.99/99[5]	N, L
155.5-158.5p[2]	3 000	200	Window Channel for 183 GHz	0.1	99.99	N, C
164.0-167.0P	3 000[1]	200/10[5]	Water vapor profile; precip over land, snowfall	0.1/0.005[5]	99.99/99[5]	N, C, L
174.8-182.0p, 182.0-185.0P, 185.0-190.0p, 190.0-191.8P	17 000[1]	200/10[5]	O_3, NO; snowfall, cloud ice, water profile retrieval	0.1/0.005[5]	99.99/99[5]	N, C, L
200.0-209.0P	9 000[1]	3	NO, Atmospheric constituent	0.005	99	L
226.0-231.5P	5 500	200/3[5]	Atmospheric constituent, window for 325 GHz water vapor channel	0. 2/ .005[5]	99.99/99[5]	N, L
235.0-238.0p	3 000	3	NO, O_3, CO_2	0.005	99	L
250.0-252.0P	2 000	3	NO	0.005	99	L
275-285.4	10 400	3	N_2O, ClO	0.005	99	N, L
296-306	10 000	200/3[5]	Wing channel for temperature sounding OXYGEN, HNO_3, HOCl, N_2O, O_3, $O^{17}O$,	0.2/0.005[5]	99.99/99[5]	N, L
313.5-355.6	42 100	200/3[5]	Water vapour profiling, cloud, Wing channel for temperature sounding HDO, ClO, HNO_3, H_2O, O_3, HOCl, CH_3Cl, $O^{18}O$, CO, BrO, CH_3CN, N_2O, HCN	0.3/0.005[5]	99.99/99[5]	N, C, L
361.2-365	3 800	200/3[5]	Wing channel for water vapour profiling O_3	0.3/0.005[5]	99.99/99[5]	N, L
369.2-391.2	22 000	200/3[5]	Water vapour profiling H_2O	0.3/0.005[5]	99.99/99[5]	N, L
397.2-399.2	2 000	200/3[5]	Water vapour profiling	0.3/0.005[5]	99.99/99[5]	N, L
409-411	2 000	3	Temperature sounding	0.005	99	L
416-433.46	17 460	200/3[5]	Oxygen, temperature profiling	0.4/0.005[5]	99.99/99[5]	N, L
439.1-466.3	27 200	200/3[5]	Water vapour profiling, cloud HNO_3, H_2O, O_3, N_2O, CO	0.4/0.005[5]	99.99/99[5]	N, C, L
477.75-496.75	19 000	3	Oxygen, temperature profiling	0.005	99	L
497-502	5 000	200/3[5]	Wing channel for water vapour profiling BrO, $N_2{}^{18}O$, O_3	0.5/0.005[5]	99.99/99[5]	N, L
523-527	4 000	200	Wing channel for water vapour profiling	0.5	99.99	N

Frequency Band[6] (GHz)	Total BW required (MHz)	Reference BW (MHz)	Measurement(s)	Required ΔT_e (K)	Data availability (%)[3]	Scan Mode (N, C, L)[4]
538-581	43 000	200/3[5]	Water vapour profiling HNO_3, O_3, H_2O, ClO	0.5/0.005[5]	99.99/99[5]	N, L
611.7-629.7	18 000	3	Water vapour profiling, OXYGEN, H_2O, ClO_2, SO_2, HNO_3, BrO, CH_3CN, ($H^{37}Cl$), H_2O_2, HOCl, O_3, HO_2, $H^{35}Cl$, CH_3Cl, $O^{18}O$	0.005	99	L
634-654	20 000	200/3[5]	Wing channel for water vapour profiling HOCl, $H_2{}^{18}O$, SO_2, ClO, HO_2, BrO, HNO_3, O_3, NO, N_2O	0.6/0.005[5]	99.99/99[5]	N, L
656.9-692	35 100	200/3[5]	Water vapour profiling, cloud H_2O, HO_2, ClO, CH_3Cl, CO	0.6/0.005[5]	99.99/99(5)	N, C, L
713.4-717.4	4 000	3	Oxygen	0.005	99	L
729-733	4 000	3	Oxygen HNO_3, $O^{18}O$	0.005	99	L
750-754	4 000	3	Water	0.005	99	L
771.8-775.8	4 000	3	Oxygen	0.005	99	L
823.15-845.15	22 000	200/3[5]	Oxygen	0.8/0.005[5]	99.99/99[5]	N, C, L
850-854	4 000	3	NO	0.005	99	L
857.9-861.9	4 000	3	Water	0.005	99	L
866-882	16 000	200	Cloud, window	0.8	99.99	N, C
905.17-927.17	22 000	200/3[5]	Water	0.9/0.005[5]	99.99/99[5]	N, L
951-956	5 000	3	Oxygen NO, $O^{18}O$	0.005	99	L
968.31-972.31	4 000	3	Water	0.005	99	L
985.9-989.9	4 000	3	Water	0.005	99	L

(1) This bandwidth is occupied by multiple channels.

(2) This band is needed until 2018 to accommodate existing and planned sensors.

(3) Data availability is the percentage of area or time for which accurate data is available for a specified sensor measurement area or sensor measurement time. For a 99.99% data availability, the measurement area is a square on the Earth of 2,000,000 km^2, unless otherwise justified; for a 99.9% data availability, the measurement area is a square on the Earth of 10,000,000 km^2, unless otherwise justified; for a 99% data availability, the measurement time is 24 hours, unless otherwise justified.

(4) N: Nadir, Nadir scan modes concentrate on sounding or viewing the Earth's surface at angles of nearly perpendicular incidence. The scan terminates at the surface or at various levels in the atmosphere according to the weighting functions. L: Limb, Limb scan modes view the atmosphere "on edge" and terminate in space rather than at the surface, and accordingly are weighted zero at the surface and maximum at the tangent point height.
C: Conical, Conical scan modes view the Earth's surface by rotating the antenna at an offset angle from the nadir direction.

(5) First number for nadir or conical scanning modes and second number for microwave limb sounding applications

(6) P = Primary allocation, shared only with passive services (RR No. 5.340); p = primary allocation, shared with active services, and s = secondary allocation

(7) Background channel: channel used in combination with others in order to extract individual physical parameters

* First number for sharing conditions circa 2008; second number for scientific requirements that are technically achievable by sensors within the next 10 years

Resolution SFCG 21-3R3

PROTECTION OF EESS SENSORS (ACTIVE AND PASSIVE) FROM ULTRA WIDEBAND DEVICE AND SHORT RANGE DEVICE EMISSIONS

The SFCG

CONSIDERING

a) that active and passive microwave sensors on board spacecraft operating in the Earth exploration-satellite service (EESS) are an important tool for monitoring the Earth's environment;

b) that certain frequency bands are restricted for use by the passive services only and RR No. **5.340** stipulates that all emissions are prohibited in these bands;

c) that other frequency bands are allocated to the passive services and are shared with some active services;

d) that the passive sensing instruments by their nature are very sensitive to any emissions within the sensor band and operate by integrating a very low signal over time across a relatively large bandwidth (tens to hundreds of MHz);

e) that any emissions (single entry or aggregate) that raise the noise floor in bands allocated to EESS (active) and EESS (passive) service may degrade the performance of spaceborne sensors using those bands;

f) that ultra wide-band (UWB) devices generate emissions over a very wide bandwidth but typically at low power levels;

g) that the aggregate effect and the extreme wideband nature of such devices may cause interference in frequency bands allocated to active and passive remote sensing;

h) that UWB and short range device (SRD) technologies enable a wide assortment of applications including, but not limited to, through-the-wall imaging, ground-penetrating radars, collision-avoidance radars as well as communication and security applications;

i) that authorization for UWB and SRD technology usage occurs on an administration-by-administration basis;

j) that administrations can authorize usage of spectrum, within their borders, in a manner not in accordance with the Radio Regulations with the understanding that the nationally authorized usage will not affect other administrations' spectrum usage that is in accordance with the Radio Regulations.

k) that some administrations have adopted regulations permitting the operation of UWB and SRD devices on a license-exempt, non-interference basis;

l) that administrations that intend to adopt national regulations authorizing UWB or SRD technology usage typically provide a process that accepts and considers comments regarding these pending national regulations;

RECOGNIZING

1. that the automotive industry has identified the band 22-29 GHz for implementation of UWB vehicular short-range radars;

2. that the band 23.6-24 GHz is part of a set of unique critical bands that are essential for numerical weather prediction and climate monitoring and is protected by RR No. **5.340**;

3. that all studies have shown that UWB vehicular short-range radars and passive sensors operating in the 23.6-24 GHz band are incompatible, and all studies have resulted in negative margins in excess of 10 dB;

4. that although UWB vehicular radars are expected to move out of the 22-29 GHz band to bands around 79 GHz, current vehicular systems using the 22-29 GHz band will likely remain in service long after newer vehicular radars have transitioned to bands around 79 GHz and thus may have a long-lasting impact on 24 GHz EESS (passive);

5. that the deployment of UWB or SRD devices may also impact other systems in the EESS and meteorological community, such as Search and Rescue and Metaids;

6. that ITU-R Recommendations SM.1755, SM.1757, SM.1538, SM.1896 provide technical characteristics and preferred frequency bands of operation for UWB and SRD devices;

7. that PDNR ITU-R Recommendation RS.[ACTIVE_CHAR] provides characteristics and allocated frequency bands of operation for EESS (active);

8. that Recommendation ITU-R RS.1861 provides characteristics of EESS (passive) systems;

9. that Recommendations ITU-R RS.1166 and RS.2017 provide the protection criteria for EESS (active) and EESS (passive), respectively.

RESOLVES

1. that member agencies work within their administrations to ensure that UWB and SRD devices avoid emissions in bands exclusively allocated to passive services;

2. that member agencies work within their administrations to ensure that UWB and SRD devices avoid generating harmful emissions in the other bands allocated to active and passive sensors and those additional bands listed in Recommendations ITU-R RS.515 and RS.577.

3. that member agencies that become aware of an administration's intention to authorize the usage of UWB or SRD technology in bands allocated to, or adjacent to, bands allocated to EESS (active) or EESS (passive) inform the other member agencies of that fact;

4. that the member agencies, informed as in RESOLVES 3, and other affected scientific interests be encouraged to submit comments to the administration's public enquiry process regarding the proposed regulations before the UWB or SRD applications are authorised;

5. that member agencies continue to study the impact of the introduction of UWB and SRD devices into bands listed in Recommendations ITU-R RS.515 and RS.577.

Resolution SFCG 23-2R1

USE OF SYNTHETIC APERTURE RADARS IN THE BAND 5250-5570 MHz

The SFCG

CONSIDERING

a) that synthetic aperture radars on board spacecraft are an increasingly important tool for radar imaging of the Earth's surface;

b) that the C-band (near 5 GHz) is one of the most important bands for radar imaging;

c) that the band 5250 – 5570 MHz is allocated to the Earth exploration-satellite service (active) and space research service (active) on a primary basis;

d) that WRC-03 decided to allocate the bands 5250 – 5350 MHz and 5470 – 5725 MHz to the mobile service in the bands for implementation of wireless access systems, including RLANs;

e) that WRC-03 decided to allocate the band 5250 – 5350 to the fixed service for fixed wireless access (FWA) applications in certain administrations in ITU Region 3;

f) that WRC-03 decided to upgrade the allocation to the radiolocation service from secondary to primary in the band 5350 – 5650 MHz;

g) that operation by active sensors in bands allocated to the radiolocation, radionavigation and aeronautical radionavigation services has proven to be feasible both from theoretical studies and from many years of operational experience;

h) that studies have shown that outdoor usage of even one wireless access system operating in the mobile service can cause interference to narrowband spaceborne SARs in the band 5250-5350 MHz;

i) that while WRC-03 decided that operation of wireless access systems in the mobile service in the band 5250-5350 MHz should be predominantly indoor, outdoor operation of some systems would still be possible and it is very difficult for administrations to prevent deployments of these outdoor wireless access systems;

j) that taking into account considering i) above, the relevant protection of EESS (active), particularly space-borne Synthetic Aperture Radar (SAR), is not ensured in the 5250-5350 MHz band;

k) that the "other mitigation techniques" allowed by WRC-03 and in *resolves* 5 of Resolution 229 (Rev WRC-12) as possible alternative to the limitations to be applied on an individual administration basis to RLAN in the band 5 250-5 350 MHz have still not been defined by any administrations;

l) that taking into account considering k) above, wireless access system mitigation techniques that would afford the necessary protection to EESS (active) operations in the 5250 – 5350 MHz band have not been found and appear unlikely to ever be found;

m) that the technical conditions related to wireless access systems in the band 5 470-5 570 MHz are not suitable for compatibility with SAR systems of the EESS (active) service;

n) that taking into account j), l) and m) and to avoid any potential interference from RLAN, the band 5 350-5 470 MHz has been selected by a number of space agencies to operate narrowband EESS (active) SAR instruments (such as the ESA Sentinel-1 mission (3 satellites), the Canadian missions Radarsat-2 and the upcoming Radarsat-RCM (3 satellites) and the Chinese mission HY-2);

o) that all the SFCG member agencies benefit from the measurements of these instruments even if they are not operating sensors in these bands,

RESOLVES

1. that member agencies support regulatory actions within their administrations that limit wireless access systems in the band 5250 – 5350 MHz to indoor use only, to the maximum extent practicable in an effort to protect the use of this band for narrowband sensors;

2. that member agencies report any instances of interference in the bands 5250 – 5350 and 5470 – 5570 MHz to the SFCG;

3. that member agencies advocate within their administrations to avoid any allocation to wireless access systems (indoor or outdoor) in the band 5350 – 5470 MHz for the purpose of maintaining the highest reliability and availability of EESS (active) SAR measurements in this band.

Resolution SFCG 23-3

USE OF THE ALLOCATION FOR EESS (ACTIVE) IN THE BAND 432-438 MHz

The SFCG

CONSIDERING

a) that the need for monitoring forests was emphasized at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, 1992;

b) that there is a large scientific interest for using active sensors to map spatial distribution and dynamics of forest biomass, as well as to map and measure the depth of Antarctic ice and properties of arid and semi-arid regions;

c) that these radars must operate at frequencies below 500 MHz in order to penetrate dense vegetation and the Earth's surface;

d) that, in order to address this need, WRC-03 decided to allocate the band 432 – 438 MHz to the Earth exploration-satellite service (EESS) (active) on a secondary basis;

e) that among the allocated services in the 432 – 438 MHz portion of the spectrum are radiolocation, amateur, fixed and mobile;

f) that the band 433.75 – 434.25 MHz is used by space operations service (Earth-to-space) for launch command and destruct communications in the French Overseas Departments in Region 2, and in India, France and Brazil as given in RR 5.281, and that other administrations also use narrow frequency bands within this frequency range for the same purpose;

g) that there is a potential for unacceptable interference from some spaceborne synthetic aperture radars to terrestrial space object tracking radars operating in the band 420 - 450 MHz;

h) that Recommendation ITU-R RS.1260-1 provides the technical and operational constraints on the use of spaceborne active sensors within the 420 – 470 MHz frequency

range to facilitate sharing with other services allocated in this frequency range;

i) that, in order to protect the allocated services in the band 432 – 438 MHz, RR No. **5.279A** incorporates Recommendation ITU-R RS.1260-1 by reference;

j) that the radio astronomy allocation in the 406.1 – 410 MHz needs to be protected from potential unwanted emissions from active sensors operating in the Earth exploration-satellite service (active) secondary allocation in the band 432-438 MHz;

RECOGNIZING

1) that limiting the geographical areas of interest to EESS missions using this allocation (e.g. Amazonian rain forest, arid and semi-arid regions, the Antarctic) will help to minimize interference to other services allocated in this band;

2) that all objectives of the identified missions will be campaign oriented, i.e. they will be concentrating on a specific region for limited pre-determined periods (e.g. 1 month) and will not be transmitting in regions which are not of interest during those specific periods;

3) that avoidance of transmissions when in line of sight of terrestrial space object tracking radars may be necessary to avoid mutual interference between the spaceborne active sensors and the terrestrial space object tracking radars;

4) that the EES (active) service is obligated to protect launch vehicle range safety command operations where harmful interference, even for very short period of time, into launch vehicle telecommand receivers could endanger the safety of life and property;

5) that the free and open availability of advanced operational schedule information on each and every campaign would facilitate the protection of the existing allocated services in the 432 – 438 MHz band;

6) that at WRC-03, the SFCG has agreed to make such information freely available on its website and to keep such information up-to-date;

RESOLVES

1) that the SFCG will provide the free and open means for member agencies to make advanced operational schedule and sensor geographic area of coverage information available and up-to-date, via the official SFCG Web Site;

2) that member agencies submit such operational schedule and sensor geographic area of coverage information on intended spaceborne active sensing missions and their associated campaigns that will use the secondary allocation in the 432 – 438 MHz band to the SFCG Web Coordinator;

3) that member agencies with active missions and campaigns keep such operational

schedule information up-to-date;

4) that member agencies use the coordination procedure given in the Annex to ensure the protection of launch command and destruct communications;

5) that the SFCG address the concerns of the radio astronomy community with respect to potential unwanted emissions from active sensors operating in the 432 – 438 MHz band into the 406.1 – 410 MHz radio astronomy band.

ANNEX

Coordination Procedure for EESS (active) in the 432-438 MHz band with Space Operation Service Activities

This coordination activity shall be carried out as follows:

1. The Space agency responsible for the operation of EESS (active) sensor (EESS Agency) shall provide the information via SFCG Website (http://www.sfcgonline.org) sufficiently in advance of the launch of the satellite. This information will include:

   - contact point
   - satellite orbital data
   - sensor actual characteristics
   - scheduled launch date
   - planned schedule of operation
   - number of campaigns planned in an year
   - geographical areas to covered in each campaign
   - duration of operation of sensor over each region

2. When an EESS (active) campaign is planned, the space agency responsible for the operation of the EESS (active) sensor shall provide the following via the SFCG website:

   - duration and schedule of the campaign
   - geographical area to be covered

3. The Space agency carrying out the Space operation service activities (Space Operation Agency) shall examine the information given in 1 and 2 above. If the planned time period and the region of operation of the active sensor overlap that of the space operation service, Space Operation Agency shall inform the EESS Agency to switch off the EESS active sensor over the specific geographical region starting at a specific date.

4. The EESS Agency shall inform the Space Operation Agency that it has received this request and provide confirmation for this action.

5. Before the launch or during any time of the operation of EESS active sensor, if there is any change in the planned operation of EESS active sensor (in terms of time and duration of operation and area of operation), EESS Agency shall provide this information.

6. Space Operation Agency shall reexamine this information and provide its findings.

7. After the launch operations have been completed, the Space Operation Agency which has requested the EESS Agency to switch off the active sensor shall inform the EESS Agency of the end of the launch operations and the ability for the EESS Agency to resume its sensor operations.

8. During any stage of this coordination, the EESS Agency and Space Operation Agency ensure the availability of their designated contact persons.

Resolution SFCG 23-5

PROTECTION OF FUTURE RADIO ASTRONOMY OBSERVATORIES IN THE SHIELDED ZONE OF THE MOON

The SFCG,

CONSIDERING

a) that the shielded zone of the Moon (SZM) provides a unique location for radio astronomy observations shielded from interfering man-made radio transmissions on Earth or from satellites in geostationary orbit;

b) that actual planning of a radio astronomy observatory in the SZM may not happen earlier than 2050, and that its system parameters may differ considerably from those of telescopes currently in use;

c) that a radio astronomy observatory in the SZM will need to be designed and operated with the objective of minimizing its susceptibility to man-made emissions, including those from missions to the Earth-Sun L2 point and deep-space missions, especially those to Mars;

d) that such an observatory will make observations in frequency bands in addition to frequency allocations made to the radio astronomy service by the ITU;

e) that other missions, like the ones to Mars or to the Sun-Earth L2 point, will also require large bandwidths for data transfer back to Earth or to a relay satellite, and that they will inevitably illuminate the SZM under certain geometrical conditions;

f) that by the time a radio observatory in the SZM becomes operational, optical links for broadband data transfer are expected to be available and in use;

RECOGNIZING

1. that the SZM is defined in Article 22, Section V, of the ITU Radio Regulations;

2. that emissions in the SZM are prohibited for all but the space research (active) and space operations services in order to protect radio astronomy observations;

3. that Article 22, Section V, of the ITU Radio Regulations does not include emissions from deep space missions and from missions to the Sun-Earth L2 point;

4. that ITU-R has adopted Recommendation ITU-R RA.479-4 on the protection of frequencies for radio astronomical measurements in the SZM;

5. that Resolution B15 of the International Astronomical Union addresses the issue of frequency bands to be used for radiocommunications in the SZM,

RESOLVES

1. that members planning a radio astronomy observatory in the shielded zone of the Moon inform the SFCG of such plans;
2. that members, through the SFCG, work together with IUCAF to exchange planning information for missions to the Sun-Earth L2 point and for deep space missions, specifically to Mars;
3. that members, through the SFCG, work together with IUCAF to study issues of compatibility of a radio astronomy observatory in the shielded zone of the Moon, as well as the requirements of deep-space missions and Sun-Earth L2 point missions, with the view to developing an SFCG Recommendation.

Resolution SFCG 24-1R1

INTERFERENCE MITIGATION TECHNIQUES FOR FUTURE SYSTEMS PLANNING TO OPERATE IN THE 2200-2290 MHZ BAND

The SFCG

CONSIDERING

a) that interference in the 2200-2290 MHz band can occur to earth stations supporting direct space-Earth links as well as space-to-space systems using data relay satellites;

b) that interference may be caused by other satellites as well as terrestrial emitters;

c) that the band 2200-2290 MHz is presently congested and interference among users often exceeds the levels for protection in relevant ITU-R Recommendations;

d) that the number of systems using the 2200-2290 MHz band is expected to continue to increase in the future causing a corresponding increase in interference levels;

e) that systems with moderate link margins are better able to tolerate interference levels in the band than those with low link margins;

f) that use of large earth station antennas with high gains and low sidelobe levels reduces the impact of potential interference;

g) that the use of multiple ground stations that are simultaneously in view of the spacecraft can offer downlink redundancy and avoid loss of data during periods of interference;

h) that future increases in interference in the band can be reduced by ensuring that future spacecraft transmit only when in view of their cooperating earth stations;

i) that future interference in the band can also be reduced by selection of the minimum bandwidth necessary to accomplish the intended mission;

j) that most space-to Earth systems currently operating in the band use significantly less than 6 MHz;

k) that most space-to-space systems currently operating in the band use bandwidths no more than 6 MHz;

l) that larger bandwidths than the above do not promote homogeneity and tend to increase future congestion in the band;

m) that Rec. ITU-R SA.1154 concludes that sharing with high density mobile services is not feasible and should be avoided.

n) that data relay satellites are compatible with low density mobile service systems in this band and that Earth stations are incompatible with low density mobile service systems unless sufficient RF isolation exists between the mobile systems and the earth station.

o) that sufficient earth station isolation from low density mobile systems may not be feasible in all cases.

NOTING

a) that this frequency band is also heavily used by entities other than SFCG member agencies;

b) that several frequency bands are available as alternatives to the band 2200-2290 MHz;

c) that the band 25.5-27.0 GHz has the advantages of allocation to the Space Research and Earth Exploration satellite services in both space-to-Earth and space-to-space direction and offers a total bandwidth of 1.5 GHz;

d) that the use of data relay satellites may reduce the number of earth stations requiring protection from mobile interference.

e) that ITU RR No. **5.391** precludes the deployment of high density mobile service systems in the 2200-2290 MHz band.

RESOLVES

1. that systems developed for use in the 2200-2290 MHz band not transmit when beyond view of their cooperating earth stations or when beyond view of their cooperating data relay systems;

2. that systems using this band be designed to minimize their bandwidths to reduce the potential interference to other systems in the band and that, whenever practical, bandwidths should not exceed 6 MHz, to reduce future congestion in the band;

3. that due consideration be given to interference mitigation techniques including earth station geographical diversity, increased earth station antenna gain enhancing the link margin, reduced earth station antenna sidelobe levels, earth station isolation from mobile

links and the use of data relay satellites, if available, to augment and replace earth stations;

4. that other bands, like the band 25.5-27.0 GHz, be considered for high data rate systems.

Resolution SFCG 24-2

USE OF THE ALLOCATION FOR EESS (ACTIVE) IN THE BAND 94 – 94.1 GHz

The SFCG

CONSIDERING

a) that there is a large scientific interest for using active sensors to map cloud profiles in the band 94 – 94.1 GHz, as well as for astronomical observations of cosmic radio sources in this band and in adjacent bands;

b) that, in order to address this need, the Earth exploration-satellite (active) and space research (active) services have a primary allocation in the band 94 – 94.1 GHz, the use of which has been limited to spaceborne cloud radars per RR No. **5.562**;

c) that, in order to address this need, the radio astronomy service has a secondary allocation in the band 94 – 94.1 GHz, and primary allocations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz;

d) that transmissions in the band 94 – 94.1 GHz from space stations of the EESS (active) that are directed into the main beam of a radio astronomy antenna have the potential to severely damage some radio astronomy receivers;

e) that, in order to protect the radio astronomy service operations in the band 94 – 94.1 GHz, RR No. **5.562A** states that "Space agencies operating the transmitters and the radio astronomy stations concerned should mutually plan their operations so as to avoid such occurrences to the maximum extent possible.";

f) that there is a potential for detrimental interference from transmissions in the band 94 – 94.1 GHz from space stations of the EESS (active) to radio astronomy observations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz;

g) that, in order to protect the radio astronomy service operations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz, RR No. **5.149** urges administrations "to take all practicable steps to protect the radio astronomy service from harmful interference";

RECOGNIZING

1. that avoidance of transmissions by EESS (active) missions in the band 94 – 94.1 GHz in case of main-to-main beam coupling with radio astronomy stations observing in the band 94-94.1 GHz may be necessary to avoid damage to radio astronomy receivers;

2. that not all currently planned EESS (active) missions in the band 94 – 94.1 GHz will be able to switch off their transmissions;

3. that avoidance of radio astronomy observations in the band 94 – 94.1 GHz in case of main beam-to-main beam coupling with an EESS (active) mission transmitting in the band 94 – 94.1 GHz may be necessary to avoid damage to radio astronomy receivers;

4. that avoidance of radio astronomy observations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz when in line of sight of an EESS (active) mission transmitting in the band 94 – 94.1 GHz may be necessary to avoid detrimental interference to radio astronomy observations;

5. that the free and open availability of advanced operational schedule information on each and every EESS (active) mission in the band 94 – 94.1 GHz would facilitate the protection of the radio astronomy service;

6. that more than 30 radio astronomy telescopes worldwide (see Annex 2 for a non-exclusive list) will be potentially involved in observations in these bands, which are generally planned long (weeks to months) in advance;

RESOLVES

1. that the SFCG will provide the free and open means for member agencies to make advanced operational schedule information available and up-to-date via the official SFCG Web Site;

2. that member agencies submit such operational schedule information on intended spaceborne active sensing missions that will use the primary allocation in the 94 – 94.1 GHz band to the SFCG Web Coordinator;

3. that member agencies with active missions keep such operational schedule information up-to-date;

4. that member agencies and IUCAF use the mutual planning procedure given in Annex 1 to ensure the protection of radio astronomy service operations in the band 94 – 94.1 GHz.

ANNEX 1

Mutual planning procedure for EESS (active) cloud radar operations with radio astronomy service observations in the band 94 – 94.1 GHz

This mutual planning activity shall be carried out as follows:

1. The Space agency responsible for the operation of the EESS (active) sensor (EESS Agency) shall provide all relevant information via the SFCG Website (http://www.sfcgonline.org) sufficiently in advance of the launch of the satellite. This information will include all the orbital elements that are necessary to allow the avoidance of radio astronomy observations during line-of-sight transmissions from the EESS (active) sensor and the identification of the designated contact person.

2. Before the launch or during any time of the operation of EESS active sensor, if there is any change in the planned operation of EESS active sensor (in terms of time and duration of operation and area of operation), the EESS Agency shall provide this information.

3. IUCAF will inform the radio observatories that are potentially concerned of planned EESS missions and provide them with instructions on the use of the information available on the SFCG Website that will allow the planning of observations avoiding line-of-sight transmissions from the EESS (active) sensor.

4. During any stage of this mutual planning procedure, the EESS Agency and IUCAF shall ensure the availability of their designated contact persons.

ANNEX 2

Given below is a non-exhaustive list of radio observatories that will operate in the band 94 – 94.1 GHz during the next few years, as well as in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz.

List of radio observatories in the band 94 – 94.1 GHz

Radio observatory	Geographical coordinates
Bordeaux, France	E -00°31'37" N 44°50'10"
Kayseri, Turkey	E 36°17'58" N 38°59'45"
Metsähovi, Finland	E 24°23'17" N 60°13'04"
Onsala, Sweden	E 11°55'35" N 57°23'45"
Pico Valeta, Spain	E -03°23'34" N 37°03'58"
Plateau de Bure, France	E 05°54'26" N 44°38'01"
Sardinia, Italy	E 09°14'40" N 39°29'50"
Yebes, Spain	E -03°05'22" N 40°31'27"
ALMA, Chile	E -67°45' N -23°02'
Crawford Hill, NJ, USA	E -74°11'12" N 40°23'30"
FCRAO, MA, USA	E -72°20'42" N 42°23'30"
Green Bank, WVa, USA	E -79°49' N 38°26'
Haystack, MA, USA	E -71°29'18" N 42°37'24"
Itapetinga, Brazil	E -46°33'28" N -23°11'5"
Owens Valley, CA, USA	E -118°16'56" N 37°14'03"
Steward, AZ, USA	E -111°36'53" N 31°57'12"
Brewster, WA, USA	E -119.68° N 48.13°
Fort Davis, TX, USA	E -103.94° N 30.63°
Hancock, NH, USA	E -71.98° N 42.93°
Kitt Peak, AZ, USA	E -111.61° N 31.96°
Los Alamos, NM, USA	E -106.25° N 35.78°
Mauna Kea, HI, USA	E -155.46° N 19.81°

Radio observatory	Geographical coordinates
North Liberty, IA, USA	E -91.57° N 41.77°
Owens Valley, CA, USA	E -118.28° N 37.23°
Pie Town, NM, USA	E -108.12° N 34.30°
St. Croix, VI, USA	E -64.58° N 17.76°
ATCA, Australia	E 149°32'56" N -30°18'52"
Tamna, Korea	E 126º27'43" N 33º17'18"
Ulsan, Korea	E 129º15'04" N 35º32'33"
Yonsei, Korea	E 126º56'35" N 37º33'44"
MOPRA, Australia	E 149º05'58" N –31º16'04"
Nobeyama, Japan	E 138°28'32" N 35°56'29"
Purple Mountain, China	E 97°44' N 37°22'
Seoul, Korea	E 126º57'19" N 37º27'15"
Taejon, Korea	E 127°22'18" N 36°23'54"

Resolution SFCG 27-1

INTERFERENCE MITIGATION TECHNIQUES FOR FUTURE SYSTEMS PLANNING TO OPERATE IN THE 2025-2110 MHZ BAND

The SFCG

CONSIDERING

a) that interference can occur to satellites operating in the 2025-2110 MHz band from multiple earth station uplinks

b) that the number of systems using the 2025-2110 MHz band is expected to continue to increase in the future causing a corresponding increase in interference levels;

d) that use of large earth station antennas with high gains and low sidelobe levels reduces the impact of potential interference;

e) that future increases in interference in the band can be reduced by ensuring that earth stations transmit only when in view of their cooperating satellites;

f) that future interference in the band can also be reduced by selection of the minimum bandwidth necessary to accomplish the intended mission;

g) that Recommendation ITU-R SA.1154 concludes that sharing with high density mobile services in this band is not feasible and should be avoided;

h) that data relay satellites are compatible with low density mobile service systems in this band and that Earth stations are incompatible with low density mobile service systems unless sufficient RF isolation exists between the mobile systems and the earth station.

i) that low density mobile terminals currently exist in this band and operate principally as electronic news gathering (ENG);

j) that sufficient earth station isolation from these low density mobile systems may not be feasible in all cases.

NOTING

a) that this frequency band is also heavily used by entities other than SFCG member agencies;

b) that the use of data relay satellites will continue to facilitate use of the 2025-2110 MHz band by reducing interference resulting from earth stations uplinks;

c) that the 2025-2110 MHz does not allow high data rates transmissions;

d) that ITU RR No. 5.391 precludes the deployment of high density mobile service systems in the 2025-2110 MHz band.

RESOLVES

1. that earth stations or data relay satellites using the 2025-2110 MHz band not transmit when their cooperating satellites are beyond their view;;

2. that systems using this band be designed to minimize their bandwidths to reduce the potential interference to other systems in the band to reduce future congestion in the band;

3. that due consideration be given to interference mitigation techniques including earth station geographical diversity, increased earth station antenna gain , reduced earth station antenna sidelobe levels, earth station isolation from mobile links and the use of data relay satellites, if available, to augment and replace earth stations;

4. that other frequency bands should be made available as alternatives to the band 2025-2110 MHz for high data rates;

Resolution SFCG 29-1

PASSIVE BANDS OF INTEREST ABOVE 275 GHz

The SFCG,

CONSIDERING

a) that due to the continuous technological and scientific development in the bands above 275 GHz, the requirements for passive sensing must be periodically reviewed;

b) that the basic parameters related to requirements for EESS (passive) sensors are contained in Recommendation ITU-R RS.515;

c) that any proposal for revision to this Recommendation ITU-R RS.515 requires a large consensus within the user community and a coherent approach in the parameters definition across all the passive bands;

d) that three main categories of passive sensors can be identified for the use of these bands:

1. 3-dimensional vertical atmosphere sounders requiring very high data reliability and medium resolution over multiple channels,

2. imaging radiometers requiring high data reliability, medium resolution, integration over relatively large bandwidth single channels, and

3. atmospheric limb sounders requiring medium data reliability at very high resolution over many small bandwidth channels.

e) that any performance requirement has to be based on known scientific requirements for the measurement; the data resolution and availability levels must therefore be scientifically meaningful with respect to the applications for which they are used (e.g. forecasting, surface observations and climate monitoring);

f) that due to the large number of spectral lines of interest to Earth observations in the 1-3 THz region, no attempt is made to define the individual bands;

g) that the 1-3 THz region is so opaque that only limb-sounding observations from the top of the atmosphere are practical, adequate protection for passive sensing is essentially guaranteed and sharing is feasible with any terrestrial service.

RESOLVES

1. that Table 1 represents the EESS frequency bands of interest, their associated spectral lines, measurements, typical scan mode and existing or planned instruments for frequencies above 275 GHz,

2. that Member Agencies submit to the SFCG contributions to update the values contained in Table 1,

3. that Member Agencies use the information in Table 1 as a basis for contributions to the ITU-R to update appropriate Recommendations.

Table 1: Passive bands of interest for EESS above 275 GHz

Frequency band(s) (GHz)	Total Bandwidth required (MHz)	Spectral line(s) (GHz)	Measurement			Typical Scan Mode	Existing or planned Instrument(s)	Supporting information
			Meteorology – Climatology	Window	Chemistry			
275 – 285.4	10 400	276.33 **(N_2O),** 278.6 **(ClO)**		276.4-285.4	N_2O, ClO, NO	Limb		**Window** (276.4-285.4), **Chemistry** (275-279.6)
296 – 306	10 000	Window for 325.1, 298.5 **(HNO_3)**, 300.22 **(HOCl)**, 301.44 **(N_2O)**, 303.57 **(O_3)**, 305.2 **(HNO_3)**, 304.5 **($O^{17}O$)**	Wing channel for temperature sounding	296-306	OXYGEN, N_2O, O_3 , $O^{17}O$, HNO_3, HOCl	Nadir, Limb	MASTER	**Window** (296-306 GHz), **Chemistry** (298-306)
313.5 – 355.6	42 100	{318.8, 345.8, 344.5} **(HNO_3)**, 313.8 **(HDO)**, {321.15, 325.15} **(H_2O)**, {321, 345.5, 352.3, 352.6, 352.8} **(O_3)**, {322.8, 343.4} **(HOCl)**, 345.8 **(CO)**, {345.0, 345.4} **(CH_3Cl)**, 345.0 **($O^{18}O$)**, 354.5 **(HCN)**, 349.4 **(CH_3CN)**, {315.8, 346.9, 344.5, 352.9} **(ClO)**, 351.67 **(N_2O),** 346 **(BrO),**	WATER VAPOUR PROFILING, CLOUD, Wing channel for temperature sounding	339.5-348.5	H_2O, CH_3Cl, HDO, ClO, O_3 , HNO_3, HOCl, CO, $O^{18}O$, HCN, CH_3CN, N_2O, BrO	Nadir, Conical, Limb	PREMIER, CIWSIR, MASTER, MWI, GOMAS, GEM	**Water vapour line at 325.15** (BW: 3 GHz, max. offset: 9.5 GHz), **Cloud Measurements** (331.65-337.65, 314.14-348, 339-348, 320.45-324.45, 325.8-329.85, 336-344, 339-348}) **MWI cloud ice and cirrus** (313.95-317.35, 332.95-336.35), **Window** (339.5-348.5), **CIWSIR Water line** (314.15-336.15), **MASTER Chemistry** (321-326), **GEM/MASTER Chemistry** (342-346), **PREMIER Chemistry (**343.6-355.6, 313.5-325.5)

Frequency band(s) (GHz)	Total Bandwidth required (MHz)	Spectral line(s) (GHz)	Measurement			Typical Scan Mode	Existing or planned Instrument(s)	Supporting information
			Meteorology – Climatology	Window	Chemistry			
361-365	4 000	364.32 **(O_3)**	Wing channel for water vapour profiling		O_3	Nadir, Limb	GOMAS	**GOMAS Water vapour** (361-363), **Chemistry** (363-365)
369.2-391.2	22 000	380.2 **(H_2O)**	WATER Vapour profiling			Nadir, Limb	GEM, GOMAS	**Water vapour line** (369.2-391.2, BW: 3 GHz, max. offset: 9.5 GHz), **GEM/GOMAS Water vapour sounding** (379-381), **Water vapour profiling** (371-389), Polar-orbiting and GSO satellites (FY4) for precipitation over snow-covered mountains and plains (380)
397-399	2000		WATER Vapour profiling				GOMAS	
409 – 411	2000		Temperature sounding			Limb		
416 – 433.46	17 460	424.7 **(O_2)**	OXYGEN, Temperature profiling			Nadir, Limb	GEM, GOMAS	**Oxygen line** (416.06-433.46, BW: 3 GHz, max. offset: 7.2 GHz), **GEM/GOMAS Oxygen** (416-433)
439.1-466.3	27 200	{443.1, 448} **(H_2O)**, 443.2 **(O_3)**, 442 **(HNO_3)**	WATER vapour profiling, CLOUD	458.5-466.3	O_3, HNO_3, N_2O, CO	Nadir, Limb, Conical	MWI, CIWSIR,	**Water line** (439.3-456.7, BW: 3 GHz, max. offset: 7.2 GHz), **Cloud measurements** (452.2-458.2, 444-447.2, 448.8-452, 459-466), **MWI cloud ice and cirrus** (439.1-442.5, 453.5-456.9), GSO satellites (FY4) (424), **Window** (458.5-466.64), **Chemistry** (442-444)

Frequency band(s) (GHz)	Total Bandwidth required (MHz)	Spectral line(s) (GHz)	Measurement			Typical Scan Mode	Existing or planned Instrument(s)	Supporting information
			Meteorology – Climatology	Window	Chemistry			
477.75-496.75	19 000	487.25 **(O_2)**	OXYGEN, Temperature profiling			Limb	ODIN	**Oxygen line** (477.75-496.75, BW: 3 GHz, max. offset: 8 GHz), **ODIN Oxygen** (486-489)
497 – 502	5000	497.9 **($N_2{}^{18}O$)**, {497.6, 497.9} **(BrO)**, 498.6 **(O_3)**	Wing channel for water vapour profiling	498-502	O_3, CH_3Cl, $N_2{}^{18}O$, BrO, ClO	Limb, Nadir	SOPRANO, MASTER, ODIN	**Water window** (498-502), **Chemistry SOPRANO/ODIN/MASTER** (497-499)
523-527	4 000	Window for 556.9	Wing channel for water vapour profiling	523-527		Nadir		
538-581	43 000	{541.26, 542.35, 550.90, 556.98} **(HNO_3)**, 556.93 **(H_2O)**, {544.99, 566.29, 571.0} **(O_3)**, 575.4 **(ClO)**	WATER vapour profiling	538-542	HNO_3, O_3, ClO	Nadir, Limb	ODIN	**Water window** (538-542), **ODIN water vapour profiling** (546-568), **ODIN water vapour sounding** (552-562), **Chemistry** (541-558), **ODIN Chemistry** (563-581)

Frequency band(s) (GHz)	Total Bandwidth required (MHz)	Spectral line(s) (GHz)	Measurement			Typical Scan Mode	Existing or planned Instrument(s)	Supporting information
			Meteorology – Climatology	Window	Chemistry			
611.7-629.7	18 000	620.7 **(H_2O)**, 624.27 **(ClO_2)**, {624.34, 624.89, 625.84, 626.17} **(SO_2)**, {624.48, 624.78} **(HNO_3)**, 624.77 **(^{81}BrO)**, 624.8 **(CH_3CN)**, 625.04 **(H_2O_2)**, 625.37 **(O_3)**, 624.98 ($H^{37}Cl$), 625.92 **($H^{35}Cl$)**, 627.18 **(CH_3Cl)**, 627.77 **($O^{18}O$)**, {625.07, 628.46} **(HOCl),** 625.66 **(HO_2)**	WATER vapour profiling, OXYGEN		OXYGEN, ClO_2, SO_2, BrO, O_3, $H^{35}Cl$, CH_3Cl, $O^{18}O$, HOCl, HO_2, HNO_3, CH_3CN, H_2O_2	Limb	MLS, SMILES, SOPRANO	**Water line** (611.7-629.7, BW: 3 GHz, max. offset: 7.5 GHz), **MLS/SMILES/SOPRANO Chemistry** (624-629)
634-654	20 000	635.87 **(HOCl)**, 647.1 **($H_2{}^{18}O$)**, 649.45 **(ClO)**, 649.24 **(SO_2)**, 649.7 **(HO_2)**, 650.18 **(^{81}BrO)**, 650.28 **(HNO_3)**, 650.73 **(O_3)**, 651.77 **(NO)**, 652.83 **(N_2O)**	Wing channel for water vapour profiling	634.8-651	$H_2{}^{18}O$, HOCl, ClO, HO_2, BrO, HNO_3, O_3, NO, N_2O, SO_2	Limb, Nadir	MLS, SMILES	**Window** (634.8-651), **MLS/SMILES Chemistry** (634-654)

Frequency band(s) (GHz)	Total Bandwidth required (MHz)	Spectral line(s) (GHz)	Measurement			Typical Scan Mode	Existing or planned Instrument(s)	Supporting information
			Meteorology – Climatology	Window	Chemistry			
656.9-692	35 100	658 **(H_2O)**, 660.49 **(HO_2)**, 688.5 **(CH_3Cl)**, 691.47 **(CO)**, 687.7 **(ClO)**	WATER vapour profiling, CLOUD	676.5-689.5	HO_2, ClO, CO, CH_3Cl	Limb, Nadir, Conical	CIWSIR, MWI, MLS	**Water line** (669.7-676.5)**, Cloud Measurements** (665.2-671.2, 677-692), **MWI cloud ice and cirrus** (656.9-662.7, 665.3-671.1), **Window** (658.3-669.7,676.5-689.5), **MLS Chemistry** (659-661), **CIWSIR Chemistry** (677-692),
713.4-717.4	4000	715.4 **(O_2)**	OXYGEN			Limb		
729-733	4000	731 **(HNO_3)**, 731.18 **($O^{18}O$)**	OXYGEN		$O^{18}O$, HNO_3	Limb		
750-754	4 000	752 **(H_2O)**	WATER			Limb		
771.8-775.8	4 000	773.8 **(O_2)**	OXYGEN			Limb		
823.15-845.15	22 000	834.15 **(O_2)**	OXYGEN					**Oxygen line** (823.15-845.15, BW: 3 GHz, max. offset: 9.5 GHz)
850-854	4 000	852 **(NO)**			NO	Limb		
857.9-861.9	4 000	859.9 **(H_2O)**	WATER			Limb		
866-882	16 000		CLOUD, WINDOW			Conical	CIWSIR	**Cloud Measurements (**866.5-869.5, 868-881, 878.5-881.5), **Window** (866.9-881.9)
905.17-927.17	22 000	916.17 **(H_2O)**	WATER					
951-956	5 000	952 **(NO)**, 955 **($O^{18}O$)**	OXYGEN		$O^{18}O$, NO	Limb	SOPRANO	
968.31-972.31	4 000	970.3 **(H_2O)**	WATER			Limb		
985.9-989.9	4 000	987.9 **(H_2O)**	WATER			Limb		

Resolution SFCG 30-1

BASIC GENERAL PARTITIONING AND SHARING CONDITIONS FOR THE BAND 401 – 403 MHz FOR FUTURE LONG-TERM COORDINATED USE OF DATA COLLECTION SYSTEMS ON GEOSTATIONARY AND NON-GEOSTATIONARY METSAT AND EESS SYSTEMS

The SFCG,

CONSIDERING

a) that Data Collection Systems (DCS) are operated on geostationary and non-geostationary MetSat and EESS systems in the frequency band 401 – 403 MHz;

b) that for next generation DCS systems on both geostationary and non-geostationary MetSat and EESS systems, bandwidth requirements have significantly increased;

c) that the increased spectrum requirements for both geostationary and non-geostationary MetSat and EESS systems require all operators to respect a basic general partitioning of the band 401 – 403 MHz for current and future DCS systems accompanied by a number of sharing conditions;

d) that in the framework of SFCG and CGMS, sharing conditions and a basic general partitioning of the band 401 – 403 MHz for current and future DCS systems have been developed;

RESOLVES

1. that operators of current and future DCS systems on geostationary and non-geostationary MetSat and EESS satellites plan frequency use in accordance with the basic general partitioning of the band 401 – 403 MHz as shown in Annex 1, taking into account the sharing conditions as detailed in Resolves 2 to 6 below;

2. that the band 401.7 - 402.435 MHz remains available only for DCS on geostationary MetSat systems in cross-support. However, within this frequency range, the non-geostationary MetSat system Meteor-3M, which is planned for use in the band 401.899 – 401.998 MHz, will only operate over the territory of the Russian Federation;

3. that the band 402.435 – 402.850 MHz will only be used for DCS on geostationary MetSat systems, noting that an ARGOS GEO component may also use a part of this band when compatible and coordinated with the geostationary DCS systems;

4. that the band 401.1 – 401.4 MHz will be used for DCS on geostationary MetSat systems. However, within this frequency range, the bands 401.1 – 401.2 MHz and 401.3 – 401.4 MHz can also be used for ARGOS-4 platforms under the following conditions:

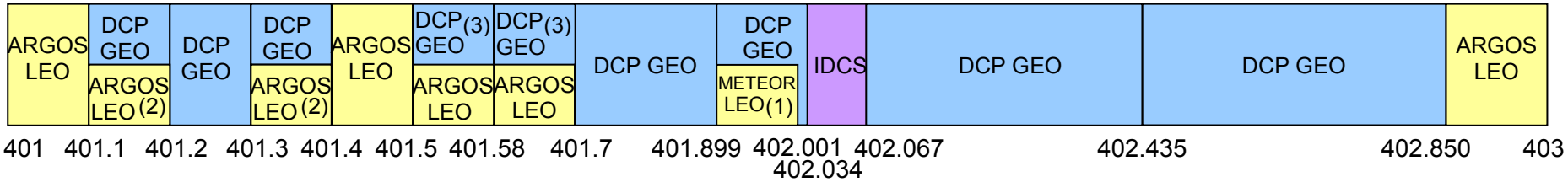
    - Maximum EIRP of -3 dBW;
    - Maximum number of ARGOS-4 active platforms to be deployed in each of the two sub-bands not to exceed 1000 within the visibility circle of FY-2 and FYMETSAT-4 satellites;
    - Maximum duty cycle (ratio of transmission duration over the repetition period) of each platform not to exceed 0.01 (on average 0.6 sec over 60 sec);

5. that the bands 401 – 401.1 MHz, 401.4 – 401.7 MHz and 402.850 – 403 MHz, will be designated to the ARGOS LEO system (ARGOS-B and ARGOS-4). However, the sub-band 401.5 – 401.7 MHz can also be used by DCP GEO systems of the Russian Federation, noting that for the sub-band 401.58 – 401.7 MHz these systems must be limited to operation over Russian territory with a maximum EIRP of 16 dBW;

6. that the band 402.034 – 402.067 MHz will be dedicated to the International Data Collection Systems (IDCS).

Annex 1

Basic general partitioning of the band 401 – 403 MHz for future long-term coordinated use of DCS systems on geostationary and non-geostationary MetSat and EESS systems



(1) The following conditions contained in Resolves 2 of Resolution SFCG 30-1 apply: In the band 401.899 – 401.998 MHz the non-geostationary MetSat system Meteor-3M will only operate over the territory of the Russian Federation.

(2) The following conditions contained in Resolves 4 of Resolution SFCG 30-1 apply for the use of the bands 401.1 - 401.2 MHz and 401.3 - 401.4 MHz by ARGOS-4 platforms:

- Maximum EIRP of -3 dBW;
- Maximum number of ARGOS-4 active platforms to be deployed in each of the two sub-bands not to exceed 1000 within the visibility circle of FY-2 and FYMETSAT-4 satellites;
- Maximum duty cycle (ratio of transmission duration over the repetition period) of each platform not to exceed 0.01 (on average 0.6 sec over 60 sec).

(3) The following conditions contained in Resolves 5 of Resolution SFCG 30-1 apply: The band 401.5 – 401.7 MHz can also be used by DCP GEO systems of the Russian Federation, noting that for the sub-band 401.58 – 401.7 MHz these systems must be limited to operation over Russian territory with a maximum EIRP of 16 dBW.

Resolution SFCG 32-1R2

SFCG OBJECTIVES FOR WORLD RADIOCOMMUNICATION CONFERENCES

The SFCG,

CONSIDERING

a) that its member agencies are vitally interested in having provisions in the ITU Radio Regulations which enhance future systems operations of the space science services;

b) that it is critical to ensure the availability and protection of the frequency bands necessary for spaceborne Earth observation applications and in particular:
- disaster prediction, detection and mitigation;
- global warming and climate change monitoring;

c) that several SFCG member agencies are interested in human exploration of the Moon and Mars and are actively planning for such missions;

d) that several SFCG member agencies are also interested in space research satellite missions to investigate the characteristics of our solar system, the physical phenomena taking place in space and the structure of the universe;

e) that changes to the Radio Regulations can only be accomplished at World Radiocommunication Conferences (WRCs);

f) that on the agendas of these WRCs, items of interest to SFCG member agencies may be included;

g) that the agenda for WRC-2015 is given in Resolution **807 (WRC-12)**;

h) that it is essential for SFCG member agencies to coordinate their Conference preparations and to provide the necessary rationale for their requirements in order to achieve the desired results at WRCs;

NOTING

that consideration of the frequency allocations required to implement space systems to be used in disaster prediction, disaster detection, disaster mitigation and environmental

(including weather and climate) monitoring is critical for public safety and property protection;

RESOLVES

1. that the SFCG WRC Objectives identified in Annex 1, for the next and subsequent competent World Radiocommunication Conferences shall be actively pursued by Member Agencies through participation at the relevant national, regional and ITU meetings;

2. that, in preparation for WRCs, Annexes 1 and 2 shall be updated in the light of Conference agendas, evolving Objectives, and changing status of studies;

3. that Annex 2 shall list items of interest to SFCG members for consideration at a future conference, but not yet sufficiently mature for inclusion in Annex 1.

4. that member agencies will urge their Administrations to make proposals to competent WRCs which satisfy these Objectives.

Annex 1 to SFCG Resolution 32-1R2

SFCG WRC-15 Objectives

Introduction

This Annex presents the objectives of SFCG members concerning issues affecting space science services on the agenda of the World Radiocommunication Conference 2015 (WRC-15). The contents may be used by SFCG members to inform their Administrations, and to facilitate conference preparation and WRC consideration.

The presentation is organized to align with the Agenda for the WRC-15 as presented in Resolution **807 (WRC-12)**. Not all of the items in that Agenda are of interest to the SFCG and therefore only those specific agenda items, relating to SFCG issues, are discussed herein.

The SFCG is concerned with the effective use and management of those radio frequency bands that are allocated by the Radio Regulations of the ITU to the Space Research, Space Operations, Earth Exploration Satellite, and Meteorological Satellite services. SFCG promotes spectrum efficiency and recognizes the need for and the value of sharing frequency bands between more than one radio service, in cases where mutually agreed sharing and protection criteria have been established based upon the results of ITU-R studies.

However, in frequency bands allocated to the space science services, and where sharing has been shown to be infeasible, the SFCG holds the view that such sharing should not be implemented, and would support any review by Administrations that might lead to a reduction in the number of such infeasible sharing situations in the Table of Frequency Allocations contained in the ITU Radio Regulations (RR).

SFCG attaches a particular importance to the protection of frequency bands used by space-based passive sensors to provide vital ecological and environmental data that is unobtainable by any other means. Such passive sensors depend for their successful operation on frequency bands that are defined by the physical laws.

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Agenda Item 1.1 to consider additional spectrum allocations to the mobile service on a primary basis and identification of additional frequency bands for International Mobile Telecommunications (IMT) and related regulatory provisions, to facilitate the development of terrestrial mobile broadband applications, in accordance with Resolution **233 (WRC-12)**;

Resolution **233 (WRC-12)** calls for the study of additional mobile broadband spectrum requirements including IMT and the study of potential candidate frequency bands. The Resolution also invites WRC-15 to take into consideration the results of these studies and take appropriate action.

The agenda item does not specify bands of study but studies will likely concentrate on bands below 6 GHz, in which there are a number of frequency bands of interest for SFCG. WP5D is currently considering whether to identify suitable frequency ranges above 6 GHz.

SFCG Objective

SFCG supports the protection of existing space science service and GNSS allocations. No allocations of spectrum to support mobile broadband systems, IMT or RLAN, should be made in space science service bands unless acceptable sharing criteria and conditions are developed.

On the basis of the list of frequencies where studies have been called for in JTG 4-5-6-7, the main frequency bands of concern to SFCG member agencies are:

- the 410-420 MHz band, used for proximity and docking operations at the International Space Station. This band was identified by WP5D as suitable for IMT. However, no studies have been put forward supporting its identification for IMT or RLAN systems within the JTG.
- the 1400 – 1427 MHz band, used for EESS (passive) (e.g. Aquarius, SMOS, SMAP missions), whose adjacent bands 1375 – 1400 MHz and 1427 – 1452 MHz have been proposed for IMT identification. Considering current technical studies, SFCG is of the view that any decision made about identification of the bands 1375 – 1400 MHz and 1427 – 1452 MHz for broadband mobile will have to be associated with the inclusion of relevant mandatory unwanted emissions limits in the 1400 – 1427 MHz band in the RR;
- the 1695 – 1710 MHz band, used for meteorological satellite applications. This band is used by all meteorological-satellite systems with Earth stations operated by almost all National Meteorological and Hydrological Services (NMHS) and many other users. This band is essential for providing operational and time-critical meteorological information to the users around the world. For this reason SFCG is opposed to an allocation/identification of the frequency band 1695 – 1710 MHz for terrestrial mobile broadband applications including IMT except if such allocation/identification ensures the protection of MetSat Earth station operations in that band;
- the 3400 – 4200 MHz band, used for Galileo Data Distribution Network and the dissemination of meteorological data by systems like EUMETCast, CMACast and GEONETCast;

- the 5350 – 5470 MHz active remote sensing band, used for SARs (e.g. Radarsat, GMES Sentinel-1 satellites), and altimeters (e.g. GMES Sentinel-3 satellites, HY-2). On the basis of the technical studies, which show that RLANs cannot share the band 5350 – 5470 MHz with EESS (active) and that no credible (practical or effective) mitigation technique has been identified, SFCG opposes an allocation to the MS in this band for use by terrestrial mobile broadband applications.

SFCG does not support the consideration of bands above 6 425 MHz under this agenda item at WRC-15.

In addition, SFCG opposes any revisiting of the conditions set in RR No. 5.391 pertaining to the bands 2025 – 2110 MHz and 2200 – 2290 MHz used for space research, earth exploration-satellite and space operation services and therefore objects to any IMT identification in these bands under agenda item 1.1.

Status

JTG 4-5-6-7 is the responsible group and WPs 7B and 7C are among the contributing groups. A list of frequency bands to be studied by the JTG has been identified. Taking into account technical studies, compatibility between mobile systems (IMT or RLAN) and systems of any other services appears problematic, as expected, given the forecasted density and mobility of the IMT systems. At the February 2014 meeting of JTG 4-5-6-7 questions were raised regarding the overall spectrum requirements of IMT. However, this matter was liaised to WP5D as the appropriate group for making that determination.

It is to be noted that potential IMT target frequency bands above 6 GHz will more than likely be the subject of a new proposed AI for WRC-18 and are not covered under this WRC-15 AI.

JTG studies have shown that the current unwanted emissions level of -60 dBW/27 MHz, as recommended in WRC Resolution 750 for the mobile service, does not ensure protection of passive sensors in the 1400-1427 MHz band from potential IMT systems. It is noted that the current recommended limit has not been applied to the only known case of IMT usage of the adjacent band 1427-1452 MHz. JTG currently concludes (as in PDNR ITU-R RS.[EESS 1.4 GHz]) that unwanted emissions levels of -75/80 dBW/27 MHz (for Base stations) and -65 dBW/27 MHz (for terminal stations) in the 1400-1427 MHz band are required. (Note: the first value for base stations covers the case of an IMT allocation on one side of passive band and the second value covers the case of an IMT allocation on both sides of the passive band).

DNR ITU-R SA.[METSAT 1.7 GHZ] shows that the required protection area around MetSat stations from which potential IMT base stations in the 1 695-1 710 MHz frequency band would be up to several hundred kilometres whereas for IMT mobile terminals, the required separation distances for NGSO case could be up to more than 120 kilometres, even considering low density deployment in rural areas. Therefore, sharing between IMT base stations and MetSat stations in the 1 695-1 710 MHz frequency band is not feasible and would similarly not be feasible with user terminals in most countries of the world.

DNR ITU-R SA.[2025 - 2290 MHz] has also been agreed in JTG concluding that sharing is not feasible between LTE systems and incumbent DRS forward and return links operating in the 2 025-2 110 MHz and 2 200-2 290 MHz frequency bands in the space research (space-to-

space), Earth exploration-satellite (space-to-space) and space operations (space-to-space) services. This reaffirms the previous ITU-R studies as given in Recommendation ITU-R SA.1154 incorporated by reference in RR No. 5.391 that states that administrations shall not introduce high-density mobile systems in these bands.

JTG studies summarized in PDNR ITU-R RS.[EESS RLAN 5 GHz] show that sharing between RLAN and EESS(active) in the band 5350-5470 MHz is not feasible unless additional mitigation techniques are identified to compensate the compatibility deficit shown to be between 6 and 30 dB.

It is also noted that as few as 2 outdoor RLAN operating in the 250 km^2 SAR footprint would be sufficient to exceed the EESS (active) protection criteria. So far the studies in JTG have not resulted in the identification of any mitigation technique that could credibly be implemented and enforced. It is highly probable that the interference scenarios offer no room for potential mitigation techniques that would allow for filling a gap of up to 30 dB. Therefore, any RLAN identification in the 5350-5470 MHz band would put at risk current and planned EESS (active) sensors that are essential to many Earth observation programs.

At its May 2014 meeting, WP7C liaised to JTG 4-5-6-7 its view that possible mitigation techniques proposed by RLAN proponents including use of dynamic frequency selection, connected databases and image post-processing techniques will be either ineffective in mitigating interference to EESS (active) or impractical for implementation on a global basis. At its May 2014 meeting WP5A liaised to JTG 4-5-6-7 stating that WP 5A is unable to comment on the feasibility and appropriateness of implementing the proposed mitigation methods by RLAN devices in order to protect incumbent services in the 5350-5470 MHz band.

Agenda Item 1.3 to review and revise Resolution **646 (Rev.WRC-12)** for broadband public protection and disaster relief (PPDR), in accordance with Resolution **648 (WRC-12)**; Resolution **648** calls for studies on broadband PPDR and the revision of Resolution **646**.

SFCG Objective

SFCG supports the protection of existing space science service allocations. No additional identification of spectrum to support PPDR should be made in space science service bands unless acceptable sharing criteria are developed. SFCG should monitor the evolution of the agenda item in order to avoid PPDR identification immediately above 406.1 MHz (noting the connection with AI 9.1.1).

Status

WP 5A is the responsible group and WPs 7B and 7C are interested groups. WP5A preliminary studies indicate that required spectrum bandwidth for broadband PPDR is 2x10 MHz. The potential candidate frequency ranges under discussion are 400 MHz, 700 MHz, 4940-4990 and 5850-5925 MHz. WP5A starts to develop new Report covering Broadband PPDR which would be complementary to ITU-R Report M.2033. As of May 2014, no concerns to space science services have been identified regarding PPDR under this agenda item.

Agenda Item 1.5 to consider the use of frequency bands allocated to the fixed-satellite service not subject to Appendices **30**, **30A** and **30B** for the control and non-payload communications of unmanned aircraft systems (UAS) in non-segregated airspaces, in accordance with Resolution **153 (WRC-12)**;

Resolution **153 (WRC-12)** calls for possible regulatory actions to support the use of FSS frequency bands for the UAS Control and Non Payload Communications (CNPC) links ensuring the safe operation of UAS CNPC links.

The potentially affected space science service bands are: 8025-8500 MHz EESS and SRS and 13.75-14 GHz SRS(s-s). Other frequency bands of direct interest to SFCG among those currently identified for studies by WP 5B in their PDNR ITU-R M.[UAS-FSS] are the srs bands 14-14.3 GHz and 14.4-14.47 GHz, and the EESS (passive) band 18.6-18.8 GHz.

SFCG Objective

SFCG supports the protection of existing space science service allocations while recognizing the practical requirement of UAS CNPC links, in particular for beyond line of sight operations (BLOS), in FSS bands. There is a secondary SRS allocation in the band 13.75-14 GHz (primary status with respect to FSS systems for some GSO SRS networks for which API has been received prior to a certain date). No changes to the FSS allocation in the 13.75-14 GHz band should be made unless acceptable sharing criteria are developed with the SRS. Although it can be assumed that the focus will be more on FSS Ku and Ka bands, the SFCG also seeks to ensure that this item will not lead to authorising UAS in the FSS X-band allocations shared with EESS and METSAT. SFCG also supports the protection of secondary srs allocations in 14-14.3 GHz and 14.4-14.47 GHz bands. Finally, any use of FSS bands for UAS CNPC links in 18.6-18.8 GHz band must meet the provisions of RR Nos. 5.522A and 5.522B.

Status

WP 5B is the responsible group and WPs 7B and 7C are interested groups. Approved Draft CPM text includes two methods to satisfy the agenda item.

Method A enables the use of the FSS for UAS CNPC applications operated in accordance with ICAO standards and procedures, through a footnote and associated Resolution. The intention being that compliance with the Resolution would ensure that all required technical, operational, and regulatory conditions are met. This Method will permit FSS links supporting UAS CNPC to operate without adverse effects to existing and future FSS networks. The footnote would only be applied to frequency bands allocated to the FSS not subject to Appendix 30, 30A, or 30B in the frequency ranges 10.95-14.5 GHz, 17.8-20.2 GHz and 27.5-30 GHz, as appropriate, for which studies have been conducted.

Method B proposes no change to the Radio Regulation. Some administrations see a considerable technical, operational and regulatory obstacles for the use of FSS for UAS CNPC links. Moreover, existing allocations for AMS(R)S as well as AMSS and MSS, under certain conditions could satisfy the requirements for UAS CNPC in the frequency bands of these services.

An additional method proposing allocations to AMS(R)S in the relevant frequency bands was also proposed. However based on legal advice that the scope of the agenda item did not include the possibility to consider additional allocations, this method was considered to be outside the scope of the agenda item and is therefore not included in this section of the CPM text.

CPM text on this agenda item does not include any agreed text on analysis of results of the study. Only input contributions, reflecting different approaches, will be listed.

Agenda Item 1.6.1 to consider possible additional primary allocations to the fixed-satellite service (Earth-to-space and space-to-Earth) of 250 MHz in the range between 10 GHz and 17 GHz in Region 1 and review the regulatory provisions on the current allocations to the fixed-satellite service within that range in accordance with Resolution **151 (WRC-12)**.

Resolution **151 (WRC-12)** calls for studies of possible bands for new primary allocations to the fixed-satellite service of 250 MHz in both directions in Region 1 within the bands 10-17 GHz, with particular focus on the frequency range that is contiguous (or near contiguous) to the existing fixed-satellite service allocations, while protecting the existing primary services in the band 10-17 GHz;

Resolution **151** excludes from consideration modification of Nos. **5.502** and **5.503** and Resolution **144 (Rev.WRC-07)**. This effectively ensures that the regulatory protection provided by these footnotes to SRS (s-s) in the 13.75-14 GHz band will remain unchanged by this agenda item. Potentially affected space science service bands are: 10.6-10.7 GHz EESS (passive) SRS (passive); 13.25-13.75 GHz EESS (active) and SRS (active); 13.4-13.75 GHz srs; 14.5-15.35 GHz srs; 15.2-15.35 GHz eess (passive) and srs (passive); 15.35-15.4 GHz EESS (passive) and SRS (passive); 16.6-17.1 GHz srs (deep space) (Earth-to-space). Resolution **151** also precludes the consideration of the Appendix 30B band 12.75-13.25 GHz thereby ensuring the protection of the secondary srs (deep space) (space-to-Earth) allocation in this band.

SFCG Objective

SFCG supports the protection of existing space science service allocations. No additional allocation of spectrum to support FSS (E-s or s-E) should be made in space science service bands unless acceptable sharing conditions are agreed. There is particular concern with the possible allocation of FSS (Earth-to-space) in the 13.25-13.75 GHz band allocated to EESS (active). This band is used for active remote sensing (altimeters and scatterometers) by missions such as Cryosat, Jason-2, -3, Jason-CS, Sentinel-3, and HY-2. Prior studies have shown incompatibility between these services. Therefore, SFCG supports no new allocation to FSS (E-s) in the band 13.25-13.75 GHz.

Other services to be protected are the EESS (passive) and SRS (passive) in the band 10.6-10.7 GHz, eess (passive) and srs (passive) in the band 15.2-15.35 GHz, the srs in the bands 13.4-13.75 GHz and 14.5-15.35 GHz, and the standard frequency and time signal-satellite (Earth-to-space) service in the band 13.4-13.75 GHz.

The band 10.6-10.7 GHz is allocated to EESS (passive). RR No.5.340 prohibits all emissions in the band 10.68-10.7 GHz. Therefore, SFCG supports no new allocation to FSS (s-E) or FSS (E-s) in the band 10.6-10.7 GHz.

The frequency band 13.4-13.75 GHz is used by DRS systems for forward inter-orbit links and for return feeder links. The frequency band 14.5-15.35 GHz is used by DRS systems for return inter-orbit links and for forward feeder links and also for wideband SRS downlinks to transmit high rate scientific data from LEO, GSO or HEO SRS satellites. The feasibility of sharing between these SRS links and FSS links requires further study using protection criteria of ITU-R Recommendations SA.609 and SA.1155 and technical characteristics of ITU-R Recommendations SA.1414 and SA.1626. In case an allocation for FSS would be adopted in these bands, the SRS forward and return inter-orbit links and down links notified before WRC-15 must receive co-equal status with FSS.

In addition, the band 13.4-13.75 GHz will be used by the ACES system under the standard frequency and time signal-satellite (Earth-to-space) service and its future operation needs to be ensured.

Status

WP 4A is the responsible group and WPs 7B and 7C are contributing groups. Prior sharing studies between FSS (Earth-to-space) and EESS (active) for the adjacent frequency range 13.75-14 GHz clearly concluded that sharing was not feasible. For this reason the EESS (active) allocation in that range was suppressed and the EESS (active) allocation was shifted to 13.25-13.75 GHz so as to avoid frequency overlap with FSS (E-s).

ITU studies concluded that sharing between EESS (active) and FSS (E-to-s) is not feasible,

Liaison statements have been exchanged between WP4A and WP7C clarifying the parameters in the FSS deployment model and the protection criteria of the EESS (active) missions in the band. Analyses conducted on a global basis have shown some degree of incompatibility between FSS (E-s) and EESS (active). Analyses are continuing that examine the availability when specific measurement areas of interest for the EESS (active) are considered using the criteria of Recommendation ITU-R RS.1166-4. Studies have shown that sharing may be feasible with FSS (space-to-Earth) under the deployment model provided by WP 4A and with a number of limitations on FSS such as PFD, antenna size, etc.

WP 4A also conducted sharing studies between proposed FSS (space-to-Earth) and FSS (Earth-to-space) and EESS (passive) for the band 10.6-10.7 GHz and concluded that sharing was not feasible. These study results are incorporated in the working document.

To date the draft CPM text being prepared by WP4A includes a no change (NOC) method and an allocation method separately for FSS (Earth-to-space) and FSS (space-to-Earth) in each of three band segments 13.4-13.75 GHz, 14.5-14.8 GHz and 14.8-15.1 GHz (example Regulatory text is provided for only 13.4-13.75 GHz FSS (Earth-to space) with regulatory text for the remaining bands still to be completed.

Agenda Item 1.6.2 to consider possible additional primary allocations to the fixed-satellite service (Earth-to-space) of 250 MHz in Region 2 and 300 MHz in Region 3 within the range 13-17 GHz; and review the regulatory provisions on the current allocations to the fixed-satellite service within this range, taking into account the results of ITU-R studies, in accordance with Resolution **152 (WRC-12)**;

Resolution **152 (WRC-12)** calls for studies of possible bands for a new primary allocation to the fixed-satellite service in the Earth-to-space direction of 250 MHz in Region 2 and 300 MHz in Region 3 within the bands 13-17 GHz.

Resolution **152** excludes from consideration modification of RR Nos. **5.502** and **5.503** and Resolution **144 (Rev.WRC-07)**. This effectively ensures that the regulatory protection provided by these footnotes to SRS (s-s) in the 13.75-14 GHz band will remain unchanged by this agenda item. Also excluded from consideration is the 13-13.25 GHz band (RR Appendix 30B). Potentially affected space science service bands are: 13.25-13.75 GHz EESS (active) and SRS (active); 13.4-13.75 GHz srs; 14.5-15.35 GHz srs; 13.25-13.75 GHz EESS (active) and SRS (active); 15.35-15.4 GHz EESS (passive) and SRS (passive); 16.6-17.1 GHz srs (deep space) (Earth-to-space).

SFCG Objective

SFCG supports the protection of existing space science service allocations. No additional allocation of spectrum to support FSS (Earth-to-space) should be made in space science service bands unless acceptable sharing conditions are agreed. There is particular concern with the possible allocation of FSS (Earth-to-space) in the 13.25-13.75 GHz band allocated to EESS (active). This band is used for active remote sensing (altimeters and scatterometers) by missions such as Cryosat, Jason-2, -3, Jason-CS, Sentinel-3, and HY-2. Prior studies have shown incompatibility between these services. Therefore, SFCG supports no new allocation to FSS (Earth-to-space) in the band 13.25-13.75 GHz.

Other services to be protected are the srs in the bands 13.4-13.75 GHz and 14.5-15.35 GHz and the eess (passive) and srs (passive) in the band 15.2-15.35 GHz.

The frequency band 13.4-13.75 GHz is used by DRS systems for forward inter-orbit links and for return feeder links. The frequency band 14.5-15.35 GHz is used by DRS systems for return inter-orbit links and for forward feeder links and also for wideband SRS downlinks to transmit high rate scientific data from LEO, GSO or HEO SRS satellites. The feasibility of sharing between this SRS links and FSS links requires further study using protection criteria of ITU-R Recommendations SA.609 and SA.1155 and technical characteristics of ITU-R Recommendations SA.1414 and SA.1626. In case an allocation to FSS is adopted in these bands, the SRS forward and return inter-orbit links and down links notified before WRC-15 must receive co-equal status with FSS.

In addition, the band 13.4-13.75 GHz will be used by the ACES system under the standard frequency and time signal-satellite (Earth-to-space) service and its future operation needs to be ensured

Status

WP 4A is the responsible group and WPs 7B and 7C are concerned groups. Prior sharing studies between FSS (Earth-to-space) and EESS (active) for the adjacent frequency range 13.75-14 GHz clearly concluded that sharing was not feasible. For this reason the EESS (active) allocation in that range was suppressed and the EESS (active) allocation was shifted to 13.25-13.75 GHz so as to avoid frequency overlap with FSS (E-s).

Liaisons statements have been exchanged between WP4A and WP7C clarifying the parameters in the FSS deployment model and the protection criteria of the EESS (active) missions in the band. Analyses conducted on a global basis have shown some degree of incompatibility between FSS (E-s) and both EESS (active) and srs. Analyses are continuing that examine the availability when specific measurement areas of interest for the EESS (active) are considered using the criteria of Recommendation ITU-R RS.1166-4.

To date the draft CPM text being prepared by WP4A includes a no change (NOC) method for the bands 13.0-13,4 GHz, 13.4-13.75 GHz, 14.5-14.8 GHz, 14.8-15.1 GHz and 15.1-17 GHz and separate allocation methods for FSS (Earth-to-space) each of three band segments 13.4-13.75 GHz, 14.5-14.8 GHz and 14.8-15.1 GHz (example regulatory text is provided for only 13.4-13.75 GHz FSS (Earth-to space)).

Agenda Item 1.8 to review the provisions relating to earth stations located on board vessels (ESVs), based on studies conducted in accordance with Resolution 909 (WRC-12);

Resolution **909 (WRC-12)** calls for review of the provisions relating to ESVs which operate in the FSS in the uplink bands 5 925-6 425 MHz and 14-14.5 GHz and consider possible modifications to Resolution **902 (WRC-03)**.

The potentially affected space science service band is: 14-14.3 GHz srs.

SFCG Objective

SFCG supports the protection of existing space science service allocations. No revision to the provisions relating to ESVs should be made in 14-14.5 GHz band unless acceptable sharing criteria are developed.

Status

WP 4A is the responsible group and WPs 7B and 7C are interested groups. There were extensive discussions at the February 2014 WP4A meeting on ESV's with many differing views. The meeting produced three possible methods for satisfying the agenda item in addition to NOC:

- Increasing off-shore protection distances in the C and Ku bands.
- Establishment of different protection distances for different maximum e.i.r.p. density levels (with reduction antenna diameters to 1.2 m and increase of number of ESV passes in C band)
- Establishment of different protection distances for different maximum e.i.r.p. density levels with considering the increasing the number of ESV passes in the C & Ku bands

SFCG remains concerned that any change from the existing fixed distances from shore needs to be verifiable and enforceable.

Agenda Item 1.9.1 to consider, in accordance with Resolution **758 (WRC-12)** possible new allocations to the fixed-satellite service in the frequency bands 7 150-7 250 MHz (space-to-Earth) and 8 400-8 500 MHz (Earth-to-space), subject to appropriate sharing conditions;

Resolution **758** calls for technical and regulatory studies on the possible new allocations to the FSS in the frequency bands 7 150-7 250 MHz (space-to-Earth) and 8 400-8 500 MHz (Earth-to-space) in order to ensure compatibility with existing services, with a view to extending the current worldwide allocation to the FSS in the bands 7 250-7 750 MHz (space-to-Earth) and 7 900-8 400 MHz (Earth-to-space). Resolution **758** excludes small VSAT-like usage in the possible new allocations and specifies that FSS operations be from fixed, known locations. Potentially affected space science service bands are: 7100-7155 MHz SOS, 7145-7190 MHz SRS (deep space) (Earth-to-space); 7190-7235 MHz SRS (Earth-to-space) and SOS; 8400-8450 MHz SRS (deep space) (space-to-Earth); 8450-8500 MHz SRS (space-to-Earth). It is to be noted that under Agenda Item 1.11, parts of the 7150-7250 MHz band are being considered for the addition of an EESS (Earth-to-space) allocation.

SFCG Objective

SFCG supports the protection of the science services in all frequency bands as indicated above. No new allocations to the FSS should be made in these frequency bands unless acceptable solutions are found to the following issues:

- Large coordination zones to be imposed around current and future SRS earth stations;
- Mechanisms to ensure full protection of SRS (deep space and near Earth) spacecraft as well as SOS links.

Status

WP 4A is the responsible group and WP 7B is a contributing group. Two scenarios of particular concern are:

- (1) the potential for FSS (Earth-to-space) interference to SRS (space-to-Earth) reception due to non-line-of-sight propagation in the 8400-8500 MHz band; and
- (2) the potential for FSS (space-to-Earth) interference to SRS (Earth-to-space) reception in the 7150-7235 MHz band, including critical near-Earth operation phases of deep space SRS missions such as LEOP, and Earth flybys and sample return in the 7150-7190 MHz band.

ITU-R studies have shown that large coordination zones surrounding SRS earth stations are needed in the scenario (1) to avoid interference. With regard to scenario (2), an e.i.r.p mask to be applied to FSS space station has been proposed for the protection of SRS spacecraft while in near Earth domain which needs to be assessed by space agencies.
The newly proposed e.i.r.p. mask reduces but does not eliminate the possibility of interference to the SRS spacecraft during its near-Earth operations. Further studies would be needed to ensure the protection of deep space SRS missions.

The draft CPM text contains two methods :

- No change;
- Allocation to FSS in the 8400-8500 MHz and 7150-7250 MHz bands with appropriate regulatory conditions such as limitation to GSO FSS, specific earth stations with a minimum antenna diameter, obligations of coordination, e.i.r.p. mask for FSS space stations, and no protection from SRS.

Draft CPM text was liaised to WP7B. In this liaison statement WP4A also stated that it has received a proposal for a revision of RR No. **5.460** and RR No. **5.465** to clarify the reference to deep space as a result of discussions at the WP4A meetings. WP4A considers modification of the above RRs to be in the purview of WP7B.

Sharing in these same SRS bands with the mobile satellite service was found to be infeasible under WRC-12 AI 1.25. Many of the same conditions that made sharing with MSS infeasible also apply to sharing with FSS in these bands, particularly the 7150-7190 MHz band, however provisions requiring FSS operation from fixed, known locations and exclusion of small VSAT terminals may facilitate sharing within the 8400-8500 MHz band.

Agenda Item 1.9.2 to consider, in accordance with Resolution **758 (WRC-12)** the possibility of allocating the bands 7 375-7 750 MHz and 8 025-8 400 MHz to the maritime-mobile satellite service and additional regulatory measures, depending on the results of appropriate studies;

Resolution **758** calls for technical and regulatory studies on the possible new allocations to the maritime mobile-satellite service (MMSS) in the frequency bands 7375-7750 MHz (space-to-Earth) and 8025-8400 MHz (Earth-to-space) while ensuring compatibility with existing services,

The potentially affected space science service bands are: 7450-7550 MHz MetSat (s-E, GSO); 8175-8215 MHz MetSat (E-s); and 8025-8400 MHz EESS (s-E) and 8400-8450 MHz SRS (deep space) (space-to-Earth).

SFCG Objective

SFCG supports the protection of existing METSAT and EESS allocations as well as the protection of SRS (s-E) (deep space) allocation from adjacent band interference. No new allocations to the MMSS should be made in the frequency band 8025-8400 MHz. It is noted that the International Maritime Organisation has no interest in this allocation. Particular concern is noted with regard to potential interference to EESS (s-E) operations in 8025-8400 MHz at high latitudes from ships operating in proximity, and out-of-band interference to SRS (deep space) (s-E) reception in the 8400-8450 MHz band. Large exclusion zones would be needed to avoid interference to existing and future EESS and SRS earth stations from potentially large numbers of ships. Many of the more than 100 existing EESS and SRS earth stations are located near coastal areas (e.g., Svalbard, McMurdo, Maspalomas, Lannion, Wallops) and could be seriously affected by emissions from vessels navigating in the area up to distances of hundreds of km from the coastline. SFCG considers that the enforcement of these large exclusion zones would not be feasible in practice, leading to interference that will be very difficult to track due to the mobile nature of the systems. It is also to be noted that any new EESS/SRS Earth station would require updating the database of the exclusion zones.

Therefore SFCG is opposed to this proposed allocation to MMSS in the frequency band 8025-8400 MHz.

Status
WP 4C is the responsible group and WP 7B is a contributing group. Preliminary sharing studies using reasonable assumptions for MMSS systems were conducted by WP7B and liaised to WP4C. Required separation distances of between 280 km and over 500 km were found depending on the location of EESS and SRS (deep space) ground stations. The sharing studies provided by WP7B were incorporated into the working document toward a preliminary draft new report on sharing carried over in the WP4C Chairman's Report. WP4C has not fully responded to questions from WP7B on planned MMSS operations. Information on the unwanted emission characteristics of an MMSS earth station is still required. WP4C has confirmed that there have been no requirements put forward for non-geostationary orbit MMSS systems.

Agenda Item 1.10 to consider spectrum requirements and possible additional spectrum allocations for the mobile-satellite service in the Earth-to-space and space-to-Earth directions, including the satellite component for broadband applications, including International Mobile Telecommunications (IMT), within the frequency range from 22 GHz to 26 GHz, in accordance with Resolution **234 (WRC-12)**;

Resolution **234 (WRC-12)** calls for sharing and compatibility studies towards additional allocations to the mobile-satellite service in the Earth-to-space and space-to-Earth directions, within portions of the bands between 22 GHz and 26 GHz, while ensuring protection of existing services within these bands as well as taking into account No. **5.340** and No. **5.149**.

Resolution **234 (WRC-12)** also recognizes that unwanted emissions in the band 23.6-24 GHz will need to be limited to ensure protection of systems of the EESS (passive), SRS (passive) and radio astronomy services.

SFCG Objective

SFCG supports the protection of all the space science bands in the range 22-26 GHz considered under this agenda item. No new allocations to the MSS should be made unless acceptable sharing criteria with the affected space science service are developed.

The main frequency bands at risk for SFCG member agencies are:

1) The SRS Earth-to-space allocation in the band 22.55 – 23.15 GHz
2) The Inter-satellite band 22.55 – 23.55 GHz and the first 750 MHz of the Inter-satellite band 25.25 – 27.5 GHz.
3) The allocations to EESS (passive) in the bands 23.6-24 GHz (purely passive, RR No. 5.340, but to be protected against unwanted emissions taking into account interference apportionment and the levels contained in ITU Resolution 750 (rev. WRC-12)) as well as the band 22.21 – 22.5 GHz.
4) The first 500 MHz of the EESS/SRS space-to-Earth band 25.5 – 27.0 GHz

Note - The lack of clarity on the technical parameters of these new MSS systems needed for appropriate compatibility studies with science services is another element of concern for SFCG.

Status

WP 4C is the responsible group and WPs 7B and 7C are contributing groups. At the last WP 4C meeting, the UAE have proposed to focus on the bands 22.55-23.15 GHz for the downlink and 24.25-24.45 GHz for the uplink. Another option has been suggested offline by the UAE: 24.25-24.45 for the uplink, and 24.45-24.65 GHz for the downlink. To finish, the Russian Federation has studied the bands 23.15-23.55 GHz (used by Iridium ISS links) for the downlink, and 25.25-25.5 GHz for the uplink.

So far, the CPM text contains two methods: one is a NOC, while the other in square brackets is to make an allocation in some parts of the 22-26 GHz band, with everything to be defined.

Compatibility study with the EESS (passive) allocations has never been performed so far due to the lack of information regarding proposed MSS characteristics. During the May 2014 WP 7C meeting, a liaison statement has been sent to WP 4C, which stated WP 7C concern on potential inclusion of the EESS (passive) band and/or adjacent bands to EESS (passive) allocations into the possible Methods of the draft CPM text without appropriate compatibility study with EESS (passive) band(s).

Agenda Item 1.11 to consider a primary allocation for the Earth exploration-satellite service (Earth-to-space) in the 7-8 GHz range, in accordance with Resolution **650 (WRC-12)**;

Resolution **650 (WRC-12)** calls for study of the spectrum requirements and compatibility studies in the 7-8 GHz range for EESS (Earth-to-space) telecommand operations in order to complement telemetry operations of EESS (space-to-Earth) in the 8 025-8 400 MHz band.

Resolution **650** indicates that priority is given to the band 7 145-7 235 MHz. Potentially affected space science service bands are: 7145-7190 MHz SRS (deep space) (E-s); 7190-7235 MHz SRS (E-s). Also, noting that under Agenda Item 1.9.1 possible new allocations to the FSS in the frequency band 7 150-7 250 MHz (space-to-Earth) are being considered.

SFCG Objective

SFCG supports a primary allocation to EESS (E-s) in the band 7190-7250 MHz as provided for in Method A of the Draft CPM Report. This would satisfy the EESS spectrum requirements identified.

The frequency range 7235-7250 MHz would be used for those cases of EESS spacecraft links presenting a difficult sharing scenario with SRS spacecraft and SOS links in the frequency range 7190-7235 MHz.

SFCG does not support an allocation to EESS (E-to-s) in the 7145-7190 MHz band to EESS (E-s) due to incompatibility with SRS (deep space) .

Status

WP 7B is the responsible group.

ITU-R studies of the bandwidth requirements show a need for 56 MHz for EESS (E-s) in case the band is shared with other satellite services as given in ITU-R Report SA.2272.

ITU-R studies have indicated that there will be difficulties in sharing between EESS and SRS (deep space) in the 7 145-7 190 MHz band during some critical phases of the SRS (deep space) missions whereas coordination should allow compatibility between SRS and EESS (E-s) in the 7 190-7 235 MHz.

While it was confirmed that the bands above 7125 MHz are not used for MS systems, it was shown that sharing with FS systems is feasible on the basis of the Appendix 7 coordination mechanisms already applied to the SRS earth station case in this band. The results of studies between EESS (E-s) and FS are summarised in the Report ITU-R SA.2275 "Sharing between the EESS (Earth-to-space) and the fixed service in the 7-8 GHz range".

Studies have also shown compatibility with the SOS systems allocated in the Russian Federation territory.

On this basis, an allocation in the range 7190-7250 MHz has been proposed to provide the required bandwidth and at the same time to protect the existing services.

Three methods were proposed, two add a new EESS (Earth-to-space) allocation and the third is NOC. All three methods would suppress Resolution 650 (WRC-12), consequentially.

Method A: This method would add a global primary allocation to the EESS in the band 7 190-7 250 MHz in the Table of Frequency Allocations in RR Article **5**. It would also consequently modify RR Appendix **7**, Table 7b as well as Tables 21-2 and 21-3 in RR Article **21**.
In addition, there are three options with respect to additional regulatory provisions, the three options are:

> **Option 1** - Addition of a new footnote in RR Article 5 limiting the EESS use of the band 7 190-7 250 to non-geostationary EESS satellite systems.
> **Option 2** - Modify RR footnote No. 5.460 in order to indicate that geostationary EESS satellite systems shall not claim protection from existing and future stations of the FS and MS, and that No. 5.43A does not apply.
> **Option 3** - this is Option 2 with additional restriction to allow only TT&C operations of the EESS spacecraft in the band 7 190-7 250 MHz, because the aim of the Resolution 650 (WRC-12) is to obtain a new allocation in the band 7-8 GHz for the TT&C operations.

Method B – Similar to method A, this method would add a global primary allocation to the EESS in the band 7 190-7 250 MHz in the Table of Frequency Allocations in RR Article **5**. It would also consequently modify RR Appendix **7**, Table 7b as well as Table 21-3 in RR Article **21**. However, it does not modify Table 21-3.
In addition, this method adds the following restrictions to the new EESS allocation:

- Limits to non-geostationary satellite systems;
- Requires coordination with SOS under RR No. **9.11A** in the frequency band 7 190-7 235 MHz;
- EESS (Earth-to-space) space stations shall not claim protection from SRS earth stations in the frequency band 7 190-7 235 MHz nor shall they claim protection from

existing and future stations in the FS and MS in the frequency band 7 235-7 250 MHz.

Method C - No change in the RR Article **5**.

Note - Given that there is an apparent misunderstanding among some regions regarding the possibility of interference to the fixed service SFCG has requested its members to intervene at their regional meetings and explain why the support for this allocation would not create problems to any other service in this band, in particular to the fixed service.

Agenda Item 1.12 to consider an extension of the current worldwide allocation to the Earth exploration-satellite (active) service in the frequency band 9 300-9 900 MHz by up to 600 MHz within the frequency bands 8 700-9 300 MHz and/or 9 900-10 500 MHz, in accordance with Resolution **651 (WRC-12)**;

Resolution **651 (WRC-12)** calls for a possible extension of the current worldwide allocation to the EESS (active) in the frequency band 9 300-9 900 MHz by up to 600 MHz on a primary and/or secondary basis, as appropriate, within the frequency range 8 700-9 300 MHz and/or 9 900-10 500 MHz while ensuring protection of existing services and taking due account of the safety services allocated in the frequency band 9 000 to 9 300 MHz. This agenda item, which was also supported by SFCG, intends to enable higher image resolutions of less than 30 cm from next generation X-band SAR sensors.

Potentially affected space science service bands are: 8400-8450 MHz SRS (deep space) (s-E), 8 450-8 500 MHz SRS (s-E), and 10 600-10 700 MHz EESS (passive) and SRS (passive), all might be affected through potential unwanted emissions (OOBE), also largely depending on the WRC-15 decision, where extended frequency spectrum would eventually be allocated.

SFCG Objective

SFCG supports an extension of the current worldwide allocation to the Earth exploration-satellite (active) service in the frequency band 9 300-9 900 MHz by 600 MHz. Compatibility with SRS (space-to-Earth) links in the 8 400-8 500 MHz band and the EESS (passive) in the 10.6-10.7 GHz band will have to be ensured, in accordance with the appropriate protection criteria, taking into account any available mitigation techniques that would reduce the level of unwanted emissions in those two bands and the need for operational coordination with SRS (deep space) operators.

Status

ITU-R WP 7C is the responsible group for this Agenda Item. WP's 5A, 5B, 5C, 7B, and 7D are contributing groups.

WP7C has identified two methods to satisfy the agenda item. Method A would establish a primary EESS (active) allocation in 9 900-10 500 MHz where Method B would establish a primary EESS (active) allocation in 9 200-9 300 MHz and 9 900-10 400 MHz. Both methods would include footnotes ensuring that EESS (active) operations requiring less than 600 MHz would be strictly carried out in the existing 9 300-9 900 MHz allocation. The SFCG objectives are met through either method.

Current EESS (active) operators would prefer to have the center frequency of the band as close to 9 600 MHz as possible.

Report ITU-R RS.2274 verifies the needs for a future radar image resolution of better than 30cm and shows that this can only be achieved with a total contiguous bandwidth of 1 200 MHz.

The characteristics of future 1200 MHz EESS SAR4 chirp transmissions are described in the separate ITU-R Recommendation ITU-R RS.2043 which provides the reference system information for sharing studies.

Sharing and compatibility studies are completed, or at least well advanced for the RDS, showing that:

- Sharing is feasible between EESS (active) and fixed service, amateur service, amateur satellite service and mobile service without any specific constraint on any of these services.
- The impact of radionavigation (RNS) and radiolocation (RLS) systems emissions into SAR receivers is acceptable without any specific constraint on either of these services in the frequency bands proposed for a possible extension.
- With regard to the EESS (active) impact on the RN and RL services, comprehensive studies need to be finalized. Significant progress has been achieved particularly in the frequency range 9 900-10 500 MHz.
- Studies of the effect of EESS (active) SAR systems on stations of the radioastronomy service are finished and described in draft new report ITU-R RS.[EESS-9GHz_OOBE]. The main issue is the potential physical damage of the low-noise amplifier front-end of a victim RAS station in the unlikely case of main-beam to main-beam coupling. To avoid damage, PDN Recommendation ITU-R RS.[EESS9GHz-RAS-Mitigation] is under development. It should be noted that the application of this Recommendation will also solve the problem of an exceedance of the 2% of data loss.
- Regarding the protection of SRS (deep space), methods for the reduction of out-of-band emissions from EESS SAR4 systems have been studied. The results are described in draft new report ITU-R RS.[EESS-9GHz_OOBE]. Mitigation techniques and an operational coordination procedure have been proposed to avoid any harmful interference to the SRS receivers, particularly during critical events, and to avoid the possibility of damaging or saturating the receivers. They are defined in the new PDN Recommendation ITU-R RS.[EESS9GHz-SRS-Mitigation].
- The protection of EESS (passive) from unwanted emissions in the band 10.6-10.7 GHz is ensured due to attenuation of unwanted emissions as well as due to the difference in local time of the ascending node (LTAN) between EESS (active) and EESS (passive) satellites. The results of the studies are described in draft new report ITU-R RS.[EESS-9GHz_OOBE].

Agenda Item 1.13 to review No. **5.268** with a view to examining the possibility for increasing the 5 km distance limitation and allowing space research service (space-to-space) use for proximity operations by space vehicles communicating with an orbiting manned space vehicle, in accordance with Resolution **652 (WRC-12)**.

Resolution **652** calls for sharing studies between SRS (space-to-space) systems communicating in proximity with orbiting manned space vehicles and systems operating in the fixed and mobile (except aeronautical mobile) services in the band 410-420 MHz; and for WRC-15 to consider modifying No. **5.268** to allow the removal or relaxation of the 5 km distance limitation without modifying the current pfd limits and to clarify more general use of the 410-420 MHz band for SRS (space-to-space) systems beyond extra-vehicular activities.

SFCG Objective

SFCG supports removing the 5 km distance limitation and explicitly allowing space research service (space-to-space) use for proximity operations by space vehicles communicating with an orbiting manned space vehicle.

Status

WP 7B is the responsible group. Studies were carried out to show that the existing pfd limit will be met at the Earth's surface. This pfd limit provides the required protection to the terrestrial services. This will remain unchanged, therefore sharing studies with terrestrial services are not needed. Regulatory provisions are needed in the CPM text to retain the existing pfd limitation. WP7B has developed draft CPM text including a single method to satisfy the agenda item in line with the SFCG objective.

Agenda Item 1.14 to consider the feasibility of achieving a continuous reference time-scale, whether by the modification of Coordinated Universal Time (UTC) or some other method, and take appropriate action, in accordance with Resolution **653 (WRC-12)** which calls for studies on the feasibility of achieving a continuous reference time-scale for dissemination by radiocommunication systems;

Resolution **653** recognizes that that a change in the reference time-scale may have operational and therefore economic consequences. As a result, all space science service operations are potentially impacted.

SFCG Objective

SFCG is of the opinion that space science satellite operations and launches would benefit from a continuous time scale.

Status

WP 7A is the responsible group. Polarized views continue to be maintained. Some Administrations favour maintaining UTC with leap second adjustments and the creation of a separate continuous timescale based on TAI (Temps Atomique International) while other Administrations favour elimination of leap second adjustments within UTC arguing that the irregular insertion (or deletion) of leap seconds poses threats to systems that are increasingly dependent on an uninterrupted time source.

Agenda Item 1.17 to consider possible spectrum requirements and regulatory actions, including appropriate aeronautical allocations, to support wireless avionics intra-communications (WAIC), in accordance with Resolution **423 (WRC-12)**;

Resolution **423** calls for studies of possible regulatory actions, including appropriate aeronautical allocations, to support the implementation of WAIC systems. Frequency bands within existing worldwide aeronautical mobile service, aeronautical mobile (R) service and aeronautical radionavigation service allocations are to be considered; however, additional frequency bands above 15.7 GHz for aeronautical services are to be considered if spectrum requirements cannot be met in those existing frequency band allocations.

Potentially affected space science service bands coinciding with "existing worldwide aeronautical mobile service, aeronautical mobile (R) service and aeronautical radionavigation service allocations" below 15.7 GHz are: 4200-4400 MHz eess (passive), 5350-5460 MHz EESS (active) and 13.25-13.4 GHz EESS (active) and SRS (active) (both subject to RR No. **5.498A**).

SFCG Objective

SFCG supports the protection of existing space science service allocations. No identification of bands for WAIC systems operations should be made in bands allocated to science services unless acceptable sharing criteria with the affected space science service are developed. Given that the WAIC proponents are seeking safety service allocations for WAIC operations, studies also need to verify that the proposed WAIC systems would not receive harmful interference from the existing space science services operating with their current technical and operational parameters.

Status

WP 5B is the responsible group and WPs 7B and 7C are concerned groups.

Two methods to address the agenda item are proposed. The first method adds a new allocation to the AM(R)S reserved exclusively for WAIC systems in the frequency band 4 200-4 400 MHz with an accompanying Resolution. The second method provides the same regulatory changes as the first method, except it proposes a recommendation incorporated by reference. Studies indicate that EESS (passive) (which operation is allowed on a secondary basis in this band) could still operate with little interference due to the e.i.r.p. mask developed for the protection of radio altimeters.

Sharing/compatibility studies for the 22.5-22.55 GHz and 23.55-23.6 GHz bands have also been initiated for additional bands of the WAIC applications. WP5B has concluded that no other frequency band was suitable for WAIC applications.

Agenda Item 1.18 to consider a primary allocation to the radiolocation service for automotive applications in the 77.5-78.0 GHz frequency band in accordance with Resolution **654 (WRC-12)**;

Resolution **654** calls sharing studies and regulatory solutions to consider a primary allocation to the radiolocation service in the band 77.5-78 GHz, and also compatibility studies in the band 77.5-78 GHz with services operating in the adjacent bands 76-77.5 GHz and 78-81 GHz;

Potentially affected space science service bands are: 77.5-78 GHz srs (s-E); 76-77.5 GHz srs (s-E); 78-79 GHz srs (s-E); and, 79-81 GHz srs (s-E).

SFCG Objective

SFCG supports the protection of existing space science service allocations. SFCG further supports a radiolocation allocation in 77.5-78 GHz for automotive applications as a means of removing such applications from the 23.6-24 GHz band. Every effort should be made to restrict the use of the potential radiolocation allocation to automotive radars to avoid application of these radars on helicopters, since this would potentially affect earth stations of SRS. Therefore SFCG supports Method A of the Draft CPM Report.

Status

WPs 5A and 5B are the responsible groups and WPs 7B and 7C are contributing groups. The Draft CPM text proposes two methods to satisfy the agenda item 1.18. Both provide a primary allocation to the RLS in frequency band 77.5-78 GHz on a worldwide basis that can be used by automotive applications. Method A limits the RLS allocation to automotive applications while the Method B would provide a general RLS allocation not limited to automotive applications. No SRS (space-to-Earth) systems have been identified to date in the frequency range 76 GHz to 81 GHz and therefore no sharing studies were performed.

Agenda Item 7 "to consider possible changes, and other options, in response to Resolution 86 (Rev.Marrakesh, 2002) of the Plenipotentiary Conference, an advance publication, coordination, notification and recording procedures for frequency assignments pertaining to satellite networks, in accordance with Resolution **86 (Rev. WRC-07)** to facilitate rational, efficient, and economical use of radio frequencies and any associated orbits, including the geostationary-satellite orbit;

This standing agenda item to the WRCs deals with any possible changes to the Radio Regulations affecting the advance publication, coordination, notification and recording of satellite networks.

SFCG Objective

SFCG supports possible changes to the Radio Regulations to improve the handling of the advance publication, coordination, notification and recording procedures for satellite networks. SFCG has identified five issues of potential interest to space science services.

1. Should WRC-15 decide to address satellite filing procedures to facilitate the unique mission lifecycle of nanosatellites or picosatellites, SFCG believes any changes to satellite filing procedures to facilitate the unique mission lifecycle of nanosatellites or picosatellites should be in alignment with studies conducted in Working Party 7B and be carefully developed to ensure they apply exclusively to nanosatellites or picosatellites.

2. SFCG supports a clarification as to how the BR would address non-compliance with the requirement to inform the Radiocommunication Bureau within 6 months that use of frequency assignments have been suspended (as required under RR No.11.49). WRC-12 had modified this provision but left it unclear as to the consequence of not complying with the modified provision.
3. SFCG does not support regulatory changes requiring coordination under RR Section **II** of Article **9** for non-geostationary satellites communicating to geostationary satellites via inter-satellite links (data relay links).
4. SFCG will monitor Draft CPM text being considered that would either: a) suppress the required Advance Publication Information submissions for satellite networks that are subject to coordination provisions in the Radio Regulation; or, b) eliminate the six months required between receipt of API and coordination submissions. While such modifications are intended primarily to address the sometimes abused use of advantages stemming from API filings for commercial GSO satellite networks, this could be applicable to some GSO space services systems. In general, this would not be applicable to most NGSO space science systems.
5. SFCG will monitor Special Committee consideration of draft CPM text that suggests RR provisions that would maintain the bringing into use status of assignments of a satellite that failed on orbit during the BIU period specified in RR 11.44B.

Status

WP 4A is the responsible group for any technical aspects of this agenda item and the Special Committee is the responsible group for the regulatory and procedural aspects of the agenda item. WP 4A will complete its draft CPM text considerations at its July 2014 meeting, and the Special Committee will consider CPM text at its December 2014 meeting.
While not an issue explicitly under Agenda item 7, WP 7B is responsible for CPM text development under AI 9.1.8 addressing nanosatellites or picosatellites. The Special Committee-Working Party (SC-WP) and WP 4A have developed similar draft CPM texts for the second and fourth issues while the SC has pending draft CPM text for the fifth item.

WP 4A also is to consider one Administration's contribution that proposes an overhaul of the RR concerning space services. Another Administration has countered that with a proposal suggesting that fixes to the space regulations should be addressed specifically in a piecemeal or ad hoc manner on the basis of established need. As the proposals can be far reaching, SFCG Members should monitor the work in WP4A for possible consequential impacts to Radio Regulations affecting the space science services.

Agenda Item 9.1.1 Protection of the systems operating in the mobile-satellite service in the band 406-406.1 MHz (under Res. **205 (Rev. WRC-12)**)

Resolution **205** calls for studies with a view to ensuring the adequate protection of MSS systems in the frequency band 406-406.1 MHz from any emissions that could cause harmful interference taking into account the current and future deployment of services in adjacent bands as noted in *considering f)*;

The revised Resolution **205** resolves to conduct, and complete in time for WRC-15, the appropriate regulatory, technical and operational studies with a view to ensuring the adequate protection of MSS systems in the frequency band 406-406.1 MHz from any emissions that

could cause harmful interference (see No. **5.267**), Cospas-Sarsat space segment providers have developed protection criteria for the Cospas-Sarsat search and rescue instruments and local user terminals in the 406.0-406.1 MHz band in order to protect them against broadband out-of-band emissions and against narrow-band spurious emissions. These protection criteria have been recognized at the ITU level through Recommendation ITU-R M.1478-1. However, these protection criteria do not provide protection against emissions in adjacent bands which could hinder the Cospas-Sarsat system's ability to detect and/or relay signal from beacons.

Cospas-Sarsat is developing the relevant protection criteria for submission to the ITU and translation into an ITU-R recommendation.

SFCG Objective

In order to ensure adequate protection of MSS systems in the frequency band 406-406.1 MHz and to detect and successfully process 406 MHz distress signals, SFCG supports a revision of Resolution **205 (Rev WRC-12**) containing appropriate mitigation measures, such as establishment of a guard band above 406.1 MHz concerning new frequency assignments to mobile networks.

Status

WP 4C is the responsible group and WPs 7B and 7C are concerned groups. WP4C developed a working document toward a preliminary draft new report and draft CPM text on this agenda item during their September 2012 meetings. These documents were subsequently refined at the April 2013 WP4C meetings based on administration inputs and liaisons from WP7B and WP7C. At the February 2014 meeting Working Party 4C developed liaison statements inviting Working Parties 5A, 7B and 7C to examine the preliminary draft new Report ITU-R M.[Agenda Item 9.1.1] - Protection of the 406-406.1 MHz band (Annex 5 to Document 4C/289), which provides compatibility analysis between the mobile satellite systems dedicated to distress and safety of life (RR No. **5.267**, RR Article **31**) in operation within the band 406-406.1 MHz and the services in operation in the vicinity of the 406-406.1 MHz band. The study illustrates the need for WRC-15 to revise Resolution **205 (Rev.WRC-12)** with a view of having an adequate protection of the MSS in the band 406-406.1 MHz in order to detect and successfully process 406 MHz distress signals while not putting undue constraints to existing and planned systems in the adjacent frequency bands 390-406 MHz and 406.1-420 MHz. WPs 5A, 7B and 7C were also invited to examine the impact to Earth exploration-satellite (Earth-to-space) and meteorological aids services in operation below 406 MHz.WP7B confirmed that data collection systems (DCS) do not significantly contribute to the broadband interference into search and rescue receivers, therefore no restrictions would be required on DCS.

Agenda Item 9.1.5

"Consideration of technical and regulatory actions in order to support existing and future operation of fixed-satellite service earth stations within the band 3 400-4 200 MHz, as an aid to the safe operation of aircraft and reliable distribution of meteorological information in some countries in Region 1 (Resolution 154 (WRC-12))"

SFCG Objective

SFCG supports technical and regulatory actions to protect the FSS operations in the band 3400-4200 MHz for the dissemination of meteorological data.

Status
This AI is under the responsibility of WP 4A and SC. In order to safeguard the availability of the 3400-4200 MHz band for the distribution of meteorological data via EUMETCast, CMACast and GEONETCast, the studies should be followed and supported in the framework of the WMO Steering Group on Radio Frequency Coordination.

Agenda Item 9.1.8 Regulatory aspects for nanosatellites and picosatellites under Resolution 757 (WRC-12)

Resolution **757 (WRC-12)** instructs the Director of the Radiocommunication Bureau to report to WRC-15 on the results of the studies which will take place in Working Party 7B under Question ITU-R 254/7.

SFCG Objective

SFCG supports contributions to studies under Question ITU-R 254/7.

SFCG favors the study of this issue, since it recognizes that a growing number of picosatellites/nanosatellites are under development in the world. At present many of these satellites operate in frequency bands allocated to the amateur-satellite service. Now there is an increasing demand for these satellites to operate in other satellite services. Many of these satellites are launched for scientific, experimental or educational purposes, sometimes in the form of constellations and there is a growing interest for commercial non-scientific applications. SFCG supports that the frequency bands used should align with the applications being supported. An investigation on how this growing number of satellites can be supported is needed.

Given the complexity in obtaining a common definition of which types of satellites should be classified under the category nanosatellites and picosatellites and because these definitions tend to relate to elements that are not relevant from a frequency management perspective (size, mass, cost), SFCG supports further consideration of modifications to the RR, if needed, to facilitate the development of nanosatellites and picosatellites, taking into account the comparatively short development time and the potential lack of advance knowledge of certain operational parameters.

Any changes to the RR in relation to this agenda item should be carefully developed to ensure protection of all satellite missions. SFCG is of the opinion that any satellite, including nanosatellites and picosatellites, will have to be registered with the ITU and must adhere to the ITU-R Radio Regulations.

Status

WP 7B is the responsible group, and WP 4A and the Special Committee are concerned groups.

Question ITU-R 254/7 has been adopted by Study Group 7 and approved by Administrations. At the May 2014 meetings of WP7B preliminary draft new Reports related to technical and operational characteristics as well as the current practices surrounding nanosatellite and picosatellite technologies were further developed. Draft CPM text from the September 2013 WP7B meetings was updated to indicate the development and conclusions of the Reports. Results of studies shall be included in the Director's Report and reflected in Section 9.1.8 of the CPM Report.

NOTE: Proposed Agenda item 2.2 of WRC-18 deals with the topic of picosatellites/ nanosatellites. See at the end of this Annex.

Agenda Item 10 "to recommend to the Council items for inclusion in the agenda for the next WRC, and to give its views on the preliminary agenda for the subsequent conference and on possible agenda items for future conferences, in accordance with Article 7 of the Convention,

General principles

It is very important to ensure that before any new agenda item is agreed at WRC-15, the following elements are already available:

1. Clear demonstration and quantification of the spectrum requirements.
2. Technical and operational parameters of the new systems for which modification of the RR is proposed.
3. Identification of the exact bands targeted for regulatory changes.
4. Preliminary studies on the sharing feasibility in these bands.

SFCG is of the view that adherence to these principles should be made conditional for adoption of any new WRC agenda item.
(NOTE - Adherence to these principles would avoid the problems encountered with agenda items like WRC-15 AI 1.1 and 1.10)

SFCG supports the inclusion of the following items on the WRC-18 agenda:

Agenda Item X.X1 *to consider the upgrade of the secondary allocation to the meteorological satellite (space-to-Earth) service in the frequency band 460 - 470 MHz to a primary status while ensuring the protection of the existing primary services in this frequency band and review the provisions of RR No.* ***5.289****.*

SFCG supports this agenda item in view of the improved protection of the Data Collection Systems using this band on several meteorological satellites.

Agenda Item X.X2 *to consider a possible allocation to the EESS (active) for radar sounders in the range of 40-50 MHz.*

SFCG supports this agenda item for remote measurements of the Earth's subsurface in order to locate water/ice/deposits using active spaceborne sensors. SFCG plans to carry out preliminary sharing studies with incumbent services in this frequency range.

Agenda Item X.X3 *to consider necessary coordination distances to protect space research service earth stations from aeronautical mobile service interference in the 2200-2290 MHz band.*

SFCG supports amending Table 10 (Annex 7) in Appendix 7 of the Radio Regulations to adjust the predetermined coordination distance between mobile (aircraft) stations and space research earth stations in the 2 200-2 290 MHz band in order to ensure proper protection of the SRS Earth stations.

Agenda Item X.X4 *to review and modify the definition of space research service (SRS) in No.* ***1.55*** *of the Radio Regulations to clarify that SRS spacecraft can operate in the region near the Earth (less than 2 million kilometers) or in the deep space region. Also review and amend as required RR Nos.* ***5.460*** *and* ***5.465****.*

SFCG supports amending the definition of space research service (SRS) in RR No. **1.55** to clarify that SRS spacecraft operate in the region near the Earth or in the deep space region and that a spacecraft intended to operate in deep space also has to operate in the region near the Earth during launch and early orbit phases, Earth flybys, or while returning to Earth. In addition, modify footnotes RR Nos. **5.460** and **5.465** to remove the ambiguity that the term "deep space" in those footnotes refers to deep-space spacecraft and not a region in space.

Status

Several proposals are under definition within the various regional Groups. Proposals for a new agenda item on IMT above 6 GHz seem to be common across many of these regional groups. In this respect attention should be placed to the points raised above as conditional for accepting such a new agenda item.

Draft Agenda WRC-18[1]

Agenda Item 2.2 to consider the appropriate regulatory procedures for notifying satellite networks needed to facilitate the deployment and operation of nanosatellites and picosatellites, in accordance with Resolution **757 (WRC-12)**;

Resolution 757 (WRC-12) invites the ITU-R to examine the procedures for notifying space networks and consider possible modifications to enable the deployment and operation of nanosatellites and picosatellites, taking into account the short development time, short mission time and unique orbital characteristics. It also invites WRC-18 to consider whether modifications to the regulatory procedures for notifying satellite networks are needed to facilitate the deployment and operation of nanosatellites and picosatellites, and to take the appropriate actions. The results of studies are to be included in the Report of the Director of the Radiocommunication Bureau to WRC-15.

SFCG Objective

The SFCG objective will be developed based upon the results of discussions under WRC-15 Agenda item 9.1.8. SFCG supports further consideration of modifications to the RR, if needed, to facilitate the development of nanosatellites and picosatellites, taking into account the comparatively short development time and the potential lack of advance knowledge of

[1] From Resolution **808 (WRC-12)** Preliminary agenda for the 2018 World Radiocommunication Conference

certain operational parameters. It may be possible to address this issue under the standing WRC Agenda item 7.

It would be beneficial to modify Study Question ITU-R 254/7 to include the following items and to complete the work prior toWRC-18:

- study the growth in numbers of nanosatellites and picosatellites;
- study and propose ways to accommodate the growth in numbers of nanosatellites and picosatellites launched within the existing regulatory framework;
- study spectrum sharing techniques for nanosatellites and picosatellites among themselves and with other radio systems.

Annex 2 to Resolution SFCG 32-1R2

Items of interest to SFCG members for consideration at World Radiocommunication Conferences beyond 2018.

1. Review RR No. **5.458** for the range 6 425 to 7 250 MHz and enhance EESS (passive) allocation status, to enable improved monitoring of soil moisture and sea surface temperature, to better understand global water circulation for oceans mainly in lower latitudes, global warming, and to improve weather prediction.

2. Identification of an EESS (Earth-to-space) allocation to be associated with the existing EESS (space-to-Earth) allocation in 25.5-27 GHz.

3. Improve allocation status for active sensors.
   Review RR Nos. **5.469A**[2], **5.476A**[3], **5.498A**[4], **5.501B**[5] and **5.513A**[6], which affect active sensor operations in the following bands:
   1. 8 550 – 8650 MHz
   2. 9 300 – 9 900 MHz
   3. 13.25 – 13.75 GHz
   4. 17.2 – 17.3 GHz

4. Review the need for RR Nos.**5.536A**[7] and **5.536B**[8] appended to the space science services' allocations in the 25. 5-27.0 GHz band, in order to improve the allocation status.

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[2]**5.469A** In the band 8 550-8 650 MHz, stations in the Earth exploration-satellite service (active) and space research service (active) shall not cause harmful interference to, or constrain the use and development of, stations of the radiolocation service. (WRC-97)

[3]**5.476A** In the band 9 300-9 800 MHz, stations in the Earth exploration-satellite service (active) and space research service (active) shall not cause harmful interference to, nor claim protection from, stations of the radionavigation and radiolocation services. (WRC-07)

[4]**5.498A** The Earth exploration-satellite (active) and space research (active) services operating in the band 13.25-13.4 GHz shall not cause harmful interference to, or constrain the use and development of, the aeronautical radionavigation service. (WRC-97)

[5]**5.501B** In the band 13.4-13.75 GHz, the Earth exploration-satellite (active) and space research (active) services shall not cause harmful interference to, or constrain the use and development of, the radiolocation service. (WRC-97)

[6]**5.513A** Spaceborne active sensors operating in the band 17.2-17.3 GHz shall not cause harmful interference to, or constrain the development of, the radiolocation and other services allocated on a primary basis. (WRC-97)

[7]**5.536A** Administrations operating earth stations in the Earth exploration-satellite service or the space research service shall not claim protection from stations in the fixed and mobile services operated by other administrations. In addition, earth stations in the Earth exploration-satellite service or in the space research service should be operated taking into account the most recent version of Recommendation ITU-R SA.1862. (WRC-12)

[8]**5.536B** In Saudi Arabia, Austria, Belgium, Brazil, Bulgaria, China, Korea (Rep. of), Denmark, Egypt, United Arab Emirates, Estonia, Finland, Hungary, India, Iran (Islamic Republic of), Ireland,

5. Upgrade from secondary to primary the allocation to EESS (active) in the band 24.05-24.25 GHz

6. Upgrade from secondary to primary the allocation to the space research service in the band 14.5-15.35 GHz.

7. Extension of 1 215-1 300 MHz active sensing allocation (EESS (active)). The 1 215-1 300 MHz allocation for EESS (active) remote sensing applications, including SARs, is useful for the purposes of disaster and environment monitoring because signals at these frequencies can penetrate most vegetation to measure parameters of the Earth's surface. However, an additional allocation would be required for L-band SARs to provide better spatial resolution or for L-band interferometric SAR to provide better interferometric displacement accuracy. Therefore, for that purpose, in addition to the existing 1 215-1 300 MHz allocation, the frequency range 1 300-1390 MHz is being considered. This additional bandwidth would provide additional resolution to SAR measurements taken in this frequency range for applications regarding the study of the deformation of the Earth's surface as well as additional frequency separation for narrow band applications for better interferometric displacement accuracy. Scatterometers can also use this frequency range for soil moisture and ocean salinity measurements in conjunction with passive sensors operating in the 1 400-1 427 MHz passive band. It is noted that the protection of passive services in this band will have to be addressed.
8. Consider possible allocations to the EESS (active) for various remote sensing applications near the following frequencies:
    - 137-138 MHz
    - 290 MHz
9. Consider if the EESS status in the 460-470 MHz frequency band (RR No. 5.289) should be upgraded to primary status in conjunction with the proposed upgrade to primary status for the meteorological-satellite (space-to-Earth) service in the same band. Compatibility between these 2 services should be studied.

Israel, Italy, Jordan, Kenya, Kuwait, Lebanon, Libya, Liechtenstein, Lithuania, Moldova, Norway, Oman, Uganda, Pakistan, the Philippines, Poland, Portugal, the Syrian Arab Republic, Dem. People's Rep. of Korea, Slovakia, the Czech Rep., Romania, the United Kingdom, Singapore, Sweden, Switzerland, Tanzania, Turkey, Viet Nam and Zimbabwe, earth stations operating in the Earth exploration-satellite service in the band 25.5-27 GHz shall not claim protection from, or constrain the use and deployment of, stations of the fixed and mobile services. (WRC-12)

SPACE FREQUENCY COORDINATION GROUP

(S F C G)

Recommendations

Recommendation SFCG 4-3R3

UTILIZATION OF THE 2 GHz BANDS FOR SPACE OPERATION

The SFCG,

CONSIDERING

a) that the frequency bands 2025-2110 and 2200-2290 MHz are shared co-equally by the space research, space operation, and Earth exploration-satellite services;

b) that bands allocated to the space operation service may be used for space tracking, space telemetry, and space telecommand (TTC) by other space services;

c) that the definition of the space operation service (RR No. **1.23**) postulates that these TTC activities by other space services normally be carried out in their service bands;

d) that the bands 2025-2110 and 2200-2290 MHz, which are already now densely occupied, are of prime importance for space science missions of SFCG agencies and will remain so for many years to come as no comparable alternative frequency allocations are available;

RECOMMENDS

1. that geostationary space systems of space services other than the space science services which are designed to operate in mission bands other than 2025 - 2110 and 2200 - 2290 MHz, but which utilize TTC systems within these bands, shall limit the use of such TTC systems to a single frequency pair per satellite and to launch, orbit insertion and emergency operations;

2. that TTC systems for geostationary satellites of space services other than the space science services should be designed in accordance with the general characteristics as contained in Table 1 below;

3. that non-geostationary satellites of services other than the space science services avoid using these bands for TTC.

TABLE I

Typical System Parameters for Space Operations of Geostationary Satellites at 2 GHz

MODE	SYSTEM PARAMETERS	VALUE
Reception at earth stations	Telemetry bandwidth	100 kHz
	Tracking bandwidth	400 kHz
	G/T earth station	20 dB/K
Transmissions from earth stations	Telecommand bandwidth	100 kHz
	Tracking bandwidth	400 kHz
	EIRP, earth station	65 dBW

Recommendation SFCG 5-1R5

USE OF THE 8450-8500 MHz BAND FOR SPACE RESEARCH, CATEGORY A[1][2]

The SFCG,

CONSIDERING

a) that the Radio Regulations permit the use of the 8450 - 8500 MHz band for Category A and Category B[3] space research missions;

b) that the band is one of only three worldwide primary allocations for space research service below 40 GHz;

c) that the band, because of crowding at 2200-2290 MHz, is particularly suitable for missions to the Libration point for example;

d) that the 8400 - 8450 MHz band is allocated for and restricted to Category B missions;

e) that the 14.0 - 15.35 GHz and 37 to 38 GHz bands have been identified as appropriate for Category A missions requiring wide (greater than 10 MHz) bandwidth;

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1 Category A missions are those having an altitude above the Earth of less than $2 \cdot 10^6$ km.

2 CCSDS has adopted a similar Recommendation.

3 Category B missions are deep space missions. Deep space is defined by the RR as distances from the Earth equal to or greater than $2 \cdot 10^6$ km.

RECOMMENDS

1. that the 8450 - 8500 MHz band be used for Category A missions requiring an occupied bandwidth of up to 10 MHz per mission and having technical requirements that are best satisfied in the band;

2. that the band be used in particular for the mission to the Libration points with bandwidth requirements up to 10 MHz;

3. that utmost care be taken in the assignment of frequencies to these missions in order to make optimum use of the limited bandwidth available to Cat. A missions, and that the maximum bandwidth, postulated in “RECOMMENDS 1” above, of 10 MHz per mission be strictly respected;

4. that the 8450 - 8500 MHz not be used for Category B missions.

Recommendation SFCG 6-1R5

INTERFERENCE FROM SPACE-TO-SPACE LINKS BETWEEN NON-GEOSTATIONARY SATELLITES TO OTHER SPACE SYSTEMS IN THE 2025-2110 AND 2200-2290 MHz BANDS

The SFCG,

CONSIDERING

a) that space-to-space transmissions between two or more non-geostationary satellites shall not impose any constraints on other space systems (RR No. **5.392**);

b) that the planned increase in the number of space-to-space links between non-geostationary satellites will nevertheless raise the likelihood of harmful interference;

RECOMMENDS

that the power spectral density of space-to-space links between non-geostationary satellites be reduced by using appropriate modulation techniques and channel coding in accordance with CCSDS recommendations, in order to reduce the potential for harmful interference to space-to-Earth, Earth-to-space, and other space-to-space transmissions, involving at least one geostationary satellite.

Recommendation SFCG 6-2R1

TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR SPACE RESEARCH, CATEGORY A[1][2]

The SFCG,

CONSIDERING

a) that many space missions require coherency between the Earth-to-space and space-to-Earth links in order to provide accurate Doppler frequency shift and range delay measurements;

b) that a turnaround frequency ratio must be defined for those missions which require coherency;

c) that standardized transponder turnaround frequency ratios are necessary for one agency's spacecraft to be supported by another agency's earth stations;

d) that care should be exercised in the selection of the numbers comprising the turnaround frequency ratios;

e) that transponder turnaround frequency ratios have previously been defined and used extensively and successfully in the 2, 7, and 8 GHz Category A frequency bands,

RECOMMENDS

1. that, for Category A missions, SFCG member agencies utilize the transponder turnaround frequency ratios listed in Table 1.

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[1] Category A missions are those having an altitude above the Earth of less than 2 X 10^6 km.

[2] CCSDS has adopted a similar Recommendation.

TABLE I - Turnaround frequency ratios for Category A[1] missions

{PRIVATE }Frequency ratio	Allocated band (MHz)	Nominal[2] available band (MHz)	Allocated band (MHz)	Nominal[2] available band (MHz)
E-S/S-E 221/240 749/880 221/900 765/240	*E - S* 2025 - 2110 7190 - 7235 2025 - 2110 7190 - 7235	*E - S* 2025 - 2110 7190 - 7235 **2075 - 2087** 7190 - 7235	*S - E* 2200 - 2290 8450 - 8500 8450 - 8500 2200 - 2290	*S - E* 2200 - 2290 8450 - 8500 8450 - 8500 **2256 - 2270**
E-S/E-S 221/765	*E - S* 2025 - 2110	*E - S* **2077 - 2090**	*E - S* 7190 - 7235	*E - S* 7190 - 7235
S-E/S-E 240/900	*S - E* 2200 - 2290	*S - E* **2253 - 2267**	*S - E* 8450 - 8500	*S - E* 8450 - 8500

(1) Category A missions are those whose distance from the Earth is less than 2 X 10^6 km.

(2) The nominal available band for a particular direction is determined by the frequency ratio and the width of the allocated band for the other direction. The figures listed are approximate. For some frequency ratios, for example 221/900, the width of the nominal available band in one of the directions will be less than the allocation width in that direction. These cases are shown in bold face type.

Recommendation SFCG 7-1R5

TRANSPONDER TURNAROUND FREQUENCY RATIOS AND RADIO FREQUENCY CHANNEL PLANS FOR SPACE RESEARCH, CATEGORY B [(1)(2)]

The SFCG,

CONSIDERING

a) that accurate frequency references are required on many space missions to obtain Doppler frequency and range information;

b) that standardized turnaround ratios are especially necessary for those missions which require support of earth stations operated by two or more member agencies;

c) that care should be exercised in the selection of the numerical factors which make up the turnaround frequency ratios;

d) that full coverage of the 32 and 34 GHz bands, while maximizing coherency with the 7 and 8 GHz bands, requires the use of multiple ratios;

e) that certain turnaround frequency ratios have been used extensively and successfully in certain band combinations;

f) that the SFCG has agreed to adopt and utilize the 2, 7, 8, 32, and 34 GHz Deep Space Network channel plans when selecting frequencies for the deep space missions;

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1) Category B missions are deep space missions. Deep space is defined by the RR as distances from the Earth equal to or greater than $2 \cdot 10^6$ km.

2) CCSDS has adopted a similar Recommendation.

RECOMMENDS

1. that SFCG member agencies use the transponder turnaround frequency ratios listed in Table I below;

2. that SFCG member agencies utilize the Deep Space Network channel plans, Table II below, when selecting frequencies for Category B (deep-space) missions;

TABLE I - Frequency ratios and associated bands for Category B missions

Frequency ratio	Allocated band (MHz)	Available[(1)] coherent band (MHz)	Allocated band (MHz)	Available[(1)] coherent band (MHz)
E-S/S-E	*E - S*	*E - S*	*S - E*	*S - E*
221/240	2110 - 2120	2110 - 2118	2290 - 2300	2291 - 2300
221/880	2110 - 2120	2110 - 2120	8400 - 8450	8402 - 8442
221/3344	2110 - 2120	2110 - 2120	31.8 - 32.3 (GHz)	31.93 - 32.08 (GHz)
749/240	7145 - 7190	7147 - 7178	2290 - 2300	2290 - 2300
749/880	7145 - 7190	7150 - 7190	8400 - 8450	8400 - 8448
749/3328	7145 – 7190	7156 – 7190	31.8 - 32.3 (GHz)	31.80 - 31.95 (GHz)
749/3344	7145 – 7190	7145 – 7190	31.8 - 32.3 (GHz)	31.90 - 32.10 (GHz)
749/3360	7145 - 7190	7145 - 7190	31.8 - 32.3 (GHz)	32.05 – 32.25 (GHz)
3599/3344	34.2 - 34.7 (GHz)	34.22 - 34.7 (GHz)	31.8 -32.3 (GHz)	31.91 - 32.24 (GHz)
3599/3360	34.2 – 34.7 (GHz)	34.2 – 34.6 (GHz)	31.8 – 32.3 (GHz)	31.92 – 32.3 (GHz)
E-S/E-S	*E - S*	*E - S*	*E - S*	*E - S*
221/749	2110 - 2120	2110 - 2120	7145 - 7190	7151 - 7185
221/3599	2110 - 2120	2110 - 2120	34.2 - 34.7 (GHz)	34.37 - 34.52 (GHz)
749/3599	7145 - 7190	7145 - 7190	34.2 - 34.7 (GHz)	34.34 - 34.54 (GHz)
S-E/S-E	*S - E*	*S - E*	*S - E*	*S - E*
240/880	2290 - 2300	2291 - 2300	8400 - 8450	8400 - 8433
240/3344	2290 - 2300	2290 - 2300	31.8 - 32.3 (GHz)	31.91 - 32.05 (GHz)
880/3328	8400 – 8450	8408 – 8450	31.8 - 32.3 (GHz)	31.8 - 31.96 (GHz)
880/3344	8400 – 8450	8400 – 8450	31.8 - 32.3 (GHz)	31.92 - 32.11 (GHz)
880/3360	8400 - 8450	8400 - 8450	31.8 - 32.3 (GHz)	32.07 - 32.26 (GHz)

(1) The available coherent band refers to the range of frequencies within which a set of channels that are coherent with those in another deep-space allocation may be specified. The band is determined by the frequency ratio and the allocation width. For the 2, 7, and 8 GHz bands, the available coherent band is approximately equal to the allocated band. For the 32 and 34 GHz allocations, the width of the available coherent band for a given frequency ratio is substantially less than the allocation width, and these cases are shown in bold face type.

TABLE II – Channel frequencies (in MHz) for Category B (deep-space) missions

Band:	2 E-S	2 S-E	8 E-S	8 S-E	32 S-E	32 S-E	32 S-E
Factor:	221	240	749	880	3328	3344	3360
Channel		F2DN					
1		2290.185185	7147.286265			31909.913580	32062.592592
2		2290.555556	7148.442132			31915.074083	32067.777787
3		2290.925926	7149.597995	8400.061729		31920.234571	32072.962966
4		2291.296296	7150.753857	8401.419752		31925.395059	32078.148146
5	2110.243056	2291.666667	7151.909724	8402.777780		31930.555562	32083.333340
6	2110.584105	2292.037037	7153.065587	8404.135803		31935.716050	32088.518519
7	2110.925154	2292.407407	7154.221450	8405.493826		31940.876538	32093.703699
8	2111.266204	2292.777778	7155.377316	8406.851853		31946.037042	32098.888893
9	2111.607253	2293.148148	7156.533179	8408.209876		31951.197530	32104.074073
10	2111.948303	2293.518519	7157.689045	8409.567903	31803.456798	31956.358033	32109.259267
11	2112.289352	2293.888889	7158.844908	8410.925927	31808.592595	31961.518521	32114.444447
12	2112.630401	2294.259259	7160.000771	8412.283950	31813.728392	31966.679009	32119.629626
13	2112.971451	2294.629630	7161.156637	8413.641977	31818.864203	31971.839512	32124.814821
14	2113.312500	2295.000000	7162.312500	8415.000000	31824.000000	31977.000000	32130.000000
15	2113.653549	2295.370370	7163.468363	8416.358023	31829.135797	31982.160488	32135.185179
16	2113.994599	2295.740741	7164.624229	8417.716050	31834.271608	31987.320991	32140.370374
17	2114.335648	2296.111111	7165.780092	8419.074073	31839.407405	31992.481479	32145.555553
18	2114.676697	2296.481481	7166.935955	8420.432097	31844.543202	31997.641967	32150.740733
19	2115.017747	2296.851852	7168.091821	8421.790124	31849.679014	32002.802470	32155.925927
20	2115.358796	2297.222222	7169.247684	8423.148147	31854.814810	32007.962958	32161.111107
21	2115.699846	2297.592593	7170.403550	8424.506174	31859.950622	32013.123462	32166.296301
22	2116.040895	2297.962963	7171.559413	8425.864197	31865.086419	32018.283950	32171.481481
23	2116.381944	2298.333333	7172.715276	8427.222220	31870.222216	32023.444438	32176.666660
24	2116.722994	2298.703704	7173.871143	8428.580248	31875.358027	32028.604941	32181.851854
25	2117.064043	2299.074074	7175.027005	8429.938271	31880.493824	32033.765429	32187.037034
26	2117.405092	2299.444444	7176.182868	8431.296294	31885.629621	32038.925917	32192.222213
27	2117.746142	2299.814815	7177.338735	8432.654321	31890.765432	32044.086420	32197.407408
28	2118.087191		7178.494598	8434.012344	31895.901229	32049.246908	32202.592587
29	2118.428241		7179.650464	8435.370371	31901.037041	32054.407411	32207.777782
30	2118.769290		7180.806327	8436.728395	31906.172838	32059.567899	32212.962961
31	2119.110339		7181.962190	8438.086418	31911.308634	32064.728387	32218.148140
32	2119.451389		7183.118056	8439.444445	31916.444446	32069.888891	32223.333335
33	2119.792438		7184.273919	8440.802468	31921.580243	32075.049379	32228.518514
34			7185.429782	8442.160491	31926.716040	32080.209867	32233.703694
35			7186.585648	8443.518518	31931.851851	32085.370370	32238.888888
36			7187.741511	8444.876542	31936.987648	32090.530858	32244.074068
37			7188.897377	8446.234569	31942.123460	32095.691361	32249.259262
38				8447.592592	31947.259256	32100.851849	32254.444442
39				8448.950615	31952.395053	32106.012337	32259.629621
40					31957.530865	32111.172840	32264.814816
41					31962.666662	32116.333328	32269.999995
42					31967.802458	32121.493816	32275.185174

Note:
F2DN = (N-14)*(10/27) + 2295 MHz, where N is the channel number. The value of F2DN is rounded to the nearest Hz. Frequencies in the 2 GHz E-S band are then computed and rounded to the nearest Hz. Frequencies in other bands are derived from 2 GHz E-S frequencies by using the corresponding ratio of frequency factors, and then rounding to the nearest Hz.

TABLE II (continued) Channel frequencies (in MHz) for Category B (deep-space) missions

Band:	34 E-S	32 S-E	32 S-E
Factor:	3599	3344	3360
Channel			
L1			31803.333335
L2			31808.518514
L3			31813.703694
L4			31818.888888
L5			31824.074068
L6			31829.259262
L7			31834.444442
L8			31839.629621
L9			31844.814816
L10			31849.999995
L11			31855.185174
L12			31860.370369
L13			31865.555548
L14			31870.740728
L15			31875.925922
L16			31881.111102
L17			31886.296296
L18			31891.481475
L19			31896.666655
L20			31901.851849
L21			31907.037029
L22			31912.222223
L23			31917.407403
L24			31922.592597
L25			31927.777777
L26	34204.385040		31932.962971
L27	34209.939046		31938.148151
L28	34215.493068		31943.333345
L29	34221.047074		31948.518525
L30	34226.601080	31801.543210	31953.703704
L31	34232.155103	31806.703713	31958.888898
L32	34237.709109	31811.864201	31964.074078
L33	34243.263131	31817.024704	31969.259272
L34	34248.817137	31822.185192	31974.444452
L35	34254.371144	31827.345681	31979.629631
L36	34259.925166	31832.506184	31984.814826
L37	34265.479172	31837.666672	31990.000005
L38	34271.033178	31842.827160	31995.185184
L39	34276.587201	31847.987663	32000.370379
L40	34282.141207	31853.148151	32005.555558
L41	34287.695213	31858.308639	32010.740738
L42	34293.249235	31863.469142	32015.925932
L43	34298.803241	31868.629630	32021.111112
L44	34304.357264	31873.790133	32026.296306
L45	34309.911270	31878.950621	32031.481486
L46	34315.465276	31884.111109	32036.666665
L47	34321.019298	31889.271613	32041.851860
L48	34326.573304	31894.432101	32047.037039
L49	34332.127311	31899.592589	32052.222218
L50	34337.681333	31904.753092	32057.407413

Band:	34 E-S	32 S-E	32 S-E
Factor:	3599	3344	3360
Channel			
1	34343.235339	31909.913580	32062.592592
2	34348.789362	31915.074083	32067.777787
3	34354.343368	31920.234571	32072.962966
4	34359.897374	31925.395059	32078.148146
5	34365.451396	31930.555562	32083.333340
6	34371.005402	31935.716050	32088.518519
7	34376.559408	31940.876538	32093.703699
8	34382.113431	31946.037042	32098.888893
9	34387.667437	31951.197530	32104.074073
10	34393.221459	31956.358033	32109.259267
11	34398.775465	31961.518521	32114.444447
12	34404.329471	31966.679009	32119.629626
13	34409.883494	31971.839512	32124.814821
14	34415.437500	31977.000000	32130.000000
15	34420.991506	31982.160488	32135.185179
16	34426.545529	31987.320991	32140.370374
17	34432.099535	31992.481479	32145.555553
18	34437.653541	31997.641967	32150.740733
19	34443.207563	32002.802470	32155.925927
20	34448.761569	32007.962958	32161.111107
21	34454.315592	32013.123462	32166.296301
22	34459.869598	32018.283950	32171.481481
23	34465.423604	32023.444438	32176.666660
24	34470.977626	32028.604941	32181.851854
25	34476.531632	32033.765429	32187.037034
26	34482.085638	32038.925917	32192.222213
27	34487.639661	32044.086420	32197.407408
28	34493.193667	32049.246908	32202.592587
29	34498.747689	32054.407411	32207.777782
30	34504.301696	32059.567899	32212.962961
31	34509.855702	32064.728387	32218.148140
32	34515.409724	32069.888891	32223.333335
33	34520.963730	32075.049379	32228.518514
34	34526.517736	32080.209867	32233.703694
35	34532.071759	32085.370370	32238.888888
36	34537.625765	32090.530858	32244.074068
37	34543.179787	32095.691361	32249.259262
38	34548.733793	32100.851849	32254.444442
39	34554.287799	32106.012337	32259.629621
40	34559.841822	32111.172840	32264.814816
41	34565.395828	32116.333328	32269.999995
42	34570.949834	32121.493816	32275.185174

Band:	34 E-S	32 S-E	32 S-E
Factor:	3599	3344	3360
Channel			
H1	34576.503856	32126.654319	32280.370369
H2	34582.057863	32131.814808	32285.555548
H3	34587.611869	32136.975296	32290.740728
H4	34593.165891	32142.135799	32295.925922
H5	34598.719897	32147.296287	
H6	34604.273920	32152.456790	
H7	34609.827926	32157.617278	
H8	34615.381932	32162.777766	
H9	34620.935954	32167.938269	
H10	34626.489960	32173.098757	
H11	34632.043983	32178.259260	
H12	34637.597989	32183.419748	
H13	34643.152011	32188.580252	
H14	34648.706017	32193.740740	
H15	34654.260040	32198.901243	
H16	34659.814046	32204.061731	
H17	34665.368068	32209.222234	
H18	34670.922074	32214.382722	
H19	34676.476080	32219.543210	
H20	34682.030103	32224.703713	
H21	34687.584109	32229.864201	
H22	34693.138131	32235.024704	
H23	34698.692137	32240.185192	
H24		32245.345681	
H25		32250.506184	
H26		32255.666672	
H27		32260.827160	
H28		32265.987663	
H29		32271.148151	
H30		32276.308639	
H31		32281.469142	
H32		32286.629630	
H33		32291.790133	
H34		32296.950621	

Note:
F2DN = (N-14)*(10/27) + 2295 MHz, where N is the channel number. The value of F2DN is rounded to the nearest Hz. Frequencies in the 2 GHz E-S band are then computed and rounded to the nearest Hz. Frequencies in other bands are derived from 2 GHz E-S frequencies by using the corresponding ratio of frequency factors, and then rounding to the nearest Hz.

Recommendation SFCG 11-1R4

USE OF THE BAND 1670-1710 MHz FOR METEOROLOGICAL SATELLITE SERVICES

The SFCG,

CONSIDERING

a) that the ITU Radio Regulations allocate the band 1670-1710 MHz to the meteorological-satellite service on a primary basis;

b) that the band could be used for both geostationary and non-geostationary satellites and their associated earth stations with thousands of user stations worldwide;

c) that non-geostationary satellites, operating in bands below 1698 MHz could cause interference to the reception of transmissions from geostationary meteorological satellites.

d) that WRC-03 allocated the band 1668 – 1675 MHz to the mobile-satellite service (Earth-to-space);

NOTING

a) that existing earth stations in the meteorological satellite service operating in the band 1670-1675 MHz, notified before 1 January 2004, continue to be protected by RR No. **5.380A**

RECOMMENDS

1. that the band 1670-1695 MHz be used for the reception of data from DCPs (Data Collection Platforms), spacecraft telemetry and raw image data from geostationary meteorological satellites at main earth stations at relatively few fixed locations;

2. that the band 1679-1690 MHz be used for the reception of data from DCPs and disseminated data from geostationary meteorological satellites at user stations;

3. that the band 1690-1698 MHz be used for the reception of disseminated data from geostationary meteorological satellites at user stations as well as for the reception of spacecraft

telemetry and emergency weather alerts;

4. that the band 1698-1710 MHz be used for the reception of direct read-out and pre-recorded image data from non-geostationary meteorological satellites at user stations.

5. that when extending the operation of future non-geostationary satellites from 1698 – 1710 MHz into 1695 – 1710 MHz, protection of the reception of transmissions from geostationary meteorological satellite systems operating below 1698 MHz should be facilitated through inter-operator coordination, as appropriate.

Recommendation SFCG 12-2

USE OF THE 14.0 - 15.35 GHz AND 16.6 - 17.1 GHz BANDS FOR SPACE RESEARCH, CATEGORY A[1]

The SFCG,

CONSIDERING

a) that some SFCG member agencies are actively pursuing plans for space research missions which require very large bandwidths, e.g. spaceborne VLBI, geodesy and geodynamics;

b) that bandwidth requirements in excess of 10 MHz are increasingly difficult to satisfy in the frequency bands allocated to space research below 10 GHz;

c) that the 8450 - 8500 MHz region has been identified as appropriate for Category A missions requiring less than 10 MHz bandwidth, as specified in Recommendation SFCG 5-1R4;

d) that the 14 - 15.35 GHz band is densely occupied by the fixed service (14.3 - 15.35 GHz) and Earth-to-space links of the fixed-satellite service (14 - 14.8 GHz) and that, consequently, assignment of Earth-to-space links of the space research service is difficult;

e) that the 16.6 - 17.1 GHz band is allocated to radiolocation, primary and to space research, (deep space) (Earth-to-space), secondary;

f) that there are currently no plans by SFCG member agencies to use the 16.6 - 17.1 GHz band for space research, (deep space) (Earth-to-space), and that consequently, at a future competent World Radio Communications Conference, the limitation to deep-space should be suppressed;

g) that the sharing situation in the 14.0 - 15.35 GHz and 16.6 - 17.1 GHz bands, where the space research service has only a secondary status is difficult and does not lend itself to the use of classical modulation schemes which exhibit a high interference potential and a high susceptibility to interference;

[1] Category A missions are those having an altitude above the Earth of less than 2 X 10^6 km

h) that spectrum spreading types of modulation can considerably alleviate the sharing problems addressed above;

i) that SFCG members should ensure compatibility between their operations in the 14.0 - 15.35 and 16.6 - 17.1 GHz bands;

j) that certain parts of the 14.0 - 15.35 GHz band have existing and planned assignments to data relay satellites (Earth-to-space, space-to-space);

RECOMMENDS

1. that the 14.0 - 15.35 GHz band be used for space-to-Earth transmissions of space research Category A missions;[2]

2. that the 16.6 - 17.1 GHz band be used for Earth-to-space transmissions of space research Category A missions;[3]

3. that the spectrum of data transmissions in the bands shall be sufficiently spread so as to ensure adequate protection for services operating in the band;

4. that existing and planned frequency assignments to data relay satellites (Earth-space, space-space) be protected.

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[2] The 14.3 - 14.4 GHz and 14.47 - 14.5 GHz bands are not allocated to space research and will consequently have to be used in accordance with the provisions of RR No. **4.4**.

[3] See CONSIDERING e) and f).

Recommendation SFCG 12-4R3

METHODS FOR REDUCTION OF POTENTIAL INTERFERENCE BETWEEN SYSTEMS IN THE SPACE SCIENCE SERVICES IN DENSELY OCCUPIED BANDS

The SFCG,

CONSIDERING

a) that certain frequency bands allocated to the science services are very densely occupied;

b) that frequency management methods, such as advance planning of a frequency assignment, may not always be successful because of the prevailing occupation of the bands;

c) that the temporary switch-off of emissions from a spacecraft is a recognized method to reduce the number of potential cases of interference;

d) that SFCG Procedures for Inter-Agency Frequency Coordination (RES SFCG A12-1) foresee that spacecraft transmissions can be temporarily interrupted in case of conflict among several missions and provides priority guidelines for such cases;

e) that the RR No. **22.1**, Cessation of Emissions, demands that spacecraft be equipped with devices ensuring immediate cessation of emissions whenever required;

RECOMMENDS

1. that, as a general means of reducing potential interference in densely occupied bands, such as the 2200 - 2290 MHz and the 8025-8400 MHz bands, space agencies limit their space-Earth transmissions to those periods when they are in contact with a receiving earth station or a data relay satellite;

2. that, as a means to reduce the number of potential interference cases among spacecraft, space agencies be prepared to temporarily switch off emissions from the spacecraft concerned, in accordance with the priority guidelines laid down in Chapter 4 of the SFCG Procedures for Inter-Agency Frequency Coordination (RES SFCG A12-1);

3. that the devices on spacecraft used to switch off emissions postulated by RR No. **22.1** be designed with the highest practicable level of reliability and be qualified for a large number of switching cycles during the lifetime of the spacecraft.

Recommendation SFCG 12-5R1

LIMITATIONS ON EARTH-SPACE LINK POWER LEVELS[1]

The SFCG,

CONSIDERING

a) that occupation of frequency bands used by space agencies is increasing rapidly;

b) that in many cases the same frequency will be shared by several spacecraft;

c) that the 2025 - 2110 MHz band is also shared with space-to-space links from data relay satellites to user satellites, which are limited to relatively small power levels by the provisions of RR No. **21.16** (Table 21-4) and are consequently particularly susceptible to interference;

d) that excessive EIRP from earth stations will make intra-service frequency sharing increasingly difficult and result in an inefficient use of the radio frequency spectrum;

e) that excessive EIRP from earth stations likewise unnecessarily complicates the coordination with terrestrial services and may increase in some cases the coordination area;

f) that the required EIRP from an earth station is determined by P_c/N_o, E_b/N_o, and the minimum signal level required by the spacecraft receiver;

RECOMMENDS

1. that space agencies limit the EIRP on Earth-to-space links to that required for safe spacecraft operation, by means of one or several of the following:

   - avoid, whenever practicable, using high power transmitters having a fixed output but instead adjust the transmitted power to the minimum needed to meet project requirements;

   - obtain the required EIRP by using reasonable antenna diameter in order to reduce both sidelobe radiation and transmitter power (Guideline: antenna diameter/rf

[1] CCSDS has adopted a similar recommendation (CCSDS401(3.2.1.)B-1).

wavelength equal to or greater than 70);

- make compliance with Recommendation ITU-R SA.509 a requirement in antenna specifications;

2. that spacecraft equipment designers endeavour to provide similar margins with regard to minimum P_c/N_o, minimum E_b/N_o and the minimum signal required by the spacecraft receiver.

Recommendation SFCG 13-3R3

DATA RELAY SATELLITE CHANNEL PLANS FOR THE 23 AND 26 GHZ BANDS

The SFCG,

CONSIDERING

a) that the frequency bands 22.55 - 23.55 GHz and 25.25 - 27.50 GHz are allocated to the inter-satellite service,

b) that the band 22.55 - 23.55 GHz is recommended for forward inter-orbit links from geostationary data relay satellites (DRS) to low-orbiting spacecraft and the band 25.25 - 27.5 GHz is recommended for return inter-orbit links from low-orbiting spacecraft to DRSs (Recommendation ITU-R SA.1019);

c) that data relay satellites use these bands for inter-orbit links;

d) that ESA, NASA and JAXA through the Space Networks Interoperability Panel (SNIP) have recommended that data relay satellites be designed to allow interoperable cross-support of each other's user spacecraft,

e) that SNIP has recommended a standard channel plan in these frequency bands;

f) that in addition to the SNIP recommended frequencies, DRS systems could make use of channel centre frequencies throughout the 22.55 - 23.55 band;

g) that four DRS cross-support channels near 23 GHz overlap with Non-GSO inter-satellite links of the Hibleo-2 (Iridium) satellite system in the frequency range 23.183-23.377 GHz;

h) that the bands 22.81-22.86 GHz and 23.07 – 23.12 GHz are identified in RR No. **5.149** for the radio astronomy service and need to be taken into account;

RECOGNIZING

1) that turn-around ratios often drive the selection of forward link channels based on the selected return link channel

2) that not all DRS satellites have the capability to support all identified DRS cross support channels

RECOMMENDS

1. that DRS systems using the 22.55 - 23.55 GHz band for forward inter-orbit links use the following channel centre frequencies:

22.605 GHz
22.665 GHz
22.725 GHz
22.785 GHz
22.845 GHz[1]
22.905 GHz
22.965 GHz
23.025 GHz
23.085 GHz[1]
23.145 GHz
23.205 GHz
23.265 GHz
23.325 GHz
23.385 GHz
23.445 GHz
23.505 GHz

2. that these forward channels have a minimum bandwidth of 50 MHz;

3. that, whenever practicable, priority be given to making assignments for forward inter-orbit links outside the range 23.183 – 23.377 GHz in order to reduce the potential for mutual interference with the Hibleo-2 (Iridium) system;

4. that DRS systems using the 25.25 - 27.50 GHz band for return inter-orbit links use the following channel centre frequencies:

25.600 GHz
25.850 GHz
26.100 GHz
26.350 GHz
26.600 GHz
26.850 GHz

[1] These channels may not be available on a global basis due to overlap with bands used by the radio astronomy service.

27.100 GHz
27.350 GHz

5. that these return channels have a minimum bandwidth of 225 MHz;

6. that data relay satellites be able to transmit forward signals on either left-hand or right-hand circular polarisation, and receive return signals on the same polarisation;

7. that data relay satellites transmitting a tracking beacon in these bands use one of the following frequencies;

23.530 GHz
23.535 GHz
23.540 GHz
23.545 GHz

8. that such tracking beacons be transmitted with left-hand circular polarisation.

Recommendation SFCG 14-1R1

PROTECTION OF DEEP SPACE RESEARCH EARTH STATIONS FROM LINE-OF-SIGHT INTERFERENCE IN THE BANDS 2290-2300 MHz, 8400-8450 MHz AND 31.8-32.3 GHz

The SFCG,

CONSIDERING

a) that, for deep space Earth stations, data availability objectives have been used to determine the maximum acceptable performance degradation;

b) that, based on the maximum acceptable performance degradation for these stations, the maximum allowable interference power at the deep space station receiver has been derived and is:

Table 1: Maximum Allowable Interference Power to Deep Space Earth Station Receivers

{PRIVATE }Frequency	Maximum allowable interference power spectral density (dB(W/Hz))
2290-2300 (MHz) 8400-8450 (MHz) 31.8-32.3 (GHz)	-222 -221 -217

c) that, for the purpose of initiating a process of coordination, it is agreed that the corresponding maximum power spectral flux density is:

Table 2: Maximum Interference Power Spectral Flux Density

{PRIVATE }Frequency	Maximum interference power spectral flux density (dB(W/m^2/Hz))
2290-2300 (MHz) 8400-8450 (MHz) 31.8-32.3 (GHz)	-257.0 -255.1 -249.3

d) that any source exceeding the maximum allowable interference power is potentially harmful to space research (deep space), whether that interference arises from a source operating in-band or from in-band spectral components arising from a source operating in an adjacent band;

e) that loss and subsequent reacquisition of deep space earth station receiver synchronization due to momentary interference in a low data rate channel results in a data outage significantly exceeding the duration of the initiating interference event;

NOTING

that a predicted interference potential exceeding the maximum power spectral flux density may be found acceptable on a case-by-case basis;

RECOMMENDS

1. that when a predicted interference potential exceeds the maximum interference power spectral flux density given in Table 2, the provisions of RES SFCG A12-1 shall be applied;

2. that the values given in Table 2 apply for sources whether operating directly in-band or out of band and producing in-band spectral components.

Recommendation SFCG 14-2R5

USE OF THE 37 - 38 GHz SPACE RESEARCH SERVICE ALLOCATION

The SFCG,

CONSIDERING

a) that the 37-38 GHz band is allocated to the space research service in the space-to-Earth direction;

b) that the band pair 37 – 37.5 GHz and 40 – 40.5 GHz was originally allocated for the purpose of supporting communications systems for manned planetary exploration as well as development and operation of manned planetary missions in the lunar environment;

c) that this band pair is the only one allocated for this purpose and that the safety of astronauts/cosmonauts depends on the continued availability of this band pair;

d) that, considering distance alone, the received PFDs from the planetary missions, manned or unmanned, are weaker by more than 50 dB compared to those of the Category A missions, including L2, Lunar, GSO, MEO, and LEO missions;

e) that the 37-38 GHz space research allocation may be used for very high data rate transmission from the space-based VLBI observatories as they are more RFI-tolerant than the other Category A missions;

f) that high density fixed service and fixed satellite service systems are planned to be operated in 37-38 GHz and 37.5-38 GHz respectively;

RECOMMENDS

1. that the 37 – 37.5 GHz band be maintained available for implementation of space-to-Earth links for manned and unmanned planetary missions and for development and operation of manned planetary missions in the Lunar environment, recognizing that manned missions have higher priority than unmanned missions ;

2. that Earth-to-space links for manned lunar and manned and unmanned planetary exploration be implemented in the band 40 – 40.5 GHz or other Earth-to-space bands as appropriate;

3. that to protect the manned planetary missions, all incompatible lunar missions cease their operations when manned planetary missions are present in the deep space environment;

4. that sun-Earth libration point (L2) missions considering to use the 37 – 38 GHz band implement their space-to-Earth links in the 37.5 – 38 GHz portion of the band, with associated Earth-to-space links in the 40 – 40.5 GHz band or other Earth to space bands as appropriate;

5. that Space VLBI systems implementing time-critical data downlinks requiring up to 1 GHz of real-time bandwidth utilize the band 37 – 38 GHz, recognizing the need for operational coordination, when required, with manned lunar and planetary exploration systems

6. that Category A space research service missions, that can share with FSS, be accommodated in the 37.5-38 GHz portion of the band with associated Earth-to-space links in appropriate bands;

7. that Member agencies take into account the information contained in the Annex when examining intra-service sharing in the 37-38 GHz band.

ANNEX to Recommendation SFCG 14-2R5

USE OF THE 37 - 38 GHz SPACE RESEARCH SERVICE ALLOCATION

This Recommendation provides guidelines for 37-38 GHz SRS downlink band partitioning. Some typical space research activities are recognized and a few major parameters of each activity are listed in Table I:

TABLE I

Activity:	**Range (km)**	**Required or Requested Bandwidth (Min-Max) (MHz)**	**Spreading Loss Variation (dB)[1]**	**Range-Based Relative Performance (dB)**
1) Planetary Exploration Missions (Mars)	min 60E6 max 39E7	80 – 8000[3] 2 – 200[2]	16	-52 +/-8
	2 000 000	(ITU Planetary/Near Earth Definition)		
2) Libration point missions (L2, S-E)	1 500 000	200[4]	Nil	-6
3) Lunar exploration missions	380 000	500[5]	Nil	0 (Ref.)
4) High data rate space-based astronomy missions (e.g. S-VLBI)	typ: 5 000 - 40 000 max:2 000-400 000	1 000[6]	18 46	29 +/-9 23 +/-23
5) Missions employing Near-Earth Orbiters	200 - 2 000	500[7]	20	56 +/-10

1) For constant spacecraft EIRP.

2) Present technology: (50W/5m dish)(50k/34m dish)(QPSK/R=1/2 code) supports 1-5 Mb/s at max Mars range (2-10 MHz required). Projected technology (100W/10m dish)(50k/70m dish)(Turbo) supports 100 Mb/s at max Mars range (200 MHz required). A bandwidth request of at least 100 MHz will not nearly fulfill the projected capability at min Mars range.

3) Minimum range bandwidths derived from the bandwidths projected for the maximum range.

4) ESA, 1999 proposal.

5) NASDA, 1998 request (METS).

6) NASA, 1998 request (ARISE). Two polarizations required.

7) Suggested maximum.

Recommendation SFCG 14-3R9

USE OF THE 8025-8400 MHz BAND BY EARTH EXPLORATION SATELLITES

The SFCG,

CONSIDERING

a) that Earth exploration-satellites are an increasingly important tool for acquiring information about the Earth and its environment;

b) that the 8025-8400 MHz band is allocated to the EESS on a primary basis;

c) that the band 8025-8400 MHz is shared with the fixed, mobile and fixed-satellite (Earth-to-space) services and the band 8175-8215 MHz is also shared with the meteorological satellite (Earth-to-space) service;

d) that use of the band by EESS systems operated by commercial interests, military organisations and space agencies is increasing and could result in harmful interference among EESS systems;

e) that proper selection of orbit parameters for sun-synchronous satellites can be a very effective interference mitigation technique which in general requires coordination at a very early stage;

f) that homogeneity among a set of technical parameters will lead to a more efficient use of the orbit/spectrum resource by the EESS systems;

g) that high gain antennas radiate power only towards a limited portion of the Earth surface;

h) that isoflux antennas have a more homogeneous power flux density distribution across the surface of the Earth as compared to omnidirectional antennas;

i) that broadcast modes generally cause higher levels of interference due to continuous transmissions and relatively high power spectral densities but have typically lower bandwidth requirements;

j) that proper selection of bandwidth and power efficient modulation and coding

techniques could result in smaller occupied bandwidths and lower adjacent channel interference;

k) that higher order advanced modulation schemes such as 16 phases PSK and above need less bandwidth than currently used QPSK and 8PSK but generally require higher power flux densities which can to some extent be compensated by selection of proper channel coding;

l) that a number of other interference mitigation techniques such as polarisation discrimination, earth station separation and earth station antenna discrimination can also contribute to lower interference levels;

m) that Earth-based, deep space research receivers operated in the adjacent 8400-8450 MHz band are extremely sensitive and highly susceptible to interference with relevant protection criteria given in Recommendation ITU-R SA.1157;

n) that time-critical events occur in both deep space research and EESS operations;

o) that most of the techniques proposed to reduce interferences between Earth Exploration Telemetry links also reduces adjacent emissions received by Deep Space stations in the 8400-8450 MHz band;

p) that a primary allocation to the Earth Exploration Satellite Service is also available in the band 25.5 – 27 GHz,

q) that variable coding and modulation (VCM) techniques exist and are used operationally for space to Earth links of telecommunication satellites,

r) that VCM techniques can be used to compensate for range variations and that with simple coarse range compensations using VCM, significant bandwidth or power reduction can be obtained,

s) that reliable and efficient power-controllable RF solid state power amplifier technologies are available which may allow for a close control of the link budget, and thus can contribute to mitigating the interference risk.

RECOGNIZING

i) that increasing congestion of the 8025 – 8400 MHz band and requirements for higher data rates will lead to increasing levels of interference,

ii) that guidelines for use of the band are desirable to maximize the capacity of the band and to minimize harmful interference,

NOTING

that all RECOMMENDS below are considered of equal importance

RECOMMENDS

1. that Earth exploration-satellites operating in a non broadcasting mode radiate only when transmitting data to one or more earth stations;

2. that phasing of the orbital parameters for sun-synchronous satellites should be considered for which early coordination is required in accordance with the most recent version of Resolution SFCG A12-1;

3. that, whenever practicable, low sidelobe, high gain satellite antennas be used and if high gain satellite antennas are not practicable, isoflux antennas should be considered instead of omnidirectional antennas;

4. that broadcast modes be avoided whenever practicable or, if unavoidable, consider the use of a portion of the lower half of the band 8025-8400 MHz;

5. that future EESS networks consider characteristics of existing networks[1] in order to maintain a relatively homogeneous operational environment;

6. that new Earth exploration-satellites using non-directional antennas developed after 1 January 2007 be designed to limit their power flux-density on the Earth's surface to less than -123dB(W/m^2 MHz) at their sub-satellite points.

7. that bandwidth and power efficient modulation and coding techniques[2] be used, taking also into account Recommendation SFCG 21-2 regarding adjacent channel interference and the desire to preserve a homogeneous power flux density environment;

8. that SFCG member agencies consider implementing VCM, where practicable, when operating high data rate EESS links in the 8025-8400 MHz frequency band;

9. that due consideration also be given to other interference mitigation techniques such as polarisation discrimination, geographical separation of earth stations and large earth station antennas with low sidelobes meeting at least the performance as specified in Recommendation ITU-R S.465;

10. that, in order to minimize the need for operational coordination, Earth exploration satellites utilize, to the maximum extent possible, appropriate techniques to prevent unwanted emissions exceeding the ITU-R deep space interference criterion (Rec. ITU-R SA.1157) in the band 8400 – 8450 MHz, including on-board filtering, large geographical separation between EESS and deep-space Earth stations, low-sideband modulations, and one or more of the applicable techniques given in RECOMMENDS 1 through 9;

11. that Earth exploration-satellites use the 25.5-27.0 GHz band, once suitable infrastructure becomes available, if the techniques given in RECOMMENDS 1 through 10 cannot adequately mitigate both in-band and adjacent-band interference;

12. that operational coordination be used only as the last resort to mitigate interferences among EESS missions and from EESS missions to deep-space Earth stations,

13. that agencies consider, whenever practicable, the use of on-board power-controllable RF power amplifiers for link budget optimization.

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[1] See SFCG X-Band database

[2] Guidelines for implementation of bandwidth efficient modulation & coding schemes have been developed by CCSDS

Recommendation SFCG 15-1R3

USE OF THE 400.15-401 and 410-420 MHz SPACE RESEARCH ALLOCATIONS FOR PROXIMITY LINKS

The SFCG,

CONSIDERING

a) that the 400.15-401 MHz band is allocated to the space research service (space-to-space) on a primary basis for communications with manned space vehicles (RR No. **5.263**);

b) that the 410-420 MHz band is allocated to the space research service (space-to-space) on a primary basis for communications with an orbiting space vehicle (RR No. **5.268**);

c) that the 400.15-401 and 410-420 MHz bands are particularly well suited for reliable and safe proximity communications between space vehicles;

RECOMMENDS

1. that the 400.15-401 MHz space research allocation be used for low data rate space to space communications with manned space vehicles;

2. that the 410-420 MHz space research allocation be used for low and medium data rate space to space communications with orbiting space vehicles

3. that other potential space research users such as wideband proximity operations and high data rate space-to-space links be encouraged to use other bands as appropriate (see REC SFCG 15-2R4).

Recommendation SFCG 15-2R4

USE OF THE BAND 25.25-27.5 GHz FOR INTER-SATELLITE (DATA RELAY SATELLITE AND PROXIMITY LINKS)

The SFCG

CONSIDERING

a) that Article **5** of the Radio Regulations allocates the 25.25-27.5 GHz band to the inter-satellite service, restricted to space research, Earth exploration-satellite, and medical and industrial applications, on a primary basis;

b) that Recommendation SFCG 13-3R1 identifies the standard channel plan adopted by the Space Network Interoperability Panel (SNIP) for use by data relay satellite (DRS) networks;

c) that requirements for wide band proximity links in the 25.25-27.5 GHz band have been identified for high data rate communications between co-orbiting, free-flying radio elements;

RECOMMENDS

1. that DRS systems using the band 25.25-27.5 GHz avoid assignment of channels with the 25.60 GHz and 27.35 GHz centre frequencies for data relay return links to users operating proximity links in the bands 25.25-25.60 GHz and 27.225-27.5 GHz;

2. that the implementation of proximity operation communication links in the 25.25-27.5 GHz band be constrained to the sub-bands 25.25-25.60 GHz and 27.225-27.5 GHz.

Recommendation SFCG 18-1

USE OF THE BANDS 31.3 – 31.8 GHz AND 36 – 37 GHz FOR EESS PASSIVE SENSING

The SFCG,

CONSIDERING

a) that 31.3 – 31.8 GHz is essential as the only window for remote sensing of surface information to be used in connection with the atmospheric profile temperature measurements performed in the 50 – 60 GHz band, and that in this band the data loss acceptable by the EESS (passive) is less than 0.01%;

b) that in a number of countries the upper part of this band, 31.5-31.8 GHz, is also allocated to the fixed and mobile services on a primary basis;

c) that 36 – 37 GHz is the most suitable band for snow detection (i.e., shallow snow, snow water equivalent) and has been used for more than 20 years for climatological studies of snow, sea ice, soil moisture, microwave vegetation index and land surface temperature;

d) that in the future a reduction of the current 1000 MHz bandwidth allocated from 36-37 GHz may become possible, in the light of technological developments;

e) that current and planned EESS passive sensors are centred on 36.5 GHz;

f) that the two bands serve different purposes and are unique in their nature;

RECOMMENDS

1. that the 31.3 – 31.8 GHz allocation be maintained for EESS (passive) without the addition of any new primary allocation to active services;

2. that the 36 – 37 GHz allocation be maintained for EESS (passive);

3. that, if at a future date, the reduction of the bandwidth in the 36-37 GHz band becomes feasible, the reduced band be centred on 36.5 GHz.

Recommendation SFCG 18-2

MINIMUM EARTH STATION G/T REQUIREMENTS FOR RECEPTION OF NON-GEOSTATIONARY EESS IN THE 8025-8400 MHz BANDS

The SFCG,

CONSIDERING

a) that the 8025 – 8400 MHz band is extensively used by the Earth exploration-satellite service for space-to-Earth transmissions;

b) that the ITU has defined PFD limits on the Earth's surface in the RR No. **21.16** for the purpose of facilitating sharing between EESS and terrestrial services in the 8025-8400 MHz band, with which all spacecraft must comply;

c) that the space-to-Earth links in the 8025-8400 MHz band typically operate with suppressed carrier modulation and uncoded BER's between 10^{-3} and 10^{-5}, with 3 dB of link margin;

d) that with existing ITU PFD limits, an earth station G/T greater than or equal to 25 dB/K will achieve the performance in considering c);

RECOMMENDS

that users of the 8025-8400 MHz band utilise earth stations with a G/T of 25 dB/K or more.

Recommendation SFCG 21-1

SPECTRUM CONSIDERATIONS FOR FORMATION FLYING SYSTEMS

The SFCG,

CONSIDERING

a) that a number of Member Agencies are planning space missions that make use of multiple spacecraft flying in various "distributed" configurations ranging from close proximity flying to widely separated constellations in both near-Earth orbit and in deep space;

b) that the spacecraft must have a sensory and control system in order to maintain a precise relative position;

c) that the spacecraft must have a sensory and control system in order to attain a specified attitude, with all spacecraft targeting the desired object;

d) that the spacecraft must be able to communicate with each other;

e) that radio-navigation links for formation flyers use, in most cases, omni-directional types of antennas, and power-limited transmitters;

f) that inter-satellite links must be designed so as to avoid interference with onboard communication systems;

g) that formation flyers operating at altitudes lower than that of geostationary orbit may make passive (receive only) use of GNSS signals;

h) that many frequency bands are available that could be used to support these communication links, each with its own advantages and disadvantages;

i) that timely guidance from the SFCG to mission planners on the selection of the optimal frequency bands, could save the mission(s) time and budget resources;

j) that several formation flying systems are planned to operate in the same L2 region;

k) that radionavigation satellite, space research and intersatellite service allocations may be suitable for use in maintaining communications and relative positioning between spacecraft flying in formation;

RECOGNISING

that the operation of Global Navigation Satellite Systems (GNSS) is a public safety service and emissions that could jeopardise such operation are to be avoided;

RECOMMENDS

1. that frequency bands allocated to the Radionavigation-Satellite Service (RNSS) below 6 GHz not be used for transmissions by formation flying systems;

2. that formation flying systems operating below 20,000 km utilise available GNSS signals for position and attitude determination whenever practicable;

3. that, for planning purposes, for intersatellite communications and navigation requirements, reference be made to the table of frequency bands shown in the annex to this Recommendation;

4. that, to avoid inter-system interference problems, agencies coordinate their design choices for systems planned to operate in the same spatial region.

ANNEX to REC 21-1

FREQUENCY BANDS SUITABLE FOR IMPLEMENTING CROSS-LINKS IN MULTIPLE SPACECRAFT "FORMATION FLYING" SYSTEMS

BAND	FREQUENCY RANGE	SERVICE	COMMENTS
S	2025 - 2110 MHz 2200 - 2290 MHz	SRS (space-to-space) SRS (space-to-space)	
Ku	13.75 – 14.3 GHz 14.5 – 15.35 GHz	srs srs	These allocations are secondary
Ka	22.55 – 23.55 GHz 25.5 – 27.0 GHz 32.3 – 33.4 GHz	ISS ISS ISS, RNSS	
W	59 – 64 GHz 65 – 71 GHz	ISS ISS	

Recommendation SFCG 21-2R3

EFFICIENT SPECTRUM UTILISATION FOR SPACE SCIENCE SERVICES ON SPACE-TO-EARTH LINKS; CATEGORY A

The SFCG,

CONSIDERING

a) that frequency bands allocated to the space science services are becoming more congested as space missions multiply, data rates increase and other services enter these bands;

b) that usage of spectrum beyond what is actually required increases the potential for interference to other users and at the same time may result in a higher susceptibility to interference from other users of the band;

c) that notified bandwidth requirements beyond the amount of spectrum actually required generally increases the coordination burden;

d) that the use of PCM/PM/Bi-phase or PCM/PM/NRZ modulation is only justified when a distinct carrier component is required and for symbol rates below 2 Ms/s [1];

e) that in some exceptional cases, such as data relay satellite inter-orbit links, PFD limits laid down in RR No. **21.16** cannot be met with efficient modulation schemes;

f) that some frequency bands of the space science services are allocated with a secondary status resulting in very difficult sharing conditions, which may require the use of spread spectrum-type modulations;

g) that quaternary or higher order filtered modulation schemes have bandwidth characteristics which generally reduce coordination burdens and that spectrum shaping can be used to significantly reduce the occupied bandwidth;

h) that a common residual carrier modulation system in use is PCM/PSK/PM;

i) that the use of sub-carriers shall be limited, as stipulated by REC SFCG 21-3;

j) that trellis-coded modulators act as an encoder and a modulator[2]**;**

k) that telemetry is sometimes transmitted simultaneously with a ranging signal;

RECOMMENDS

1. that space agencies use the most bandwidth efficient modulation schemes practicable for their missions;

2. that, PCM/PM/Bi-phase or PCM/PM/NRZ modulation only be used when a carrier component is technically necessary and for symbol rates below 2 Ms/s.

3. that the emitted spectrum[3,4] for all Space Science Services projects that will utilize space-to-Earth link frequency assignments in the bands 2200–2290 MHz, 8025–8400 MHz and 8450–8500 MHz, adhere to the spectral emission masks in Figure 1;

4. that transmissions that include a ranging signal be exempt from the spectrum masks in Fig 1;

5. that PCM/PSK/PM transmissions in accordance with REC SFCG 21-3 be exempt from the spectrum masks in Fig 1.

---

[1] For non spectrum modifying modulation, the symbol rate is defined as the baseband single line bit rate following error correcting coding (if applicable) and Bi-phase encoding (if used) at the input of the RF modulator. This definition makes this recommendation more stringent for lower order modulations. See figure 2.

[2] For trellis-coded modulation, the symbol rate is defined as the baseband single bit rate at the input of an equivalent M-PSK modulator. This definition makes this recommendation more stringent for lower order modulations. See figure 3

[3] Measured relative to the peak of the telemetry spectrum and excluding the residual carrier as well as all spurious emissions.

[4] PCM/PM/Bi-phase emissions with symbol rates up to 300 ks/s may deviate from the low rate mask by up to 5 dB in the slope region and up to 10 dB in the plateau region

Figure 1: Spectral Emission Masks

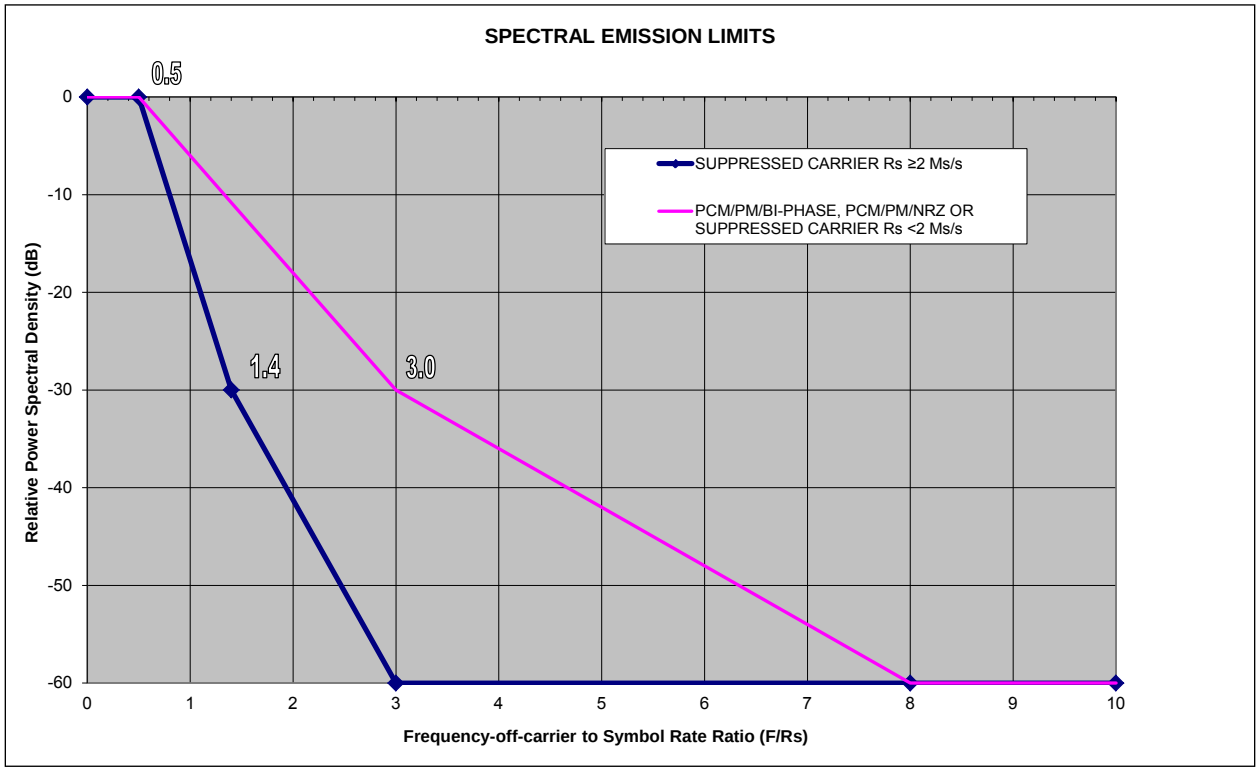


Figure 2: Non Spectrum Modifying Modulation Definitions

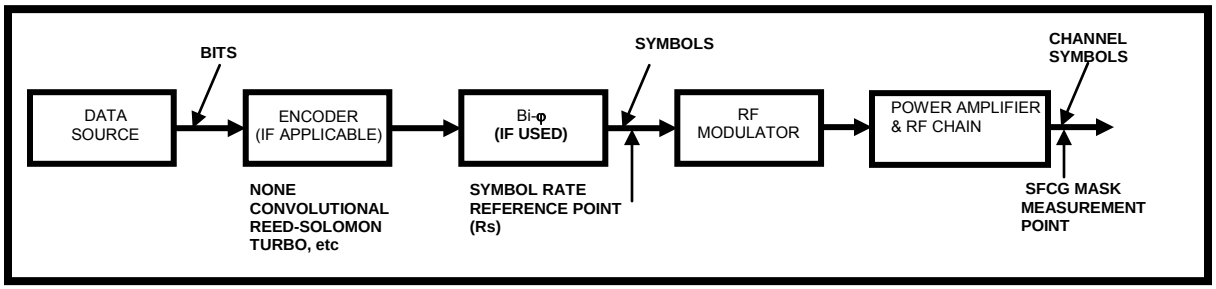
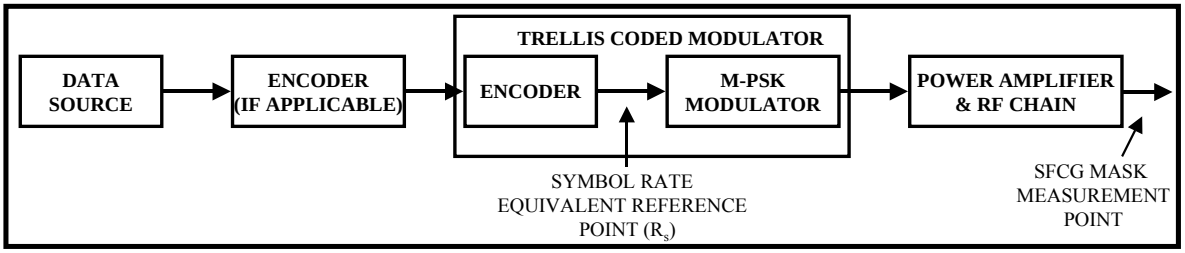


Figure 3: Trellis-Coded Modulation Definitions



Recommendation SFCG 21-3R1

USE OF SUB-CARRIERS FOR SPACE SCIENCE SERVICES ON SPACE-TO-EARTH LINKS: CATEGORY A

The SFCG,

CONSIDERING

a) that frequency bands allocated to the space science services are becoming more congested as space missions multiply, data rates increase, and other services enter these bands;

b) that usage of spectrum beyond what is actually required increases the potential for interference to other users and at the same time may result in a higher susceptibility to interference from other users in the band;

c) that sub-carrier modulation techniques require substantially more spectrum compared to suppressed carrier modulation techniques;

d) that the required bandwidth with sub-carrier modulation is a function of the sub-carrier frequency and the sub-carrier-to-symbol rate ratio;

e) that for telemetry sub-carrier frequencies above 60 kHz, a sub-carrier frequency-to-highest symbol rate ratio not exceeding 4 is generally sufficient to obtain acceptable performance;

f) that the presence of telecommand feed-through and/or ranging signals may require the selection of a slightly higher value of sub-carrier frequency-to-highest symbol rate ratio[1];

g) that sub-carriers are not required any longer to separate telemetry data streams because several channels can be present simultaneously on a single RF carrier if virtual channels are used[2];

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[1] CCSDS Recommendations 401.0 (2.4.14A) B-1

[2] CCSDS Recommendation for Packet Telemetry (CCSDS 102.0-B-2)

h) that no technical reasons have been identified which would require the use of sub-carrier modulation for symbol rates above approximately 60 kilosymbol/second (ks/s)[3];

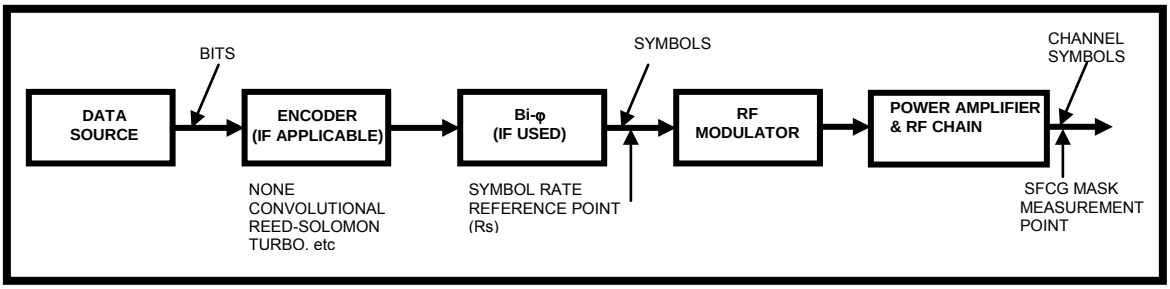
i) that eliminating sub-carriers simplifies both spacecraft and earth station data system complexity and reduces losses in the demodulation process;

RECOMMENDS

1. that, with immediate applicability to all space science service bands Category A, sub-carrier modulation shall not be used except where absolutely required and then only for symbol rates below or equal to 60 ks/s;

2. that, with immediate applicability to all space science service bands Category A, if a sub-carrier is required, it shall comply with the specifications set forth in CONSIDERING e) and f);

Figure 1: Modulation Definitions



[3] For purposes of this Recommendation, the symbol rate is defined as the baseband equivalent single line bit rate following error correcting coding (if applicable) and Bi-phase encoding (if used) but excluding any other spectrum modifying modulation. See figure 1.

Recommendation SFCG 22-1R1

FREQUENCY ASSIGNMENT GUIDELINES FOR COMMUNICATIONS IN THE MARS REGION

The SFCG,

CONSIDERING

a) that a regional communication network can be expected in the foreseeable future at Mars as missions to Mars increase in number and variety;

b) that frequencies for direct communication between a spacecraft at Mars and an Earth station are provided in the existing allocations to the space research service (SRS);

c) that separate frequencies are needed in the Mars region for compatible local communications between a surface vehicle and an orbiter, between surface vehicles, and between orbiters;

d) that major criteria for allocating frequencies include RF compatibility, technology availability and performance, operation scenarios, cost to the missions, and ability to conduct testing and emergency support from the Earth;

e) that, without sufficient frequency separation, a Mars vehicle receiving signals from the Earth can be easily interfered by a signal transmitted by itself or by a local Mars vehicle, and a Mars vehicle transmitting to the Earth can easily interfere with a local receiver;

f) that lower frequency provides better SNR performance for a communication link between two vehicles using low gain broad beam antennas, such as between a rover and a low orbiter;

g) that higher frequency provides better performance between two vehicles employing high gain antennas, such as between a large lander and an orbiter with accurately pointed antennas;

h) that testing Mars local link radios with signals transmitted from an earth station is allowed only if it does not interfere with Earth-based radio systems operating in accordance with

provisions of Radio Regulations; and that techniques such as self test on board are available to minimize the need for testing with Earth-based signals;

i) that the SFCG has resolved to provide assistance to member agencies in coordinating frequency assignment for deep space missions, including missions to Mars (see RES SFCG A 21-1);

j) that Mars missions need interoperable relay links to maintain communication with the Earth; and that such links in the UHF band have been defined in the CCSDS Proximity 1 standard;

k) that passive observations in space need to be protected to the extent provided in the Radio Regulations, particularly the quiet zone in the shielded area of the Moon.

RECOGNISING

a) that Mars local links must not interfere with the direct communication links between space and the Earth using frequencies provided in the ITU Radio Regulation;

b) that multiple frequency bands are needed for missions to meet various communications requirements and satisfy cost, mass and performance objectives.

RECOMMENDS

1. that agencies select frequencies from Table 1 for communications in the Mars region according to the specific applicability and precautions recommended in Table 2,

2. that testing Mars local links in flight with signals transmitted from an Earth station be minimized and strictly non-interfering to the Earth-based radio systems operating under the provisions of Radio Regulation;

3. that assignment of Mars local link frequencies be coordinated within the SFCG in accordance with RES A 21-1.

Table 1: Summary of Frequency Bands for Communications in the Mars Region

Link	Frequency
Space-to-Earth:	2290-2300 MHz 8400-8450 MHz 31.8-32.3 GHz
Earth-to-space :	2110-2120 MHz 7145-7190 MHz 34.2-34.7 GHz
Orbit-to-surface:	435-450 MHz** 2025-2110 MHz 7190-7235 MHz 14.5-15.35 GHz
Surface-to-orbit:	390-405 MHz** 2200-2300 MHz 8400-8500 MHz* 16.6-17.1 GHz
Surface-to-surface:	435-450 MHz 390-405 MHz 2025-2120 MHz 2200-2300 MHz
Orbit-to-orbit:	435-450 MHz 390-405 MHz 2025-2120 MHz 2200-2300 MHz 7190-7235 MHz 8450-8500 MHz
Approach Navigation & Atmosphere Radio Science:	8400-8450 MHz

Multiple frequency bands are provided in Table 1 for each communication link. Table 2 presents specific recommendations on the use of these bands, including the merits and precautions that should be considered before choosing a band.

Figure 1 presents a graphic illustration of the vehicles and communication links, and a conceptual future scenario with frequency bands chosen from Table 1.

Note* - Using this band for the surface-to-orbit link is permitted in the near future when users are few. A user must coordinate with missions using the band for the Space-to-Earth link and operate on non-interfering basis. A user mission to be launched after January 1, 2015 must seek a waiver from the SFCG.

Note** - Operation in the reverse direction is permitted in the near term when users are few. A user must coordinate with missions using the band in the proper direction and operate on non-interfering basis. A user mission to be launched after January 1, 2010 must seek a waiver from the SFCG.

A Conceptual Scenario Circa 2010

(Numbers indicated represent frequency bands, in GHz, selected from Table 1)

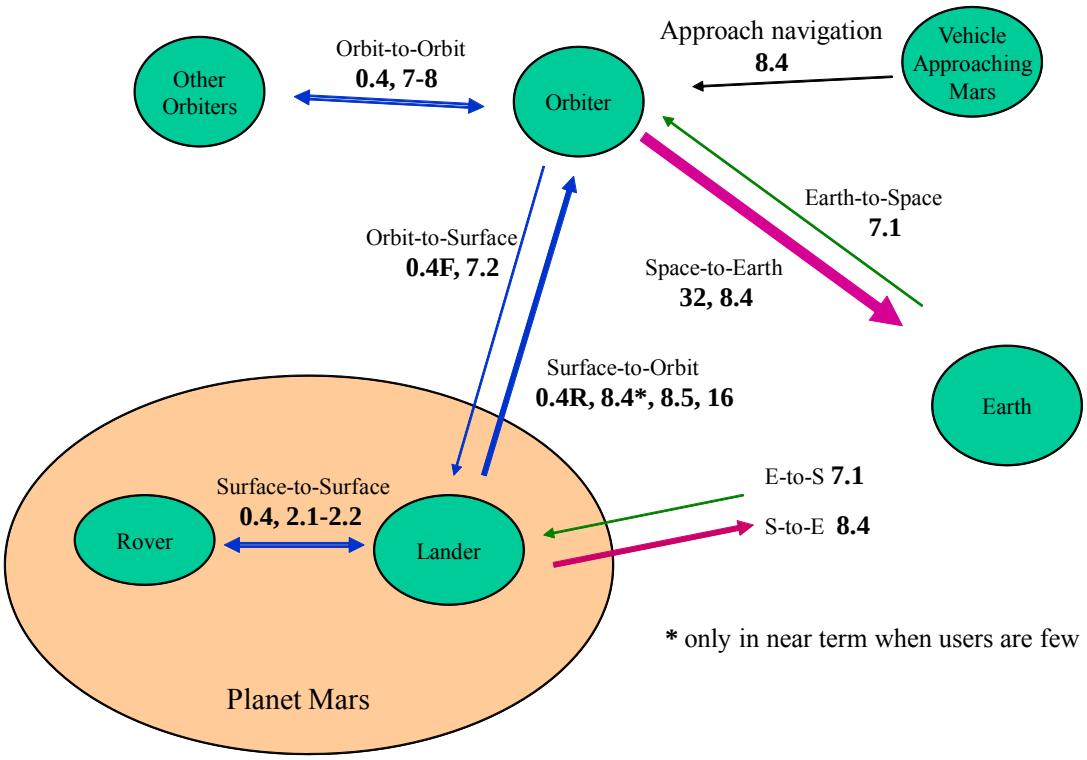


Figure 1

Note: In Figure 1, the numbers in GHz represents a subset of frequency bands from Table 1, as follows:

"0.4"	= 390-405; 435-450 MHz
"0.4F"	= 435-450 MHz
"0.4R"	= 390-405 MHz
"2.1-2.2"	= 2025-2120; 2200-2300 MHz
"7.1"	= 7145-7190 MHz
"7.2"	= 7190-7235 MHz
"7-8"	= 7190-7235; 8450-8500 MHz
"8.4"	= 8400-8450 MHz
"8.5"	= 8450-8500 MHz
"16"	=16.6-17.1 GHz
"32"	= 31.8-32.3 GHz

Table 2: Notes on The Mars Local Link Frequencies Recommended in Table 1 *October 11, 2002*

General Comments:

1. All present and planned future missions to Mars use X-Band S-to-E and E-to-S links.
2. A few missions also carry S-Band S-to-E or E-to-S links. The S-Band uplink is restricted by IMT2000.
3. For all frequencies on this table, technology or equipmrnt is available in the industry.
4. Saturation or jamming refers to strong interfering signal overwhelming the receiver operating in the same band or adjacent band. For missions at Mars satuation happens only on the same vehicle, not likely between vehicles because of the large distance between them.
5. Cross interference refers to interference from one vehicle to another. For Mars missions, such interference is not likely to occur in the adjacent band.

	Data Rate Performance	Accurate Antenna Pointing for Performance	Mass and Volume	Possible Equipment Sharing with Deep Space Space-Earth Links	Self-Interference with Deep Space Space-Earth Links	Cross Interference with Deep Space Space-Earth Links	Testing with Signals Transmitted from an Earth Station	Comments
1.0 Space-to-Earth (S-to-E)								Per ITU-R RR
2.0 Earth-to-Space (E-to-S)								Per ITU-R RR
3.0 Orbit-to-Surface (Command)								
3.1 435-450 MHz	Best at low rate, with LGA	Not required with LGA	large	none	none	none	Only on non-interfering basis (NIB)	For low rate links
3.2 2025-2110 MHz	High rate, with MGA/HGA	Required with small beamwidth (A)	small	If the lander carries an S-Band E-S receiver (Note: Deep space E-to-S is restricted by IMT2000) it is possible to modify the receiver to operate at extended frequencies.	If the orbiter carries S-Band E-S, the S-Band local link transmitter could saturate the S-Band E-S receiver unless there is adequate isolation.	none	Coordination is easier, as the band is allocated to SRS E-S, near Earth, where similar transmissions operate, although at lower power.	For high rate links. Can't share X-Band equipment.

3.3 7190-7235 MHz	Higher rate, with HGA	Required with smaller beamwidth (1/4 A)	smaller	Possible to modify the X-Band E-to-S receiver to operate at extended frequencies.	The orbiter X-Band local link transmitter could saturate an orbiter X-Band E-S receiver unless there is adequate isolation.	none	High power transmission in urban area is restricted to protect fixed and mobile services. A lesser problem in rural areas.	For high rate links. Can share X-Band equipment. Must avoid self-interference to the X-Band E-to-S link
3.4 14.5-15.35 GHz	Even higher rate than X-Band, with HGA	Required with even smaller angle (1/8 A)	even smaller than X-Band	none	none	none	NIB	For high rate links
4.0 Surface-to-Orbit (Telemetry)								
4.1 390-405 MHz	see 3.1	see 3.1	see 3.1	none	none	none	NIB	For low rate links
4.2 2200-2290 MHz	see 3.2	see 3.2	see 3.2	If the lander carriers S-Band S-E transmitter (2290-2300 MHz), it is possible to modify the transmitter to operate at extended frequencies.	An orbiter S-Band S-to-E transmitter could saturate the orbiter local link receiver unless there is adequate isolation.	none	NIB	For high rate links. Not as good as 4.4 which allows X-Band equipment sharing.
4.3 2290-2300 MHz	see 3.2	see 3.2	see 3.2	If the lander carries S-Band S-to-E transmitter, the local link can share the transmitter without modification.	An orbiter S-Band S-E link transmitter will saturate the orbiter S-Band local link receiver.	An orbiter with S-Band S-to-E link could interfere with the local link receiver if the latter is in its antenna beam.	NIB	For high rate links. Not as good as 4.4 which allows X-Band equipment sharing.
4.4 8400-8450 MHz	see 3.3	see 3.3	see 3.3	Can share without modification a lander X-Band S-to-E transmitter.	An orbiter X-Band S-E link transmitter will saturate the orbiter X-Band local link receiver.	An orbiter with X-Band S-to-E link could interfere with another orbiter receiving local X-Band link if the latter is near or in its antenna beam.	NIB	For high rate links. Must avoid cross-link interference from S-E links.

4.5 8450-8500 MHz	see 3.3	see 3.3	see 3.3	Possible to share a lander X-Band S-to-E transmitter modifed to operate at extended frequencies.	Orbiter X-Band S-to-E transmitter could saturate the orbiter local link receiver unless there is adequate isolation.	none	NIB	For high rate links
4.6 16.6-17.1 GHz	see 3.4	see 3.4	see 3.4	none	none	none	Already allocated to SRS, deep space, E-to-S, secondary	For higher rate links
5.0 Surface-to-Surface								
5.1 435-450 MHz and 390-405 MHz	see 3.1	see 3.1	see 3.1	none	none	none	NIB	For low rate links
5.2 2025-2110 MHz and 2200-2290 MHz	Low rate with LGA. Higher rate possible with MGA.	LGA does not require pointing. MGA does.	see 3.2	If lander carries S-Band space-Earth equipment, it is possible to modify it to operate at extended frequencies.	If the lander uses S-Band for space-Earth links, there will be self-jamming between the space-Earth and the local links unless there is adequate isolation.	none	Testing in the 2025-2110 MHz band can be coordinated, as it is in SRS E-S band. Testing in the 2290-2300 MHz band is on NIB.	For higher rate link with line of sight.
5.3 2110-2120 MHz and 2290-2300 MHz	see 5.2	see 5.2	see 3.2	If a lander carries an S-Band space-Earth transmitter or receiver, it can be used for local link.	If the lander uses S-Band space-Earth links, there will be self-jamming between the space-Earth and the local links.	A third vehicle using S-Band space-Earth links may interfere with the local link receiver if it is near the local link receiver, or there is not enough antenna discrimination between the Earth link transmitter and the local link receiver.	The 2110-2120 MHz band is already allocated to SRS, deep space, E-to-S. Testing the 2290-2300 MHz is on NIB.	For higher rate link with line of sight.
6.0 Orbit-to-Orbit								
6.1 435-450 MHz and 390-405 MHz	see 3.1	see 3.1	see 3.1	none	none	none	NIB	For low rate links

6.2 2025-2110 MHz and 2200-2290 MHz	see 3.2	see 3.2	see 3.2	If an orbiter uses S-Band space-Earth link, it is possible to modify space-Earth link equipment to operate at extended frequencies.	If an orbiter uses S-Band space-Earth links, there will be self-jamming between the space-Earth and the local links unless there is adequate isolation.	none	Testing in the 2025-2110 MHz band can be coordinated, as it is in SRS E-S band. Testing in the 2290-2300 MHz band is on NIB.	For high rate links. Less likely to share equipment.
6.3 2110-2120 MHz and 2290-2300 MHz	see 3.2	see 3.2	see 3.2	If orbiter carries an S-Band space-Earth link, the local link can share the same equipment.	If one vehicle uses S-Band space-Earth links, there will be self-jamming between the space-Earth and the local links on the vehicle.	see 5.3	The 2110-2120 MHz band is already allocated to SRS, deep space, E-to-S. Testing the 2290-2300 MHz is on NIB.	For high rate links. Can not share equipment with X-Band S-E links.
6.4 7190-7235 MHz and 8450-8500 MHz	see 3.3	see 3.3	see 3.3	Possible to modify the X-Band space-Earth link equipment to operate in the extended frequency range.	The X-Band transmitter could saturate the X-Band receiver on the same vehicle unless there is adequate isolation.	none	Testing in the 7190-7235 MHz band can be coordinated, as it is in SRS band. Testing in the 8450-8500 MHz band is on NIB.	For high rate llinks. Possible to share equipment with X-Band S-E link.
7.0 Mars Approach Navigation and Atmosphere Radio Science								
7.1 8400-8450 MHz	Radio metric measurement	Accurate pointing as existing on spacecraft for Earth link.	see 3.3	Sharing equipment with the X-Band S-to-E transmitter	Orbiter doing approach navigation does not operate the Earth link at the same time. Orbiter X-Band S-to-E transmitter will saturate the orbiter local link receiver. However, no simultaneously operation of the Earth link with local link is planned for approach navigation.	Cross Interference will not occur with approach navigation. It may happen with occultation radio science when receiver is in the beam of another orbiter transmitting the S-E link.	NIB	

Recommendation SFCG 23-1R1

EFFICIENT SPECTRUM UTILIZATION FOR SPACE RESEARCH SERVICE, DEEP SPACE (CATEGORY B), IN THE SPACE-TO-EARTH LINK

The SFCG,

CONSIDERING

a) that spectrum allocated to SRS, deep space, space-to-Earth, is limited to 10 MHz in the 2 GHz-band (2290-2300 MHz), 50 MHz in the 8.4 GHz-band (8400-8450 MHz), and 500 MHz in the 32 GHz-band (31.8-32.3 GHz);

b) that users and data rates in the 8.4 GHz-band continue to increase and congestion in this band is more severe than in the 2 and 32 GHz bands;

c) that the technology and ground support infrastructure for the 32-GHz allocation are available in at least one space agency;

d) that several future missions being planned are considering data rates in the 5-60 Msps range, and that advanced power generating technologies could enable an even higher data rate;

e) that spacecraft in the Mars region are much more vulnerable to mutual interference due to lack of spatial separation, and that a single unrestricted high-rate mission could occupy the entire 50 MHz allocation in the 8.4 GHz band, preventing its use by any other user in the Mars region;

f) that five or six high rate missions could conceivably coexist in the Mars vicinity in the future, making it necessary to limit the maximum allowable bandwidth for each mission to no more than 8 MHz in the 8.4 GHz Band;

NOTING

a) that deep space missions designed for destinations other than Mars, should also have restrictions on their maximum allowable bandwidths in the 8.4 GHz band, although at a less severe level, so that costly operational coordination could be minimized every time a mission arrives in the vicinity of other missions in space;

b) that an efficient spectrum usage policy should provide incentives to missions to achieve the most efficient utilization of the spectrum as practical;

c) that several modulations use bandwidths more efficiently than the traditional BPSK and some of the most efficient ones are given in CCSDS Recommendation 2.4.17B;

FURTHER NOTING

a) that a 20 dB signal to interference ratio is used successfully as a criterion to prevent interference in the selection of frequencies for many deep-space missions, and separating two missions at the point where their power spectral densities (PSDs) are each 25 dB down from their own spectral peaks is generally sufficient to prevent mutual interference;

b) that an interference spectral power flux density (SPFD) of – 255.1 dB(W/Hz/m^2) would, when received by a 70 meter antenna, be 6 dB below the noise floor of the receiving system and would raise the system temperature by 1dB;

c) that it is sometimes necessary for a deep space mission to use a telemetry subcarrier to isolate a residual carrier, which is needed for weak signal acquisition at low date rate, for radio metric measurement, or for a radio science experiment requiring spectral purity;

RECOMMENDS

1. that, in the 8400-8450 MHz band, the maximum allowable bandwidth of telemetry signals be limited according to Figure 11, wherein

   a) the lower curve applies to all missions;
   b) the upper curve applies only to the non-Mars-missions, strictly on condition that they would not interfere with the Mars missions;

2. that, in the 8400-8450 MHz band, the spectral power flux density outside the maximum allowable bandwidth be limited to ~~–266~~ –255.1 dB(W/Hz/m^2) on the surface of the Earth;

3. that member agencies use the 32 GHz-band for high rate telemetry with bandwidth requirement higher than those allowed in Figure 1;

4. that except for scientific or technical reasons, subcarrier frequencies above 60 kHz do not exceed 5 times the maximum symbol rate of the mission and do not exceed 300 kHz.

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[1] For the purpose of this Recommendation, the Symbol Rate (R_s) is defined in Figure 2.

Figure 1. Maximum Allowable Bandwidth (B25) vs. Symbol Rate (Rs[1])
(In the transition regions, B25 in MHz=k*Rs/(0.41+Rs) where k=8.53 and 12.5 for All-Missions and Non-Mars Missions, respectively)

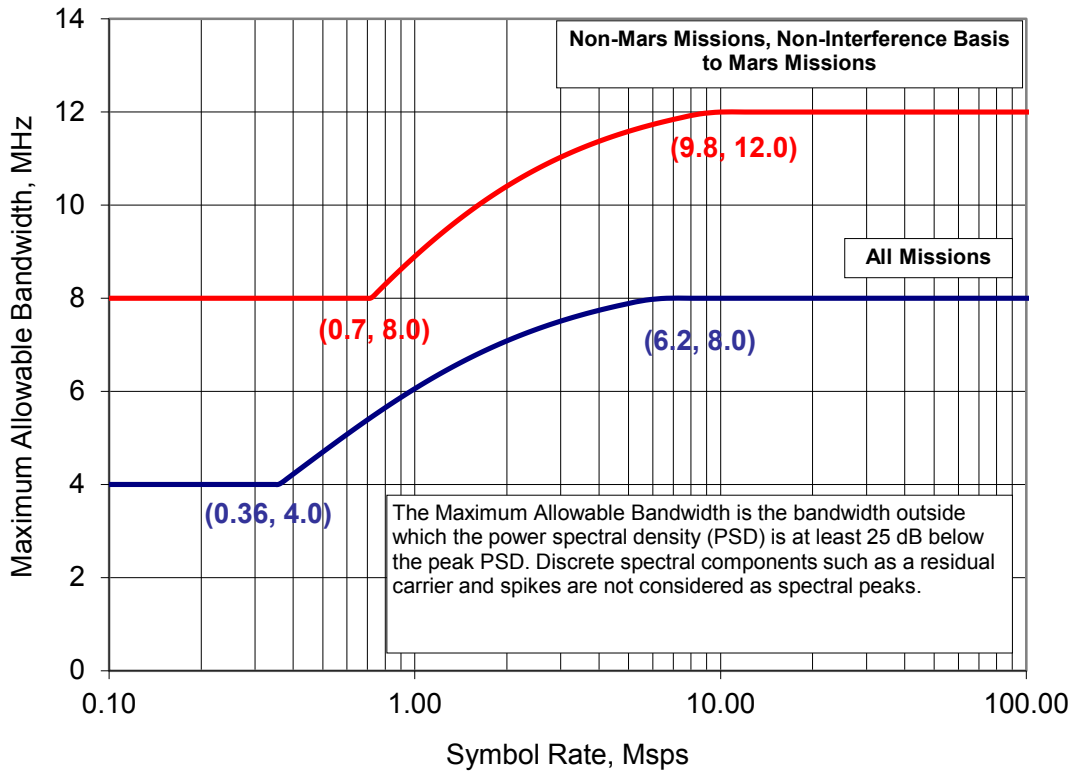
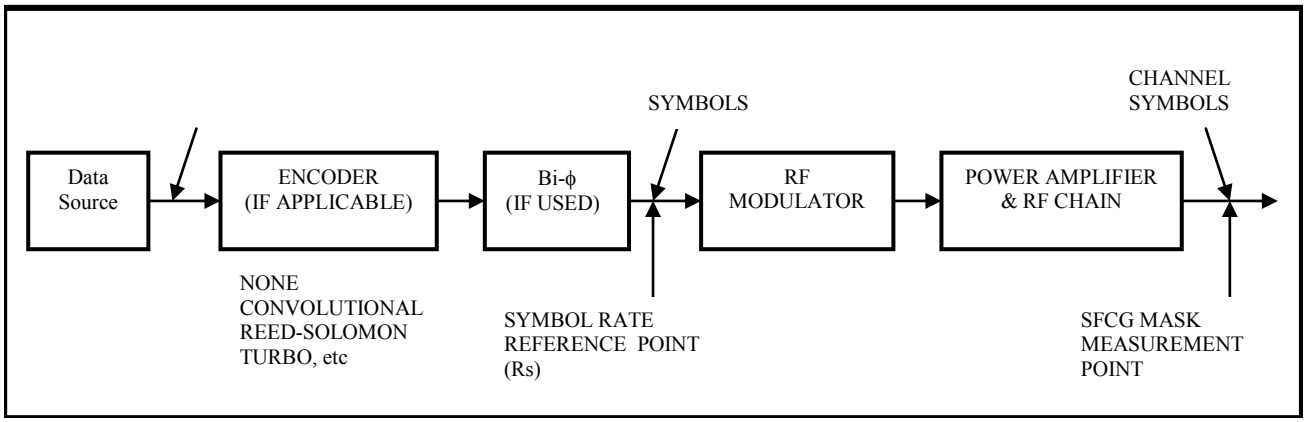


Figure 2. SFCG Symbol Rate Definition



Recommendation SFCG 23-2

ASSIGNMENT OF DIFFERENTIAL ONE-WAY RANGING TONE FREQUENCIES FOR CATEGORY B MISSIONS

The SFCG,

CONSIDERING

a) that differential one-way ranging (DOR) is commonly used by Category B missions to enhance navigation accuracy required to satisfy mission objectives;

b) that measurement accuracy requires wide frequency separation between the DOR tones, examples including several missions using 38-40 MHz separation at the 8 GHz band and two missions using 158-240 MHz separation at the 32 GHz Band;

c) that because of the required separation some of the DOR tone frequencies may have to extend outside the Category B allocations in the future;

d) that a power flux density (PFD) for reception of DOR tones of –211 dB (W/m^2) in the 8 GHz band and –204 dB (W/m^2) in the 32 GHz band provides a received tone power 30 dB above the noise spectral density for a 34 meter Earth station, which is more than sufficient to guarantee reliable operation and accurate measurement;

e) that at such PFD a DOR tone entering the side-lobe of another antenna will be weaker than the ITU-R recommended interference thresholds[1] of the services operating in the adjacent bands by at least 37 dB;

NOTING

that radio astronomy service has a stringent protection requirement that precludes sharing of the 31.3-31.8 GHz band with any other services not mentioned in the Table of Frequency Allocations of the ITU Radio Regulations within this band;

[1] As defined in ITU-R Recommendations RA.769, RS.1029, M.1466, and M.1461.

RECOMMENDS

1. that member agencies assign DOR tone frequencies within the existing Category B allocations whenever possible;

2. that member agencies, when it is necessary to assign a DOR tone frequency outside a Category B allocation, limit the Power Flux Density of each tone to–211 dB (W/m^2) in the 8 GHz Band and –204 dB (W/m^2) in the 32 GHz Band;

3. that member agencies do not assign DOR tones[2] in the 31.3-31.8 GHz band.

2 Including intermodulation products when multiple tone pairs are used simultaneously

Recommendation SFCG 24-1R1

FREQUENCY ASSIGNMENT GUIDELINES FOR ACTIVE REMOTE SENSING IN THE MARS REGION

The SFCG,

CONSIDERING

a) that concurrent active remote sensors and a regional communication network can be expected in the foreseeable future at Mars as missions to Mars increase in number and variety;

b) that frequencies for spaceborne active sensors are provided in the existing allocations to the space research service (SRS) (active);

c) that frequencies for direct communication between a spacecraft at Mars and an Earth station are provided in the existing allocations to SRS;

d) that the SFCG has resolved to provide assistance to member agencies in coordinating frequency assignment for communications on deep space missions, including missions to Mars (see RES SFCG A 21-1);

e) that special frequencies may be required for the study of physical characteristics of Mars and its moons;

f) that in accordance with Resolution SFCG 23-5, agencies planning to develop active remote sensors for use in the Mars region, work together with IUCAF to study issues of compatibility with radio astronomy observatories in the shielded zone of the Moon;

RECOGNIZING

a) that Mars active remote sensors must not interfere with the direct communication links between space and the Earth using frequency bands allocated in the ITU Radio Regulations;

b) that Mars active remote sensors also need to avoid interference with frequencies used by Mars relay networks and other communication equipment in the Mars environment;

RECOMMENDS

1. that agencies select frequencies from Table 1 for active remote sensing in the Mars region according to the specific applicability and precautions recommended in Table 2;
2. that assignment of Mars active remote sensing frequencies be coordinated within the SFCG in accordance with RES SFCG A24-1, with special attention given to ensure compatibility with communication links in the Mars region.

Table 1: Summary of Frequency Bands for Active Remote Sensing in the Mars Region

Frequency Band (MHz)
1-6
50-52
125-175*
460-480
1215-1300
2380-2385
3100-3300
5250-5570
8550-8650
9300-9900
13250-13750
17200-17300
35500-36000
78000-79000
94000-94100

*Note: This frequency band will be useful for estimation of dielectric properties of Mars' moons

Table 2 – Notes on Select Mars Active Sensing and Radiocommunications Links Frequencies Recommended in Table 1

Active Sensing Frequencies	Instrument	Adjacent Radiocommunications Links allocated in Rec 22-1R1	Guardband, Minimum Separation between Bands	Interference Mitigation
460-480 MHz	SAR Imager	435-450 MHz relay	10 MHz	Bandwidth to range from 2.5 MHz to 7.5 MHz (as for Mars Eagle) with center frequency of 465 MHz; sensor band moved to 460-480 MHz for 10 MHz guardband
2.38-2.385 GHz	SAR Imager	2.29-2.3 GHz relay and space-to-Earth	80 MHz	Bandwidth about 1 MHz with center frequency of about 2.385 GHz (as for Magellan); sensor could move to the right if necessary but stay within allocated band 2.38-2.385 GHz
8.55 - 8.65 GHz	active sensor	8.45-8.50 GHz relay	50 MHz	Bandwidth for typical SAR about 20 MHz with center frequency of 8.6 GHz; could move to the right but stay within allocated band 8.55-8.65 GHz
13.25 - 13.75 GHz	active sensor	14.5-15.35 GHz relay	750 MHz	Bandwidth for high resolution altimeter around 320 MHz (similar to TOPEX/JASON) with center frequency of 13.5 GHz; could move to left but stay within allocated band 13.25-13.75 GHz
35.5 – 36.0 GHz	active sensor, topographic mapper	34.2-34.7 GHz Earth-to-Space	800 MHz	Bandwidth for high resolution altimeter around 320 MHz (similar to TOPEX/JASON) with center frequency of 35.75 GHz; could move to right but stay within allocated band 35.5-36.0 GHz; Bandwidth for high resolution topographic mapper up to 500 MHz with center frequency of 35.75 GHz; if less than 500 MHz, could move to right but stay within allocated band 35.5-36.0 GHz

Recommendation SFCG 27-1R1

EFFICIENT SPECTRUM UTILIZATION FOR SPACE RESEARCH SERVICE, DEEP SPACE (CATEGORY B), FOR SPACE-TO-EARTH LINKS IN THE 31.8-32.3 GHZ BAND

The SFCG,

CONSIDERING

a) that spectrum allocated to space research service (SRS), deep space, space-to-Earth, is limited to 10 MHz in the 2 GHz band (2290-2300 MHz), 50 MHz in the 8.4 GHz band (8400-8450 MHz), and 500 MHz in the 32 GHz band (31.8-32.3 GHz);

b) that the 32 GHz band will be the primary Category B space-to-Earth link band for high data rate missions;

c) that the technology and ground support infrastructure for the 32 GHz allocation are available in more than one space agency;

d) that the technology and ground support infrastructure for high-rate efficient modulations offering similar performance as more conventional modulations are available in more than one space agency;

e) that future missions being planned are considering symbol rates up to 100 Msps in the near-term and even higher in the long-term;

f) that on-board advanced power generating technologies and larger ground antennas could enable downlink rates much higher than those which are common today;

g) that radioscience experiments, such as occultation and gravity mapping, require a spectrally clean residual carrier;

h) that residual carrier modulations, while spectrally less efficient, have the carrier spectral purity needed to meet radioscience requirements;

i) that use of residual carrier modulations should be restricted to low symbol rates;

j) that a 60 MHz bandwidth limitation for links with low symbol rates will allow for accommodation of the number of high and low data rate links in the 31.8-32.3 GHz band expected by SFCG member agencies;

NOTING

a) that, CCSDS Rec. 2.4.20B recommends efficient modulations for the 32 GHz band;

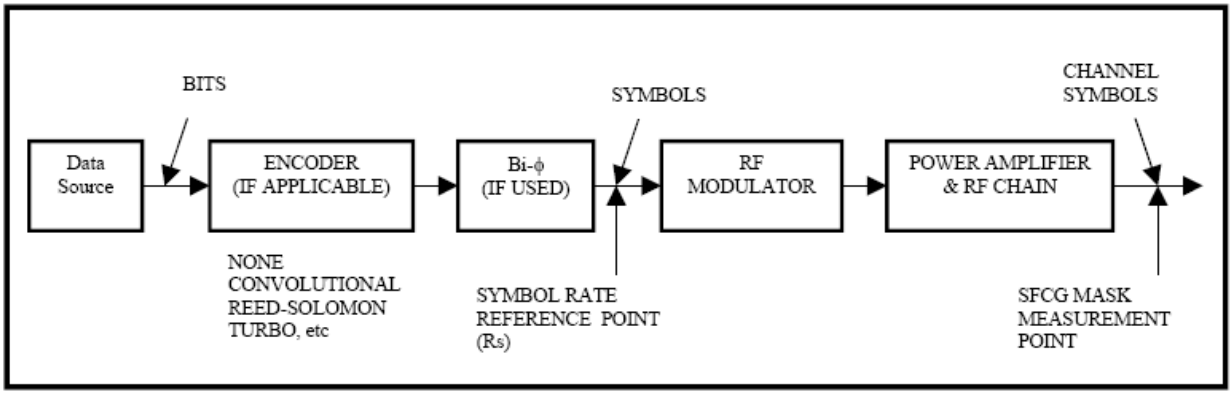
b) that, based on current plans, it is not expected that the 32 GHz band will be congested until after 2015;

RECOMMENDS

1) that, in the 31.8-32.3 GHz band, links with telemetry symbol rates of 20 Msps or more use bandwidth efficient modulation with spectral efficiency similar to GMSK (BT_S=0.5 where T_S=1/R_S) for missions planned to be launched after 2015[1];

2) that the 20-dB bandwidth[2] for links with telemetry symbol rates less than 20 Msps not exceed 60 MHz.

[1] For the purpose of this Recommendation, the Symbol Rate (R_s) is defined as:



[2] The 20-dB bandwidth is the bandwidth of the transmitted telemetry signal beyond which the power spectral density (PSD) remains always below the modulation peak PSD (excluding the residual carrier) by 20 dB.

Recommendation SFCG 29-1

EFFICIENT SHARING OF THE 25.5 - 27.0 GHz BAND BETWEEN EESS (s-E) AND SRS (s-E)

The SFCG,

CONSIDERING

a) that the 25.5 - 27.0 GHz band is allocated to the Earth exploration-satellite service (EESS) (space-to-Earth), the space research service (SRS) (space-to-Earth) and the 25.25 - 27.50 GHz band is allocated to the inter-satellite service[1] (ISS);

b) that EESS and SRS near-Earth missions in the 25.5 – 27.0 GHz band may be compatible under certain conditions;

c) that the power flux densities at the Earth's surface from SRS missions are very low for Lunar missions and extremely low for sun-Earth Lagrange and deep-space missions;

d) that due to the low power flux density, deep-space missions are very vulnerable to interference and have stringent protection criteria;

e) that multiple administrations are planning to fly manned missions to the Lunar environment and beyond;

f) that manned missions have more stringent protection criteria than unmanned missions;

g) that due to atmospheric attenuation, specifically rain attenuation and the power flux density limits specified in Article 21 of the Radio Regulations, it may be difficult to achieve link availabilities greater than 99.9% in the 25.5 – 27.0 GHz band;

---

[1] Use of the 25.25-27.5 GHz band by the inter-satellite service is limited to space research and Earth exploration-satellite applications.

h) that the planned use of the 25.5 to 27 GHz band by SRS and EESS missions is not compatible with manned SRS mission protection criteria specified in Recommendation ITU-R SA.609;

i) that the 25.5 to 27 GHz band is planned to be used by EESS missions for various Earth observing, Earth exploration, and climate monitoring missions;

j) that the availability of the 25.5 – 27.0 GHz band is crucial to near-Earth SRS and EESS missions with high data rate requirements;

k) that interference from transmitting geostationary satellites has the potential to significantly degrade link margins and even cause loss of sensitive links of SRS missions if these satellites operate near the currently applicable PFD limits (see Annex 1);

l) that Article **21** of the Radio Regulations limits the power flux density at the surface of the Earth to levels between -115 and -105 dB(W/m^2/MHz) depending on the angle of arrival;

m) that reducing the power flux density limits below the limits specified in Article 21 of the Radio Regulations for geostationary satellites would provide necessary protection to Lunar and Lagrange SRS missions;

n) that space-to-Earth links of typical non-GSO satellites can always meet the power flux-density limit required to protect a DRS satellite while non-GSO satellites with orbits above 1 370 km may need some allowance to exceed it for a small percentage of time,

RECOGNIZING

1) that the space-based collection of global weather and climate data in support of the Global Earth Observation System of Systems (GEOSS) is becoming increasingly important to the worldwide community;

2) that the 25.5 to 27 GHz band is planned to be used by manned SRS missions for data transmissions that do not involve astronauts and vehicle safety;

3) that non-GSO satellites should also comply with Recommendation ITU-R SA.1155 “Protection criteria related to the operation of data relay satellite systems”;

RECOMMENDS

1) that deep-space missions not use the 25.5 - 27.0 GHz SRS (space-to-Earth) band unless mission requirements cannot be satisfied in other bands specifically allocated for deep-space operations;

2) that if, for a compelling reason, a deep-space mission requires the use of the 25.5 – 27.0 GHz band, the mission not claim interference protection from near-Earth missions in excess of the protection criteria of Recommendation ITU-R SA.609 applicable to unmanned missions in the 25.5 - 27.0 GHz band;

3) that manned SRS missions not claim interference protection from EESS and unmanned SRS missions in excess of the protection criteria of Recommendation ITU-R SA.609 applicable to unmanned missions in the 25.5 - 27.0 GHz band;

4) that to provide additional protection to lunar and Lagrange SRS missions, EESS and SRS missions in geostationary orbits restrict their PFD levels to -115 dB(W/m^2/MHz) in the band 25.5 to 27.0 GHz for all angles of arrival at the surface of the Earth (see Annex 1).

5) that EESS or SRS satellites in non-geostationary orbits with space-to-Earth satellite links shall not produce a power-flux-density (pfd) greater than –133 dB(W/m2) in 1 MHz at any DRS satellite location on the geostationary orbit. This limit may be exceeded no more than 0.1% of the time for non-GSO systems with altitudes greater than 1370 km (see Annex 2).

Annex 1

Potential impact of geostationary satellites on sensitive links of SRS missions

1 Introduction

The 25.5-27.0 GHz band is an important downlink band for the Earth exploration-satellite (EESS) and space research services (SRS). This band is planned to be used for EESS as well as SRS missions. The latter ones could operate at any distance from a low Earth orbit to the Sun-Earth Lagrange points. A number of extensive studies addressed compatibility between various types of missions concluding that all potential applications can share the band 25.5-27.0 GHz without problems except for geostationary satellites operating close to the power flux-density limits of Article 21 of the Radio Regulations. This Annex provides a summary of the various study results and the background for the corresponding reduced power flux-density limits for geostationary satellites.

2 Characteristics of potential victim SRS systems

The most sensitive SRS missions are satellites near the Lagrangian points L1/L2 and near the moon. Figure 1 illustrates such science applications and the corresponding interference constellation.

FIGURE 1

Various mission types with potential deployment in the band 25.5-27.0 GHz

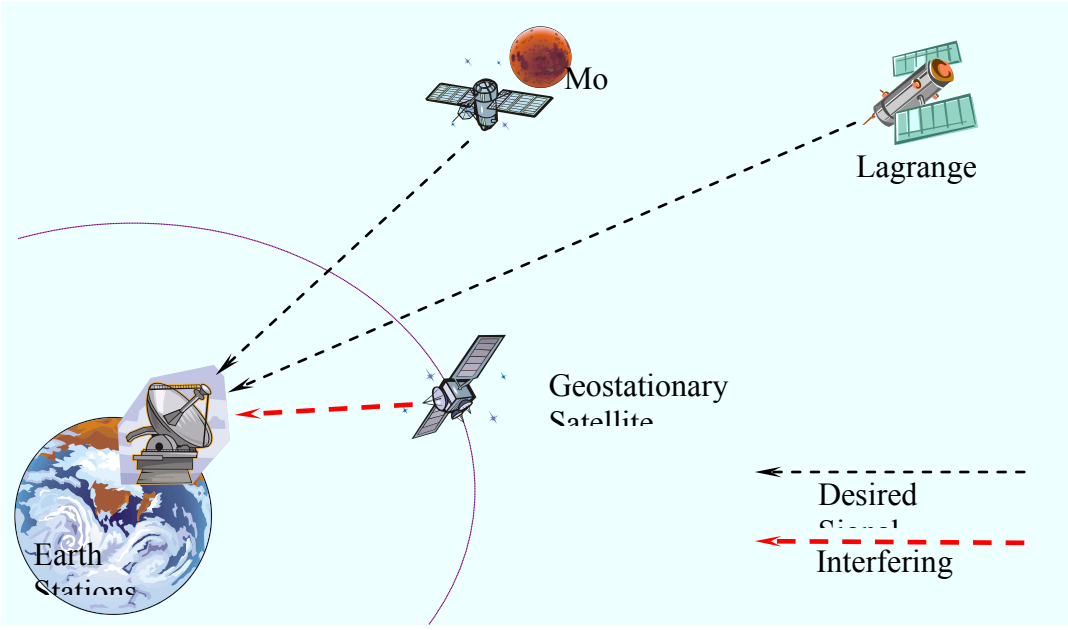


Table 1 shows characteristics for lunar systems analysed in one of the detailed studies. As shown in this table, the link margin is equivalent to Co/No – Co/No required. These margins are calculated from the system data using standard assumptions related to data rate, coding, and availability.

TABLE 1

Essential characteristics for representative Lunar SRS victim systems

		Representative 26 GHz satellite victim systems	
Parameters	**Units**	**LRO Lunar**	**Cx Lunar, 50 MHz**
Frequency	MHz	25 650	26 000
Slant range	km	401 427	404 943
Tx power	dB(W)	16.0	17.0
Tx power split	dB	–3.0	0.0
Tx gain	dBi	42.9	43.5
Max. pfd at Earth	dB(W/m^2/MHz)	–143.0	–141.4
Data rate	Mbps	50.0	25.0
Rx gain	dBi	71.3	70.4
Link losses	dB	–7.5	–9.7
Rain/Atmos loss	dB	–1.25	–2.8
Temp	K	510.0	446.7
Co/No	dB	10.3	13.6
Co/No Required	dB	2.9	2.2
Margin	dB	7.4	11.4

Another detailed study used the James Web Space Telescope (JWST) as a representative example for Lagrangian missions. Two different data rates have been considered with 14 and 56 Ms/s. The adjustable data rate helps to maintain a link in case of heavy rain events. Table 2 shows a summary of the assumptions for Lagrangian SRS victim missions.

TABLE 2

Essential characteristics for Lagrangian SRS victim systems

	JWST-14	**JWST-56**	
SRS satellite orbit height	1 500 000	1 500 000	km
Power of SRS satellite	13.1	13.1	dBW
Bandwidth of main lobe with QPSK	14	56	MHz
SRS satellite antenna diameter	1.05	1.05	m
SRS satellite maximum antenna gain	46.2	46.2	dBi
SRS earth station antenna diameter	34.0	34.0	m
SRS system noise temperature	200	200	K
Technical receiver and pointing losses	3.0	3.0	dB
Required Es/No for QPSK with channel coding	2.5	2.5	dB
Margin for atmospheric attenuation	20.0	13.9	dB

For all assessments, the protection criteria as contained in Recommendation ITU-R SA.609 have been taken as the baseline. It specifies an interference density level of -156 dBW/MHz not to be exceeded for more than 0.1% of time.

3 Assumed characteristics of interfering geostationary systems

Relevant link budget characteristics for some potential geostationary systems are shown in Table 3. GSO-1 is representative for the Alpha-Sat mission with a channel bandwidth of 405 MHz. The satellite design is based on a 0.7 m parabolic antenna. For the simulations, an earth station in Madrid has been assumed as a worst case. GSO-1 is expected to be quite representative for several types geostationary systems planned for deployment in this band. GSO-2 is a hypothetical system and could be representative for a low elevation system with high availability for a dedicated earth station. The satellite was assumed at a GSO position of 48° E. The elevation angle towards central Spain is 20°. GSO-3 may be representative for a high availability system with several smaller earth stations within a sub-region. An example could be a system transmitting to a number of direct data read-out stations. GSO-3 was assumed at 14° E serving a number of smaller user stations in Spain. Even with a 1.4 m onboard parabolic antenna, the main beam covers a rather large region as shown in Fig. 2. Similar situations may be found with other sensitive SRS earth station locations.

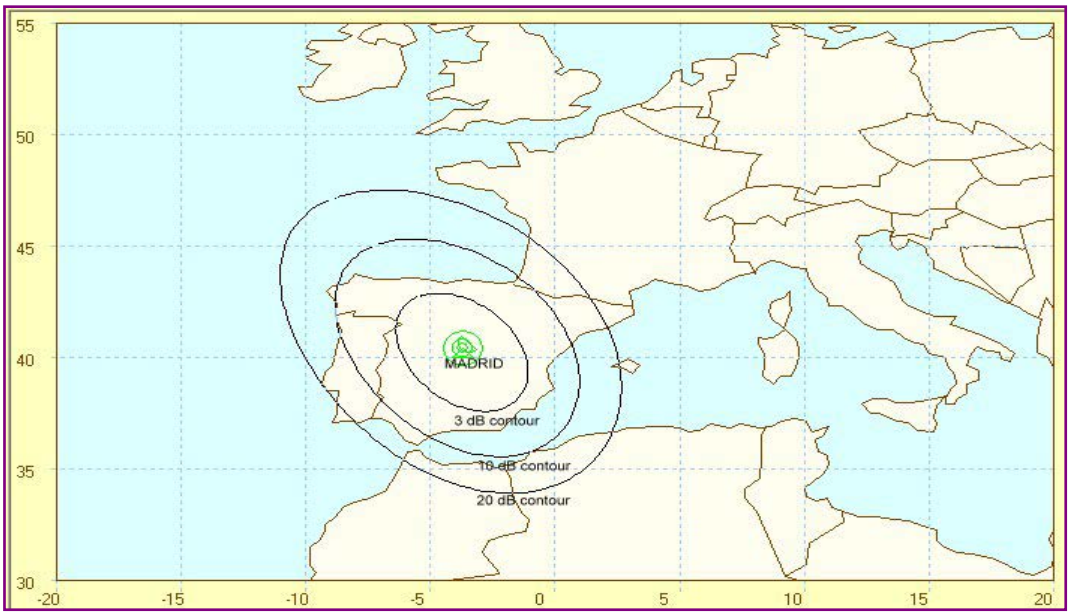
TABLE 3

Key parameters for geostationary satellite systems

	GSO-1	**GSO-2**	**GSO-3**
Transmit power (dBW)	14.0	20.0	23.0
Satellite antenna gain (dBi)	43.1	46.2	49.7
Satellite EIRP (dBW)	57.3	66.2	72.7
Bandwidth of main lobe for 600 Mbit/s and QPSK (MHz)	600	600	600
Maximum PFD at receive site (dBW/m^2/MHz)	–130.2	–121.5	–114.6
Assumed link availability (%)	99.90	99.98	99.98
Signal attenuation for assumed availability (dB)	8.4	21.5	15.0
Earth station antenna diameter (m)	7.3	10.0	2.0

FIGURE 2

Footprint contours towards Madrid for a geostationary satellite at 14° E



4 Assessment of interference to SRS missions

One approach was based on an *I*/*N* criterion is typically used to determine if intersystem interference will result in unacceptable interference to any of the available SRS or EESS systems.

Based on Recommendation ITU-R SA.609, the received interference level from all sources should not exceed the following aggregate level:

Io/No not to exceed –6 dB more than 0.1% of the time.

This analysis moved beyond the basic Io/No interference criterion and took into account the relatively large link margins that many of the SRS and EESS systems have. It looked at the degraded link margin, denoted simply by "margin":

$$\text{margin} = Co/(No+Io)_{measured} - Co/No_{required}$$

The basic criterion for determining whether interference is within acceptable levels was that the following:

margin not to fall below α dB more than 0.1 % of the time.

where "α" is a value that is discussed below. A possible value for α would be 0, as this is the level below which the link could not be closed.

However, it was considered not to be prudent to allow the entire link margin to be consumed by interference from other non-GSO or GSO systems, so α may in fact be a value greater than 0. It should be emphasized that use of this type of interference criterion allows the study to move beyond the traditional *I*/*N* interference analysis approach to analyze the degradation to the systems' link margins.

Some key assumptions used for the simulation were that victim and interfering sources are assumed to operate using the same centre frequency. Furthermore, the interferer's total power is averaged over its bandwidth and 3 dB is added to account for the peak density, assuming PSK modulation. High-gain satellite antenna patterns follow the reference radiation pattern of Recommendation ITU-R S.672. Earth station antenna patterns follow the pattern in Recommendation ITU-R F.1245.

Robledo and Cebreros are two locations in central Spain which support sensitive SRS missions such as to Lagrangian points or, potentially, to the Moon. In view of the long distances to L1 and L2, the power flux-density of the received signals is rather low, requiring large earth stations up to 35 m with a high *G*/*T*. As far as interference statistics are concerned, all earth stations at similar latitudes will show similar results. The only significant difference will be the atmospheric attenuation which can differ to a large degree between the various potential sites.

Regarding potential interference to Lagrangian SRS missions caused by geostationary satellites with characteristics as provided in Table 3, some studies concluded that typical implementation such as AlphaSat would just meet the SA.609 criterion assuming its earth station would be located in central Spain. For the systems GSO-2 and GSO-3, an excess of the SA.609 criterion by 8 to 15 dB would occur even with a reduced PFD limit of –115 dBW/m^2/MHz. However, non-compliance with Recommendation ITU-R SA.609 does not necessarily mean that harmful interference will occur. Links around 26 GHz need significant margins to achieve a link availability in excess of 99% down to elevation angles of 5 to 10 degrees. For example, Robledo and Cebreros need margins of around 10 dB to close a link down to elevation angles of 5° for 99% of time. For operation down to 10°, a margin of 5.4 dB would still be required. This results in a practical situation where the interference events in excess of the SA.609 criterion in many cases only reduce the margin without causing a loss of the link. The link outage due to atmospheric attenuation is much higher as compared to interference. When considering the actual data loss due to interference, the required Es/(No+Io) can be met for 99.98% of time even in the case of geostationary satellites operating at a reduced PFD limit of –115 dBW/m^2/MHz. However, a geostationary satellite operating at the PFD limits of RR 21.16 could cause harmful interference resulting in a loss of the link. Potential interference to Lunar SRS missions caused by the same satellites are of similar magnitude.

Table 4 presents a summary of the results of other analyses regarding interference from a hypothetical GSO satellite mission into a number of victim missions similar to the ones listed in Table 1. Table 4 shows the margin without interference as well as the degraded margins into the SRS missions due to interference from a GSO mission at 107º W with

PFD levels of –105 to –125 dBW/m^2 MHz.. GSO-107 W transmits to WSC (White Sands) with an elevation angle to the earth station greater than 25 deg.

A hypothetical GSO mission that operated at the PFD limit of –105 dB(W/m^2/MHz) could cause interference levels in excess of the interference criterion, as a GSO mission may be always in view of a victim earth station, while an non-GSO mission is not. However, such a high PFD level would only be necessary if very small earth stations were used (e.g. 1 or 2 m) and if a high availability were required.

TABLE 4

Single-entry interference margin results for GSO case at the 0.1% level

			Margins at 0.1% level		
Victim Mission	**Rx Station**	**C/N Margin (dB) w/o interference**	**GSO 107W; PFD=-105 @90EL**	**GSO 107W; PFD=-115 @90EL**	**GSO 107W; PFD=-125 @90EL**
LRO	WSC	7.4	-0.1	6.1	7.4
Cx Lunar, 50 MHz	WSC	11.4	3.0	9.7	11.4

Based on the results shown in Table 4, it may be seen that the margin at the 0.1% level is negative or substantially degraded for the lunar missions LRO and Cx Lunar if the interfering GSO satellite uses a power flux-density that just meets the limits contained in Article 21 of the Radio Regulations. For interference into LRO, the margin is reduced from 7.4 to –0.1 dB and for Cx Lunar it is reduced from 11.4 to 3.0 dB. In both of these cases, the margins are reduced to values which can be considered too small. Figures 3 and 4 show the corresponding interference statistics for the LRO and Lunar Cx missions. However, if the PFD is limited to a maximum value of –115 dBW/m^2/MHz for all angles of arrival then degradation due to interference is substantially reduced. Further reducing the PFD to a maximum value of –125 dBW/m^2/MHz for all angles of arrival would not offer much additional improvement.

In summary, all studies concluded that interference from geostationary satellites operating at the same power flux-density as Earth observation satellites would cause interference levels which are at least an order of magnitude above the SA.609 criteria and significantly higher as compared to non-GSO EESS missions due to the increased visibility. Nevertheless, excess of SA.609 interference density criteria will not lead to unacceptable Es/(No+Io) conditions if the geostationary satellites operate below –115 dBW/m^2/MHz. However, geostationary satellite operating at the PFD limits of RR 21.16 could cause substantial interference. In many regions of the world with small or moderate rain attenuation, geostationary systems can generally be deployed without the need to operate even close to the current PFD limits. A PFD limit of around –115 dBW/m^2/MHz for geostationary satellite systems at all angles of arrival would therefore provide adequate protection to SRS missions without putting undue constraints on geostationary satellites.

FIGURE 1

Interference margin chart for GSO-107W into LRO

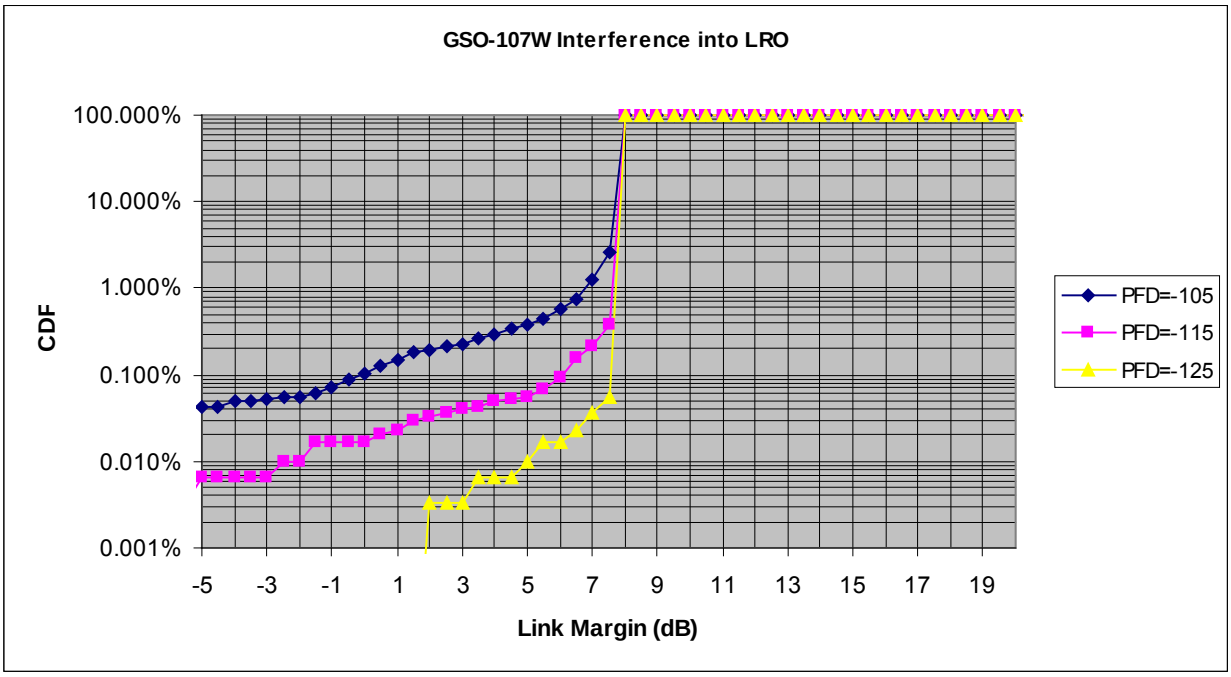
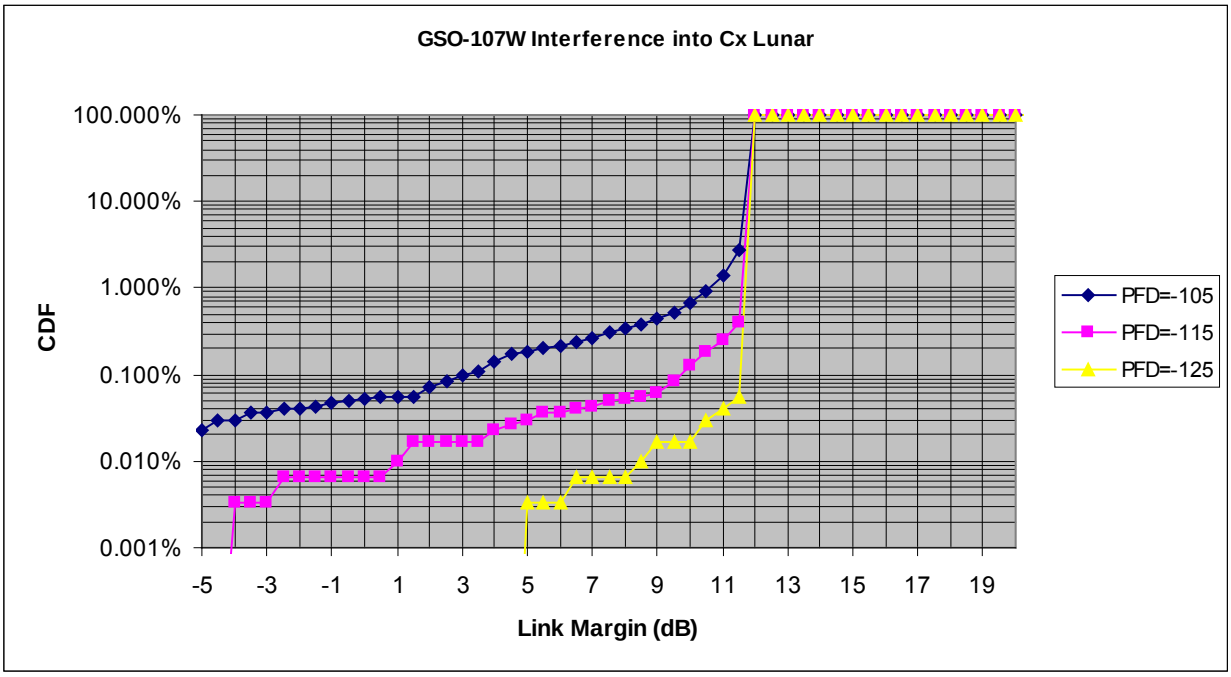


FIGURE 2

Interference margin chart for GSO-107W into Cx Lunar



Annex 2

Power flux-density limits on the geostationary orbit for non-GSO satellites

Recommendation ITU-R SA.1155 specifies a maximum allowable interference power spectral density of $P_{sd} = -178$ dBW/kHz which can be converted to −148 dBW/MHz in view of the generally very wide receiver bandwidth of DRS satellites. The corresponding pfd value can be calculated by taking into account the effective antenna area:

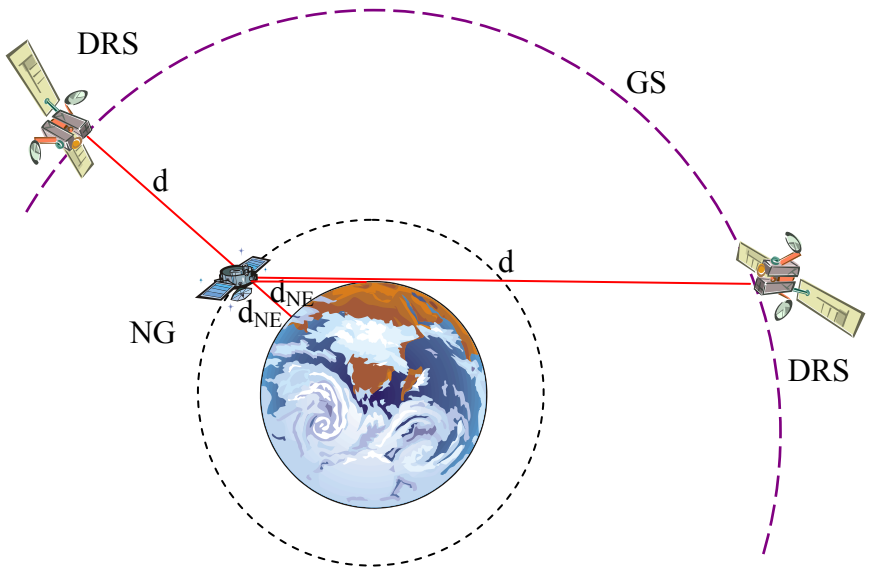
$$PFD_{\lim it} = P_{sd} - 10 \cdot \log(\eta \pi \frac{D^2}{4}) = -148 + 1.05 - 10 \cdot \log(\eta D^2)$$

The largest antenna of current DRS satellites has a diameter of 4.9 metres. The efficiency η can be assumed with 50%. The corresponding pfd value would be –157.7 dBW/m^2/MHz. The allowable time percentage of 0.1% specified in Recommendation ITU-R SA.1155 cannot be applied to the pfd limit, as this would neglect the fact that both antennas are moving relative to each other, and that exposure of the DRS GSO location with the specified pfd limit results only in maximum allowable interference when the DRS antenna is pointing directly at the EESS satellite.

It is assumed that a percentage of interference excess is acceptable that corresponds to the main-lobe beamwidth. For a 4.9 m antenna, the first side-lobe angle is around 0.22 degrees (one-sided). The probability of another satellite with asynchronous orbit parameters to be within this main-lobe beamwidth is around 3.7×10^{-6}, thus considerably less than 1×10^{-3} as specified in Recommendation ITU-R SA.1155. The first side-lobe gain is assumed to be around 25 dB lower according to Recommendation ITU-R S.672. This results in a pfd limit of –132.7 dBW/m^2/MHz. In order to determine a suitable distance d_{NE}, operation of a non-GSO satellite at the PFD limit has been assumed. The following two cases may then be considered as illustrated in Fig. 5.

FIGURE 5

Non-GSO satellite interference to data relay system satellites on GSO



Case 1 assumes maximum PFD of –115 dBW/m^2/MHz towards a 5° angle of incidence at the surface of the Earth and consequently also maximum PFD towards DRSS-1. This is typically the case with parabolic antennas or due to shielding by the spacecraft itself in case of cardioid antennas. For simplicity, the PFD towards DRSS-1 has been assumed equal to the PFD towards the 5° angle of incidence. In reality, the level will be more than 3 dB lower due to a slightly longer distance and shielding of half of the antenna main lobe by the Earth.

Case 2 assumes maximum PFD of –105 dBW/m^2/MHz towards a 90° angle of incidence at the surface of the Earth and also maximum PFD towards DRSS-2 via the antenna backlobes. This could be the situation for transmissions via omni-directional antennas.

The related distances can be derived from the following equations:

$$PFD = \frac{EIRP}{4 \cdot \pi \cdot d^2}$$

$$EIRP = PFD_1 \cdot (4 \cdot \pi \cdot d_{NE}{}^2) = PFD_2 \cdot (4 \cdot \pi \cdot d_{NG}{}^2)$$

$$d_{NE} = \sqrt{\frac{PFD_2}{PFD_1}} \cdot d_{NG}$$

$$h_O = \sqrt{R^2 + d_{NE}{}^2} - R$$

where:

d_{NE1} : distance from the non-GSO satellite to the 0° angle of arrival location;

d_{NG1} : distance from the non-GSO satellite to DRSS-1 ($d_{NG1} = d_{NE1}$ + 41 680 km);

d_{NE2} : distance from the non-GSO satellite to its sub-satellite point (90° angle of arrival);

d_{NG2} : distance from the non-GSO satellite to DRSS-2 (d_{NG2} = 35 787 km - d_{NE2});

h_0 : orbit height of non-GSO satellite;

R : Earth radius (6 378 km).

For case 1, PFD_1 = –115 dBW/m^2/MHz, PFD_2 = –133 dBW/m^2/MHz and the corresponding minimum non-GSO orbit height would be 2 380 km.

For case 2, PFD_1 = –105 dBW/m^2/MHz, PFD_2 = –133 dBW/m^2/MHz and the corresponding minimum non-GSO orbit height would be 1 370 km.

As the minimum orbit height of 1 370 km represents the worst case, this distance has been taken as the basis for the Recommendation.

Recommendation SFCG 29-2

FREQUENCY ASSIGNMENT GUIDELINES FOR ACTIVE REMOTE SENSING IN THE LUNAR REGION

The SFCG,

CONSIDERING

a) that concurrent active remote sensors and a regional communication network can be expected in the foreseeable future in the Lunar region as missions to the moon increase in number and variety;

b) that frequencies for spaceborne active sensors are provided in the existing allocations to space research service (SRS) (active);

c) that frequencies for direct communication between a spacecraft in the Lunar region and an earth station are provided in the existing allocations to SRS;

RECOGNISING

a) that active remote sensors in the Lunar region must not interfere with the direct communication links between space and the Earth using frequency bands allocated in the ITU Radio Regulations;

b) that active remote sensors in the Lunar region also need to avoid interference with frequencies used by Lunar relay networks and other communication equipment in the Lunar environment;

c) that in accordance with Resolution SFCG 23-5, agencies planning to develop active remote sensors for use in the Lunar region, work together with IUCAF to study issues of compatibility of a radio astronomy observatory in the shielded zone of the Moon;

RECOMMENDS

1. that agencies select frequencies from Table 1 for active remote sensing in the Lunar region according to the specific applicability and precautions recommended in Table 2;

2. that assignment of Lunar active remote sensing frequencies be coordinated within the SFCG with special attention given to ensure compatibility with communication links in the Lunar region;

3. that this Recommendation be reexamined when RAS observatories in the shielded zone of the Moon are being deployed.

Frequency Band (MHz)
1-15
50-52
148-151
460-480
1215-1300
2378-2387
3100-3300
5250-5570
8550-8650
9300-9900
13250-13750
17200-17300
35500-36000
78000-79000
94000-94100

Table 1: Summary of Frequency Bands for Active Remote Sensing in the Lunar Region

Active Sensing Frequencies	Instrument	Adjacent Radiocommunications Links allocated in Rec 22-1R1	Guardband, Minimum Separation between Bands	Interference Mitigation
460-480 MHz	SAR Imager	435-450 MHz relay	10 MHz	Bandwidth to range from 2.5 MHz to 7.5 MHz (as for Mars Eagle) with center frequency of 465 MHz; sensor band moved to 460-480 MHz for 10 MHz guardband
2.38-2.385 GHz	SAR Imager	2.2-2.3 GHz relay and space-to-Earth	80 MHz	Bandwidth about 1 MHz with center frequency of about 2.385 GHz (as for Magellan); sensor could move to the right if necessary but stay within allocated band 2.38-2.385 GHz
8.55 - 8.65 GHz	active sensor	8.45-8.50 GHz relay	50 MHz	Bandwidth for typical SAR about 20 MHz with center frequency of 8.6 GHz; could move to the right but stay within allocated band 8.55-8.65 GHz
13.25 - 13.75 GHz	active sensor	14.5-15.35 GHz relay	750 MHz	Bandwidth for high resolution altimeter around 320 MHz (similar to TOPEX/JASON) with center frequency of 13.5 GHz; could move to left but stay within allocated band 13.25-13.75 GHz
35.5 – 36.0 GHz	active sensor, topographic mapper	34.2-34.7 GHz Earth-to-Space	800 MHz	Bandwidth for high resolution altimeter around 320 MHz (similar to TOPEX/JASON) with center frequency of 35.75 GHz; could move to right but stay within allocated band 35.5-36.0 GHz; Bandwidth for high resolution topographic mapper up to 500 MHz with center frequency of 35.75 GHz; if less than 500 MHz, could move to right but stay within allocated band 35.5-36.0 GHz

Table 2 – Notes on Select Lunar Active Sensing and Radiocommunications Links Frequencies Recommended in Table 1 (based on interference analysis of SRS (active) and radiocommunications links in the Mars Region)

Recommendation SFCG 29-3

EMERGENCY COMMUNICATIONS FOR MANNED SPACE FLIGHT

The SFCG

CONSIDERING

a) that manned space exploration spacecraft and space stations require continuous and reliable communication with Earth stations;

b) that the technical characteristics and operational requirements of emergency space communication channels may be different from those of routine links between Earth stations and manned vehicles in space flight, including those for near-Earth, lunar, and planetary missions;

c) that there are many advantages in the use of predefined sets of frequency pairs with specific channels for manned space exploration emergency communications;

d) that existing space research service allocations for communications could be used for emergency radiocommunication channels for manned space flight;

e) that manned space flight requires provisions for emergency communications for the entire duration of a mission;

f) that a number of administrations are either directly involved in manned space flights, or have space-faring interests, and may be able to operationally contribute to radio communications that have an emergency nature;

g) that under emergency situations, a crippled manned spacecraft may have the requirement to communicate at low power levels using an omnidirectional antenna, and need to operate in a frequency band that has a very low amount of interference;

h) that space research service allocations in the 2 025-2 120 MHz and 2 200-2 300 MHz bands generally have desirable characteristics for emergency communications links,

NOTING

a) that it is desirable to promote and encourage multi-national collaboration if emergency conditions occur during manned space flights;

b) that an emergency communications link should be independent of the primary nominal command & telemetry links;

c) that the use of space research service channels for emergency communication is not considered to be a safety service application;

d) that the sub-band 2293-2297 MHz is a key band for current and future deep space missions and should not be considered for manned emergency communications,

FURTHER NOTING

a) that Article V of the United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, provides that, "States Parties to the Treaty shall regard astronauts as envoys of mankind in outer space and shall render to them all possible assistance in the event of accident, distress, or emergency landing on the territory of another State Party or on the high seas";

b) that this Article further provides that, "In carrying on activities in outer space and on celestial bodies, the astronauts of one State Party shall render all possible assistance to the astronauts of other States Parties.",

RECOMMENDS

1. that a manned spacecraft experiencing an emergency situation use the 2290-2300 MHz band, excluding the 2293-2297 MHz sub-band, to transmit to the Earth, directly and/or through a DRS;

2. that transmissions to a manned spacecraft experiencing an emergency situation, either directly or through a DRS, use the bands 2025-2110 MHz and/or 2110-2120 MHz;

3. that unwanted emissions in the 2293-2297 MHz band from manned spacecraft emergency transmitters meet the applicable deep space protection criteria stated in Recommendation ITU-R SA.1157;

4. that specific emergency communication frequencies within the bands given in recommends 1 and 2 be coordinated prior to launch through the normal SFCG process.

ENCOURAGES

1 that, when practicable and upon request, member agencies with suitable facilities assist the requesting agency in the reception of emergency signals from a manned spacecraft experiencing an emergency situation;

2 that, when practicable and upon request, member agencies with suitable facilities assist the requesting agency in providing transmission capabilities to support a manned spacecraft experiencing an emergency situation.

Recommendation SFCG 30-1

USE OF DIFFERENTIAL ONE WAY RANGING TONES IN THE 8400-8450 MHZ BAND FOR CATEGORY-B SRS MISSIONS

The SFCG

CONSIDERING

a) that Differential One Way Ranging (DOR) or Delta DOR (DDOR) is a valuable technique to obtain high precision navigation data needed by deep space missions for critical events such as orbit insertions, close encounters with asteroids or celestial bodies, and landings;

b) that this technique uses one or more pairs of tones each at a fixed frequency offset from the carrier;

c) that these tones are modulated on the downlink carrier using a fixed modulation angle and transmitted to Earth without telemetry modulation;

d) that DOR tones received by the earth stations generally are weak and do not normally pose any interference risk to other missions;

e) that DOR tones from a high power deep space mission can cause interference to another deep space mission when both spacecraft are in or near the same antenna beamwidth;

f) that such interference can be detrimental when it occurs during a critical mission event;

g) that potential for interference is worse for Mars missions using the 8400-8450 MHz band;

h) that the effectiveness of resolving the DOR tone interference problem in the 8400-8450 MHz band through the frequency channel selection process is extremely limited;

i) that the carrier tracking loops of deep space earth stations are most vulnerable to DOR tone interference;

j) that a DOR tone with a received power stronger than -200 dBW may interfere with the operation of the carrier tracking loop; but that much stronger DOR tones are needed to achieve the performance required by some deep space missions;

k) that there is more flexibility in planning and execution of the DOR measurements than most deep space critical events;

l) that use of a PN waveform instead of tones can reduce interference to the carrier tracking loop;

m) that an interference cancellation technique can make the ground receiving system more immune to DOR tone interference;

n) that operational coordination may be needed to minimize DOR tone interference;

RECOMMENDS

1. that deep space missions that have the capability to reduce the power of their X-band DOR tones, remove any excess power in their DOR tones to minimize potential interference to other deep space missions;

2. that deep space missions being designed for launch after 2016 have the capability to control the power of their X-band DOR tones by a method such as:

    a. implementing command-selectable modulation indices for DOR tones;

    b. turning on telemetry modulation with a suitable modulation index and subcarrier frequency to off load any excess power;

    c. using a combination of (a) and (b) above;

3. that deep space missions publish in the SFCG database the transmitted power levels and frequencies of the DOR tones and intermodulation products that are part of the DOR operations;

4. that deep space missions provide and update spacecraft trajectory data to facilitate coordination of DOR tone passes;

5. that deep space missions in or near Mars coordinate their X-band DOR tone passes with other Mars missions before the scheduled passes take place;

6. that deep space missions using X-band DOR tones away from Mars coordinate their X-band DOR tone passes with other deep space missions having a conjunction during these scheduled passes;

7. that coordination of deep space missions' DOR passes be based on the following priorities:

a. the deep space downlinks during a mission critical event, including the return of critical science data;

b. the deep space downlinks in preparations for and immediately after execution of a critical mission event, including DOR measurements immediately preceding a navigation-enabled critical spacecraft event such as landing, encounter, etc.;

c. routine downlinks of deep space missions;

d. routine DOR measurements of deep space missions;

8. that future deep space missions consider using PN for the DOR waveform instead of tones once CCSDS has developed the necessary standard and this is proven to reduce the potential for interference to other deep space missions;

9. that member agencies consider possible inclusion of an interference cancellation capability in their ground receivers.

Recommendation SFCG 30-2

EFFICIENT USE OF THE 25.5 – 27.0 GHz FREQUENCY BAND BY FUTURE EARTH EXPLORATION SATELLITE SYSTEMS AND SPACE RESEARCH SATELLITE SYSTEMS

The SFCG,

CONSIDERING

a. that the 25.5 - 27.0 GHz frequency band is allocated to the Earth exploration-satellite service (EESS) (space-to-Earth), the space research service (SRS) (space-to-Earth) and the 25.25 - 27.50 GHz frequency band is allocated to the inter-satellite service (ISS);

b. that EESS and SRS missions in the 25.5 – 27.0 GHz frequency band are likely to transmit payload telemetry data at very high rates;

c. that the very high data rates will impose the use of high gain pointable transmit antennas onboard satellites;

d. that, contrary to fixed isoflux antennas used in the 8025-8400 MHz frequency band, high gain antennas do not allow to compensate for the range variation of about 10 dB from 5 to 90 degrees elevation, thus leading to an excessive and unnecessary link margin at high elevations;

e. that atmospheric attenuation in the 25.5-27 GHz frequency band may be as high as 35 dB at low elevations for an availability of 99.9% and still 15 dB for an availability of 99%;

f. that administrations may decide to counteract atmospheric attenuation by designing their space-Earth links with considerable margins so as to ensure necessary availability;

g. that the RR Article 21 power flux density limits at the Earth's surface in the 25.5-27 GHz frequency band are of -115dBW/m^2/MHz for elevations of 5 degrees and less and of -105 dBW/m^2/MHz for elevation of 25 degrees or more;

h. that manned missions may have different operational constraints than unmanned missions that may preclude the implementation of certain advanced operational techniques,

FURTHER CONSIDERING

i. that operational adjustment of the transmit power along a pass is costly, inefficient and may affect the reliability of the onboard high power amplifier;

j. that variable coding and modulation (VCM) techniques exist and are used operationally for space-Earth links of telecommunication satellites;

k. that VCM techniques can be used to compensate for range variations, variations of atmospheric attenuation or both;

l. that already with simple coarse range compensation using VCM, a data throughput increase of typically 90% or a bandwidth reduction by a factor of typically 1.6 can be obtained while finer and more performing range compensation will be feasible in most cases;

m. that adaptive coding and modulation (ACM) would allow even more efficient use of the link through real-time compensation of atmospheric attenuation;

n. that higher elevation angle tracking techniques, in which transmissions begin at relatively large elevations angles (e.g. 30 degrees), present an efficient means of increasing data throughput for Lagrangian points and lunar orbit missions,

RECOGNIZING

1. that developing systems operating with unnecessary huge margins may lead to premature interference problems either between EESS missions or into SRS missions;

2. that, due to range variations along a pass and atmospheric attenuation, huge margins are necessary if the onboard transmitter operates with fixed transmit power, modulation, coding and data rate,

RECOMMENDS

1. that SFCG member agencies consider implementing variable coding and modulation (VCM) or adaptive coding and modulation (ACM), where practicable, when operating high data rate EESS and SRS space-Earth links in the 25.5 – 27 GHz frequency band;

2. that SFCG member agencies consider implementing higher elevation tracking methods, where practicable, when operating high data rate SRS space-to-Earth links in Lagrangian and lunar orbits in the 25.5 – 27 GHz frequency band.

Recommendation SFCG 32-1

METHODOLOGY FOR THE COMPUTATION OF AGGREGATE INTERFERENCE FROM THE HIGH DENSITY FIXED SERVICE (HDFS) TO A DEEP-SPACE EARTH STATION IN 37-38 GHZ BAND

The SFCG

CONSIDERING

a) that there are only a limited number of deep space earth stations in operation worldwide;

b) that large number of HDFS transmitters around a deep space earth station make the computation of the interference from the HDFS transmitters to the earth station extremely difficult;

c) that HDFS transmitters close to each other have highly correlated propagation path losses in the direction of a deep space earth station and HDFS transmitters far away from each other have independent propagation statistics in the direction of the earth station;

d) that the use of aggregate EIRP (AEIRP), which groups HDFS transmitters in a geographical area, with highly correlated propagation statistic, as a single transmitter greatly simplifies the computation of the HDFS interference to deep space earth stations;

NOTING

a) that the Radio Regulations have allocated the 37-38 GHz band to space research service (SRS) as primary;

b) that the Radio Regulations have also allocated the 37-38 GHz band to fixed service (FS), as primary, making the band available for HDFS deployment;

c) that Rec. ITU-R SA.1396 specifies the deep space protection criterion in the 37-38 GHz band for non-line-of-sight propagation weather statistics as 0.001% of the time for manned missions and 0.1% of the time for unmanned missions;

d) that Rec. ITU-R P.452 specifies methodologies for computing non-line-of-sight propagation losses as functions of the terrain and atmospheric condition, as well as the distance between a transmitter and a receiver;

RECOMMENDS

1. that AEIRP is used to represent the total transmit power from a group of HDFS transmitters in an area with highly correlated propagation statistics in the direction of a deep space earth station;

2. that HDFS transmitters around a deep space earth station be divided into azimuth sectors using the earth station as the center, with the assumption that the propagation statistics are independent for HDFS transmitters in different azimuth sectors;

3. that within each azimuth sector, the HDFS transmitters be further divided into zones in radial direction from the deep space station and the HDFS transmitters in each zone be represented by a single transmitter with the AEIRP of all the transmitters in that zone;

4. that some zones within an azimuth sector can then be organized into a zone group depending on geographic factors with the assumption that the propagation statistics within each zone group are highly correlated and the propagation statistics among different zone groups are independent;

5. that the Monte Carlo simulation method described in the Annex is used to determine whether the interference from HDFS transmitters meets the deep space protection criterion.

Annex

Computing the total interference power spectral density for a deep-space earth station from the HDFS transmitters is a difficult problem due to the large number of HDFS transmitters. To simplify the problem, the area surrounding the earth station is partitioned into sectors, zones, and zone groups as shown in Figure A.1. The HDFS transmitters in a zone is represented by a single transmitter at the center of the zone with EIRP that is equivalent to the aggregate EIRP of all the HDFS transmitters in that zone in the direction of the deep space earth station.

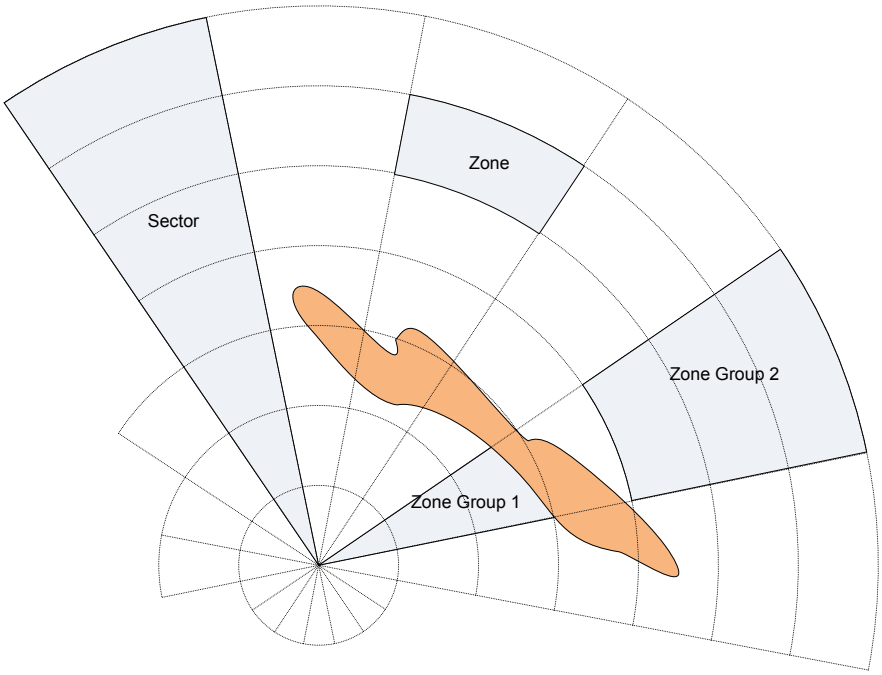


Figure A.1, Partitioning the area surrounding a deep space earth station into sectors, zones, and zone groups. The brown object denotes a mountain range that divides a sector into different zone groups due to distinct terrain profiles.

The aggregate interference from the HDFS transmitters around a deep space earth station antenna is expressed as

$$S = \sum_{n=1}^{K} G_n \sum_{m=1}^{M_n} A_{nm} \cdot \frac{1}{L_{nm}(p_n)} \qquad (1)$$

where K is the number of zone groups, G_n is the deep space earth station antenna gain toward the n-th zone group, M_n is the number of zones in the n-th zone group, A_{nm} is the AEIRP spectral density of the zone[n,m] (i.e. zone-m in the n-th zone group) toward the deep-space earth station receiver (W/Hz), $L_{nm}(p_n)$ is the p_n-th percentile of the propagation loss of the zone[n,m] due to intervening terrain and atmospheric conditions. $L_{nm}(p_n)$ should be computed

using Rec. ITU-R P.452, including the clear-air (diffraction, tropospheric scatter, and ducting) and hydrometeor-scatter methods. In a zone group, all zones have the same weather statistics, hence, the same p_n. The weather statistics for the propagation losses is assumed to be independent for different zone groups.

Rec. ITU-R SA. 1396 specifies that non-line-of-sight interference density should be no more than -217 dBW/Hz for 0.001% weather statistics for manned missions and for 0.1% for unmanned missions operating in the 37-38 GHz band. Monte Carlo simulations should be used to determine whether the aggregate interference power spectral density from the HDFS transmitters meets the deep space earth station protection criterion for a given azimuth pointing. The lowest possible elevation angle of the earth station should be used in the simulations as the dominant interference would most likely come from such elevation angle. Monte Carlo simulations should be repeated such that the deep space protection criterion is satisfied for all azimuth sectors around the earth station.

Recommendation SFCG 32-2

COMMUNICATION FREQUENCY ALLOCATIONS AND SHARING IN THE LUNAR REGION

THE SFCG

CONSIDERING

a. that a regional communication network at the Moon can be expected in the foreseeable future as missions to the lunar region increase in number and variety;

b. that frequencies for direct communication between a spacecraft in the lunar region and an earth station are provided in the existing allocations to Space Research Service (SRS);

c. that separate frequencies are needed in the lunar region for compatible local communications between a surface vehicle and an orbiter, between surface vehicles, and between orbiters;

d. that major criteria for allocating frequencies in the lunar region include RF compatibility, technology availability and performance, mission scenarios, cost, and ability to conduct testing and emergency support from the Earth;

e. that the major benefit of an agreed frequency plan for the lunar region enables interoperability and sharing of communications infrastructure and service assets to support individual or joint exploration missions to accomplish complex objectives;

f. that envisioned lunar missions will involve complex communications architectures using earth stations that can communicate with near-Earth relay satellites, lunar orbiting satellites, and lunar surface elements in view of Earth based space stations;

g. that it is envisioned that missions in the lunar region will employ Lunar Relay Satellites (LRS) to allow relay communication coverage and to forward data gathered from lunar surface elements to earth stations;

h. that it is envisioned that missions in the lunar region by multiple administrations either independently or jointly can occur during the same time period and each mission may employ

many simultaneous communications links with another orbiter, the lunar surface elements, LRS, lunar communications terminals (LCT) and earth stations;

i. that sufficient frequency separation is required to enable compatible and simultaneous communications for a multiplicity of spacecraft in the lunar region with each other, earth stations, LRS, local lunar based vehicles, a lunar outpost and lunar vehicles transmitting to an earth station;

j. that lower frequency provides better SNR performance for a communication link between two vehicles using low gain broad beam antennas, such as between a vehicle in the lunar region and a LRS;

k. that higher frequency provides wider bandwidth and higher data throughput performance between two vehicles employing high gain antennas, such as between a large lander and an LRS with accurately pointed antennas;

l. that techniques such as self test on board are available to minimize the need for testing with Earth-based signals;

NOTING

a) that the SFCG has resolved to provide assistance to member agencies in coordinating frequency assignment for lunar and Martian missions (see RES SFCG A26-1);

b) that, according to the provisions of the Radio Regulations, testing lunar local link radios with signals transmitted from an earth station is allowed only if it does not interfere with Earth-based radio systems operating in accordance with the Radio Regulations;

c) that lunar missions need interoperable relay links to maintain communication with the Earth;

d) that passive observations in space need to be protected to the extent provided in the Radio Regulations.

RECOGNISING

a) that lunar local links must not interfere with the direct communication links between space and the Earth using frequencies provided in the Radio Regulations;

b) that multiple frequency bands are needed for missions to meet various communications requirements and satisfy cost, mass and performance objectives.

RECOMMENDS

1. that agencies select frequencies from Table 1 for communications in the lunar region according to the specific applicability in Table 2,

2. that testing lunar local links in flight with signals transmitted from an earth station be minimized and non-interfering to the Earth-based radio systems operating under the provisions of the Radio Regulations;

3. that assignment of lunar local link frequencies be coordinated within the SFCG in accordance with RES A 26-1.

Table 1: Recommended Frequency Bands for Communications in the Lunar Region

Link	Frequency	
Earth to Lunar Orbit	2025-2110	MHz
	7190-7235	MHz
	22.55-23.15	GHz
	40.0-40.5	GHz
Lunar Orbit to Earth	2200-2290	MHz
	8450-8500	MHz
	25.5-27.0	GHz
	**37-38	GHz
Earth to Lunar Surface	2025-2110	MHz
	7190-7235	MHz
	22.55-23.15	GHz
Lunar Surface to Earth	2200-2290	MHz
	8450-8500	MHz
	25.5-27.0	GHz
Lunar Orbit to Lunar Surface	390-405	MHz
	2025-2110	MHz
	2483.5-2500	MHz
	22.55-23.15	GHz
Lunar Surface to Lunar Orbit	435-450	MHz
	1610 -1626.5	MHz
	2200-2290	MHz
	25.5-27	GHz
Lunar Surface Wireless Network	390-405	MHz
	410-420	MHz
	435-450	MHz
	2.4-2.48	GHz
	*25.25-25.60	GHz
	*27.225-27.5	GHz
Lunar Relay to Lunar Relay Cross Link	13.75-14	GHz
	14.5-15.35	GHz
	22.55-23.55	GHz
	25. 6-27.225	GHz
	**37-38	GHz
	40-40.5	GHz

* 25.25-25.60 and 27.225-27.5 GHz bands subject to SFCG Rec. 15-2R4
**37-38 GHz band subject to SFCG Rec.14-2R5

Table 2: SFCG Baseline Lunar Communications Services Requirements

Link Type	Frequency Band	Users	Service Type	Data Rate per User	Notes
1.0 Earth to Lunar Orbit (E-LO) and Lunar Orbit to Earth (LO-E)	2025-2110 MHz (E-LO)	Lunar Orbiters	Voice/ Commands	72 kbps	
	2200-2290 MHz (LO-E)	Lunar Orbiters	Voice/Data	256 kbps	
	7190-7235 MHz (E-LO)	Lunar Orbiters	Commands/ Ranging	Up to 1 Mbps	
	8450-8500 MHz (LO-E)	Lunar Orbiters	Telemetry/ Ranging	Up to 10 Mbps	Subject to SFCG Rec. 5-1 R5
	22.55-23.15 GHz (E-LO)	Lunar Orbiters	Voice/data (comm & nav)/ video	10 Mbps	
	25.5-27.0 GHz (LO-E)	Lunar Orbiters	Voice/data/video	25 Mbps	
	37-38 GHz (LO-E)	Relay Satellites	Trunk line (uplink)	400 Mbps	Subject to SFCG Rec. 14-2R5
	40-40.5 GHz (E-LO)	Lunar Relay Satellites	Trunk line (downlink)	1200 Mbps	Subject to SFCG Rec. 14-2R5

Link Type	Frequency Band	Users	Service Type	Data Rate per User	Notes
2.0 Lunar Surface to Earth (LS-E) and Earth to Lunar Surface (E-LS)	2025-2110 MHz (E-LS) /2200-2290 (LS-E) GHz	Surface Hubs (Hab, Landers, Rovers, etc), LCT	Voice/TT&C/ Nav	150 kbps/3Mbps	

	2025-2110 MHz (E-LS) /2200-2290 (LS-E) MHz	End nodes (EVA, Science sites, robotic assistants)	Voice or health status/TT&C	8 kbps	
	7190-7235 MHz (E-LS)	Surface Landers (Landers, Rovers, etc)	Commands/ Ranging	Up to 1 Mbps	
	8450-8500 MHz (LS-E)	Surface (Landers, Rovers, etc)	Telemetry, Ranging	Up to 10 Mbps	Subject to SFCG Rec. 5-1 R5
	22.55-23.15 (E-LS)/25.5-27(LS-E) GHz	LCT	Voice/TT&C/ data/ video	25 Mbps/100 Mbps	
	22.55-23.15 (E-LS) /25.5-27 (LS-E) GHz	Surface hubs (Hab, Landers, Rovers, etc)	Voice/TT&C/ data/ video	10 Mbps/ 25Mbps	

Link Type	Frequency Band	Users	Service Type	Data Rate per User	Notes
3.0 Lunar Orbit to Lunar Surface (LO-LS) and Lunar Surface to Lunar Orbit (LS-LO)	390-405 MHz (LO-LS)	Orbiter, Lunar Module, Rover, Lander	Command	1 kbps	
	435-450 MHz (LS-LO)	Orbiter, Lunar Module, Rover, Lander	Data/ Telemetry	8 kbps, 32 kbps, 1Mbps	
	1610-1626.5 MHz (LS-LO)	Rover	Voice/ TT&C / Data (comm & nav)	10 kpbs (bi-directional)	Number of Users depending on Number of Orbital

					Relays
		EVAs	Voice/ TT&C / Data (comm & nav)	10 kpbs (bi-directional)	
		Surface hubs (Hab, Landers, etc)	Voice/ TT&C / Data (comm & nav)	10 kpbs (bi-directional)	
	2025-2110 (LO-LS)/2200-2290 (LS-LO) MHz	Surface Hubs (Hab, Landers, etc)	Voice/ TT&C	150 kbps (bi-directional)	
		LCT	Voice/TT&C	3 Mbps (bi-directional)	
		EVAs, Robotics Assistants	Voice/health & status	8 kbps (bi-directional)	

Link Type	Frequency Band	Users	Service Type	Data Rate per User	Notes
3.0 Continued Lunar Orbit to Lunar Surface (LO-LS) and Lunar Surface to Lunar Orbit (LS-LO)	2483.5 - 2500 MHz (LO-LS)	Rover-Orbiter	Voice/ TT&C / Data (comm & nav)	10 kbps (bi-directional)	Number of Users depending on Number of Orbital Relays
		EVAs-Orbiter	Voice/ TT&C / Data (comm & nav)	10 kbps (bi-directional)	
		Surface hubs (Hab, Landers, etc) - Orbiter	Voice/ TT&C / Data (comm & nav)	10 kbps (bi-directional)	
	22.55-23.15 (LO-LS) /25.5-27 (LS-LO) GHz	LCT	Voice/TT&C/ data/video	200 Mbps/400 Mbps	To Lunar Relay
	22.55-23.15 (LO-LS) /25.5-27 (LS-LO) GHz	Surface hubs (Hab, Landers, etc)	Voice / TT&C	25/10 Mbps	To Lunar Relay

Link Type	Frequency Band	Users	Service Type	Data Rate per User	Notes
4.0 Lunar Surface Communications	390-405 MHz	Lunar Module Rover, Lander	Telemetry, Data	128 kbps,1 Mbps	
	410-420 MHz	Lunar Module, Rover, Lander	Command/Telemetry/Data	Up to 1 Mbps	
	435-450 MHz	Lunar Module, Rover, Lander	Command	1 kbps	
	2.4 – 2.48 GHz	EVAs	Voice/data (comm & nav)/ low rate video	3 Mbps (max, rate will drop as distance increases)	
	2.4 - 2.48 GHz	Rover - LCT	Voice/data (comm & nav)/video	30 Mbps (max)	
	2.4 – 2.48 GHz	EVAs – Landers Rover	Voice/data (comm & nav)/video	3 Mbps (max)	
	25.25-25.6 GHz	Base Station to LCT	Voice/data (comm & nav)/video	20 Mbps	Subject to SFCG Rec. 15-2R4
	27.225-27.5 GHz	User Radio to LCT	Voice/data (comm & nav)/video	9.5 Mbps	Subject to SFCG Rec. 15-2R4

Link Type	Frequency Band	Users	Service Type	Data Rate per User	Notes
5.0 Lunar Relay to Lunar Relay Cross Link	13.75 -14 GHz	LRS	User data	Up to 300 Mbps	
	14.5 - 15.35 GHz	LRS	User data	Up to 300 Mbps	

Acronym List for typical lunar communication elements

E	Earth
EVA	Extra Vehicular Activity
Hab	Habitat
LCT	Lunar Communications Terminal
LO	Lunar Orbit
LRS	Lunar Relay Satellites
LS	Lunar Surface
SRS	Space Research Service

Recommendation SFCG 32-3

PROTECTION CRITERIA FOR GSO SPACE RESEARCH SATELLITES IN THE 7190-7235 MHZ BAND

The SFCG,

CONSIDERING

a) that the currently applicable protection criteria for interference into GSO SRS satellite uplinks in the 7190-7235 MHz band are contained in Recommendation ITU-R SA.609;

b) that interference from typical Lagrange and lunar mission uplinks as well as other near Earth space missions into GSO SRS satellite receivers may exceed these protection criteria by a large amount;

c) that interference from out-of-band emissions by SRS deep-space earth stations operating in the adjacent 7145-7190 MHz band into GSO SRS satellite receivers may exceed these protection criteria;

d) that for GSO SRS missions a minimum margin of 3 dB in the Signal to Noise ratio may be necessary for the protection of the Earth to space links,

RECOGNIZING

that the GSO SRS satellite uplinks typically have large link margins, and so could withstand significantly larger levels of interference than allowed by SA.609;

RECOMMENDS

1) that GSO SRS system uplinks in the 7190-7235 MHz band do not claim protection from lunar, Lagrange and other near Earth mission uplinks in this band;

2) that GSO SRS missions operating in the 7190-7235 MHz band do not claim protection from out-of-band emissions originating from uplinks by SRS deep-space earth stations in the adjacent 7145-7190 MHz band.

Recommendation SFCG 33-1R1

PROTECTION OF SPACE RESEARCH LINKS IN THE 8 400 – 8 450 MHZ AND 8 450 – 8 500 MHZ BANDS FROM UNWANTED EMISSION OF EESS (ACTIVE) SYSTEMS OPERATING AROUND 9.6 GHZ

The SFCG,

CONSIDERING

a. that the 9 300 – 9 800 MHz band is allocated to EESS (active) on primary basis;

b. that the 9 800 – 9 900 MHz band is allocated to EESS (active) on secondary basis;

c. that the 8 400 – 8 450 MHz band is allocated to Space Research Service (SRS) Category B (space-to-Earth) on primary basis, and the 8 450 – 8 500 MHz band is allocated to space research service (SRS) (space-to-Earth) on primary basis;

d. that SRS deep space critical events such as launch, orbit insertion, planetary fly-by, entry-descend-landing, often determine the success of the missions;

e. that the 8 400 – 8 450 MHz band is used by nearly all SRS Category B missions for the support of critical events and the 8 450 – 8 500 MHz band is used by nearly all SRS Lagrange and lunar missions;

f. that interference during the SRS Category B mission critical events can lead to the loss of spacecraft or loss of critical data and must be prevented;

g. that protection criteria of the SRS Category B missions in the 8 400 – 8 450 MHz band is given in Recommendation ITU-R SA.1157 ;

h. that the unwanted emission of EESS (active) in the 9 300 – 9 900 MHz band may exceed the SRS Category B protection criterion in the 8 400 – 8 450 MHz band;

i. that, during routine operations of the SRS Category B missions unwanted emission of EESS (active), exceeding the protection criterion of SRS Category B with a small probability, may be acceptable;

j. that critical events of SRS Category B systems must be protected 100% of the time;

k. that unwanted emission from EESS (active) may exceed the saturation levels and the damage levels of SRS earth station receivers used to support Category B and Lagrange and lunar missions, as shown in the Annex,

RECOMMENDS

1. that EESS (active) satellites use the methods described in the Annex to reduce their out of band emissions in the 8 400 – 8 500 MHz band in order to reduce the probability of saturating and to avoid damaging SRS earth station receivers used to support Category B and Lagrange and lunar missions, and causing interference to SRS Category B missions critical events;

2. that if the application of the methods described in the Annex is not adequate to eliminate damage, saturation and interference events as described in RECOMMENDS 1, operators of EESS (active) and SRS Category B and Lagrange and lunar missions use operational coordination to predict and mitigate any remaining events;

3. that in order to facilitate operational coordination, operators of EESS (active) and SRS Category B and Lagrange and lunar missions share the orbital and telecom characteristics of their respective operations, including the up–to-date trajectory of their missions, antenna pointing, and schedule of critical events.

Annex

This annex computes the unwanted emission of EESS (active) systems in the 9 300 – 9 900 MHz band using the parameters from Report ITU-R RS.2094. Several mitigation techniques to reduce the out-of-band (OOB) emission of EESS (active) system in the 8 400 – 8 500 MHz SRS bands are presented. The protection levels for damage and saturation of RF front-end components of SRS earth stations are also discussed.

1. Protection of deep-space SRS space-to-Earth links from harmful interference

Recommendation ITU-R SA.1157 gives the protection criterion of deep-space research earth stations as –221 dB(W/Hz) for the SRS frequency band 8 400 - 8 450 MHz The calculation of non-line-of-sight interference due to trans-horizon propagation should be based on weather statistics that apply for 0.001% of the time. Recommendation ITU-R SA.1157 provides the protection criterion for receiver systems in SRS deep-space spacecraft. Compliance to the protection criterion for these assets determines the mission success of SRS deep-space missions. Harmful interference during mission critical events, e.g. orbit insertions, planetary fly-bys, and entry-descent-and-landing (EDL) phases, can cause potential loss of a spacecraft or the loss of irreplaceable data. There are also critical events such as one-time scientific observations where a spacecraft penetrates the atmosphere of a planet or a moon, or it impacts a moon, a planet, an asteroid, or a comet. The spacecraft may be destroyed in the process, and therefore, the data transmitted during the approach or the moments before and during the impacts define the success of the missions. Therefore, the protection of SRS deep-space spacecraft and earth stations during mission critical events, to the extent demanded by Recommendation ITU-R, is crucial for the success of SRS deep-space missions. In addition, spacecraft emergencies for deep space systems should be considered as critical events.**2. Characteristics of EESS (active) systems in the 9.6 GHz band**

The 9 300 – 9 900 MHz band, typically identified by as the 9.6 GHz EESS (active) band, is used by synthetic aperture radar (SAR) systems. Report ITU-R RS.2094 provides the characteristics of three SAR systems operating in band.

Table 1
Characteristics of SAR 1, SAR 2 and SAR 3 systems

Parameter	SAR1	SAR2	SAR3
Orbital altitude (km)	400	619	506
Orbital inclination (degrees)	57	98	98
RF centre frequency (GHz)	9.6	9.6	9.6
Peak radiated power (W)	1 500	5 000	25 000
Pulse modulation	Linear FM chirp	Linear FM chirp	Linear FM chirp
Chirp bandwidth (MHz)	10	400	450

Parameter	SAR1	SAR2	SAR3
Pulse duration (μs)	33.8	10-80	1-10
Pulse repetition rate (pps)	1 736	2 000-4 500	410-515
Duty cycle (%)	5.9	2.0-28.0	0.04-0.5
Range compression ratio	338	< 12 000	450-4 500
Antenna type	Slotted waveguide	Planar array	Planar phased array
Antenna peak gain (dBi)	44.0	44.0-46.0	39.5-42.5
e.i.r.p. (dBW)	75.8	83.0	83.5-88.5
Antenna orientation from Nadir	20˚ to 55˚	34˚	20˚ to 44˚
Antenna beamwidth	5.5˚ (El) 0.14˚ (Az)	1.6-2.3˚ (El) 0.3˚ (Az)	1.1-2.3˚ (El) 1.15˚ (Az)
Antenna polarization	Linear vertical	Linear HH or VV	Linear horizontal/ vertical
System noise temperature (K)	551	500	600

3. Unwanted emission of EESS (active) systems in the 8 400 – 8 500 MHz band

The unwanted emission levels of the three SAR systems described in Table 1 in the 8 400 – 8 450 MHz band are shown in Table 2. The LFM (linear FM) SAR systems are assumed to have 10 ns rise-time and fall-time with trapezoidal waveforms. The pulse durations for SAR2 and SAR3 systems are 10 μs and 1 μs, respectively. The SRS deep space earth station antenna gain is 74 dBi.

Table 2

Unwanted emission from SAR1, SAR2, and SAR3 in the 8 400 – 8 450 MHz band

Parameter	SAR1	SAR2	SAR3
e.i.r.p. (dBW)	76	83	86
Bandwidth (MHz)	10	400	450
Minimum slant range (km)	424	654	536
Space loss (dB)	-164	-167	-166
Rx antenna peak gain (dBi)	74	74	74
Polarization loss (dB)	-3	-3	-3
Spectral roll-off (dB)	-109	-86	-78
Rx interference PSD (dB(W/*Hz*))	-196	-185	-174
Deep-space protection criterion (dB(W/*Hz*))	-221	-221	-221
Exceedance of protection criterion (dB)	25	36	47

Table 2 shows that the unwanted emission of SAR1, SAR2, and SAR3 systems exceeds the deep space protection criterion by 25-47 dB. The unwanted emission from the SAR systems is computed based on theoretical roll-off. Higher unwanted emission is possible if EESS (active) systems include components that increase the out-of-band (OOB) emission such as high-efficiency power amplifiers operating in saturation. Further analysis of the effects of EESS (active) power amplifiers in saturation mode on EESS (active) OOB emission is needed. Computation of unwanted emission of the SAR systems using Annex 8 of Rec. ITU-R SM.1541 results in higher wanted emission, and hence, higher interference to the deep space space-to-Earth links in the 8 400 – 8 450 MHz band.

The level of unwanted emissions falling in the band 8 450 – 8 500 MHz would even be higher due to the reduced frequency separation. Although studies show that there would not be any harmful interference issue for this band, there may be a risk of saturation and damage of the Earth station receivers in case of direct illumination, which requires specific mitigation techniques to also apply in this band. See also section 5.

4. Mitigation techniques

Several interference mitigating techniques are described in this section. Potential interference from the unwanted emissions of MHz EESS (active) systems can be reduced using one or a combination of some of the techniques described. Generally, the first three techniques, pulse shaping, antenna pointing, and filtering, can significantly reduce the unwanted emission of EESS (active) systems.

4.1. Pulse shaping

Pulse shaping changes the envelope of the LFM chirp pulses to reduce the out-of-band emission of the radar. Compared to a LFM system with 10 ns rise-time and 10 ns fall-time, pulse shaping with trapezoid waveforms and raised-cosine waveforms with 100 ns rise time and 100 ns fall-time can theoretically reduce the unwanted emission of LFM radars by about 20 dB and 60 dB, respectively. Table 3 shows that the 100-ns rise-time and 100 ns fall-time trapezoid waveform can reduce the unwanted emission of SAR1 system to be below the protection level of SRS deep space, although the unwanted emissions of SAR2 and SAR3 still exceed the protection level. With the raised-cosine pulse shaping, the unwanted emissions of all three SAR systems are below the protection criterion. It should be noted that imperfections and nonlinearities of various components in the EESS (active) transmit chain will likely increase the out-of-band emission. More analysis is needed to understand the effectiveness of this technique.

Table 3

Unwanted emission of EESS (active) with 100-ns rise-time and fall-time trapezoid waveform in the 8 400 – 8 450 MHz band

Parameter	SAR1	SAR2	SAR3
e.i.r.p. (dBW)	76	83	86
Bandwidth (MHz)	10	400	450
Minimum slant range (km)	424	654	536
Space loss (dB)	-164	-167	-166
Rx antenna peak gain (dBi)	74	74	74
Polarization loss (dB)	-3	-3	-3
Spectral roll-off (dB)	-135	-106	-95
Rx interference PSD (dB(W/*Hz*))	-222	-205	-191
Deep-space protection criterion (dB(W/*Hz*))	-221	-221	-221
Exceedance of protection criterion (dB)	-1	16	30

Table 4

Unwanted emission of EESS (active) with 100-ns rise-time and fall-time raised-cosine waveform in the 8 400 – 8 450 MHz band

Parameter	SAR1	SAR2	SAR3
e.i.r.p. (dBW)	76	83	86
Bandwidth (MHz)	10	400	450
Minimum slant range (km)	424	654	536
Space loss (dB)	-164	-167	-166
Rx antenna peak gain (dBi)	74	74	74
Polarization loss (dB)	-3	-3	-3
Spectral roll-off (dB)	-168	-147	-137
Rx interference PSD (dB(W/*Hz*))	-255	-246	-233
Deep-space protection criterion (dB(W/*Hz*))	-221	-221	-221
Exceedance of protection criterion (dB)	-34	-25	-12

Discussions with radar design experts indicate that the benefits of a specific pulse shaping at signal generation stage of the SAR can be lost in the high saturation mode of the power amplifier chain used to minimize power dissipation (heat).

4.2. Antenna pointing

All three SAR systems in Report ITU-R RS.2094 have highly directional antennas. For example, the antenna peak gain of SAR2 system is between 43 and 46 dBi. The antenna pattern rolls-off quickly in horizontal (or azimuth) direction to –3 dBi. If SAR2 can point the antenna away from the SRS earth stations such that the antenna gain is –3 dBi towards the SRS earth stations, the unwanted emission of SAR2 system can be reduced by 46 to 49 dB. Similar technique will also work for SAR1 and SAR3 systems.

4.3. Filtering

Depending on the implementations of EESS (active) systems, transmit filters and waveguides with steep cut-off below the EESS (active) band can be implemented to limit the unwanted emission of the systems. Filtering techniques have been successfully implemented by EESS

space-to-Earth links in the 8 025-8 400 MHz band to reduce the unwanted emission of EESS downlinks by 40 dB and more in the 8 400-8 450 MHz band.

SAR systems may use phased array antennas which are composed of several hundreds of transmission and receive (TR) modules including high-power amplifiers. Any output filtering would have to be applied to the high power stages of these modules and, thus, increases the system complexity, costs, and performance losses of the radar.

4.4. Selection of sweep range and pulse width

The unwanted emission of LFM radars is a function of both the frequency sweep range and pulse width of the LFM chirp signal. The unwanted emission increases as the chirp sweep range increases, and also as the pulse width of the chirp signal decreases. It may be possible for an EESS (active) operator to vary the radar sweep range and pulse duration to reduce the unwanted emission, especially when the EESS (active) antenna is pointing near an SRS earth station. The effectiveness of these techniques is limited. They may reduce the unwanted emission of an EESS (active) system by just a few decibels.

4.5. Geographic separation

It is also possible to reduce the interference from EESS (active) systems through geographic separation. EESS (active) systems may keep a minimum slant range from an SRS earth station to maintain a minimum free space loss resulting in an exclusion zone. Taken to extreme, EESS (active) systems may refrain from transmission whenever there is line-of-sight between the EESS (active) systems and an SRS earth station.

5. Damage and saturation to front end of the SRS earth station receivers

NASA and ESA have provided characteristics of potential damage levels to their SRS earth station receivers if their earth stations are exposed to the EESS (active) radiation under very unfavorable geometry, i.e. near-boresight coupling of antennas. These levels are –107 dBW in the band 8 400-8 500 MHz for the ESA earth stations and –105 dBW in the band 8 200-8 700 MHz for the NASA earth stations as measured directly at the input terminal of the receiver front-ends (LNA). These damage levels should not be exceeded for any amount of time. The potential saturation level for the NASA earth station is –115 dBW. The unwanted emission from the EESS (active) should be below this level especially during the critical events of SRS missions.

SPACE FREQUENCY COORDINATION GROUP

(S F C G)

Reports

Report **SFCG 29-1R1**

GUIDELINES FOR INTERFERENCE RISK ASSESSMENT BETWEEN EARTH OBSERVATION SATELLITES IN THE BAND 8025-8400 MHz

1. INTRODUCTION

This report presents a methodology for interference assessment between EESS missions in the band 8025-8400 MHz. It was compiled based on studies conducted by SFCG member agencies in the past. Various documents presented at SFCG meetings suggested means to compute interference, in particular documents SF27-19/D, SF27-40/D ,SF26-28/D which makes reference to many other documents presented in the past by ESA, NASA and CNES) and SFCG-28 Action Item No. 28/5.

The objective is to propose default values for mission characteristics when they are not available in the SFCG databases and where no other source for missing information can be identified.

Interference analyses are necessary to prevent or minimize interference between satellite missions operating in the same frequency band. These analyses should result in estimations as close as possible to reality. Method and parameter values exposed in this document have been selected keeping in mind the goal of realism of potential simulations to assess interference risks.

The 8025-8400 MHz band is allocated to the Earth Exploration Satellite Service (EESS) for space-to-earth transmissions. To date, this band is largely used by many space agencies with earth observation programs, as well as various worldwide industry space missions. It is possible that use of the band 8025 – 8400 MHz will increase in the future.

Mission planning requires checking whether the new mission would generate harmful interference to any other current or future mission operating in the same frequency band. Such a study typically helps determining the new mission frequency plan, its RF link characteristics and orbit In addition, mission coordination requires assessment of the impact of mission plan changes on an identified case of interference between missions. For both cases, preliminary studies can be conducted based on available data on current missions, and also for future missions in the case of a general interference risk assessment.

The SFCG has created a database with the objective to record all existing missions and future missions when their planning is sufficiently advanced. This database is considered as the main reference for missions information. Nevertheless, the database is not complete and many satellite missions are not referenced or not completely described in the database. In addition, another database dedicated to X-band EESS missions is available and kept up to date by the SFCG. The latter is also considered as a reference for information on earth observation missions, in case of missing information in the SFCG Database.

The values and models in this report have been compiled to assist in the harmonization of interference risk assessment amongst SFCG member agencies. Considerable efforts were put into proposals for models and default input parameters for interference risk assessments in the 8025-8400 MHz band. In order to remain as realistic as possible when proposing default values and models for interference computations, it was assumed that current EESS missions operating in X-band are representative of the existing technologies for payload data transmission. The technologies broadly applied in the field of image data transmission are proposed to be considered as default characteristics for missions for which those are not available either in none of the SFCG databases, or from any other source of information.

The following values and models can be applied to conduct interference risk analyses. The first part introduces default values for parameters, when they are neither available in the SFCG databases nor from any other sources. The second part lists models which may be used for link budget and interference computations. These values and models in this report are not to be considered as a mandatory methodology for interference computations. The intention of this document is to provide reference information which can be considered in the modelling effort and default parameters that can be used when the required information needed is missing in the SFCG Databases and can also not be obtained from any other source of information. SFCG member agencies may make an explicit reference in their interference risk assessment studies to the source of information for scenarios configuration, when different from the SFCG databases and main models used when different from the ones described in the present report.

2. DEFAULT VALUES FOR COMPUTER SIMULATIONS

This section contains default values for most of the parameters that are needed for running interference computations.

Based on the existing missions the following values appear appropriate for consideration as default parameter values for simulation of future missions or current missions when the reference databases do not provide sufficient technical information.

a) Orbital parameters:

i. Semi-major axis: For most of the missions the semi-major axis may be a random value between 6978 km and 7203 km (apogee between 600 and 825 km). Additionally, for sun synchronous missions the semi-major axis must be set so that the computed orbit matches the sun synchronous orbit equation which defines the orbit precession rate.

ii. Inclination: For most of the missions the inclination value may be a random value between 97° and 99°. Additionally, for sun synchronous orbit (SSO) missions the inclination value must be set in order to make the computed orbit match the sun synchronous orbit equation. As an example, for SSO missions, if the altitude is 700 km (semi-major axis is 7078 km), then the inclination would have to be 98.2°.

iii. RAAN: The right angle of ascending node (RAAN) can be a random value for non-SSO missions. For SSO missions, the RAAN can be determined from the orbit's mean local time.

iv. Mean Anomaly: For most of the missions a random value can be considered. In order to accurately model orbital train missions, specific values need to be provided.

v. Eccentricity: Since most of the missions are in circular or nearly-circular orbits, a zero value eccentricity should be considered, when not specified.

vi. Argument of perigee: The argument of perigee can be a random value.

b) RF payload characteristics:

i. Transmitted EIRP flux density: For missions identified in the SFCG X-band database the average value of the transmitted power spectral density is -63 dBW/Hz. Users may want to update this value based on the latest version of the SFCG X-band database. Whenever the actual value is not specified, this default value may be used.

ii. Signal bandwidth, BW:

1. When the BW is not specified, but the symbol rate is specified, the BW may be estimated to be twice the channel symbol rate (R in Msps). More precisely, and in order to ensure that the BW is within the allocated frequency range, the BW should be defined as follows:

2. BW (MHz) = 2 * minimum ($|f_c-f_{max}|$, $|f_c-f_{min}|$, R), with f_c the carrier frequency, f_{min} the band lower bound 8025 MHz and f_{max} the band higher bound 8400 MHz. When the BW is not specified, and the symbol rate is also not specified, the symbol rate may be estimated to be the average value in the SFCG X-Band database, which is 101 Msps. The BW may then be calculated as specified in the previous paragraph.

iii. Carrier frequency:

1. For missions operating in broadcast mode, the carrier frequency may be assumed in the lower half of the band as a consequence of recommendation SFCG Rec.14-3R7.

2. For all other missions the carrier frequency can be set randomly, between 8025+R MHz and 8400-R MHz.

iv. Signal modulation: QPSK is recommended as being the mostly used technology. However, in the case of high channel symbol rate transmissions where [f_c-R, f_c+R] would exceed the EESS allocated band, 8PSK modulation can be considered.

c) On-board antenna characteristics:

i. Size: Antenna size is needed to compute parabolic antenna gain. A typical value for payload transmission is 0.3 m.

ii. Efficiency: Antenna efficiency is needed to compute parabolic antenna gain. Typically antenna efficiency values are comprised between 55% and 60%.

iii. Maximum gain: If no antenna type is given, isoflux may be assumed, as it is the more common type in the X-band. For parabolic antennas, maximum gain value may be set between 24 and 29 dBi. For isoflux antennas, maximum gain value may be set between 4 and 8.5 dBi.

d) Ground antenna characteristics:

i. Maximum gain: A value of 58 dBi may be assumed, as this is a typical value and corresponds to an antenna diameter of about 12 m. This corresponds to an antenna efficiency of 65%, which is a typical value that may also be used with other antenna sizes.

ii. Minimum elevation for visibility: When not indicated, a 5° default value can be considered.

e) Mission lifetime: If no value is given, the mission should be assumed to be operational at any time. This is worst-case but realistic, as many missions are extended to last a long time, and others are replaced by a similar follow on mission.

3. MODELS FOR LINK BUDGET AND INTERFERENCE CALCULATIONS

This section contains some of the models that are needed in link budget and interference computations, and which are considered as the most critical models in relation with their impact on link budget results. In some cases, two options are presented, and member agencies may use either one in their analysis. It is noted that when two agencies perform analyses and compare results, they should agree to use the same options if they desire to obtain the same results.

a) Simulation step and simulation duration: These two parameters are very important for the expected statistics validity when the simulation model uses the more standard non-statistical or linear time step approach. Indeed, the interference criteria are based on low percentages of time of visibility of the useful link. In order to have representative statistics it is then important to have enough visibility points in the simulation.

Option 1: The classical simulation approach: The user must estimate the number of visibility points the simulation of duration D and time step Ts will lead to. Typically, a simulation time step between 1 and 10 seconds and a 1-year duration should be precise enough for statistics with a 10^{-3} probability, if the user expects to have a number of events in the order of magnitude of 10^{2}. Besides it has shown to be a good compromise between simulation accuracy and computation run time.

Option 2: Use a number of randomly selected time increments (i.e., 10,000 time points which are randomly generated from time = 0 to time = 1 year). This allows the analyst to precisely define the degree of precision of the run. For example, if 10 error events are determined to be sufficient precision and the interference criterion is set to be a value not exceed for 0.1% of the time, then 10,000 or more time points are likely needed. Alternatively, if 100 errors events are determined to be sufficient precision, then 100,000 or more time points are likely needed.

b) Orbital extrapolators: This is a complex issue due to the many factors affecting a low earth orbit including the equatorial bulge, atmospheric drag, third body perturbations etc. However, in the context of performing analyses of the X-Band EESS interference environment, only statistical results are needed. J2 is sufficient. However, since many EESS systems are in sun synchronous orbits, and the amount of interference between two EESS systems in sun synchronous orbits is highly

dependent on the relative phase between the two systems, it is very important that the model ensure they precess at exactly the same rate.

c) Antenna patterns: The use of highly directive antenna and isoflux antenna patterns is recommended as an item of SFCG Rec.14-3R7. Thus, these two kinds of patterns can be considered for link budget computation, noting that few satellites may use horn antennas.

i. Earth station antennas

Option 1: For ground earth station, Appendix 8, Annex 3 of the ITU Radio Regulations presents an earth station antenna pattern to be used for interference studies when actual patterns are not published and the number of interfering sources is small (i.e., less than 5). However, when the number of interference systems is large (i.e., 5 or greater), or when the interference constellation is changing over time, then it is appropriate to use a pattern that represents average side-lobe levels. Recommendation ITU-R F.1245 has such a pattern.

Option 2: Bessel modelling

$$\begin{cases} G(0) = \eta * \left(\frac{\pi * D}{\lambda}\right)^2 \\ G(\theta) = \eta * \left(\frac{\pi * D}{\lambda}\right)^2 * \left(\frac{2 * J_1(u)}{u}\right)^2, \end{cases} \quad \text{with} \quad u = \frac{\pi * D}{\lambda} * \sin(\theta)$$

η the antenna efficiency, D the antenna diameter, λ the wavelength and θ the off-axis angle

ii. On-board antennas

Option 1: For on-board steerable directive antenna a Bessel modeling or equivalent is recommended. An equivalent model can be a simplified model similar to the one presented in Recommendations ITU-R S.672 and F.1245. It is then important to have in mind that the main lobe in the ITU-R S.672 model is quite large leading to higher link budget values that can bias the estimation of interferences. This model over estimates interference coming through the sidelobes. The antenna lobe effects are not represented but F.1245 averages the varying lobes
Option 2: For isoflux antenna, the following model is recommended as it leads to a uniform PFD in the spot beam area :

$$F_{dB}(\theta) = \begin{cases} 0 & \forall \theta \le 40° \\ k * \sin((\theta - 40) * 180/35) & \forall \theta \in [40°, 70°] \\ k * \sin((\theta - 40) * 180/35) - 3.5 * (\theta - 70) & \forall \theta > 70° \end{cases}$$

where k is the maximum gain value in dBi.

The pattern is represented in the figure hereafter with 6dBi maximum gain.

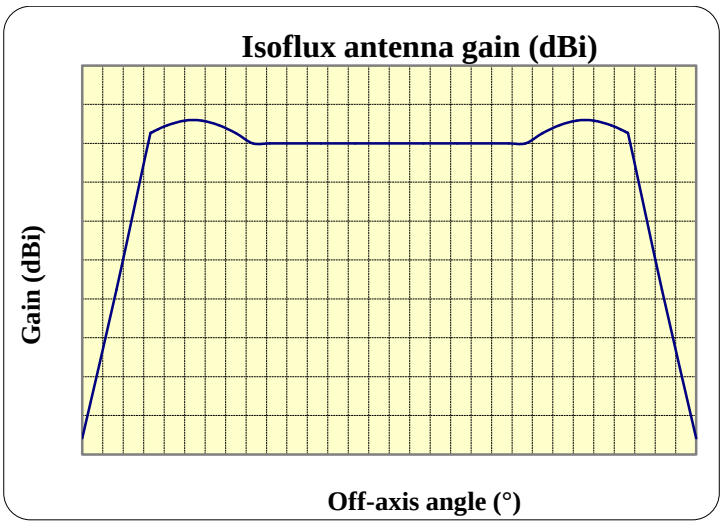


Figure 1: Isoflux antenna radiation pattern

d) Spectrum modelling:

Option 1: In many cases NRZ shaping is used and is associated with a sharp filtering, typically SRRC, with a roll-off around 0.35 . For spectrum modelling an NRZ shaping may be applied and consideration of sharp filtering beyond [f_c-R, f_c+R], with f_c being the carrier frequency and R the channel symbol rate (to be understood as: if R_B is the binary rate, taken before coding and modulation; R_B = k x R after coding and modulation and k is the number of bits inside one channel symbol).

Option 2: The assumed spectra if unknown could be a flat spectrum across the entire necessary bandwidth. If the necessary bandwidth is not known, but the symbol rate is, then the necessary bandwidth may be considered to be twice the symbol rate (i.e., the null-to-null bandwidth) for BPSK and equal to the symbol rate for QPSK. For example, if the data rate is 50 Mbps per channel and rate ½ coding is used, then the symbol rate is 100 Msps, and the necessary bandwidth is 200 MHz using BPSK.

e) Propagation models: The only propagation loss that needs to be taken into account in the EESS X-Band studies is free space loss. The other propagation losses can be ignored.

f) Interference factor:

The degradation of the victim signal due to an interfering signal depends on the spectral overlap between the victim signal and the interferer signal. Two options for computing the equivalent interference power and the equivalent interference power spectral density are given.

Option1: As spectra are not uniform the impact varies according to the overlapped area of the victim spectrum. A weighting factor may be used, which takes into consideration the spectral overlap between the victim and the interfering signals, and the actual spectral densities, and can be applied to the total power. . The following expression is a possible way to compute the weighting factor, called spectral likeness factor (SLF):

$$SLF(\Delta f) = \int_{f_v - BW_v/2}^{f_v + BW_v/2} S_i(f - \Delta f) S_v(f) df$$

with Δf the difference between the victim carrier center frequency (f_v) and the interfering carrier center frequency (f_i),

BW_v the frequency bandwidth of the victim link Earth station receiver,

$S_v(f)$ the normalised power spectral density of the victim satellite signal,

$S_i(f)$ the normalised power spectral density of the interfering signal.

A derivation of the SLF factor can be found in Annex A.

When this option is selected, the equivalent interfering power averaged over the victim receiver bandwidth is:

$$P_i = SLF(\Delta f) P_t$$

where

P_i = equivalent interfering signal power in the victim receiver

P_t = interfering signal power

Option 2: Based on the frequency overlap, it is possible to define a "Bandwidth Advantage Factor" (A_{BW}) which reduces the interfering spectral density level by that factor. The Bandwidth Advantage factor assumes that the spectral density of the interfering signal is uniform inside the interfering signal bandwidth and null outside. It is given by:

$$A_{BW}(f_i, BW_i, f_v, BW_v) = min\ (1, overlapBW_i / BW_v)$$

where

f_i and BW_i are the interfering transmitter center frequency and bandwidth, respectively

f_v and BW_v are the victim receiver center frequency and bandwidth, respectively

$overlapBW_i$ is the part of the interfering transmitter bandwidth that overlaps the victim receiver bandwidth.

Noting that with the above definition $overlapBW_i$ is always smaller or equal to BW_v and therefore that the ratio $overlapBW_i / BW_v$ is always smaller or equal to one, the formula can be further simplified as:

$$A_{BW}(f_i, BW_i, f_v, BW_v) = overlapBW_i / BW_v$$

When this option is selected, the equivalent interfering power spectral density averaged over the victim receiver bandwidth is:

$$I_i = A_{BW}\ PSD_i$$

where

I_i = equivalent interfering signal spectral density in the victim receiver

PSD_i = interfering signal peak spectral density

In case the victim receiver bandwidth BW_v is much wider than the interfering signal bandwidth BW_i or much wider than $overlapBW_i$ an additional check that PSD_i does not exceed the victim carrier recovery constraints shall be carried out.

Examples of application of this second option can be found in Annex B.

g) Protection criteria: Potentially relevant sources are Recommendation ITU-R SA.1027 and Recommendation ITU-R SA.609. It is noted that the protection criteria of SA.609 are more stringent for long term interference whereas SA.1027 is more stringent for short term interference.

Annex A – Derivation of the SLF factor

The following derivation assumes the use of a matched receiver for the victim signal.

The normalized interfering signal power at the victim receiver output can be given as:

$$P_{in}(\Delta f) = \int_{f_v - BW_v/2}^{f_v + BW_v/2} S_i(f - \Delta f)\left|H_v(f)\right|^2 df$$

with

Δf the difference between the victim carrier center frequency (f_v) and the interfering carrier center frequency (f_i),

BW_v the frequency bandwidth of the victim link Earth station receiver,

$S_i(f)$ the normalised power spectral density of the interfering signal,

$H_v(f)$ the victim receiver filter transfer function.

For a receiver matched to the transmitted signal, the normalized victim spectral density is given as:

$$S_v(f) = \left|H_v(f)\right|^2$$

yielding:

$$P_{in}(\Delta f) = \int_{f_v - BW_v/2}^{f_v + BW_v/2} S_i(f - \Delta f) S_v(f) df$$

that is hereby called Spectral Likeness Function $SLF(\Delta f)$
so that the equivalent interfering power in the receiver bandwidth can be computed by forming the following expression:

$$P_i = SLF(\Delta f)\, P_t$$

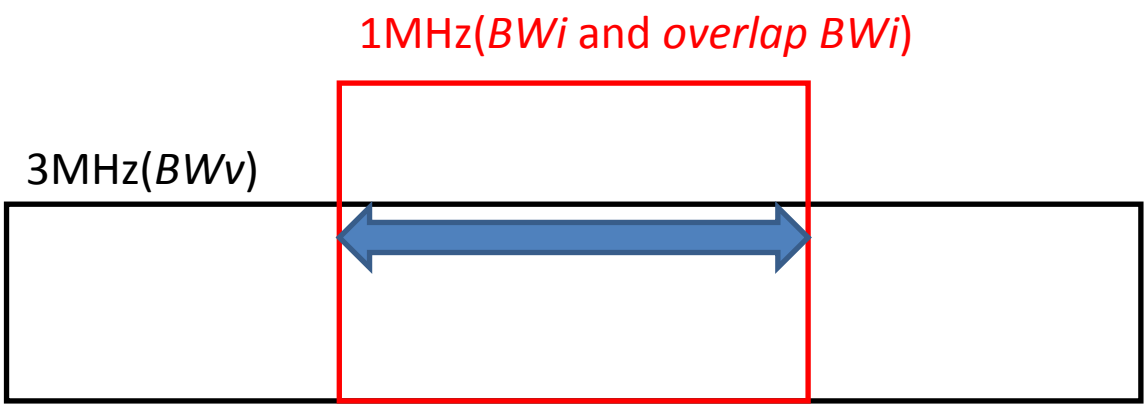
where

P_i = equivalent interfering signal power in the victim receiver

P_t = interfering signal power

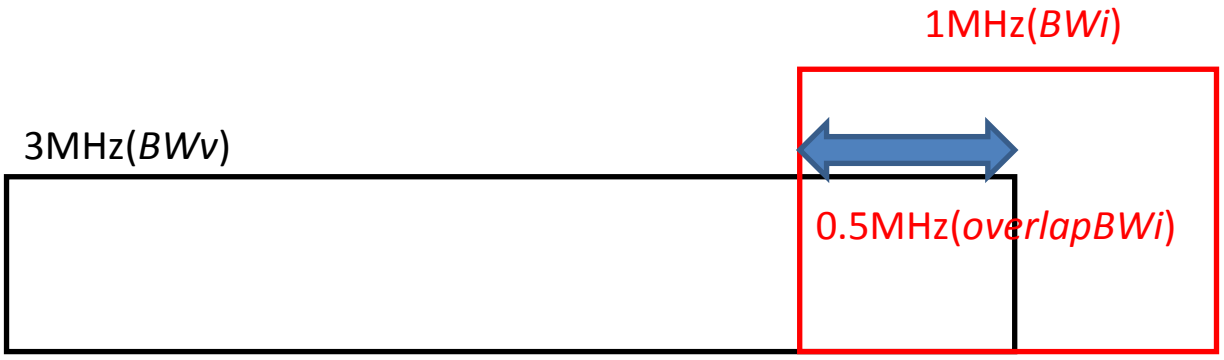
Annex B – Examples of application of option 2 for interference factor computation

B.1 $BW_v > BW_i$



$A_{BW}(f_i,BW_i,f_v,BW_v) = overlapBW_i/BW_v = 1/3 = 0.3$

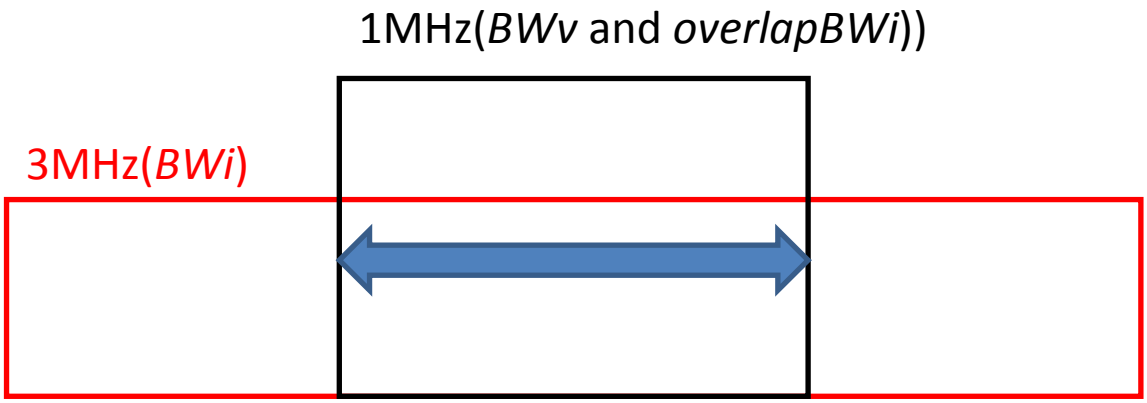
equivalent to -4.7(dB)



$A_{BW}(f_i,BW_i,f_v,BW_v) = overlapBW_i/BW_v = 0.5/3 = 0.17$

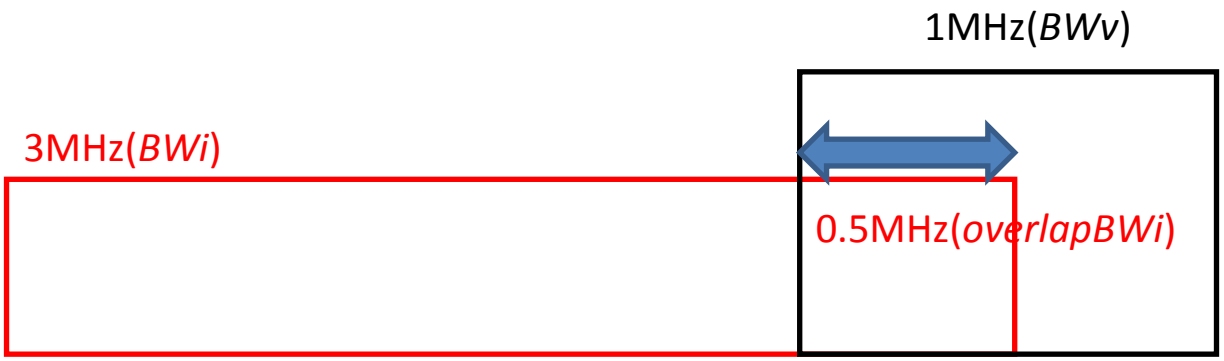
equivalent to -7.6(dB)

B.2 $BW_v < BW_i$



$A_{BW}(f_i,BW_i,f_v,BW_v) = overlapBW_i/BW_v = 1/1 = 1$

equivalent to 0(dB)



$A_{BW}(f_i,BW_i,f_v,BW_v) = overlapBW_i/BW_v = 0.5/1 = 0.5$

equivalent to -3(dB)

Report SFCG 30-1

SPECTRUM REQUIREMENTS FOR PLANNED SRS UPLINKS IN THE BAND 22.55 – 23.15 GHZ

ABSTRACT

This report presents the spectrum requirements needed for the proposed new SRS uplink allocation in the band 22.55-23.15 GHz. The general requirements are first enumerated and then specific requirements are shown for a number of space agencies. Conceptual frequency and channel plans are also developed and show that a minimum of 580 MHz would be needed to fulfil basic bandwidth requirements of several space agencies.

1. INTRODUCTION

To support the SRS missions in near Earth orbit, including missions in transit to the moon and at or near the moon, downlink (space-to-Earth) transmissions will operate in the 25.5-27.0 GHz band. This 1.5 GHz wide downlink band will be used for both scientific data retrieval and real time voice/video communication with the Earth.

An allocation to the space research service (Earth-to-space) to support lunar missions, Lagrangian missions and other near-Earth space research missions in the 22.55-23.15 GHz band is needed as a companion band to the existing 25.5-27.0 GHz SRS (space-to-Earth) allocation.

Resolution **753 (WRC-07)** recognizes that the band 22.55-23.55 GHz is allocated to the fixed, inter-satellite and mobile services, that those systems need to be protected and their future requirements be taken into account, and that non-GSO inter-satellite service links have been operating for several years and are expected to continue to operate in the 23.183-23.377 GHz band and that these links are increasingly being used in situations of emergencies and natural disaster.

Resolution **753 (WRC-07)** calls for sharing studies between space research service systems operating in the Earth-to-space direction and the fixed, inter-satellite and mobile services in the band 22.55-23.15 GHz. Appropriate sharing criteria for an allocation to the space research service in the Earth-to-space direction needs to be developed.

The number of SRS earth stations transmitting in the 22.55-23.15 GHz band will be small. Rather than building new SRS earth stations, upgrading selected existing SRS earth stations will predominate. Selecting which SRS earth stations to upgrade will be based on a number

of factors, including the type of mission to be supported. The maximum number of SRS earth stations capable of supporting lunar and/or Lagrangian missions is not expected to exceed ten to fifteen on a global basis over the next few decades.

A similar number of additional SRS earth stations may support LEO missions with typically much lower e.i.r.p. density levels in view of the significantly lower orbital heights. These earth stations are typically located in rural, isolated areas at mid latitudes.

Annex 1 presents some additional details on the estimated data rate and spectrum requirements per agency.

2. GENERAL SPECTRUM REQUIREMENTS

The requested SRS allocation at 23 GHz is the natural companion band to the recently allocated SRS downlink at 26 GHz and would meet this long term objective, enabling space agencies to plan with some certainty their longer term space exploration national strategic objectives. Both manned and robotic missions are planned with participation from many governments as well as the private sector. Due to the potential for many concurrent exploration or related systems and the large bandwidth requirements of these systems, especially those supporting manned missions, it is estimated that a combined uplink bandwidth of 600 MHz will be needed as a minimum, taking into account the projected mission support activities by several space agencies throughout the world. The bandwidth requirement is based on exclusive use of channels due to antenna beamwidth overlap, synergistic operations with existing data relay systems, selection of frequencies due to ranging constraints, and the evolution, growth, and complexity of those systems over a period of 20-30 years.

While an allocation in the range 22.55 – 23.15 GHz is necessary as a complementary uplink to the 25.5 – 27.0 GHz band, its utilization in an unbroken, contiguous format of sufficiently large bandwidth will be necessary for the following reasons. Frequency re-use is unlikely due to operational constraints since any spacecraft around the moon will be in the antenna main-beam lobe of other space agencies supporting their own lunar missions. Space agencies require their own segments of spectrum for lunar and many Lagrangian missions since antenna discrimination is not possible. Despite large earth station antennas, the moon is fully within the main lobe of such antennas. In addition, the frequencies to be selected will need to be aligned with the internationally agreed channels for data relay systems in order to provide global support either via an Earth station or via a data relay satellite. These data relay channels have a specific spacing of 60 MHz for interoperability among space agencies' data relay systems, which can support a range of data rates up to 50 Mb/sec. Furthermore, depending on the location of the Earth stations, some frequency sub-bands are not available due to operations of other services in the vicinity, such as the fixed service and/or the radio astronomy service.

Finally, there is a planned fixed turn-around ratio required between the Earth-to-space link around 23 GHz and the corresponding space-to-Earth link in the 25.5-27 GHz band. This is required for ranging purposes, and access to portions of the 26 GHz space-to-Earth allocation may not always be possible due to the presence of pre-existing assignments to co-primary services in the SRS earth station vicinity. The latter assignments constraints would further limit, in some geographic locations, the choice of available companion frequencies in the

uplink band at 23 GHz. Also, pre-existing assignments in the 23 GHz band will similarly preclude unconstrained access in some regions.

Space exploration programs demand ambitious technical evolution, with development and implementation constantly being subject to shifts in architecture. To this end the near-Earth region as well as the lunar region will need to be used as in-situ test beds for evaluating candidate hardware and software systems and concepts. This will lead to real time uplink operational control and will further increase high uplink bandwidth requirements. Proposals from a number of Administrations to WRC-07 supporting the objectives of the Space Frequency Coordination Group (SFCG) for this agenda item, originally sought the entire band 22.55 – 23.55 GHz. However, following consideration of co-frequency compatibility concerns expressed at WRC-07 with respect to the existing HIBLEO-2 system that operates above 23.18 GHz, the space research service community, in a spirit of good will and to avoid frequency overlap with HIBLEO-2, agreed to limit the bandwidth under consideration to 600 MHz.

3. SPECIFIC SPECTRUM REQUIREMENTS

Based on international coordination at SFCG meetings as well as in other fora, it is envisaged that at least six space agencies will operate lunar and Lagrangian links over the next few decades. As representative examples of future lunar mission scenarios, one 24 MHz carrier and three 12 MHz carriers have been assumed for each of six space agencies' missions . The 24 MHz channels have to be centred on the DRS cross support centre frequencies. The resulting spectral gaps may be used for additional narrow band channels not taken into account in this minimum set of requirements. Each lunar link has envisioned a 5 MHz guard band which may vary depending on the data rate of the individual channel. It is also assumed that these six agencies will operate at least one single Lagrangian link with 3 MHz bandwidth and a 1 MHz guard band. Actually applied bandwidths may vary to some extent depending on the requirements of individual space agencies.

Table 1 and Figure 1 show the bands that have been used for this example. It can be seen that the total bandwidth required is 580 MHz. The following have been implicitly assumed:

- Co-frequency sharing between lunar or Lagrangian missions on the one hand and LEO or DRS missions on the other hand will be possible.
- Co-frequency sharing between lunar or Lagrangian missions and radio astronomy service (RAS) missions will be possible but could reduce the flexibility in some locations of assigning channels for SRS ground stations nearby RAS sites.
- Co-frequency sharing among lunar missions, among Lagrangian missions, and between lunar missions and Lagrangian missions is not possible.
- The frequency plan is compatible with 60 MHz DRS channel spacing plans: each 24 MHz lunar carrier's center frequency is placed at one of these frequencies. Specifically, the following frequencies are used: 23 085, 23 025, 22 965, 22 905, 22 845, 22 785 MHz.
- The first 12 MHz lunar carrier is placed at the upper edge of the 22 550-23 150 MHz band, and the other 12 MHz carriers are placed on lower frequency adjacent channels, each having a 5 MHz guard band, and also avoid the 24 MHz Lunar carriers.

- The first 3 MHz Lagrangian carrier is placed 5 MHz lower than the final 12 MHz lunar carrier, and the other 3 MHz carriers are placed on lower frequency adjacent channels, each having a 1 MHz guard band

The actual placement of carriers may be more complex, because it has been assumed that the frequency plan is compatible with planned fixed turn-around ratio required between the Earth-to-space link around 23 GHz and the corresponding space-to-Earth link in the 25.5-27 GHz band.

4. CONCLUSION

A study of bandwidth requirements of several space agencies shows that a minimum of 580 MHz would be needed, and that even this bandwidth is a conservative estimate, as several simplifying assumptions are made in developing this conceptual plan.

Agency	Orbit	Lower Freq (MHz)	Upper Freq (MHz)
NASA	Lunar	23073	23097
		23138	23150
		23121	23133
		23104	23116
JAXA	Lunar	23013	23037
		23056	23068
		22996	23008
		22936	22948
RFSA	Lunar	22953	22977
		22876	22888
		22816	22828
		22756	22768
ISRO	Lunar	22893	22917
		22739	22751
		22722	22734
		22705	22717
CNSA	Lunar	22833	22857
		22688	22700
		22671	22683
		22654	22666
ESA	Lunar	22773	22797
		22637	22649
		22620	22632
		22603	22615
NASA	L2	22595	22598
JAXA	L2	22590	22593
RFSA	L2	22585	22588
ISRO	L2	22580	22583
CNSA	L2	22575	22578
ESA	L2	22570	22573

Table 1: Conceptual Frequency Plan

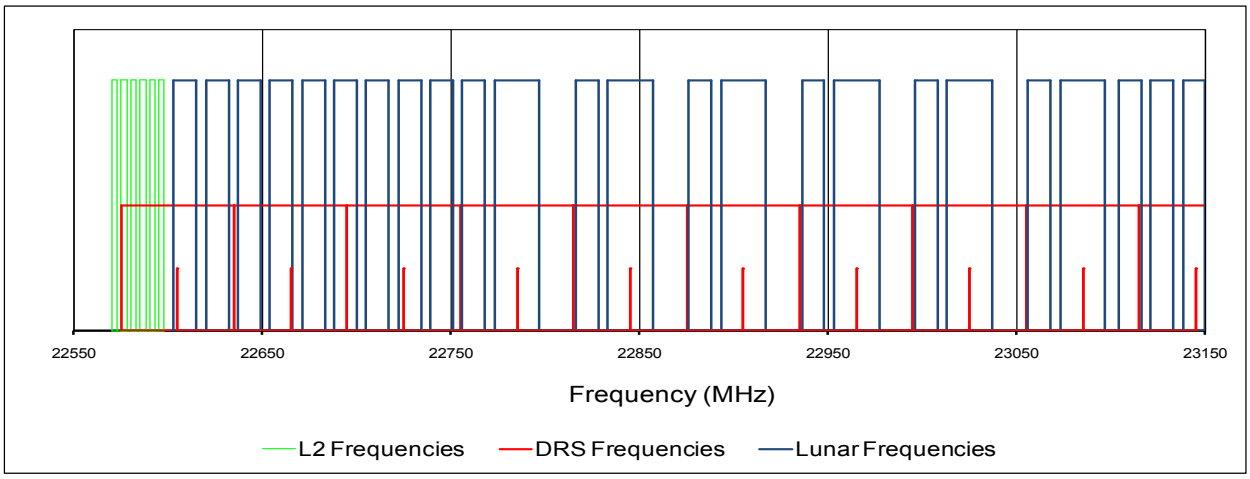


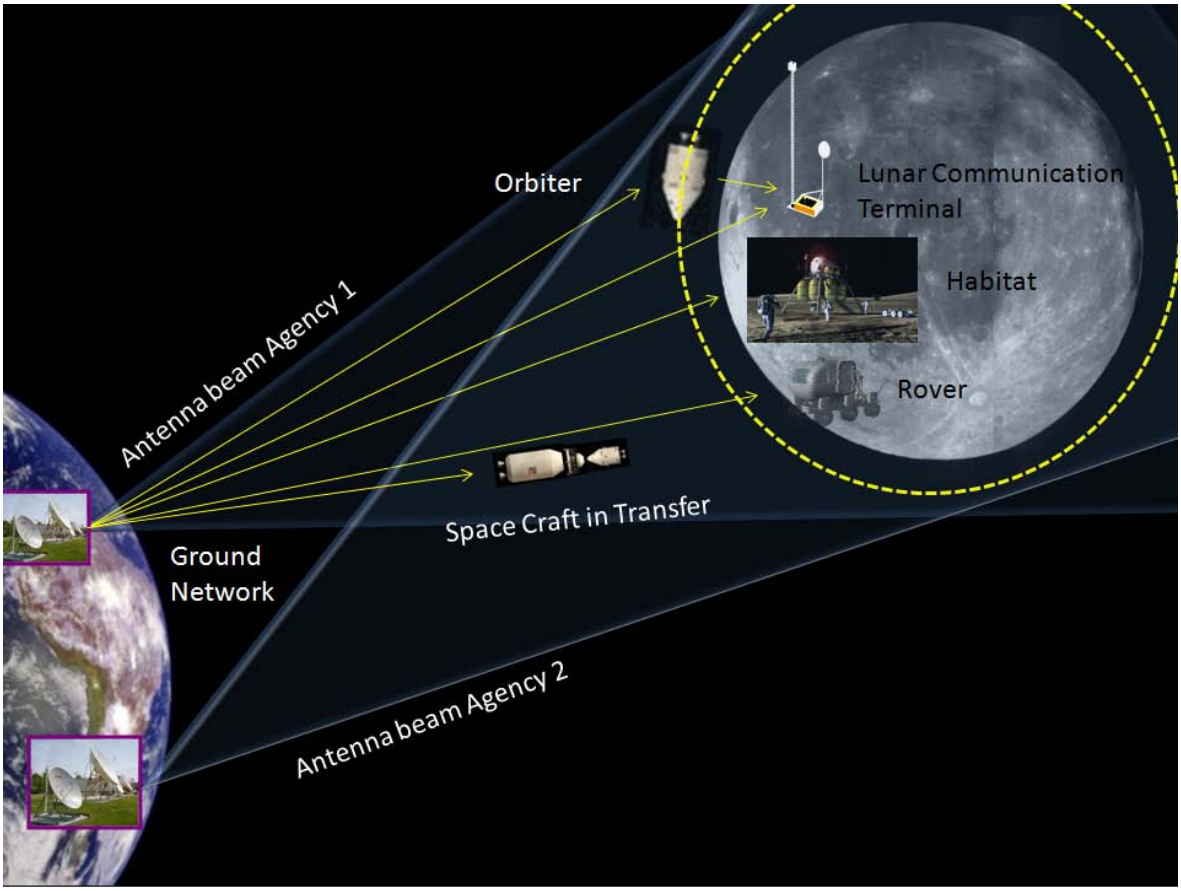
Figure 1: Conceptual Channel Plan

Annex 1: Estimated Data Rate and Spectrum Requirements per Agency

Over the past couple of years, multiple orbiting and impactor spacecrafts from several agencies have been sent to the Moon with missions to obtain high resolution lunar terrain maps, ascertain chemical composition of the Moon's surface, examine lunar soil layers and probe/record the environment on the Moon, such as its electromagnetic features and solar wind, which are crucial for future landings. These precursor missions are integral steps in the lunar exploration roadmaps for these agencies. These planned robotics and manned missions include a variety of spacecraft/vehicles on the lunar surface and orbits such as orbiters, landers, experiment packages/terminals, rovers, robotic assistants, extravehicular activities (EVAs), communications terminals, and relay satellites.

The frequency plan for the lunar region will revolve around communications from Earth to the lunar region, lunar region to Earth, lunar surface to orbit communications, lunar communications between several points on the surface, and lunar orbit to lunar orbit communications. Multiple simultaneous communications links are expected to operate in the vicinity of the Moon to control/command equipment operation, communicate with on-orbit crew, stream video, update/modify/verify software uploads, enable health diagnosis, execute detailed fault detection/isolation/recovery procedures and adjust mission plans based on science and telemetry data with precise and high resolution instructions and graphics. Figure A-1 provides an overview of the types of links typically supported simultaneously via an earth station.

Figure A-1: A conceptual scenario representing space agency lunar orbit and surface communication elements



These links will mainly be used for a wide range of bandwidth intensive applications, such as video and data transmissions. Some of the links to the surface of the moon can be a multiplex of several applications which are described in Table A-1. For the modulation techniques, filtered QPSK has been assumed. Regarding channel coding, coding rates vary between 1/2 and 7/8, depending on the specific mission application.

Link Type	Usage Description	Users	Estimated Symbol Rates (per User)	Estimated BW (per User)
Earth to Lunar Orbit	Direct high rate communications from the Mission Control Center (through an earth station) to orbiter in low lunar orbit. Contents of link include composite/multiplex data stream such as spacecraft system management controls, software maintenance updates, data encryption/authentication protocol, network security protocol, detail mission plans/instructions, in-flight maintenance procedures, voice with onboard crew, navigation updates, video conferencing and streaming video.	Orbiter/ Manned & Unmanned	10-20 MSps	10 - 20 MHz
Earth to Lunar Surface	Direct high rate communications from both the Mission Control Center and Payload Control Center (through an earth station) to communications terminal on lunar surface for re-distribution to both mobile and fixed elements on the surface of the Moon.The communications terminal serves as a "cell tower" to relay mission & system updates to multiple surface experiments and interactive capability for individual Principle Investigators with experiments they are responsible. Contents of link include experiment system management controls, software maintenance updates, data encryption/authentication protocol, network security protocol, detail mission plans/instructions, high fidelity/resolution maps, etc.	Communicatio ns Terminal/ Manned & Unmanned	20-25 MSps	20-25 MHz
Earth to Lunar Surface	Direct high rate communications from the Mission Control Center (through an earth station) to the lunar Surface Habitat. Contents of link include composite/multiplex data streams such as Habitat system management controls, Habitat software maintenance updates, data encryption/authentication protocol, network security protocol, detail mission plans/instructions, in-flight maintenance procedures, voice with crew, video conferencing and streaming video.	Habitat/ Manned	10-20 MSps	10-20 MHz
Earth to Lunar Surface	Direct high rate communications from the Mission Control Center (through an earth station) to rovers or landers on the lunar surface. Contents of link include spacecraft system management controls, detailed mission plan updates/revisions, software maintenance updates, data encryption/authentication protocol, network security protocol, high fidelity/resolution maps, video instructions, direct voice with MCC to Extra Vehicular Activity (EVA) astronauts.	Rovers/ Landers/ Manned & Unmanned	10-20 MSps	10-20 MHz
Earth to Transfer Spacecraft	Direct high rate communications from the earth station to the transfer spacecraft. Contents of link include composite/multiplex data stream such as spacecraft system management controls, software maintenance updates, detail mission plans/instructions, in-flight maintenance procedures, voice with onboard crew, navigation updates, video conferencing and streaming video.	Spacecraft Manned & Unmanned	10-25 MSps	10-25 MHz

Table A-1: Communications Requirements Matrix

Figure A-2 shows a conceptual scenario of Earth-to-lunar surface links.

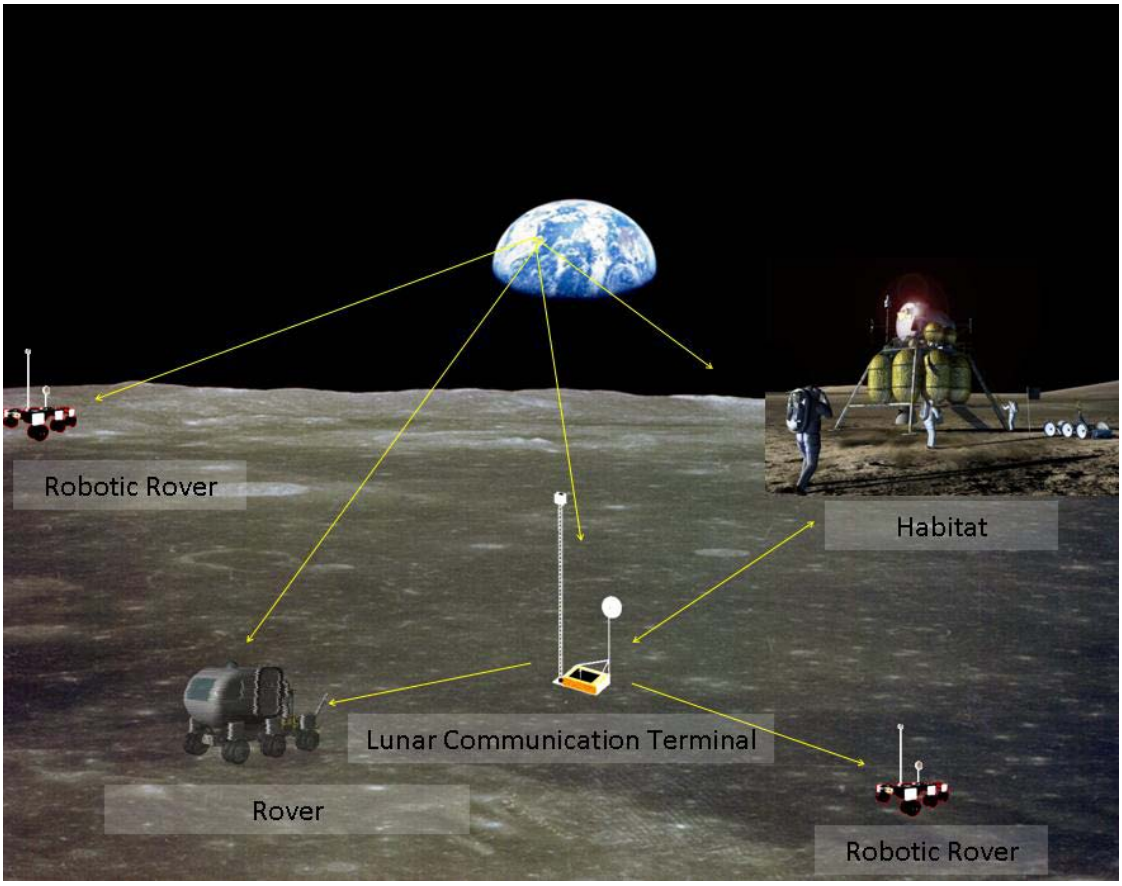


Figure A-2: A conceptual scenario representing Earth-to-Lunar Surface Communication Elements

Each agency can operate lunar missions with multiple carriers of the nature discussed above, and potentially anywhere on the surface of the Moon. The interference caused by the intersection of their respective beams would preclude co-frequency sharing among lunar missions. The same holds true for co-frequency operations of Lagrangian missions.

Additionally, co-frequency sharing between lunar and Lagrangian missions' carriers from separate earth stations is also not possible, as the geometry discussed above results in small off-axis angles between carriers.

However, co-frequency sharing is possible between other combinations of carriers. The specific compatibility of these various scenarios is shown in Table A-2.

Interf/Victim	Lunar	Lagrangian	LEO	DRS
Lunar	N	N	Y	Y
Lagrangian	N	N	Y	Y
LEO	Y	Y	Y	Y
DRS	Y	Y	Y	Y

Table A-2: Compatibility Matrix for SRS Mission Types

It should be noted that these 23 GHz links in support of LEO missions, will not be able to be used in the same manner as links in the 7 GHz band due to increased atmospheric attenuation and other physical constraints effecting in particular omni-directional antenna design.

There is a need for a guard band between each channel, since, due to the in-beam geometry and significant spectral densities of near side lobes, some out-of-band roll-off attenuation is required. Using Recommendation SM.1541, for the 12 MHz lunar links a 5 MHz guard band results in out-of-band attenuation of 12.5 dB, and for the 3 MHz Lagrangian links a 1 MHz guard band results in out-of-band attenuation of 10.0 dB. Achieving an attenuation of 12.5 dB for a 24 MHz channel will require a guard band of around 10 MHz. Depending on the actual channel bandwidths, guard bands between 1 and 10 MHz are therefore expected to be required.

Space Frequency Coordination Group

Report SFCG 31-1

OUT-OF-BAND (OOB) EMISSION MEASUREMENT DATA FOR ACTIVE SENSORS IN EESS (ACTIVE)

Abstract

This report presents analysis and measurement data of out-of- band (OOB) emissions of spaceborne active sensors in the EESS (active). The report shows the results of measurements and simulations of the -40 dB bandwidth and roll-off rates from emission spectra data on spaceborne active sensors in EESS (active) using supporting data from SFCG-27 to SFCG-31.

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1. Introduction

This report presents out-of- band (OOB) emission measurement data for spaceborne active sensors in the EESS (active). The report shows the results of measurements and simulations of the -40 dB bandwidth and roll-off rates from emission spectra data on spaceborne active sensors in EESS (active) using supporting data from SFCG-27 to SFCG-31.

The SFCG position on OOB emissions from spaceborne active sensors is that a design objective of -40 dB per decade roll-off is not technically feasible for many spaceborne active sensors. The SFCG has determined that a more realistic value would be -30 dB per decade.

The purpose of this document is to present emission measurement and simulation data on spaceborne active sensors in the EESS (active) and compares the OOB -40 dB bandwidth B_{-40} and roll-off rates with those of the simulated FFTs and equations developed within the Rapporteur Group (RG) on Unwanted Emissions (UWE).

2. ANALYSIS AND SIMULATION STUDIES OF OOB -40 DB BANDWIDTH AND ROLL-OFF RATES

Table 2-1 shows characteristics of an example of an operational EESS (active) radar for each type of radar. The RG UWE has drafted a working paper for the Annex 8 "OOB Domain Emission Limits for Primary Radar Systems" of the ITU-R Recommendation SM.1541 and the condition of 1 kW peak power has been eliminated. In these examples, the SIR-C SAR, the Jason altimeter, the ERS AMI scatterometer, and the GPM Dual-frequency Precipitation Radar satisfy the condition of operating at frequencies less than 40 GHz. Most of the spaceborne SARs, spaceborne altimeters, spaceborne scatterometers and spaceborne precipitation radars satisfy the one condition of operating below 40 GHz for Annex 8 applicability. The spaceborne cloud profile radars operate at frequencies of 94 GHz and above. The dual frequency GPM/DPR precipitation radar, scheduled for launch in late 2013, operates at about 1013 W peak power at center frequency of 13.6 GHz and at about 146 W peak power at center frequency of 35.55 GHz, thereby, also satisfying the one condition for Annex 8 applicability for the 13.6 GHz PR.

Table 2-1. CHARACTERISTICS OF OPERATIONAL EESS (ACTIVE) RADARS

Characteristics	Sensor Types				
	SIR-C SAR	***Jason Altimeter***	***ERS AMI Scatterometer***	***GPM Dual-frequency Precipitation Radar (DPR) ****	***Cloudsat Cloud Radar***
Radiated Peak Power	4400 W (1200 W)	20 W	4000 W	1013 W	1500 W
RF center frequency	1.25 GHz (5.3 GHz)	13.6 GHz	5.3 GHz	13.6 GHz	94.05 GHz
Waveform	Linear FM pulses	Linear FM pulses	Unmodulated Pulses	Unmodulated pulses	Unmodulated pulses
Viewing Geometry	Side-looking @20-55 deg off nadir	Nadir-looking	Three beams 29 deg from nadir	Nadir-looking	Nadir-looking
Footprint/ Dynamics	Fixed to one side	Fixed at nadir	Fixed to one side	Scanning across nadir track	Fixed at nadir
Swath width	15 to 90 km	26 km	500 km	245 km	1 to 2 km
Altitude	225 km	1336 km	785 km	400 km	705 km
Inclination	28 deg	66 deg	98.5 deg	66 deg	98.2 deg
Antenna Beam	Fan beam	Pencil beam	Fan beams	Pencil beam	Pencil beam
Spectrum Width	40 MHz	320 MHz	140 kHz	0.6 MHz	300 kHz

*Note: 2013 launch date scheduled for GPM DPR

2.1 Linear FM Waveforms and Measurement of -40dB Bandwidth and Roll-Off Rates from EESS (Active) Emission Data

In this section, the -40 dB bandwidth (B_{-40}) and roll-off as found in measured data for linear FM waveforms are compared with that calculated using the equations developed within the RG UWE, based on the ITU-R Recommendation SM.1541 equations. Annex 8 "OOB Domain Emission Limits for Primary Radar Systems" of the ITU-R Recommendation SM.1541 includes active spaceborne sensors in the EESS (active) and SRS (active) as space-based radars covered by this recommendation. The -40 dB bandwidth is dependent upon the waveform characteristics of the spaceborne radars within the Earth Exploration-Satellite Service (active).

Document RG-15, "Working document toward Proposed Revisions to Annex 8 of Recommendation ITU-R SM.1541" gives the proposed revised formula for the -40 dB bandwidth.

For FM-pulse radars, the 40 dB bandwidth is:

$$B_{-40dB} = 1.5(B + \sqrt{\pi} * [\ln(B * \tau)]^{0.53} * [Min(B_{rise}, B_{fall}, B_{rise\&fall}) + Max(B_{rise}, B_{fall}, B_{rise\&fall})]) \quad (2\text{-}1)$$

where :

$$B_{rise} = \frac{1}{\sqrt{\tau * t_r}}$$ To account for the rise time (2-2)

$$B_{fall} = \frac{1}{\sqrt{\tau * t_f}}$$ To account for the fall time (2-3)

$$B_{rise\&fall} = \frac{1}{(\tau * t_r * t_f)^{1/3}}$$ To account for both the rise and fall times combination (2-4)

τ	Pulse length (us) including rise and fall times
t_r	Pulse rise time (us)
t_f	Pulse fall time (us)
B	LFM bandwidth (MHz)

Equation (2-1) is valid only when the following conditions are met:

1) the product $B*Minimum(t_r,t_f)$ is greater than or equal to 0.10; and

2) that the product of B*τ or compression ratio must be greater than 10.

In all other cases, the following equations should be used:

$$B_{-40} = \frac{K}{\sqrt{t \cdot t_r}} + 2\left(B + \frac{A}{t_r}\right) \tag{2-5}$$

where A is 0.105 when K = 6.2, and 0.065 when K = 7.6.

Also in document RG-15, the proposed roll-off rate is -30 dB/decade, whereas the design objective in Annex 8 of Recommendation ITU-R SM.1541 is -40 dB/ decade.

2.2 Unmodulated Pulsed Waveforms and Calculation of -40dB Bandwidth and Roll-Off Rates from EESS (Active) Emission Data

In this section, the -40 dB bandwidth B_{-40} and roll-off as found in measured data for unmodulated pulsed waveforms are compared with that calculated using the equations developed within the RG UWE, based on the ITU-R Rec SM.1541 equations. Annex 8 "OOB Domain Emission Limits for Primary Radar Systems" of the ITU-R Recommendation SM.1541 includes active spaceborne sensors in the EESS (active) and SRS (active) as space-based radars covered by this recommendation. The -40 dB bandwidth is dependent upon the waveform characteristics of the spaceborne radars within the Earth Exploration-Satellite Service (active).

From Annex 8 of Recommendation ITU-R SM.1541, for unmodulated pulse radars the bandwidth is the lesser of:

$$B_{-40} = \frac{K}{\sqrt{t \cdot t_r}} \text{ or } \frac{64}{t} \tag{2-6}$$

where the coefficient K is 7.6. The latter expression applies if the rise time (t_r) is less than or equal to 0.014t.

2.3 Calculation of Range Spectrum Oversampling MNR

The range spectrum oversampling noise is one component of multiplicative noise in the SAR system. The range spectrum oversampling noise ratio is dependent on the time-bandwidth product (TBP), since the range spectrum skirts fall off faster with increased TBP. The calculation of the range spectrum oversampling MNR (OMNR) is the ratio of the summation over the processed part of the aliased range offset video spectrum to the summation over the processed part of the bandwidth of the range offset video spectrum, as follows:

$$OMNR = \frac{\sum_{m \neq 0} \int_{-B/2}^{B/2} S\left(f + m f_s\right) df}{\int_{-B/2}^{B/2} S\left(f\right) df}$$

where B is the range bandwidth, S is the range power spectrum, and f_s is the oversampling frequency (typically 1.125 B). Figure 2-1 illustrates the aliased multiplicative noise spectrum from oversampling.

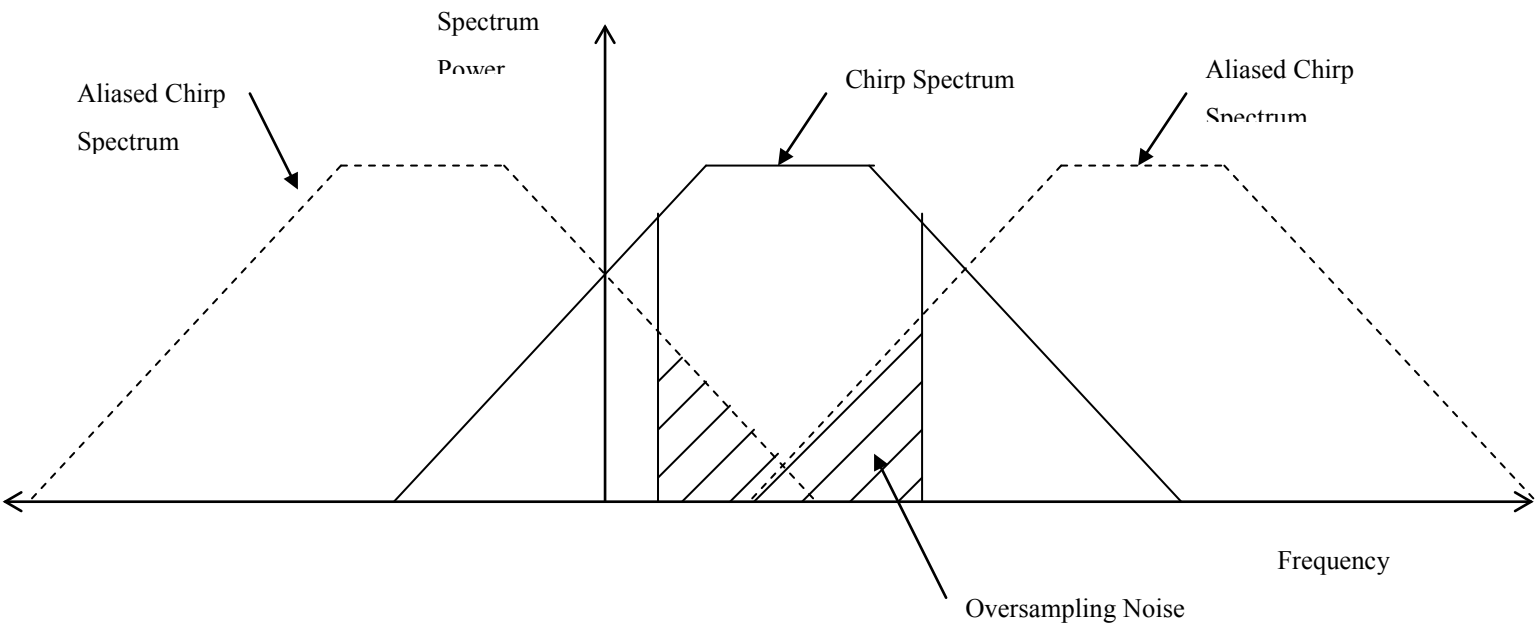


Figure 2-1. Aliased Range Spectrum with Oversampling Multiplicative Noise

For the AIRSAR measured spectrum, by summing the energy within the 40 MHz bandwidth, and comparing with the summation of the energy which the skirts of the aliased spectrum put back into the 40 MHz signal band, the OMNR is calculated to be -28 dB.

3. MEASUREMENT AND SIMULATION OF OOB EMISSIONS OF AIRBORNE ACTIVE SENSORS

3.1 AIRSAR

During the AIRSAR/LMR Compatibility Test at Ames Research Center in March 1994, the AIRSAR L-band emission spectrum was measured to aid spectrum planners and managers in assessing potential impact of the SAR on other systems in the band. The characteristics of the AIRSAR SAR are shown in Table 3.1-1. The measured SAR emission spectra are shown in Figures 3.1-1a and 3.1-1b (R=N=1.48), along with the 20 dB/decade and 40 dB/decade roll-off curves, using the ITU-R Rec SM.1541 equations and proposed equations in the JRG-71 document, respectively.

Table 3.1-1. Characteristics of AIRSAR L-band SAR

	AIRSAR
Peak Radiated Power (W)	5000
Pulse Modulation	Linear FM Chirp
Pulse Bandwidth (MHz)	40.0
Pulse Duration (µs)	5,10
Pulse Repetition Rate (pps)	152-1800
Pulse Rise/Fall Times (µs)	0.05
Duty Cycle (%)	0.076-1.8
Maximum Antenna Gain (dBi)	18
Antenna Orientation (degrees from nadir)	45.0
Antenna Polarization	Linear Vertical / Horizontal
Altitude (km)	9

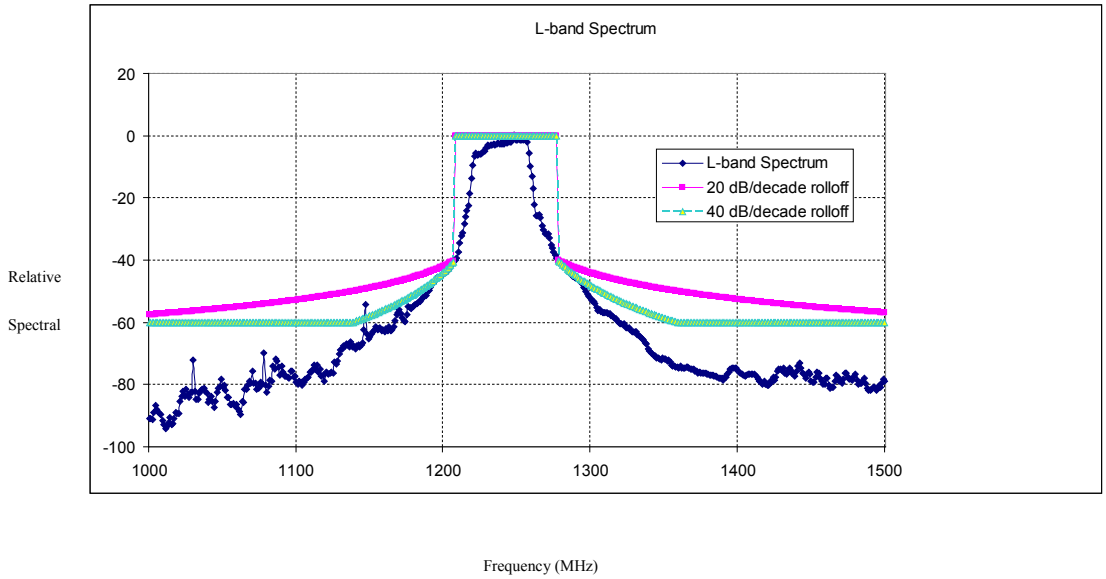


Figure 3.1-1a. Measured Emission Spectrum of AIRSAR L-band SAR with -40 dB Bandwidth Mask Using ITU-R Rec SM.1541 Equations

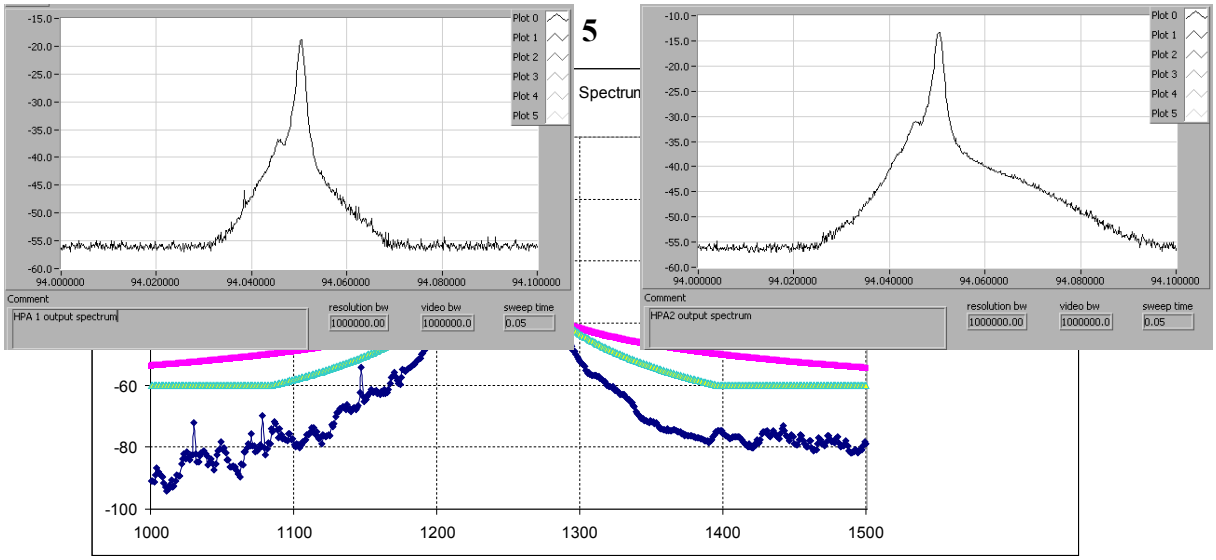


Figure 3.1-1b. Measured Emission Spectrum of AIRSAR L-band SAR with -40 dB Bandwidth Mask Using Document JRG-71 Sec 2.2 Equations

3.1.1 Simulation of AIRSAR Linear FM Pulses

The linear FM pulses were simulated as shown in Figure 3.1-2a and 3.1-2b. Figure 3.1-2a shows a rectangular pulse with bandwidth of 40 MHz and pulsewidth of 10 µs, whereas Figure 3.1-2b shows a trapezoidal pulse with bandwidth of 40 MHz, pulsewidth of 10 µs, and rise /fall times of 0.4 µs. The measured spectrum as shown in Figure 3.1-2c has skirts which fall off similarly as do the skirts in Figure 3.1-2a.

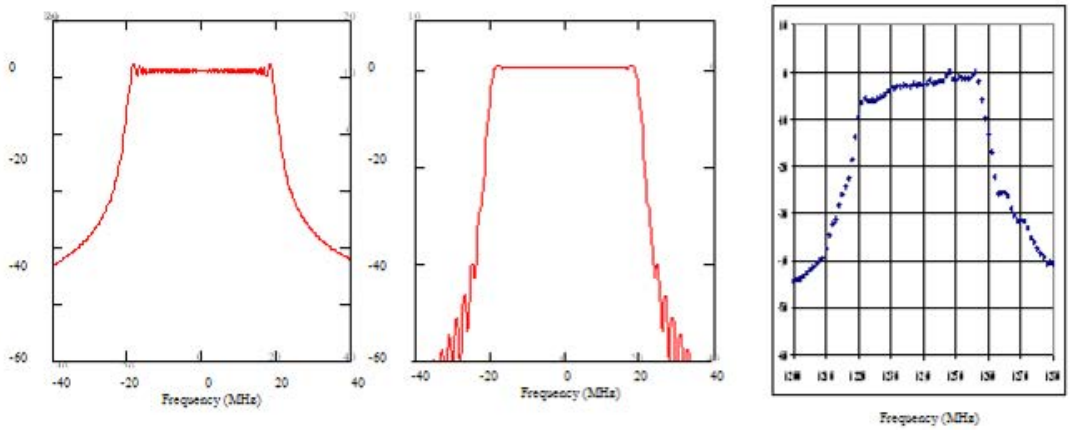


Figure 3.1-2. Comparison of Simulated Chirp Spectrum with Measured Spectrum (a) Rectangular Pulse with bandwidth=40 MHz, pulsewidth=10 µs, (b) Trapezoidal Pulse with bandwidth=40 MHz, pulsewidth=10 µs, t_r=t_f=0.4 µs, (c) Measured Chirp Pulse with bandwidth=40 MHz, pulsewidth=10 µs

3.2 UAVSAR

The UAVSAR/GPS Compatibility Tests are being performed at JPL in April 2007 and preliminary measurements of an individual UAVSAR L-band T/R module emission

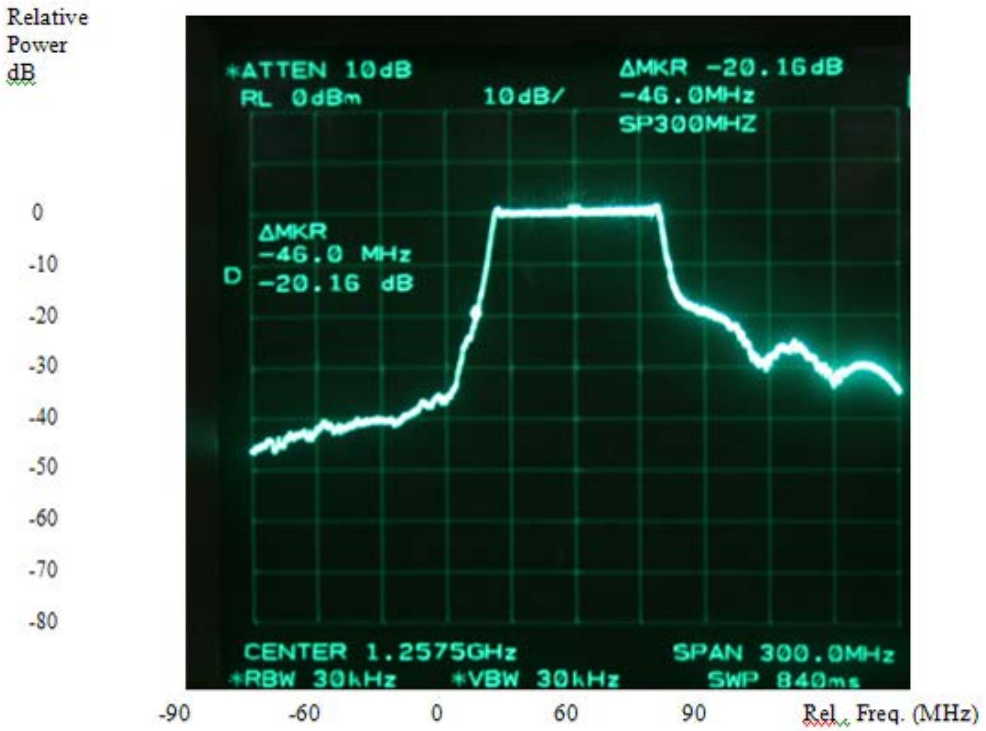


Figure 3.2-1. Preliminary Measured Emission Spectrum of an T/R module of UAVSAR L-band SAR

Table 3.2-1. Characteristics of UAVSAR L-band SAR

	UAVSAR
Peak Radiated Power (W)	1600
Pulse Modulation	Linear FM Chirp
Pulse Bandwidth (MHz)	80.0
Pulse Duration (µs)	6,8…50
Pulse Repetition Rate (pps)	350-875
Pulse Rise/Fall Times (µs)	0.1
Duty Cycle (%)	0.076-1.8
Maximum Antenna Gain (dBi)	19.5
Antenna Orientation (degrees from nadir)	45.0
Antenna Polarization	Linear Vertical / Horizontal
Altitude (km)	2-14

spectrum were performed to aid spectrum planners and managers in assessing potential impact of the SAR on GPS receivers in the band. The characteristics of the UAVSAR are shown in Table 3.2-1. The preliminary measured emission spectrum of an individual T/R module is shown in Figure 3.2-1. The UAVSAR T/R module peak output power is about 160 W, and the UAVSAR array has 14 T/R modules. It should be noted that the pulse shaping is not activated for this individual T/R module and that the 14 T/R module array will have pulse shaping which will make the spectrum more symmetrical and give faster skirts and roll-off rates to the spectrum.

3.2.1 Simulation of UAVSAR Linear FM Pulses

The linear FM pulses were simulated as shown in Figure 3.2-2a and 3.2-2c. Figures 3.2-2a and 3.2-2c show spectra of a trapezoidal pulse with bandwidth of 80 MHz, pulsewidth of 5 µs, and rise /fall times of 0.1 µs. The measured spectrum as shown in Figure 3.2-4b has skirts which fall off asymmetrically.

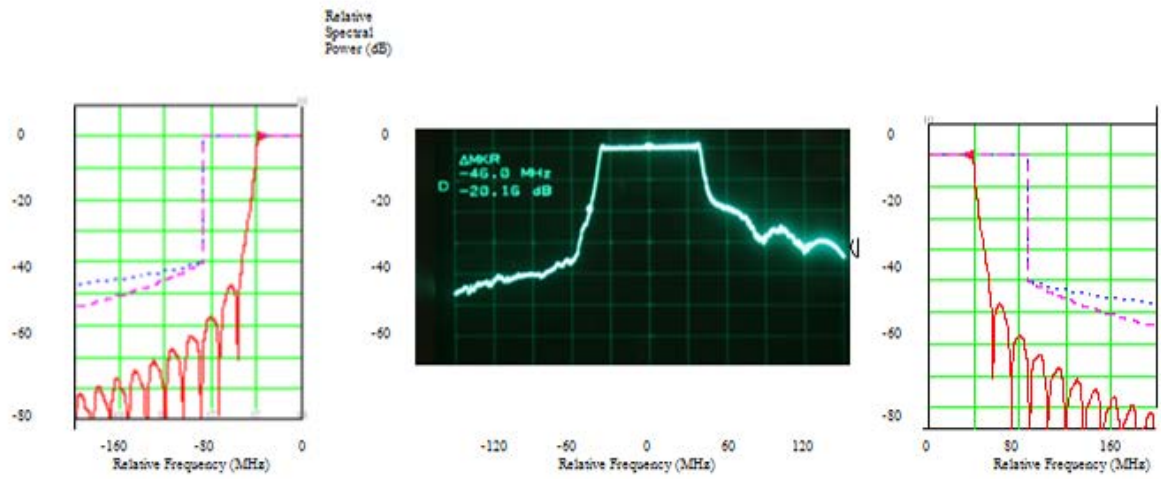


Figure 3.2-2. Comparison of Simulated Chirp Spectrum with Measured Spectrum

(a) and (c) Simulated Chirp Spectra (bandwidth=80 MHz, pulsewidth=5 µs, t_r=t_f=0.1 µs) Rolloff with Trapezoidal Pulse of Equal Rise/Fall Times (solid line), OOB Mask with 20 dB Roll-off (short-dashed line), and "Design Objective" OOB Mask with 40 dB Roll-off (long-dashed line) (b) Preliminary Measured Spectrum of individual T/R module

4. MEASUREMENT AND SIMULATION OF OOB EMISSIONS OF SPACEBORNE ACTIVE SENSORS

4.1 ALOS PALSAR

Table 4.1-1 shows the characteristics of PALSAR mounted on ALOS. Figure 4.1-1a shows the measured emission spectrum (output of ELU) of ALOS PALSAR with 40dB bandwidth mask using Rec. ITU-R SM.1541 Equations. Figure 4.1-1b shows the measured Emission Spectrum (output of ELU) of ALOS PALSAR with 40dB bandwidth mask using JRG-71 Sec. 2.2 Equations. Figures 4.1-2a and 2b show the emission spectrum for a wide range of frequencies for Figures 4.1-1a and 4.1-1b. The results of comparing measurement data and calculated values using Eqs. (2-1), (2-2), (2-3) and (2-4) are shown in Figures 4.1-1a, 1b, 4.1-2a, 4.1-2b and Table 4.1-2. Mask by JRG is more fitting with measurement data than mask by SM.1541-2. In case of the mask by SM.1541, measurement data exceed the mask around the edge of B_{-40dB}. Moreover, after the edge of B_{-40dB}, emission decreases sharply though the data is not available in higher frequencies. Figure 4.1-3 shows the measured emission spectrum at the output of Electrical Unit (ELU) of ALOS PALSAR.

Table 4.1-1 Characteristics of PALSAR

Parameter	Value
Central frequency	1270 MHz
Bandwidth	28 MHz
Pulse duration	27 μs
Pulse rise time	18.4 ns
Pulse fall time	13.5 ns

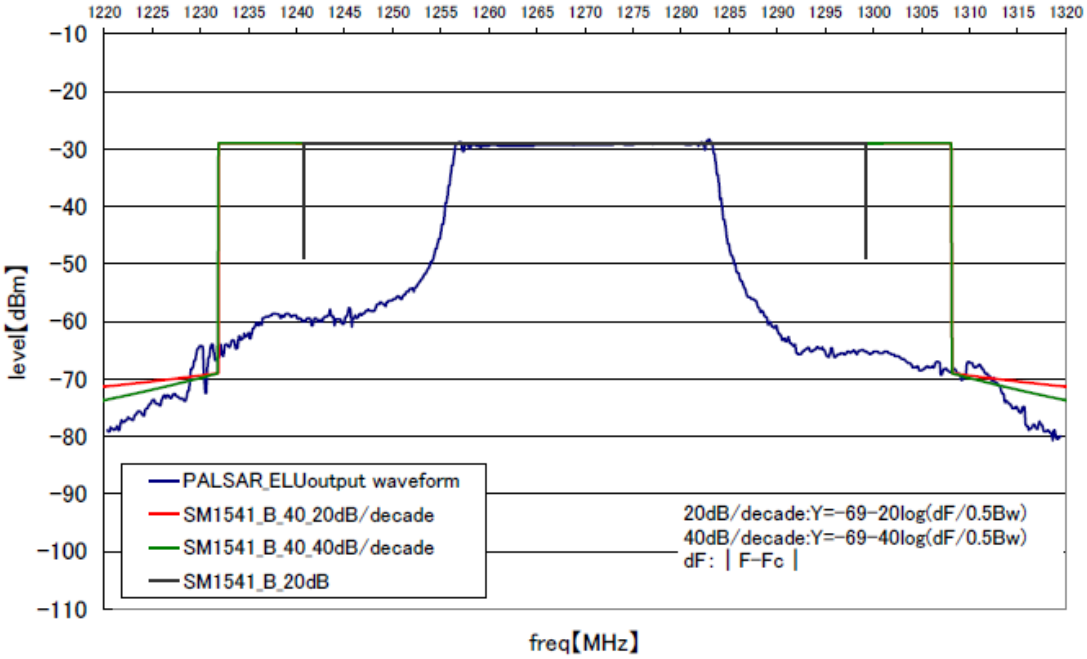


Figure 4.1-1a - Measured Emission Spectrum (output of ELU) of ALOS PALSAR with -40dB Bandwidth Mask Using Rec. ITU-R SM.1541 Equations (red for -20dB/decade rolloff and green for -40dB/decade roll-off)

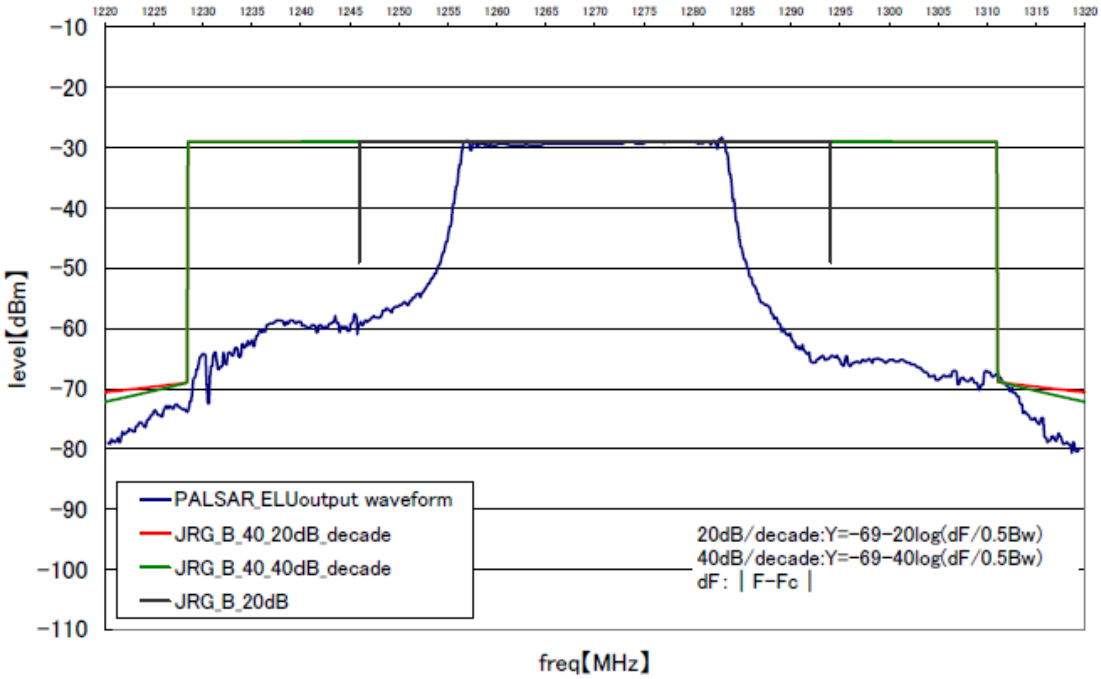


Figure 4.1-1b Measured Emission Spectrum (output of ELU) of ALOS PALSAR with -40dB Bandwidth Mask Using Document JRG-71 Sec 2.2 Equations (red for -20dB/decade rolloff and green for -40dB/decade roll-off)

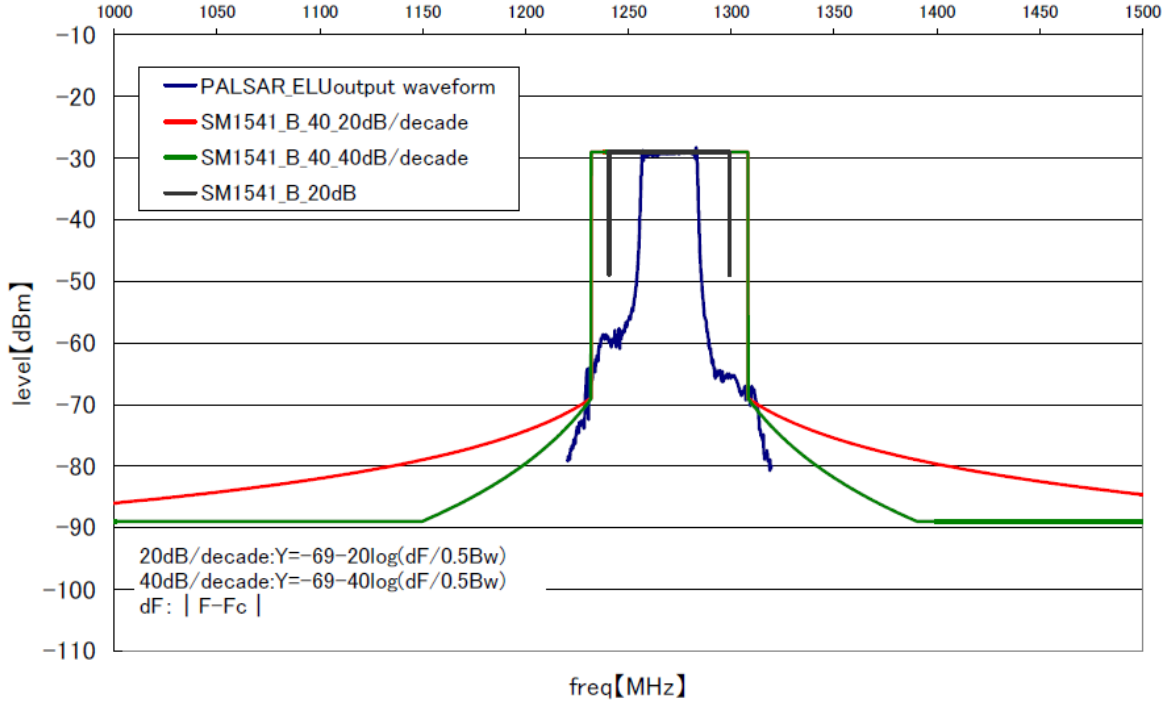


Figure 4.1-2a Measured Emission Spectrum (output of ELU) of ALOS PALSAR with -40dB Bandwidth Mask Using Rec. ITU-R SM.1541 Equations (red for 20dB/decade rolloff and green for -40dB/decade roll-off) (wide range of frequency).

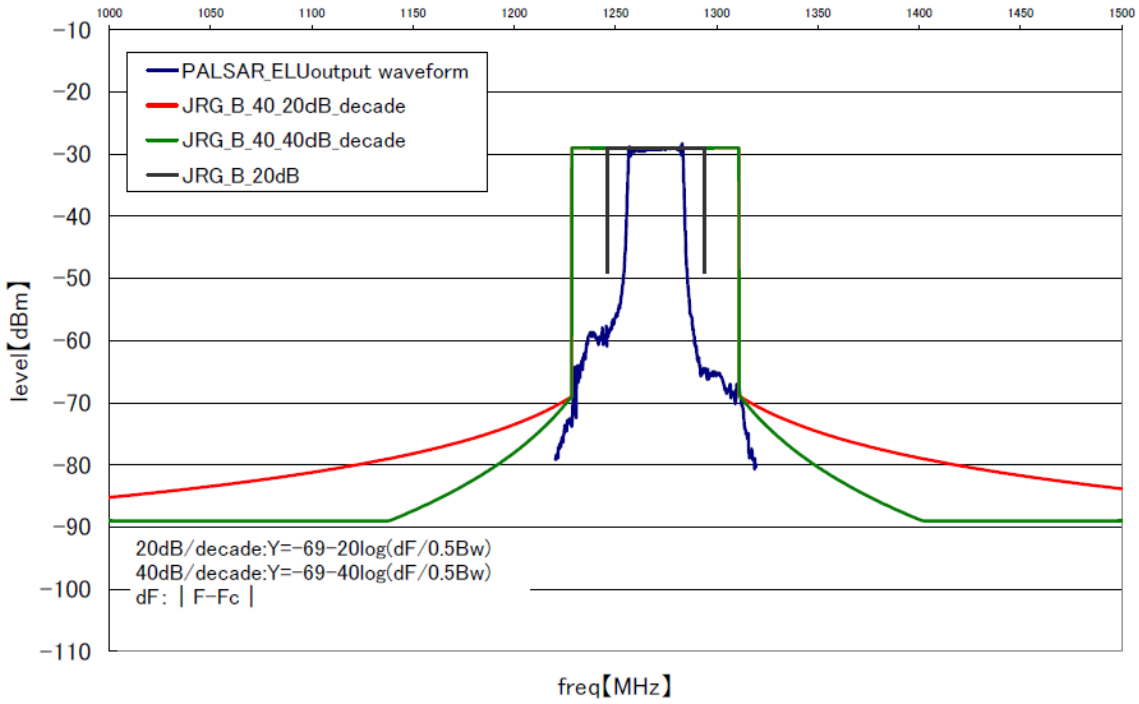


Figure 4.1-2b Measured Emission Spectrum (output of ELU) of ALOS PALSAR with -40dB Bandwidth Mask Using JRG-71 Sec.2.2 Equations (red for 20dB/decade rolloff and green for -40dB/decade roll-off) (wide frequency range)

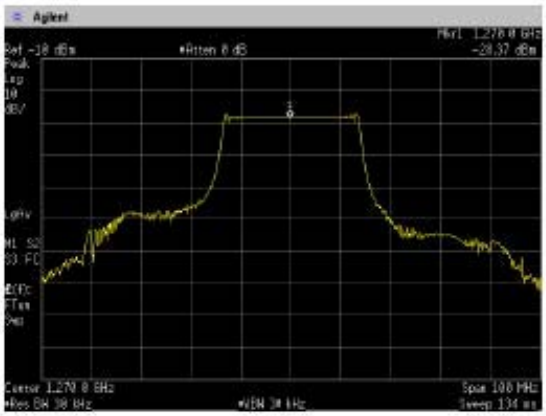


Figure 4.1-3 Measured Emission Spectrum at output of Electrical Unit (ELU) of ALOS PALSAR.

According to Rec.ITU-R M.1541-2,

$$B_{-40dB} = \frac{K}{\sqrt{t \cdot t_r}} + 2\left(B + \frac{A}{t_r}\right)、K=6.2、A=0.105 \qquad (4.1\text{-}1)$$

$$B_{-20dB} = \frac{1.79}{\sqrt{t \cdot t_r}} + 2B$$

t：Pulse duration（50%),

tr：Pulse rise time（10→90%),

B：Bandwidth

According to JRG-71,

$$B_{-40dB} = R \cdot B + N\sqrt{\pi} \cdot [\ln(B \cdot \tau)]^{0.53} \cdot \left(Min\left(B_{rise}, B_{fall}, B_{rise\&fall}\right) + Max\left(B_{rise}, B_{fall}, B_{rise\&fall}\right)\right) (\qquad (4.1\text{-}2)$$

$$B_{-20dB} = R \cdot B + N\sqrt{\pi} \cdot [\ln(B \cdot \tau)]^{0.37} \cdot Max(B_{rise}, B_{fall}, B_{rise\&fall}) + \frac{Max(B_{rise}, B_{fall}, B_{rise\&fall})}{(B * \tau)^{1.5}}$$

R,N:1.48 (See Table 3 in page 7 of SF27-22/D),

B：Bandwidth,

τ：Pulse duration（100%）

$$B_{rise} = \frac{1}{\sqrt{\tau \cdot t_r}}、B_{fall} = \frac{1}{\sqrt{\tau \cdot t_f}}、B_{rise\&fall} = \frac{1}{(\tau \cdot t_r \cdot t_f)^{1/3}}$$

Table 4.1-2 Calculated and measured Bandwidth of PALSAR

	SM.1541	JRG	Measurement data
B_{-20dB}	58.5 MHz	48.2 MHz	31 MHz
B_{-40dB}	76.2 MHz	83.2 MHz	79 MHz

Concerning -20dB, -40dB/decade, the following equations (4.1-3) and (4.1-4) are used. In case of 20dB/decade,

$$Y = -40+20\log B\text{-}40/(2|x|) \qquad |X| \geq B\text{-}40/2 \qquad (4.1\text{-}3)$$
$$= 0 \qquad |X| < B\text{-}40/2$$

In case of -40dB/decade,

$$Y = -40+40\log B_{-40}/(2|x|) \qquad |X| \geq B_{-40}/2 \qquad (4.1\text{-}4)$$
$$= 0 \qquad |X| < B_{-40}/2$$

Where

Y: relative spectral power (dB)

X: difference from center frequency (MHz),

B_{-40}: 40dB Bandwidth (MHz)

4.2 LINEAR BEAM OUTPUT DEVICES

At the European Space Agency's Research and Technology Centre ESTEC, radar unwanted emission tests were performed in August 2005. The performed tests were focused on the measurement of unwanted emissions from radar pulsed Travelling Wave Tube Amplifiers (TWTA). The objectives for these tests were:

- To analyze what discrepancies potentially arise between the theory and practical case;
- To check if the design objective as described in Annex 8 to Recommendation ITU-R SM.1541 can be reached.

In order to fulfill these objectives, both unwanted emissions from modulated and unmodulated pulsed were measured;

4.2.1 Measurement setup

In Figure 4.2-1 a block diagram is shown for the microwave measurement setup (non-radiated testing). The TWTA is a completely self-contained unit (for mounting in a standard 19-inch rack) that provides all necessary power supplies, forced-air cooling, RF components and controls. The frequency span for this TWTA is from 2 – 4 GHz.

With respect to measurements on existing radars, with this measurement setup quite some freedom is available for selecting different waveforms, i.e. non-chirp signals vs. chirped (linear FM). Results are to be compared with analytical expressions from Fourier analysis adapted for different radar pulse modulations.

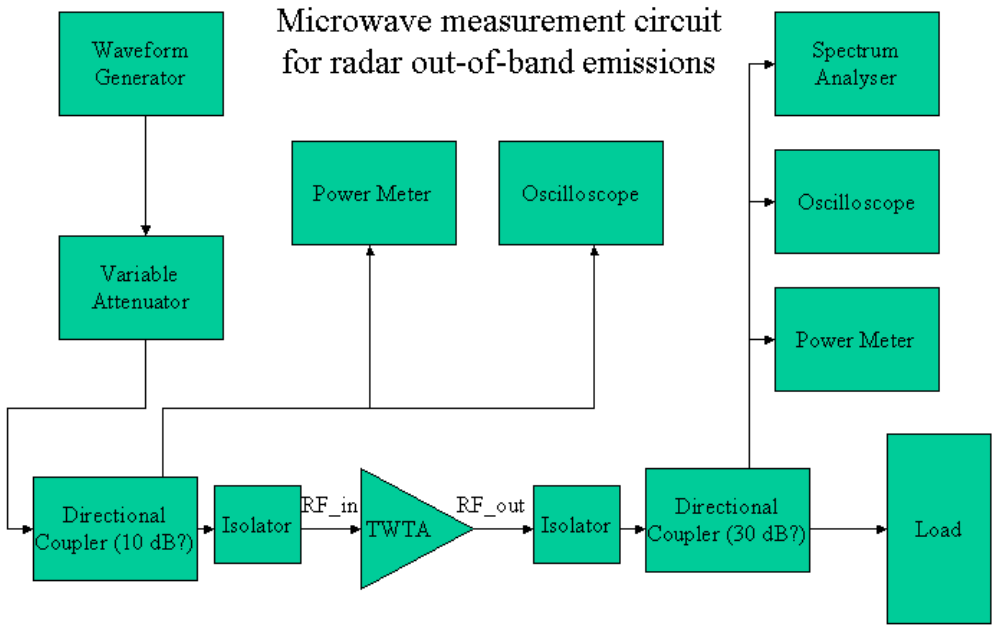


Figure 4.2-1 Measurement Circuits for OOB Emissions

There may also be a need to include a spectrum analyzer before the TWTA (this would be interesting in order to investigate the added spectral components by the tube). The chirp bandwidths to be investigated are up to 10 MHz (this would be the maximum for the used waveform generator). The attenuation numbers in the coupler-blocks (10 dB and 30 dB) are indicative and depend on several factors (mainly choice of components). The power meters before and after the tube are for control purpose (input range and tube saturation point) and initial check of the tube (gain).

4.2.2 Performed measurements

The measurement set-up was initially used to investigate unwanted emissions for unmodulated pulses with different pulse length (e.g. 1, 2, 5, 10 µs**).** This way, experience was gained in the measurement of unwanted emissions and easy comparison with Fourier analysis could readily be made. The spectrum analyzer was required to sweep up to 1 GHz with respect to the carrier. The measurement will therefore be out-of-band and spurious and will not include any higher order harmonics of the carrier (although these have been checked during the testing).

The following Table 4.2-1 reflects the performed tests for linear FM modulated pulses.

Table 4.2-1 Parameter Values for LFM Pulse Tests

	Chirp	**(MHz)**	
Pulse Length (µs)	**1**	**5**	**10**
1			
5			
10			
50			
100			

If the possibility would exist to work with different pulse rise- and fall-times (mostly dependent on the tube characteristics), this would be a bonus. In any case the pulse rise- and fall times would need to be characterized before and after the tube (oscilloscope). Unfortunately, due to the tube characteristics and the fact that the tube was driven into saturation, this was not possible. The pulse rise- and fall-times for all investigated pulses were ~10 ns

.

.2.3 Fourier Analysis

For the case of radar emissions, a method has been developed that makes use of spectral representations based on Fourier analysis in order to give an accurate estimation of the unwanted emission power levels for different radar pulses. The output of this analysis tool has been validated.

In order to arrive to accurate spectral representations of modulated and unmodulated radar signals, first the shape of the pulse needs to be taken into account. Here, trapezoidal pulses will be used where pulse rise- and fall-times are similar. The radar spectra can be compared to the OOB mask for primary radars as contained in Figure 25 of Annex 8 to Recommendation ITU-R SM.1541 (page 48). Since the mask is expressed in a frequency separation as a percentage of the –40 dB bandwidth (B_{-40}), B_{-40} is obviously dependent on the radar parameters and needs to be calculated according to formulas in Annex 8 (Rec. ITU-R SM.1541).

The sample plot in Figure 4.2-2 makes a direct comparison of the simulated spectral representation for System 2 from Rec ITU-R M.1463 and the envelope mask from SM.1541

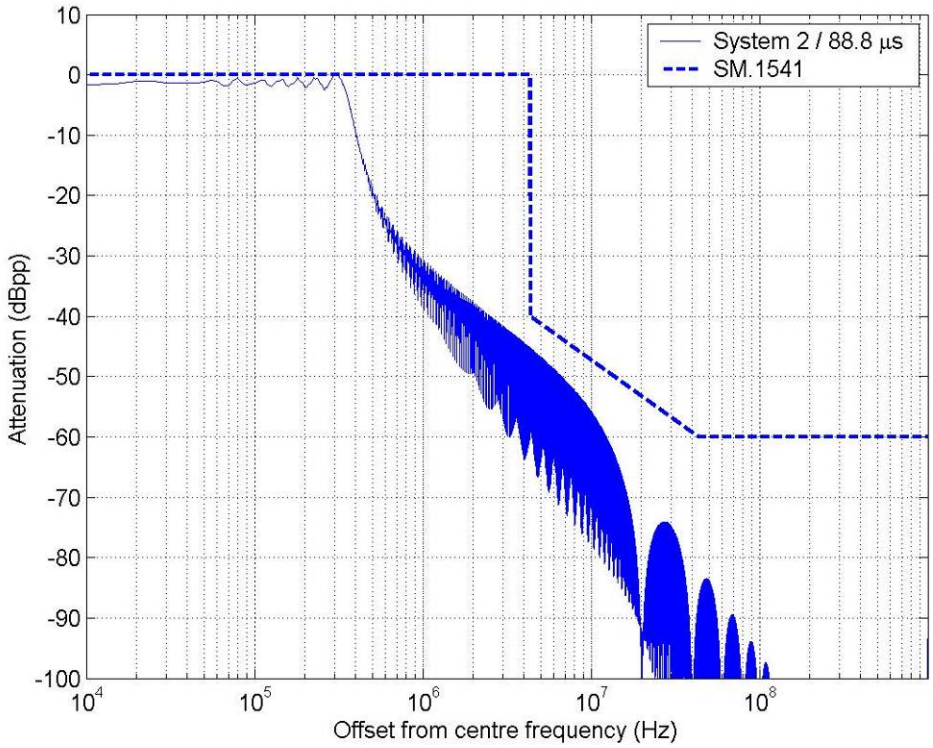


Figure 4.2-2 Sample Plot Making a Direct Comparison of the Simulated Spectral Representation for System 2 from Rec ITU-R M.1463 and the Envelope Mask from SM.1541

4.2.4 Conclusions on OOB Emissions of Linear Beam Output Devices

The measurements were done using a spectrum analyzer in its 'maximum hold' setting, which means that the measurements can basically be seen as peak envelopes. It can

be clearly seen from the figures in the two annexes that the theoretical spectra are very close to the actual measurements using the same parameters. Where this was not the case, it was often due to insufficient measurement resolution. In the laboratory setup a frequency sweeper has been used (waveform generator in the block diagram) that is expected not to have sufficient spectral purity to reach the required noise floor to conduct measurements around 100 MHz away from the carrier.

Generally, it can be concluded that for the cases under study the Fourier analysis method is suitable for the estimation of unwanted emission power levels.

Regarding the design objective, it can be concluded that for the investigated setup, different pulses and modulation, the design objective could not be reached in most cases. This result is supported by both the simulated as measured spectra. In order to reach the design objective additional pulse shaping may be required – which may not be possible or desired for a TWTA solution when driven in saturation.

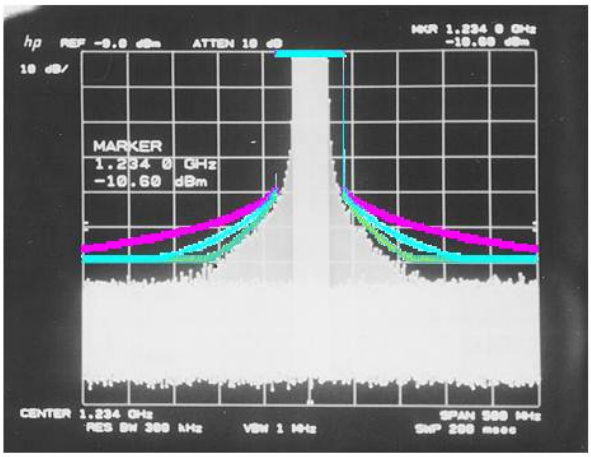
4.3 SIR-C SAR

The SIR-C radar operated aboard the shuttle in the fall of 1994 and used solid state transmitters at 1.25 GHz and 5.3 GHz. Table 4.3-1 shows the transmit pulse characteristics of the SIR-C 1.25 GHz and 5.3 GHz radars.

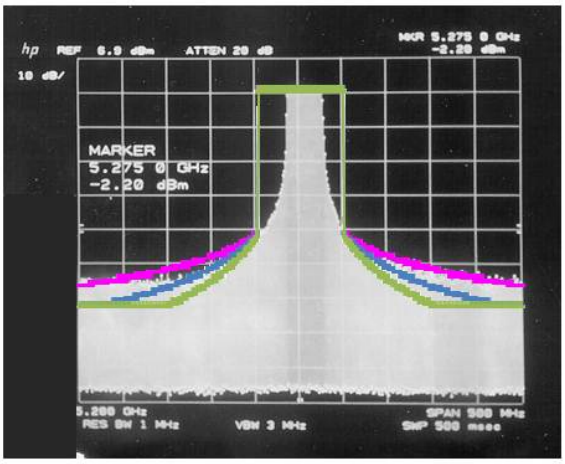
The SIR-C emission spectra at 1.25 GHz and 5.3 GHz are shown in Figure 4.3-1. The measured -40 dB bandwidths are 72 MHz and 96 MHz, respectively, for the 1.25 GHz and 5.3 GHz signals. The measured -60 dB level for the 1.25 GHz signal is 245 MHz; the noise floor for the 5.3 GHz emissions measurement is only 55 dB down from peak, so the -60 dB level measurement is not available. For the 1.5 implementation factor at the beginning of equation (2-1), the rise/fall times would have to be greater than 143 ns and 24.5 ns, respectively, for the 1.25 GHz and 5.3 GHz signals to have the -40 dB level bandwidths as measured. For the 1.25 GHz radar, with the -40 dB level bandwidth of 72 MHz, the -60 dB bandwidth values for the mask at the -20 dB/decade, -30 dB/decade and -40 dB/decade roll-off rates would be 720 MHz, 336 MHz, and 228 MHz, respectively. Thus, the measured emission spectrum for the 1.25 GHz radar meets the -30 dB/decade mask but not meet the -40 dB/decade mask.

Table 4.3-1. Transmit Pulse Characteristics of SIR-C

Parameters	1.25 GHz	5.3 GHz
RF center frequency, GHz	1.25	5.3
Peak radiated power, watts	4400	1200
Pulse type	LFM	LFM
Bandwidth, MHz	40	40
Pulse width, µs	33.8	33.8
Pulse repetition frequency, Hz	1240 to 2160	1240 to 2160
Emission bandwidth:		
-3 dB	40	40
-20 dB	44	44
-40 dB	72	96
-60 dB	245	N/A



(a) SIR-C 1.25 GHz



(b) SIR-C 5.3 GHz

Figure 4.3-1. Measured Emission Spectrum of SIR-C at 1.25 GHz and 5.3 GHz (Masks shown in red for -20 dB/decade, in blue for -30 dB/decade, and in green for -40 dB/decade rolloff)

The roll-off mask starts at the -40 dB bandwidth band edge, using either the ITU-R Rec SM.1541 equations or the document RG-15 equations. For LFM pulses, the measured spectra for SIR-C meet the roll-off rate of -30 dB/ decade. Using the document RG-15 equations and a -30 dB/ decade roll-off rate, the measured emission spectra for both 1.25 GHz and 5.3 GHz radar cases meet the emission masks.

4.4 CLOUDSAT Cloud Profile Radar

The Cloudsat cloud profile radar (CPR) was launched in 2007 and it operates at 94.05 GHz. Cloudsat uses an extended interaction amplifier (EIA) and transmits at 1.5 kW peak power. Unmodulated pulses of length 3.3 µs are used by the CPR as shown in Table 4.4-1.

Figure 4.4-1 shows the spectrum analyzer measurement over 1 MHz centered at 94.05 GHz. (Reference: "Orbit and Transmit Characteristics of the CloudSat Cloud Profiling Radar (CPR), JPL Document No. D-29695, 26 July 2004). Figures 4.4-4-6 show the calculated spectra of the transmitted signals over 1-10 MHz, 0-100 MHz, 0-1000 MHz, respectively.

Table 4.4-1. Measured Transmit Pulse Characteristics of Cloudsat CPR

Parameters	Values
RF center frequency, GHz	94.05
Peak transmit power, watts	1800
Pulse type	Unmodulated
Pulse width, µs	3.3
Pulse repetition frequency, Hz	4300
Pulse rise time, ns	50
Pulse fall time, ns	23
Emission bandwidth:	
-3 dB	1.5
-20 dB	9.1
-40 dB	61.3
-60 dB	N/A

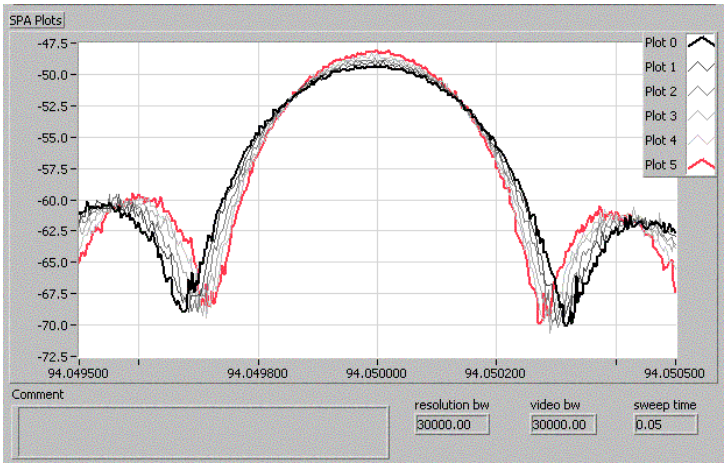


Figure 4.4-1. Spectrum analyzer measurement near 94.05 GHz center frequency (+/- 0.5 MHz).

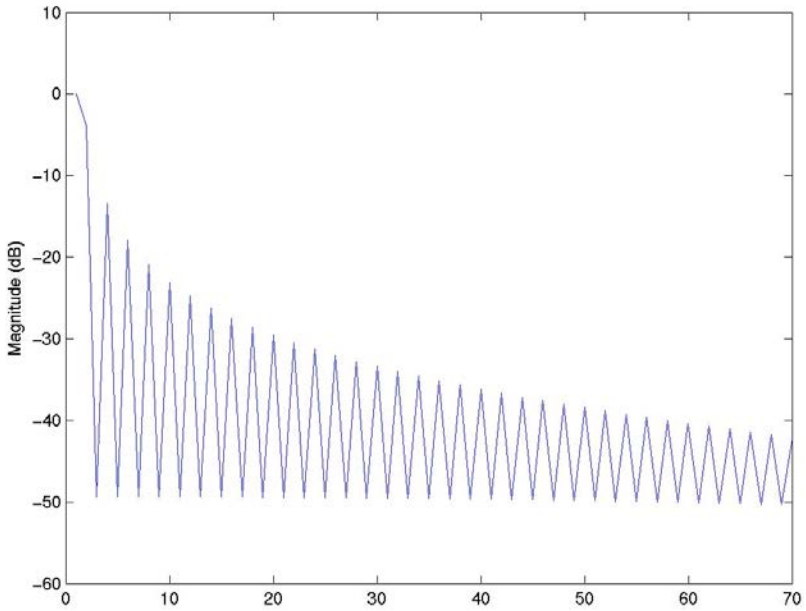


Figure 4.4-2. Calculated Spectrum of Transmitted Signal.(Horizontal axis corresponds to 0-10 MHz, approximately, relative to 94.05 GHz carrier frequency. Frequency bins are roughly 0.15 MHz.)

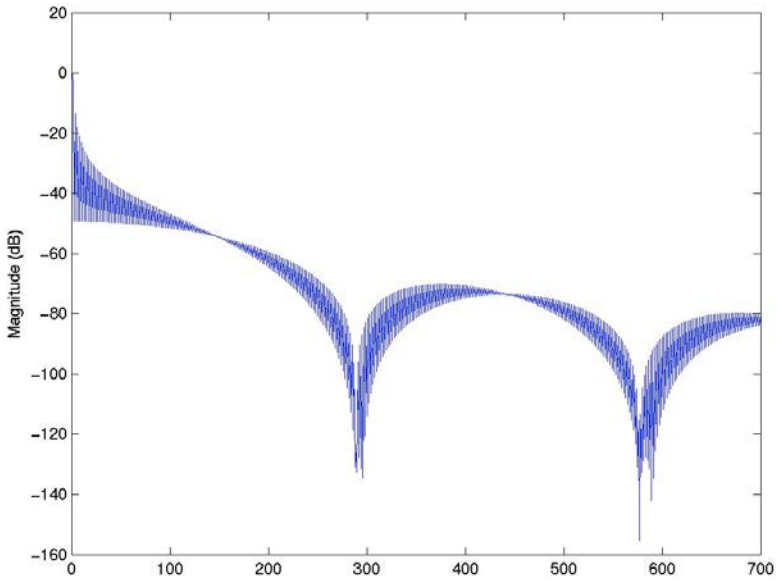


Figure 4.4-3. Calculated Spectrum of Transmitted Signal.(Horizontal axis corresponds to 0-100 MHz, approximately)

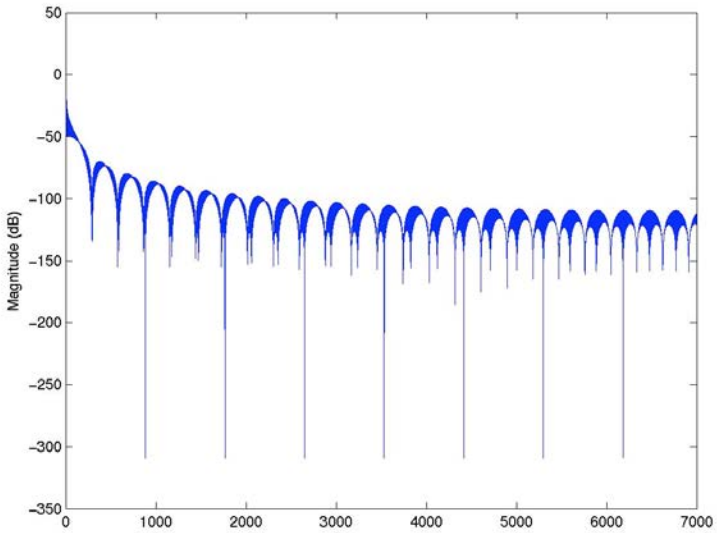


Figure 4.4-4. Calculated Spectrum of Transmitted Signal. (Horizontal axis corresponds to 0-1 GHz, approximately.)

a) HPA1 b) HPA2

Figure 4.4-5. Measured Emission Spectra of Transmitted Signals from HPA1 and HPA2

From Annex 8 of Recommendation ITU-R SM.1541, for unmodulated pulse radars the bandwidth is the lesser of:

$$B_{-40} = \frac{K}{\sqrt{t \cdot t_r}} \text{ or } \frac{64}{t} \qquad (4.4\text{-}1)$$

where the coefficient K is 7.6. The latter expression applies if the rise time (t_r) is less than about 0.014t when K is 7.6. 0.014t is about 46 ns for Cloudsat, so since the Cloudsat rise time is less than this, this latter expression of 64/t applies. For Cloudsat, according to equation (2-5), the -40 dB bandwidth = 64/t, or 19.4 MHz. The measured -40 dB bandwidth for HPA2 is 61.3 MHz (-22.8 MHz/ +38.5 MHz), and thus much greater than the calculated value using equation (2-5). The noise floor for HPA2 in Figure 4.4-5b is only 43 dB down from peak, so the measured roll-off rate between the -40 dB level and the -60 dB level is not available. The noise floor for HPA1 in Figure 4.4-5a is only 38 dB

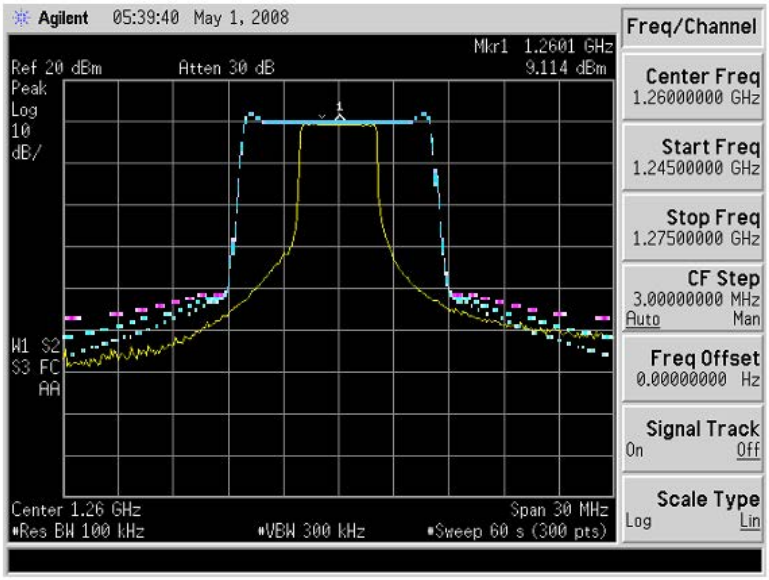
down from peak, so neither the measured -40 dB level nor the roll-off rate are available. If an implementation factor R were to be multiplied times the expression for B_{-40} in equation (2-5), it would have to have a value of 3.15 for the emission level at -40 dB down to fall within the mask. The Cloudsat CPR is at 94.05 GHz, much greater than the 40 GHz limit for Annex 8 applicability. It is recommended to look at other EESS (active) radars which use unmodulated pulses and for which the Annex 8 is applicable to check the measured values of the -40 dB bandwidth and roll-off rates against that given in Annex 8.

4.5 AQUARIUS SCATTEROMETER

The Aquarius scatterometer was launched in June, 2011 and it operates at 1.26 GHz. It transmits at 200 W peak power. The scatterometer uses a linear FM pulse which is 4 MHz wide, with pulsewidth of 1 ms and PRF of 100 Hz. Table 4.5-1 shows the scatterometer characteristics. The emission spectrum of the scatterometer pulse is shown in Figure 4.5-1. Using the document RG-15 equations, for a -3 dB bandwidth of 4 MHz, rise/fall time of 0.1 μs, the calculated -40 dB bandwidth is 10.6 MHz, compared to the measured value of 9.2 MHz. From Figure 4.5-1, the measured emission spectrum for the 1.25 GHz scatterometer appears to just meet the -30 dB/decade mask.

Table 4.5-1. Aquarius Scatterometer System Characteristics

Transmit Frequency	1260 MHz		
Transmit -3dB Bandwidth	4.0 MHz	3 dB Bandwidth	
Transmit Power	200-250 w		
Rise/fall Time	0.1 µs		
Polarization	HH, HV, VV, VH		
Transmit Pulse Length	1 ms	Linear FM Pulse	
Antenna	2.9 x 2.5 m off-set parabola with 3 feed horns		
	Antenna Beams		
	Inner	Middle	Outer
Look Angle wrt Nadir (deg)	25.9	33.9	40.3
Azimuth Angle (deg)	9.7	-15.3	6.5
Antenna Gains (dBi)	28.5	28.5	28.5
Antenna Beamwidths (deg)	~6.7	~6.7	~6.7
Timing Sequence	Beams are switched at 60 ms intervals		



(30 MHz span)

Figure 4.5-1. Measured Emission Spectra for Aquarius Scatterometer

(Masks shown in red for -20 dB/decade, in blue for -30 dB/decade, and in green for -40 dB/decade rolloff)

4.6 PALSAR-2

This section presents the measurement result of out-of-band (OOB) spectrum of PALSAR-2. We measured at the point of data at output of EX. In SFCG30, unwanted emissions about OOB had been discussed at ITU-R Rec.SM1541-2 and JRG-71. However, in ITU-R WP5B, the assessment for OOB emissions was considered to replace the equation from JRG-71 with new a equation which is discussed in WP5B.

In this section, JAXA calculated the 40dB bandwidth by using ITU-R Rec. SM-1541-2 and ITU-R WP5B output document. In the document of ITU-R WP5B, OOB domain limits and necessary bandwidth are not applicable EESS (active). However, in this document, the OOB mask is described as a reference until spurious mask which was calculated by RR appendix.3 Table II starts.

4.6.1 Analysis data and characteristics of PALSAR-2

Table 4.6-1 and 2 show the characteristics of PALSAR-2. Figure 4.6-1 and 2 show the worst case analysis result (using minimum pulse duration) emission spectrum of PALSAR-2 with 40 dB bandwidth mask using Rec. ITU-R SM.1541 Equations, and ITU-R WP5B equation (37), respectively.

Table 4.6-1 : Characteristics of PALSAR-2

Parameter	Value	Unit	Remarks
Central Frequency	1236.5 / 1257.5 / 1278.5	MHz	selectable
Bandwidth	See Table 4.6-2	MHz	variability
Pulse duration	See Table 4.6-2	μs	variability
Pulse rise time	0.005	μs	
Pulse fall time	0.003	μs	

Table 4.6-2 Bandwidth and pulse duration of PALSAR-2

mode	Spotlight	Ultra-Fine	High sensitive	Fine	ScanSAR
Chirp Bandwidth	84 MHz	84 MHz	42 MHz	28 MHz	14 MHz
Pulse duration	46 to 66 μs	51 to 71 μs	23 to 60 μs	12 to 42 μs	26 to 62 μs
Pulse duty	11.5 %	10.0 %	6.8 %	6.6 %	7.0 %

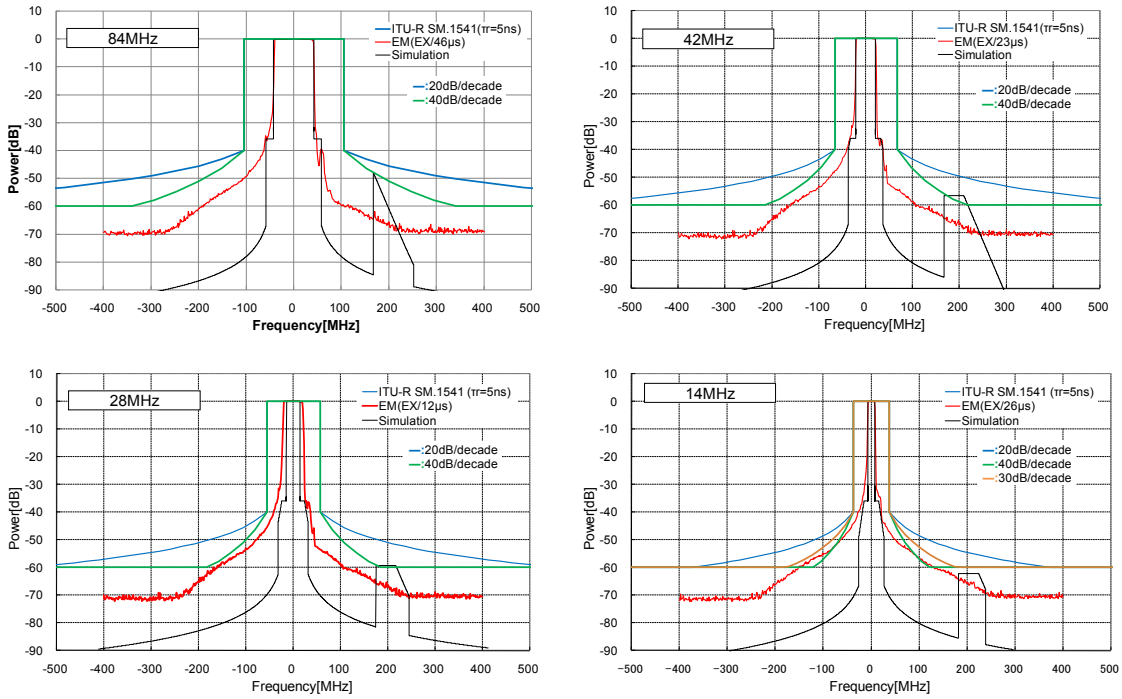


Figure 4.6-1 : The results of OOB spectrum with -40 dB Bandwidth Mask using Rec. ITU-R SM.1541 Equations (Blue : -20 dB/decade roll off, Green : -40 dB/decade roll off)

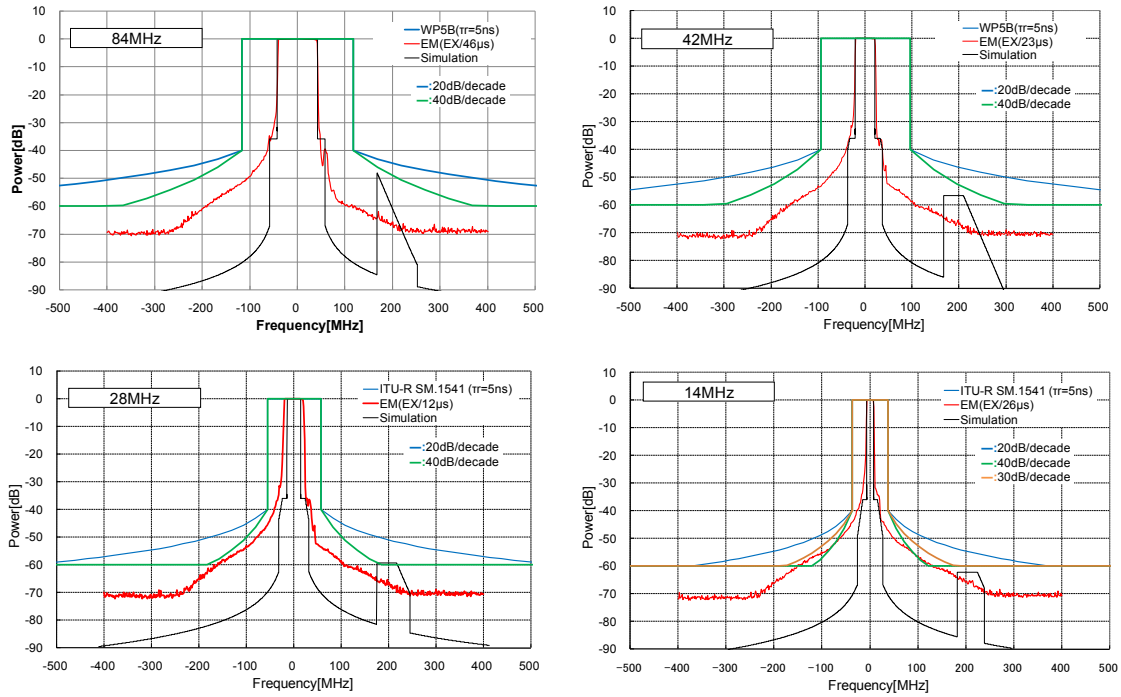


Figure 4.6-2 : The results of OOB spectrum with -40 dB Bandwidth Mask using document of ITU-R WP5B Equation (37) (Blue : -20 dB/decade roll off and Green : -40 dB/decade roll off), except 28 and 14MHz mode. (the condition of 28 and 14 MHz do not meet to calculate by WP5B)

4.6.2 The result of this analysis

Figures 4.6-1 and -2 show the result of the spectrum measurement. The previous meeting we reported our concern that the exceeded spurious appeared around at +200 MHz caused by specification of mixer and BPF in EX, however from the result of this measurement, the exceeded spurious did not appear. Because the affect of mixer and BPF is lower than our consideration. Table 4.5-3 indicates the result of 40 dB bandwidth calculated by SM.1541-2 and ITU-R WP5B equation using PALSAR-2 parameters. Using equations applied in the calculations are described below. The 40 dB bandwidth of Fine and ScanSAR mode does not meet the condition to calculate ITU-R WP5B equation. Therefore, in Figure 4.6-2, bandwidth 28 MHz and 14 MHz modes mask describe as same as SM.1541-2 results.

I. The equation of this analysis

(i) According to Rec. ITU-R SM.1541-2

$$B_{-40dB} = \frac{K}{\sqrt{t \cdot t_r}} + 2\left(B + \frac{A}{t_r}\right), K = 6.2, A = 0.105$$

$$B_{-20dB} = \frac{1.79}{\sqrt{t \cdot t_r}} + 2B$$

(ii) According to document ITU-R WP5B equation (37)

- **40dB bandwidth**

$$B_{-40dB} = 1.5\left(Bc + \sqrt{\pi} * [\ln(Bc * \tau)]^{0.53} * [\mathrm{Min}(B_{rise}, B_{fall}, B_{rise\&fall}) + \mathrm{Max}(B_{rise}, B_{fall}, B_{rise\&fall})]\right)$$

$B_{rise} = \frac{1}{\sqrt{\tau * t_r}}$	To account for the rise time
$B_{fall} = \frac{1}{\sqrt{\tau * t_f}}$	To account for the fall time
$B_{rise_fall} = \frac{1}{(\tau * t_r * t_f)^{1/3}}$	To account for both the rise and fall times combination
τ	Total Pulse length (us) including rise and fall times
t_r	100% Pulse rise time (us)
t_f	100% Pulse fall time (us)
Bc	bandwidth of the frequency deviation (total frequency shift during the pulse generation)(MHz)
π	3.141592654…..

Equation 37 is valid only when the following conditions are met;

1) The product Bc * Minimum(tr, tf) is greater than or equal to 0.10; and
2) That the product of Bc * τ or compression ratio must be greater than 10.
In all other cases, the following equation should be used as same ITU-R Rec.SM1541-2.

$$B_{-40dB} = \frac{K}{\sqrt{t \cdot t_r}} + 2\left(B + \frac{A}{t_r}\right), K = 6.2, A = 0.105$$

(iii) OOB mask limits calculation (as a reference)

Concerning -20 dB/decade and -40 dB/decade, the following equations are used.

-20 dB/decade

$Y=-40+20\log B_{-40}/(2|x|)$ $|x| \geq B_{-40}/2$

$Y=0$ $|x| < B_{-40}/2$

-40 dB/decade

$Y=-40+40\log B_{-40}/(2|x|)$ $|x| \geq B_{-40}/2$

$Y=0$ $|x| < B_{-40}/2$

Where,

Y : relative spectrum power [dB]

X : differential from central frequency [MHz]

B_{-40dB} : 40dB Bandwidth [MHz]

Table 4.6-3 : Calculated 40dB and 20dB Bandwidth of PALSAR-2 in SM.1541-2 and WP5B equations

parameter		unit	values									
ITU-R SM.1541-2			Spot		Ultra-fine		High-sens		Fine		ScanSAR	
B40	**40dB bandwidth**	**MHz**	**209.85**	**207.23**	**209.05**	**206.76**	**132.41**	**123.88**	**113.03**	**98.58**	**75.08**	**67.65**
K	constant	-	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60
t	Pulse duration @ half amplitude	us	46.00	66.00	51.00	71.00	23.00	60.00	12.00	42.00	26.00	62.00
tr	rise time	us	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
B	Bandwidth	MHz	84.00	84.00	84.00	84.00	42.00	42.00	28.00	28.00	14.00	14.00
A	constant	-	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065
ITU-R WP5B		unit	Spot		Ultra-fine		High-sens		Fine		ScanSAR	
B40	**40dB bandwidth**	**MHz**	**235.09**	**224.04**	**231.82**	**221.94**	**190.06**	**159.42**	**189.30**	**145.80**	**133.08**	**109.18**
R	constant	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
B	Bandwidth	MHz	84.00	84.00	84.00	84.00	42.00	42.00	28.00	28.00	14.00	14.00
N	constant	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
π	pi	-	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
τ	Total pulse length including rise and fall	us	46.01	66.01	51.01	71.01	23.01	60.01	12.01	42.01	26.01	62.01
tr	100% rise time	us	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
tf	100% fall time	us	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Brise	to account for the rise time	MHz	2.08	1.74	1.98	1.68	2.95	1.83	4.08	2.18	2.77	1.80
Bfall	to account for the fall time	MHz	2.69	2.25	2.56	2.17	3.81	2.36	5.27	2.82	3.58	2.32
Brise and fall	to account for the rise and fall time	MHz	11.32	10.03	10.93	9.79	14.26	10.36	17.71	11.66	13.69	10.24
Condition	B x min(tr or tf)	>0.10	0.252	0.252	0.252	0.252	0.126	0.126	0.084	0.084	0.042	0.042
	B x t	>10	3864.672	5544.67	4284.67	5964.672	966.34	2520.3	336.22	1176.2	364.11	868.11

Table 4.6-4 The result 40 dB Bandwidth in worst case analysis(minimum pulse duration)

	Modes	Rec SM.1541 [MHz]	ITU-R WP5B [MHz]	Measurement [MHz]
B_{40dB}	Spotlight	207.23	224.04	120
	Ultra-Fine	206.76	221.94	120
	High-sensitive	123.88	159.42	70
	Fine	98.58	98.58*	77
	ScanSAR	67.65	67.65*	46

Worst case analysis is at minimum pulse duration which is the same as that for the maximum bandwidth.
* : The 40 dB bandwidth of WP5B equation is same as SM.1541-2 values, because Fine mode and ScanSAR mode do not meet the condition to use the WP5B equation.

4.6.3 Conclusions on OOB Emissions of PALSAR-2

This section described the measurement result of PALSAR-2 OOB spectrum at the point of Exciter (EX) output. According to Figures and tables, the signal of PALSAR-2 does not exceed the 40 dB bandwidth calculated by both the equations of ITU-R Rec.1541-2 and WP5B document.

To keep the mask of 40dB/decade roll-off is difficult in narrow bandwidth observation modes, however, to keep the mask of 20dB/decade is possible.

The latest information, ALOS-2 project have started to manufacture the Flight Model (PFM and/or FM) of components and we plan to measure the same data.

4.7 European Space Agency Active Spaceborne Sensors

A summary of active spaceborne sensors currently in operation or planned by the European Space Agency is presented in Table 4.7-1.

Next sections include specification data and/or measurements of OOB emissions for the following ESA active sensors:

C-Band SAR on Envisat (operational).	*SAR transmitter spectrum mask as specified in ICD*
S/Ku-Band Radar altimeter on Envisat (operational)	*Altimeter transmitter spectrum mask as specified in ICD*
C-Band SAR on Sentinel-1 (planned 2013)	*SAR transmitter specifications (EM tests in preparation)*
C/Ku-Band Advanced Altimeter on Sentinel-3 (planned 2013)	*Altimeter transmitter spectrum as measured in EM model*

Table 4.7-5: Overview of ESA missions with EESS(active) sensors

Mission *(with hiperlinks to ESA website)*	**Status**	**Type of active sensor**	**Name**	**Description**	**RF center frequency**	**OOB emission spectra**
ERS-2	Operational (1995-) *De-orbit planned by end July 2011*	SAR	AMI/ SAR	**Active Microwave Instrument (AMI) in mode SAR in C-Band**. AMI-SAR has two modes of operation: *wave-mode* (2D spectra of ocean surface waves) and *image mode* (high resolution 2D all-weather images of ocean, ice and land surfaces)	5.3 GHz	---
		Scattero meter	AMI/WS	**Wind scatterometer in C-Band**. WSCAT obtains information on wind speed and direction at the sea surface.	5.3 GHz	---
		Altimeter	RA	**Single frequency radar altimeter in Ku Band.** Nadir-pointing sensor that measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography, and sea ice boundaries.	13.8 GHz	---
Envisat	Operational (2002-)	SAR	ASAR	**Advanced SAR in C band**. It ensures continuity with ERS-2 AMI/SAR	5.331 GHz	**See section 4.7.2**
		Altimeter	RA-2	**Dual-frequency radar altimeter operating in Ku and S bands**. It ensures continuity with ERS-2 RA altimeter	13.575 GHz 3.2 GHz	**See section 4.7.3**
Cryosat	Operational (2010-)	Altimeter	SIRAL	**Single frequency SAR/Interferometric radar altimeter in Ku-Band:** *SAR mode* operating a high resolution measurement on sea ice, and *SAR interferometer mode* operating on rough surfaces like on the sea ice/land limit	13.575 GHz	**---**
EarthCare	Planned (2015)	Cloud Radar	CPR	**Cloud Profiling Radar (CPR) in milimeter wave band (94 GHz).** EarthCare is a joint European-Japanese mission. The CPR	94.050 GHz	Instrument developed by JAXA/NICT

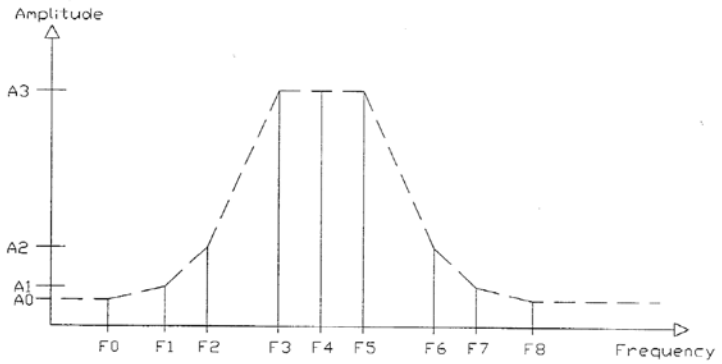
				instrument has been developed by JAXA and the National Institute of Information and Communications Technology (NICT)		
Sentinel-1	Planned (2013)	SAR	CSAR	**SAR in C-Band** for operational applications in monitoring of sea ice zones and the arctic environment, surveillance of marine environment, monitoring of land surface motion risks and mapping in support of humanitarian aid in crisis situations	5.404GHz	**See section 4.7.4**
Sentinel-3	Planned (2013)	Altimeter	SRAL	**Dual frequency advanced radar altimeter operating in Ku and C-Bands**. Ku-band is used for main range measurements and C-Band for compensation of ionospheric effects. SRAL is based on CRYOSAT heritage (SIRAL).	5.410 GHz, 13.575 GHz	**See section 4.7.5**

4.7.1 ENVISAT C-Band SAR

Instrument name	ASAR (Advanced SAR)
Instrument type	Synthetic aperture radar (imaging microwave radar)
Website info	ESA: http://envisat.esa.int/earth/www/object/index.cfm?fobjectid=3772 CEOS database: http://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=344
Mission name	Envisat
Mission status	Operational
Launch date	1 March 2001
Orbit altitude	764 km
Inclination	98.6 deg
ASAR transmitter characteristics	
Transmit power	peak: 2.5 kW (34dBW), mean: 200W (23dBW)
Antenna gain	40-45 dBi (depending on operation mode)
RF centre frequency	5.331 GHz
Pulse type	Linear FM
Pulse width	16 - 41 usec (depending on operational mode)
Pulse repetition freq	1.6-2.1 kHz
Pulse bandwidth	16 MHz

Envisat ASAR emission spectra mask and the transmitter harmonic attenuation with respect to the carrier frequency 5.331 GHz is shown in Figure 4.7-1.

The -40dB bandwidth is 30 MHz, and the spectrum follows -30dB/decade mask up to -70dB. Note that using the -40dB bandwidth equation (40) given in Recommendation ITU-R SM.1541, the calculated -40dB bandwidth is higher, 47.9MHz.



TX Output Power Spectrum Envelope at the Antenna Port with its Power A_i (dB_{ref}) versus Frequency f_i (GHz)	f_0 = 5.031 GHz f_1 = 5.301 GHz f_2 = 5.316 GHz f_3 = 5.321 GHz f_4 = 5.331 GHz f_5 = 5.341 GHz f_6 = 5.346 GHz f_7 = 5.361 GHz f_8 = 5.631 GHz	A_0 = -70 dB_{ref} A_1 = -40 dB_{ref} A_2 = -30 dB_{ref} A_3 = 0 dB_{ref}
TX Harmonic Attenuation AH_i (dBc) wrt. Carrier Frequency f_c (GHz)	0 dBc at f_c -30 dBc at 2 x f_c -40 dBc at 3 x f_c -40 dBc at 4 x f_c -42 dBc at 5 x f_c -44 dBc at 6 x f_c -46 dBc at 7 x f_c	

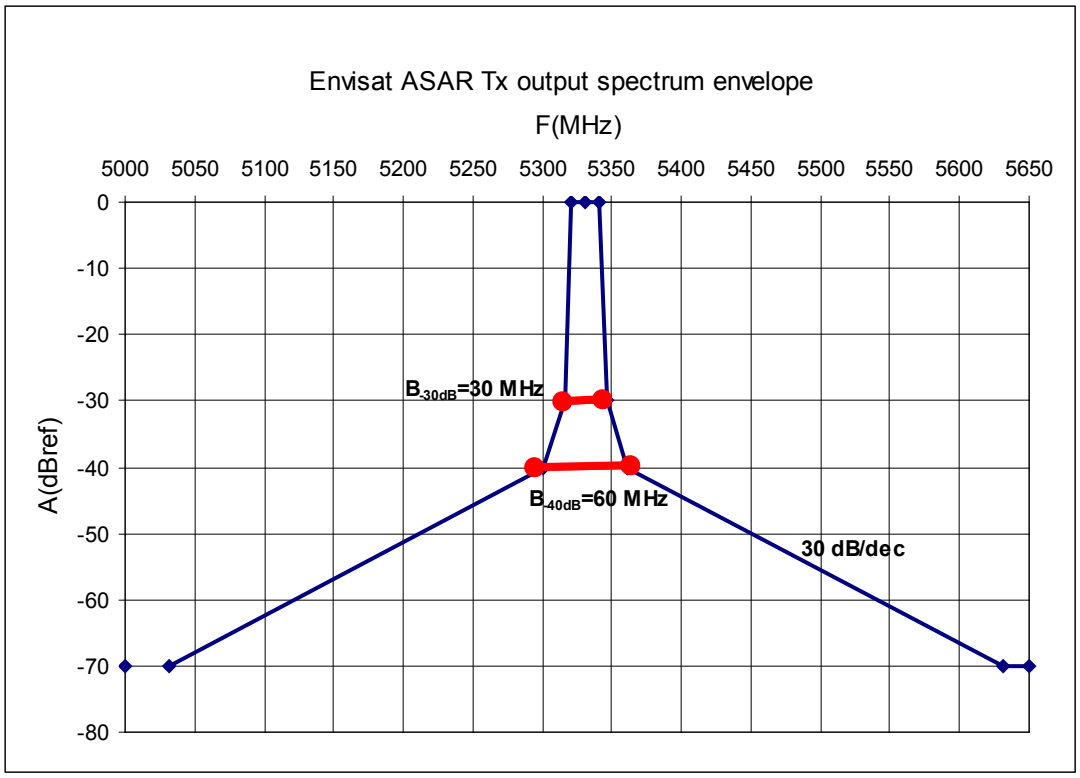


Figure 4.7-1: Envisat ASAR transmitter output spectrum envelope at antenna port (source: ENVISAT/ASAR Specific Interface Control Document, Feb 2001)

4.7.2 ENVISAT S/Ku-Band Radar Altimeter RA-2

Instrument name	**RA-2, Dual-frequency radar altimeter operating in Ku and S bands** RA-2 is a nadir pointing pulse limited radar altimeter operating at two frequencies: 13.575 GHz (Ku-band) and 3.2 GHz (S-band). S-band is lost since 2008. Operations are accomplished by automatically changing the radar pulse resolution at Ku band through selection among three pulse bandwidths available (320 - 80 - 20 MHz) plus a CW pulse for the acquisition.
Instrument type	Radar altimeter
Website info	ESA: http://envisat.esa.int/earth/www/object/index.cfm?fobjectid=3774 CEOS database: http://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=379
Mission name	Envisat
Mission status	Operational
Launch date	1 March 2001
Orbit altitude	764 km
Inclination	98.6 deg

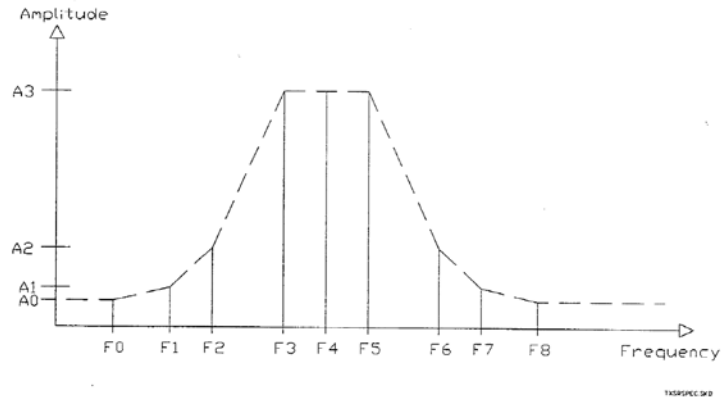
RA-2 INSTRUMENT CHARACTERISTICS

1st, 2nd central frequency (GHz)	13.575, 3.2
Pulse lenght (microsec)	20
Ku chirp bandwidths (MHz)	320, 80, 20
S chirp bandwidth (Mhz)	160
Ku transmitter peak power (W)	60
S transmitter peak power (W)	60
Ku PRF (Hz)	1795.33
SPRF (HZ)	448.83

RA-2 ANTENNA CHARACTERISTICS

PARAMETER	KU-BAND	S-BAND	REMARKS
Diameter	1200 mm	1200 mm	Maximum
f/D ratio	0.8	0.8	Maximum
Central frequency	13575 MHz	3200 MHz	Nominal
Polarization	Linear	Linear	alogn PPF Y direction (both S and Ku bands)
Bandwidth (-3dB)	360 MHz	180 MHz	Minimum
Beamwidth (-3dB)	1.30 deg	N.A.	Minimum
Peak gain	41.2 dB	29.0 dB	Minimum at antenna port
Sidelobe level to peak gain ratio	-28 dB	-23 dB	Maximum, any cut, OFB

Envisat RA-2 emission spectra mask and the transmitter harmonic attenuacion at Ku and S-Band is shown in Figure 4.7-2. The bandwidth at -32dB is 600 MHz. Out of band emission limits specified in Annex 8 of Rec.ITU-R SM.1541 do not apply for Envisat altimeter because the transmit power (60W) is less than 1kW. Note that using the -40dB bandwidth equation (40) given in Rec.ITU-R SM.1541, the calculated -40dB bandwidth would be 656MHz.



Tx Output Power Spectrum Envelope at the Antenna Port with its Power A_i versus Frequency f_i	f_1 = 13.275 GHz A_1 = -32 dB_{ref} f_2 = 13.385 GHz A_2 = -30 dB_{ref} f_3 = 13.410 GHz A_3 = 0 dB_{ref} f_4 = 13.575 GHz A_4 = 0 dB_{ref} f_5 = 13.740 GHz A_5 = 0 dB_{ref} f_6 = 13.765 GHz A_6 = -30 dB_{ref} f_7 = 13.875 GHz A_7 = -30 dB_{ref}
Tx Harmonic Attenuation AH_i wrt. Carrier Frequency f_0	-85 dBc at 2 x f_0 -110 dBc at 3 x f_0

Tx Output Power Spectrum Envelope at the Antenna Port with its Power A_i versus Frequency f_i	f_1 = 2.8 GHz A_1 = -55 dB_{ref} f_2 = 2.9 GHz A_2 = -50 dB_{ref} f_3 = 3.1 GHz A_3 = 0 dB_{ref} f_4 = 3.2 GHz A_4 = 0 dB_{ref} f_5 = 3.3 GHz A_5 = 0 dB_{ref} f_6 = 3.5 GHz A_6 = -50 dB_{ref} f_7 = 3.6 GHz A_7 = -57 dB_{ref}
Tx Harmonic Attenuation AH_i wrt. Carrier Frequency f_0 (includes unit internal filter)	-72 dBc at 2 x f_0 -85 dBc at 3 x f_0 -68.5 dBc at 4 x f_0 -87 dBc at 5 x f_0 -114 dBc at 6 x f_0 -117 dBc at 7 x f_0

Figure 4.7-2: Envisat RA-2 transmitter output spectrum envelope at antenna port (source: ENVISAT/RA-2 Specific Interface Control Document, May 1999)

4.7.3 SENTINEL-1 C-Band SAR

Instrument name	C-Band Synthetic Aperture Radar (C-SAR) polar-orbiting satellite system for the continuation of SAR operational applications after ENVISAT
Instrument type	Synthetic aperture radar (imaging microwave radar)
Website info	ESA: http://www.esa.int/esaLP/SEMBRS4KXMF_LPgmes_0.html http://esamultimedia.esa.int/docs/S1-Data_Sheet.pdf CEOS database: http://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=939
Mission name	Sentinel-1 Part of the Space Component of the European Earth Observation Programme (GMES)
Mission status	Planned
Launch date	1st satellite: May 2013 2nd satellite: 2015
Orbit altitude	700 km
Inclination	98.2 deg
ASAR transmitter characteristics	
Transmit power	peak: 4 kW (36dBW)
Antenna gain	42-45 dBi (depending on operation mode)
RF centre frequency	5.405 GHz
Pulse type	Linear FM
Pulse width	25 - 62 usec (depending on operational mode)
Pulse repetition freq	1.4-1.9 kHz
Pulse bandwidth	100 MHz

From annex 8 of Rec.ITU-R SM.1541, the necessary bandwidth, B_N, and the -40dB bandwidth, B_{-40}, for FM-pulse radars are:

$$B_N = \frac{1.79}{\sqrt{t \cdot t_r}} + 2B_c$$

$B_N = 202$ MHz

$$B_{-40} = \frac{K}{\sqrt{t \cdot t_r}} + 2\left(B_c + \frac{A}{t_r}\right)$$

with K=7.6; A=0.065 ➔ $B_{-40} = 212$ MHz

(Assuming $t_r = 24$ nsec)

Sentinel-1 project is in Phase C/D. First measurements results of the C-SAR RF spectral emission mask will be available by end 2011.

4.7.4 SENTINEL-3 C/Ku-Band Advanced Altimeter

Instrument name	**SRAL** Synthetic Aperture Radar altimeter, dual Ku-Band (main range measurements) and C-Band (compensation of ionospheric effects).
Instrument type	Radar altimeter
Modes of operation	Two radar measurement modes: - MODE LRM (mainly used over oceans) - MODE SAR (mainly used over coastal lines and ground surface)
Website info	ESA: http://www.esa.int/esaLP/SEMTST4KXMF_LPgmes_0.html http://esamultimedia.esa.int/docs/S3-Data_Sheet.pdf CEOS database: http://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=903
Mission name	Sentinel-3
Mission status	Planned
Launch date	2013
Orbit altitude	814 km
Inclination	98.6 deg

SRAL transmitter characteristics

	C-Band	Ku-Band
RF centre frequency	5.41 GHz	13.575 GHz
EESS(active) allocation	5250-5570 MHz (overall BW 320 MHz)	13.25-13.75 GHz (overall BW 500 MHz)
Transmit power	15 dBW peak (31.6W)	8.5 dBW peak (7.1W)
Antenna gain	32 dBi	42 dBi
Pulse type	Linear FM	Linear FM
Pulse width	49 usec	49 usec
Pulse repetition freq	275 to 540 Hz (depending on operation mode)	1.9 to17.8 KHz (depending on operation mode)
Pulse bandwidth	320MHz	350 MHz

The following figures show test results from EM measurements. This information is preliminary. The peak power of SRAL is below 1kW, therefore it is not within the categories of primary radar systems addressed in Annex 8 of Rec. ITU-R SM.1541-1.

SRAL Ku-Band mode LRM:
See Figure 4.7-3: SRAL-Ku Band (mode LRM) frequency response at diplexer output.
B = 349.4 MHz (see reference points in Figure)
B_{-20dB} = 400 MHz
B_{-40dB} = 490 MHz
SRAL Ku-Band mode SAR:
See Figure 4.7-4: SRAL-Ku Band (mode SAR) frequency response at diplexer output.
Measured bandwidth
B = 346.1 MHz (see reference points in Figure)
B_{-20dB} = 400 MHz
B_{-40dB} = 635 MHz

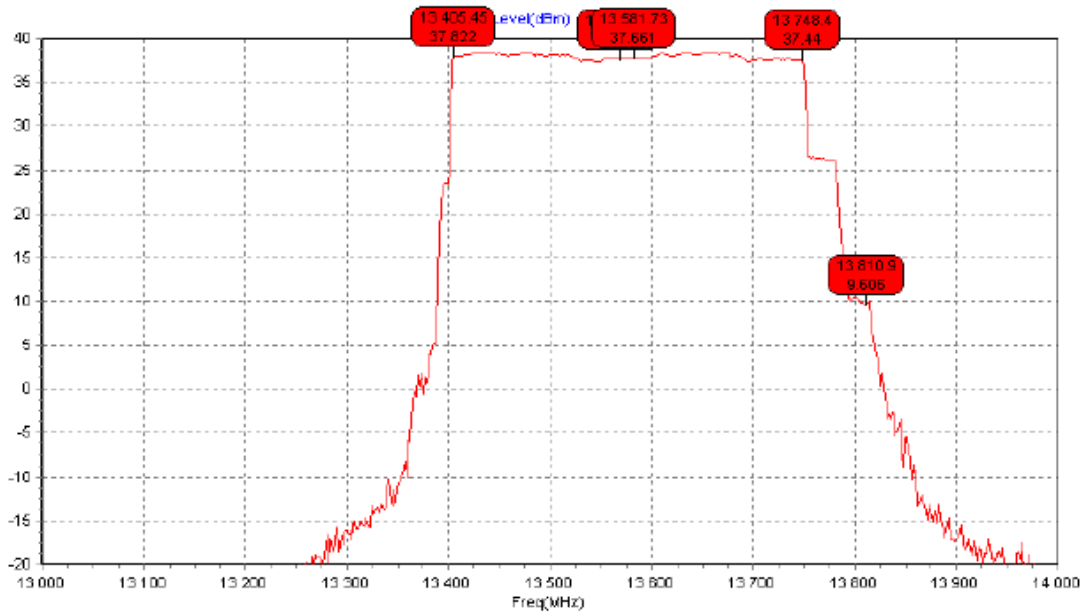


Figure 4.7-3: SRAL-Ku Band (mode LRM) frequency response at diplexer output

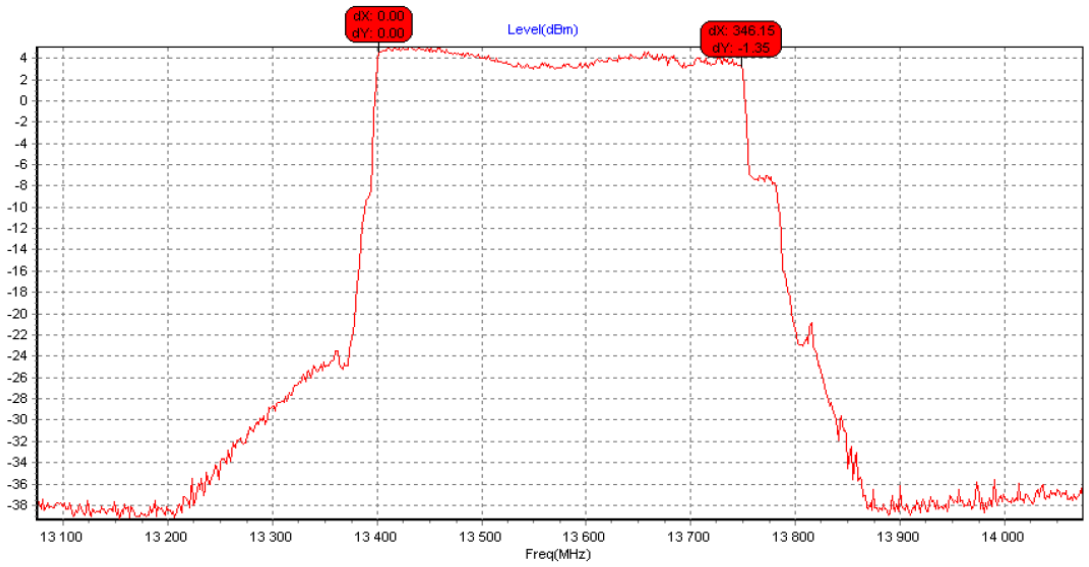


Figure 4.7-4: SRAL-Ku Band (mode SAR) frequency response at diplexer output

SRAL C-Band mode LRM:
See Figure 4.7-5: SRAL-C Band (mode LRM) frequency response at diplexer output
B = 320 MHz (see reference points in Figure)
B_{-20dB} = 400 MHz
B_{-40dB} = 500 MHz
SRAL C-Band mode SAR:
See Figure 4.7-6: SRAL-C Band (mode SAR) frequency response at diplexer output.
Measured bandwidth
B = 320 MHz (see reference points in Figure)
B_{-20dB} = 400 MHz
B_{-40dB} = 500 MHz

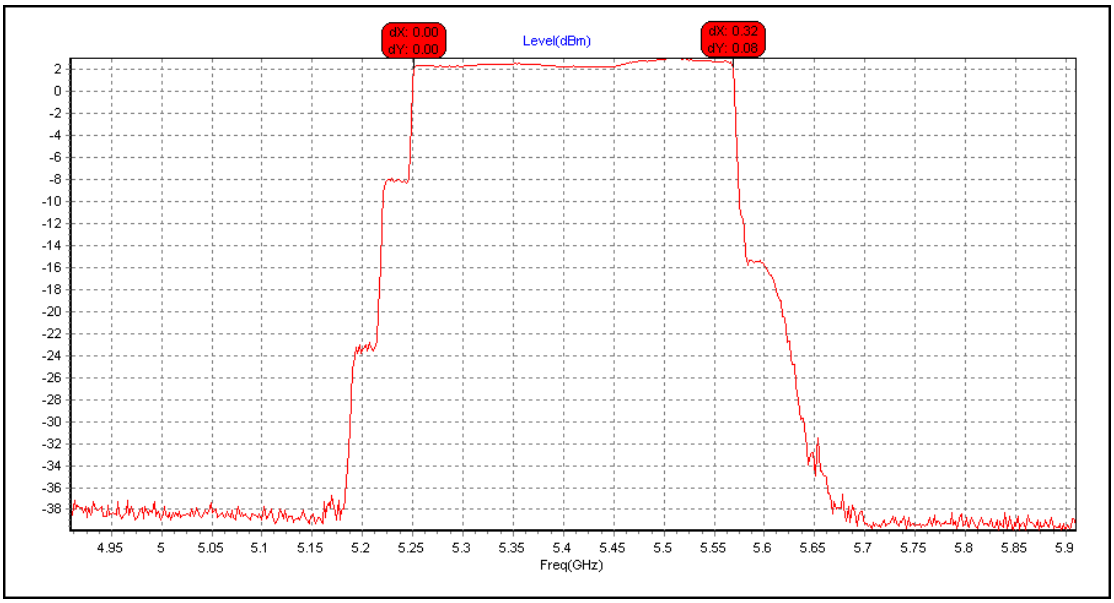


Figure 4.7-5: SRAL-C Band (mode LRM) frequency response at diplexer output

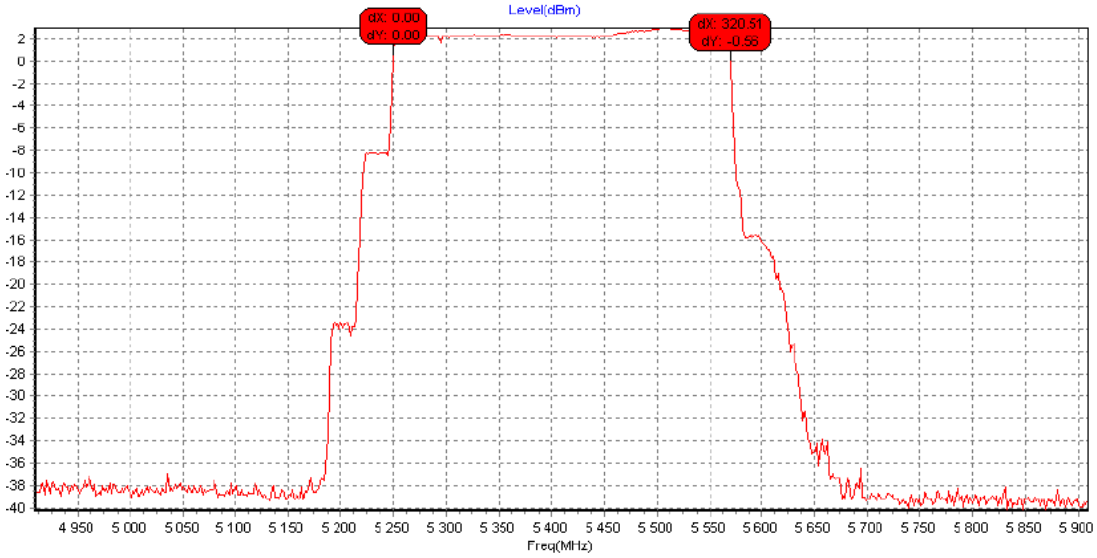


Figure 4.7-6: SRAL-C Band (mode SAR) frequency response at diplexer output

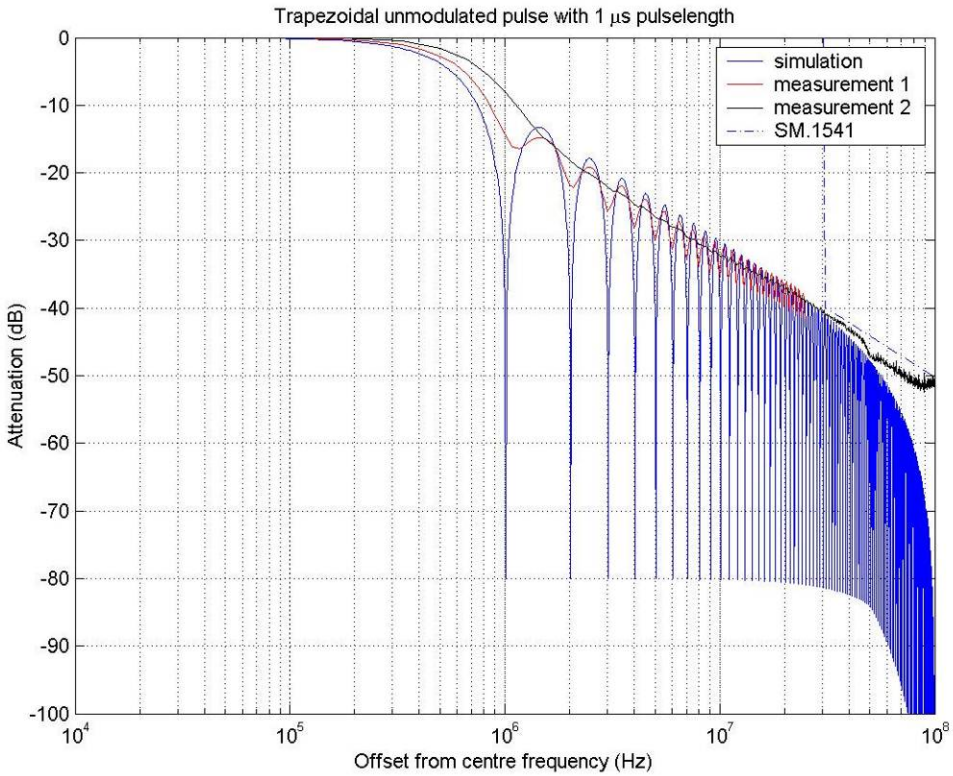
5. CONCLUSION

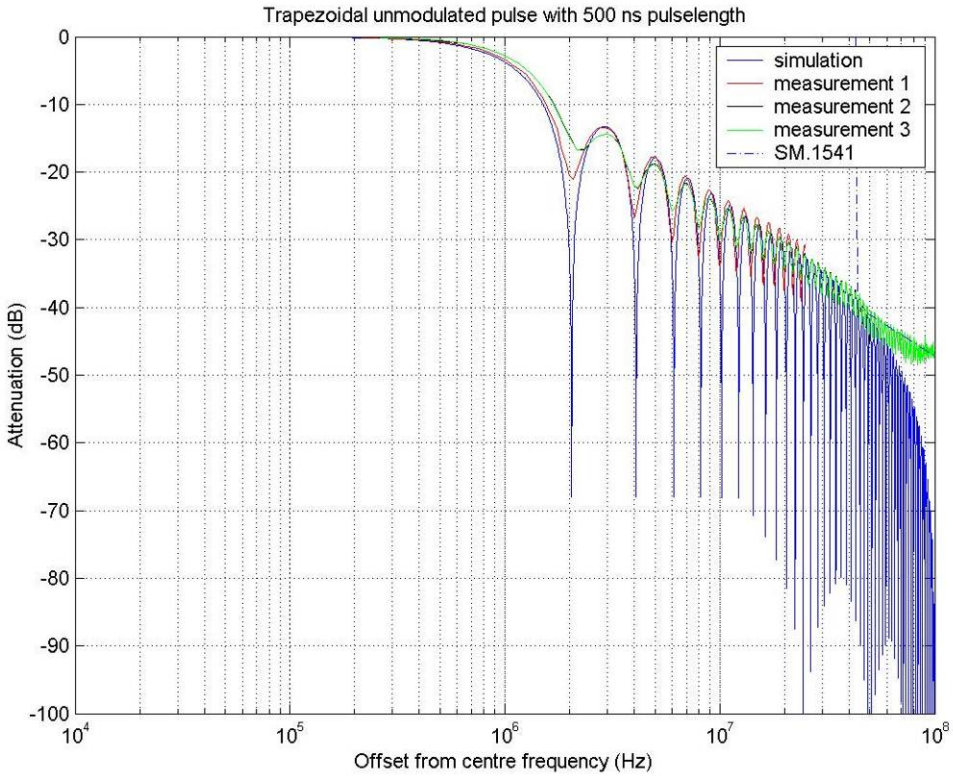
This report presents out-of- band (OOB) emission measurement data for spaceborne active sensors in the EESS (active). The report shows the results of measurements and simulations of the -40 dB bandwidth and roll-off rates from emission spectra data on spaceborne active sensors in EESS (active) using supporting data from SFCG-27 to SFCG-31.

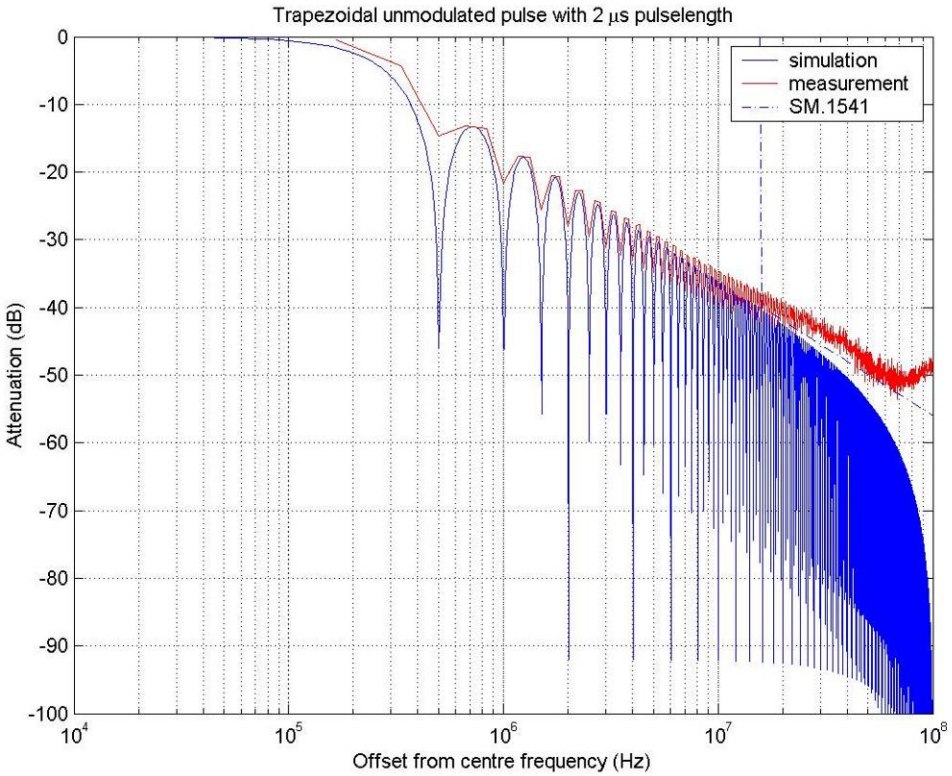
Measurements of OOB emission spectra are shown for two airborne active sensors: AIRSAR and UAVSAR. Measurements of OOB emission spectra are shown for nine spaceborne active sensors: ALOS PALSAR, SIR-C, Cloudsat, Aquarius scatterometer, PALSAR-2, ENVISAT C-band SAR, ENVISAT S/Ku-Band Radar Altimeter RA-2, SENTINEL-1 C-Band SAR, and SENTINEL-3 C/Ku-Band Advanced Altimeter. Simulations of OOB emission spectra are shown for linear beam output devices.

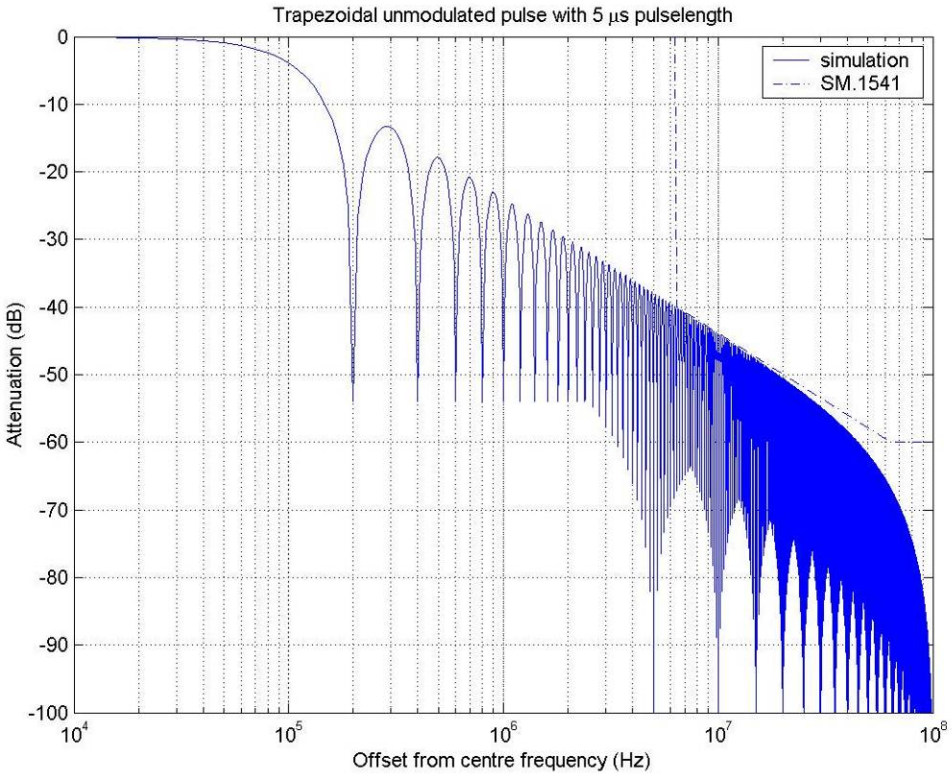
The SFCG position on OOB emissions from spaceborne active sensors is that a design objective of -40 dB per decade roll-off is not technically feasible for many spaceborne active sensors. The SFCG has determined that a more realistic value would be -30 dB per decade.

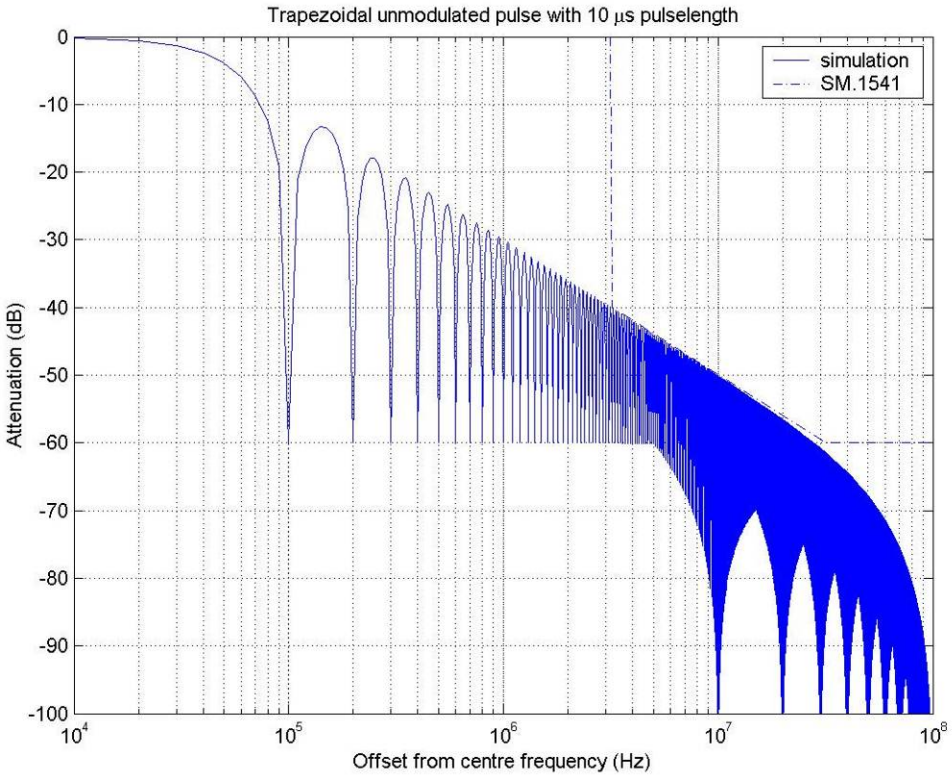
ANNEX 1: Results for trapezoidal unmodulated pulses

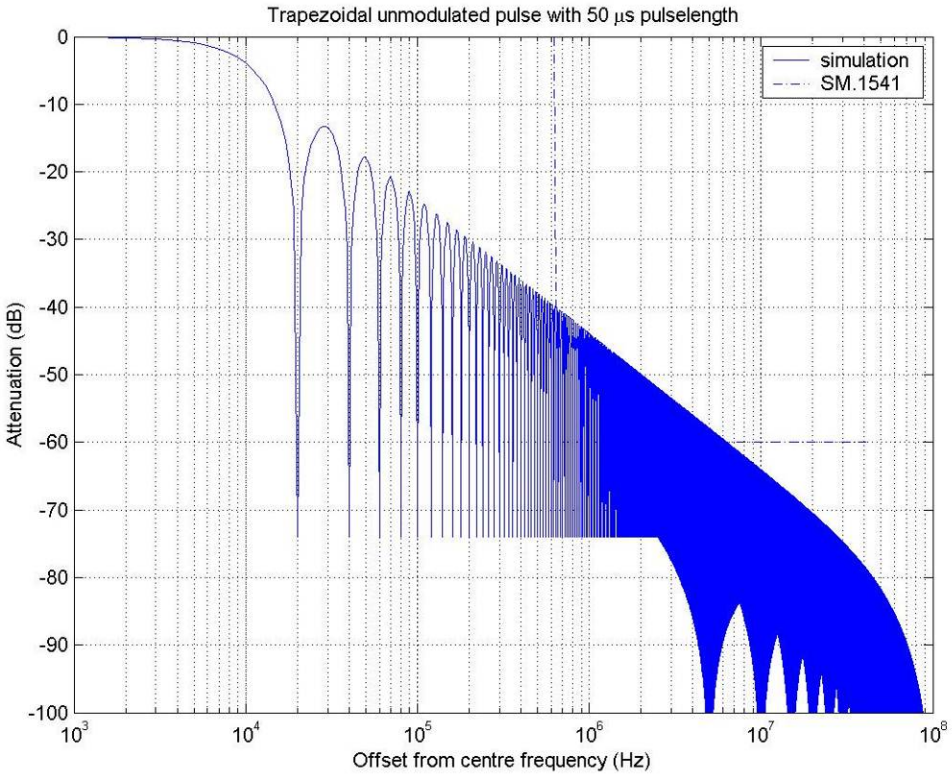


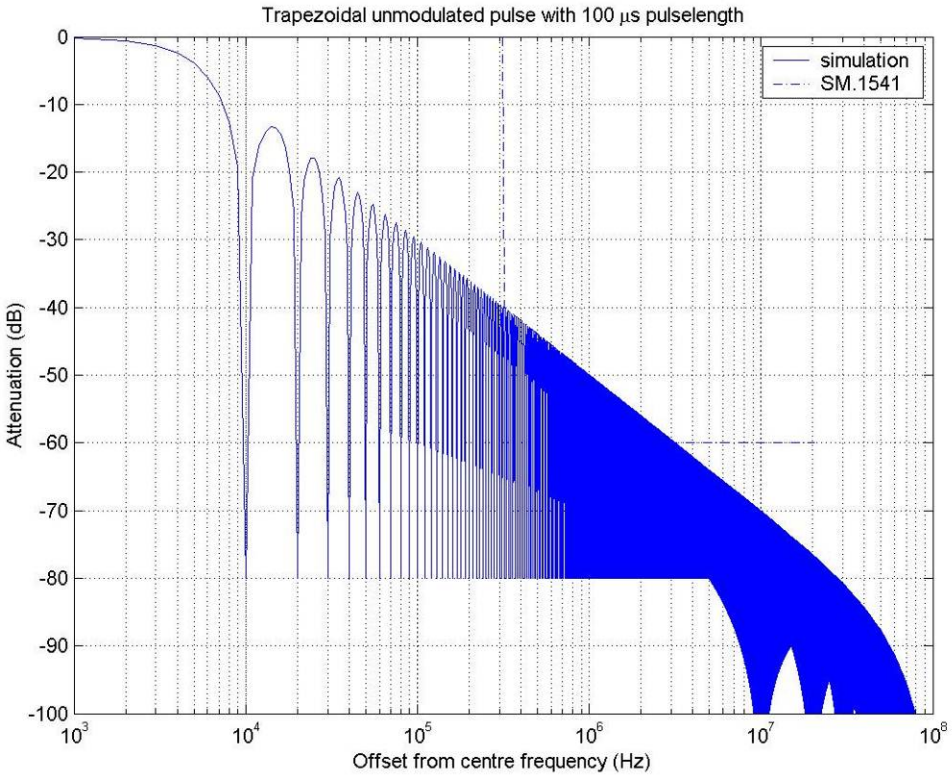


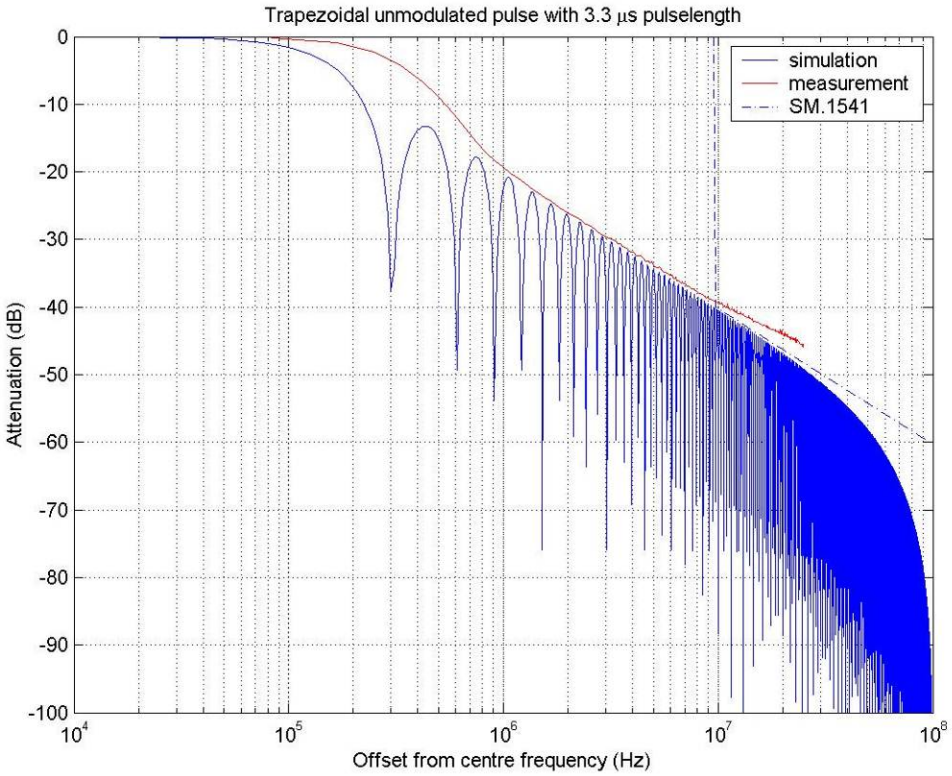

Trapezoidal unmodulated pulse with 2 μs pulselength
simulation
measurement
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)

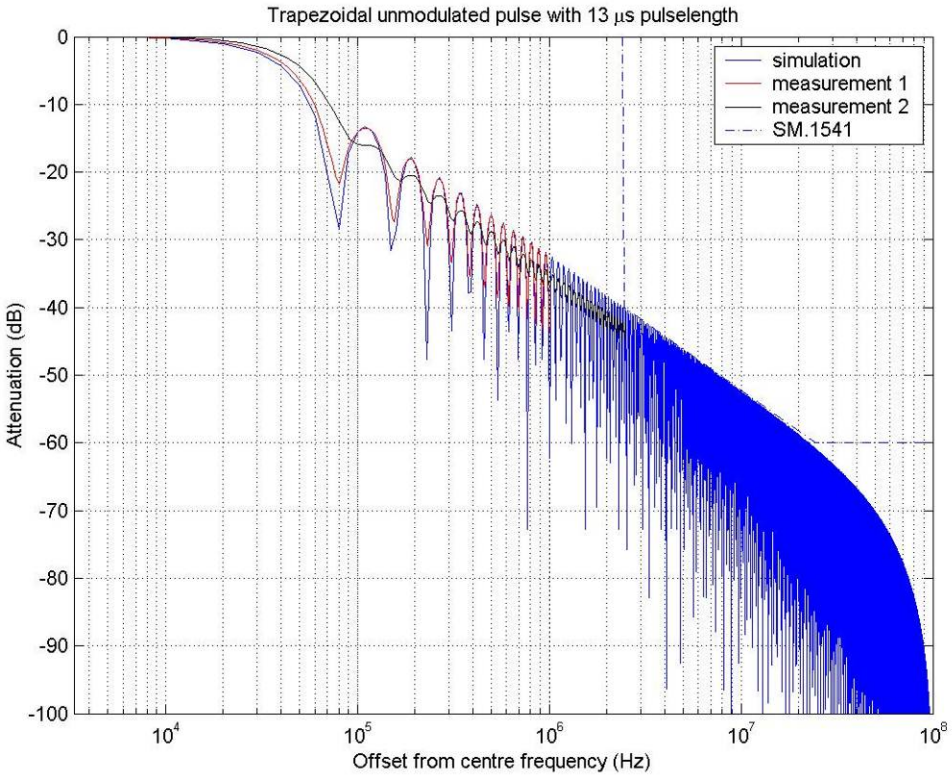

Trapezoidal unmodulated pulse with 5 μs pulselength
simulation
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)

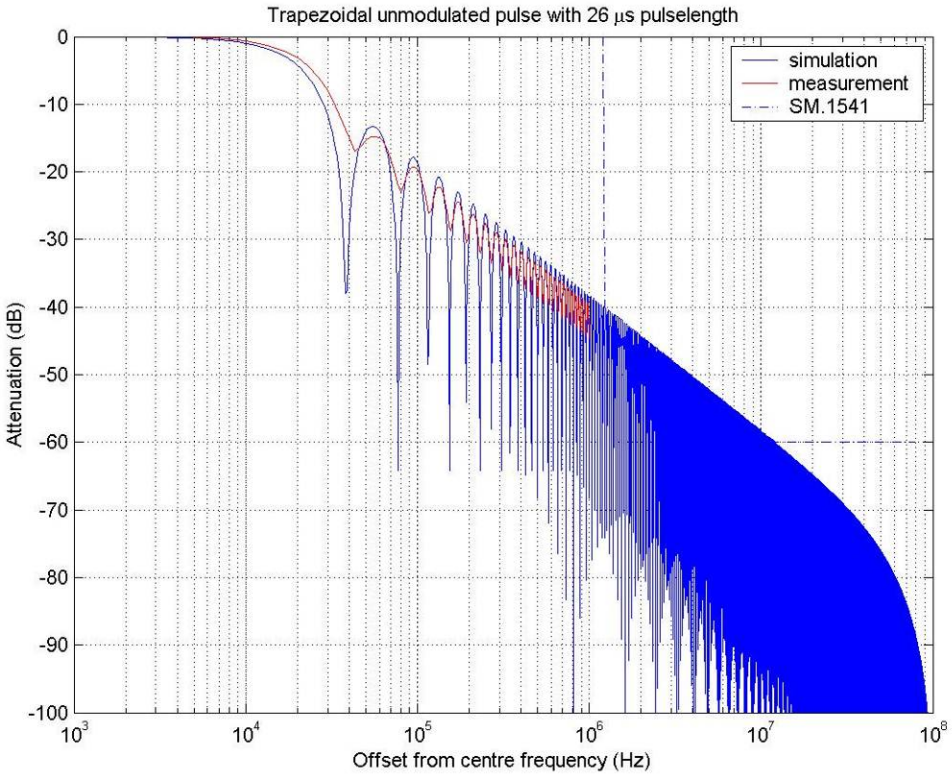

Trapezoidal unmodulated pulse with 10 μs pulselength
simulation
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^4
10^5
10^6
10^7
10^8

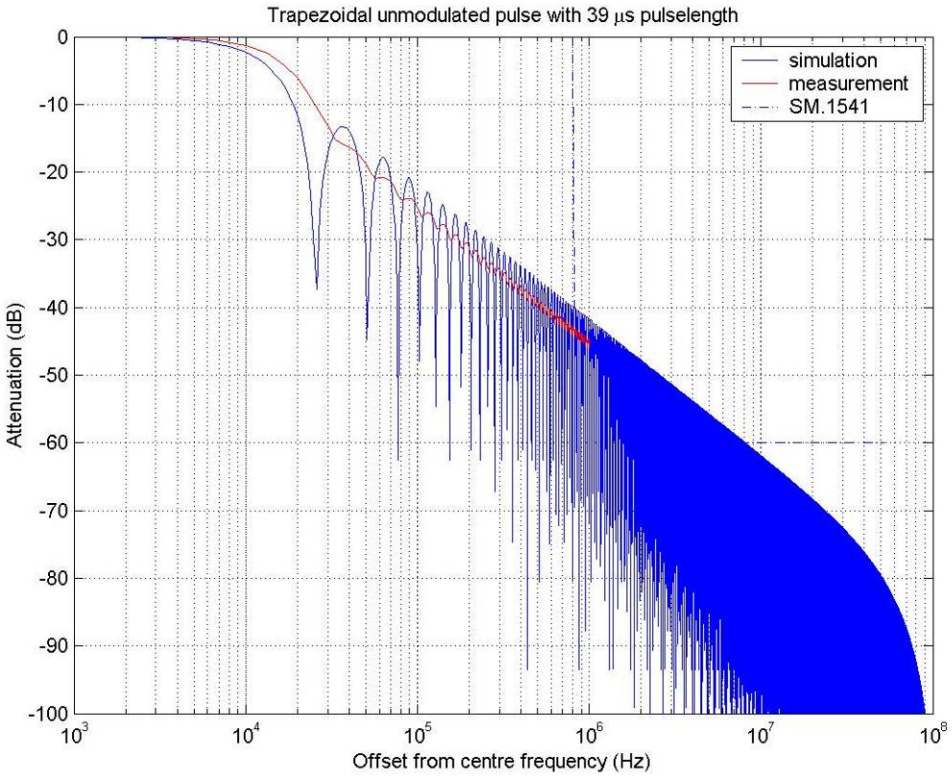

Trapezoidal unmodulated pulse with 50 μs pulselength
simulation
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^3
10^4
10^5
10^6
10^7
10^8


Trapezoidal unmodulated pulse with 100 μs pulselength
simulation
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)

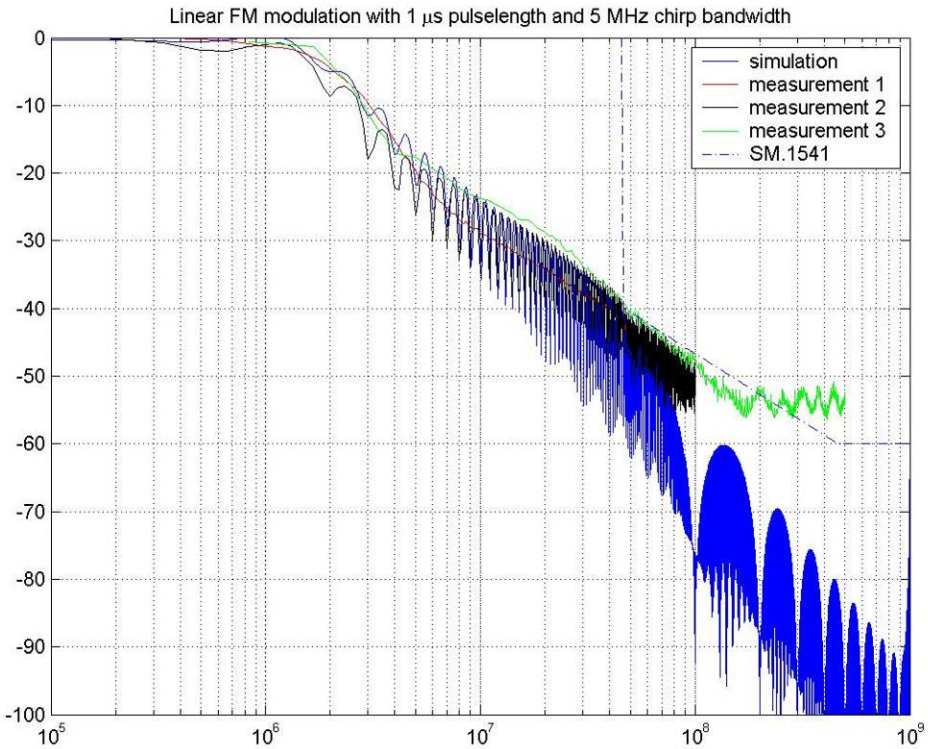

Trapezoidal unmodulated pulse with 3.3 μs pulselength
simulation
measurement
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)

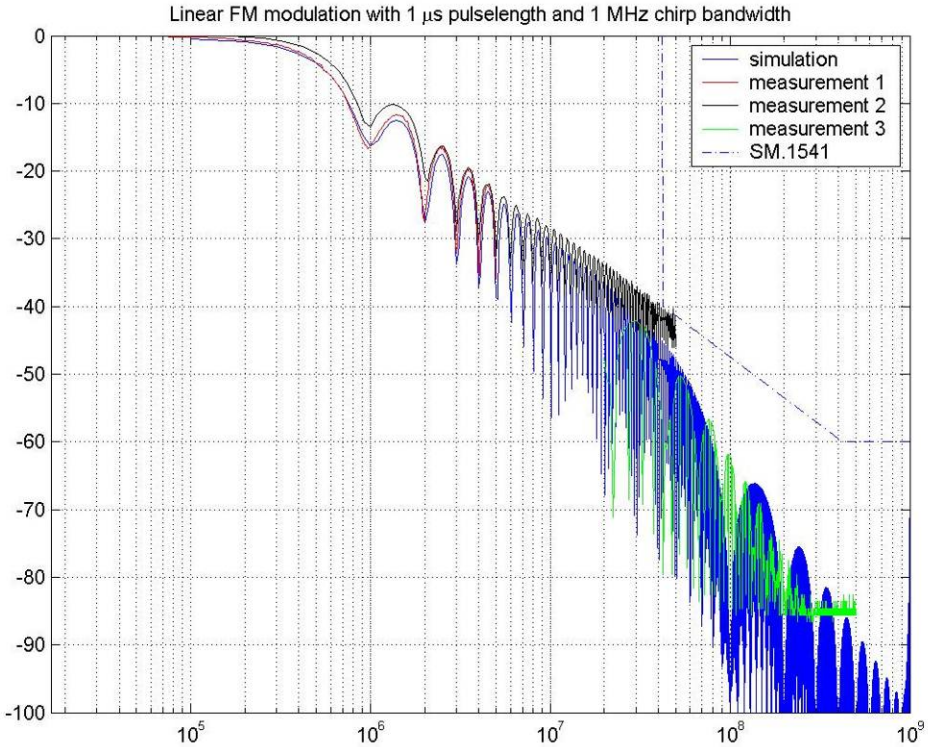

Trapezoidal unmodulated pulse with 13 μs pulselength
simulation
measurement 1
measurement 2
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)

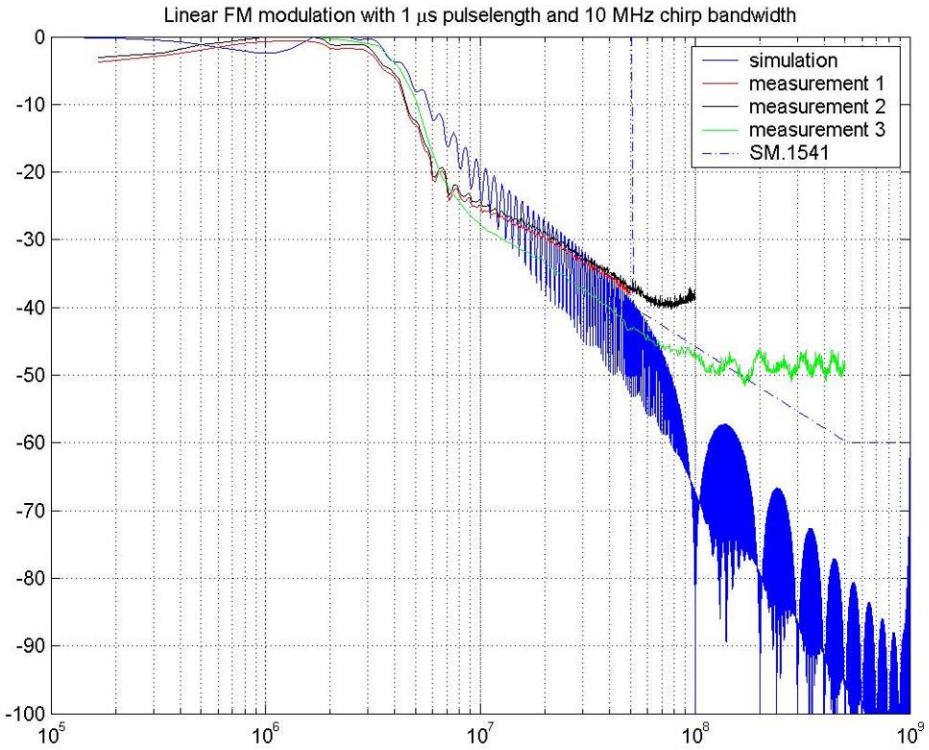

Trapezoidal unmodulated pulse with 26 μs pulselength
simulation
measurement
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)

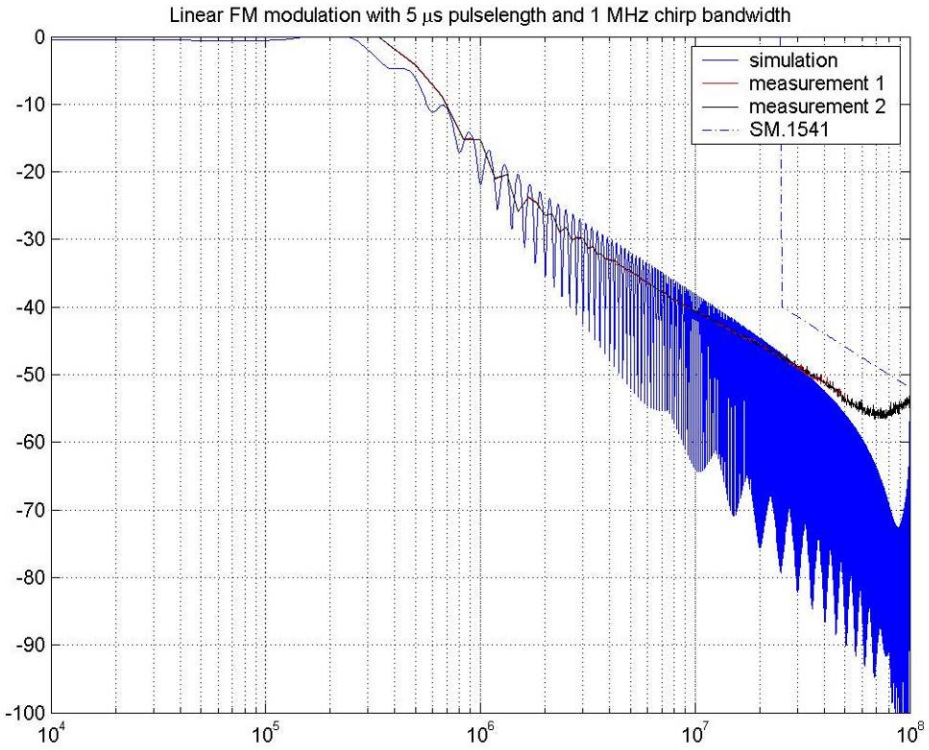

Trapezoidal unmodulated pulse with 39 μs pulselength
simulation
measurement
SM.1541
Attenuation (dB)
Offset from centre frequency (Hz)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^3
10^4
10^5
10^6
10^7
10^8

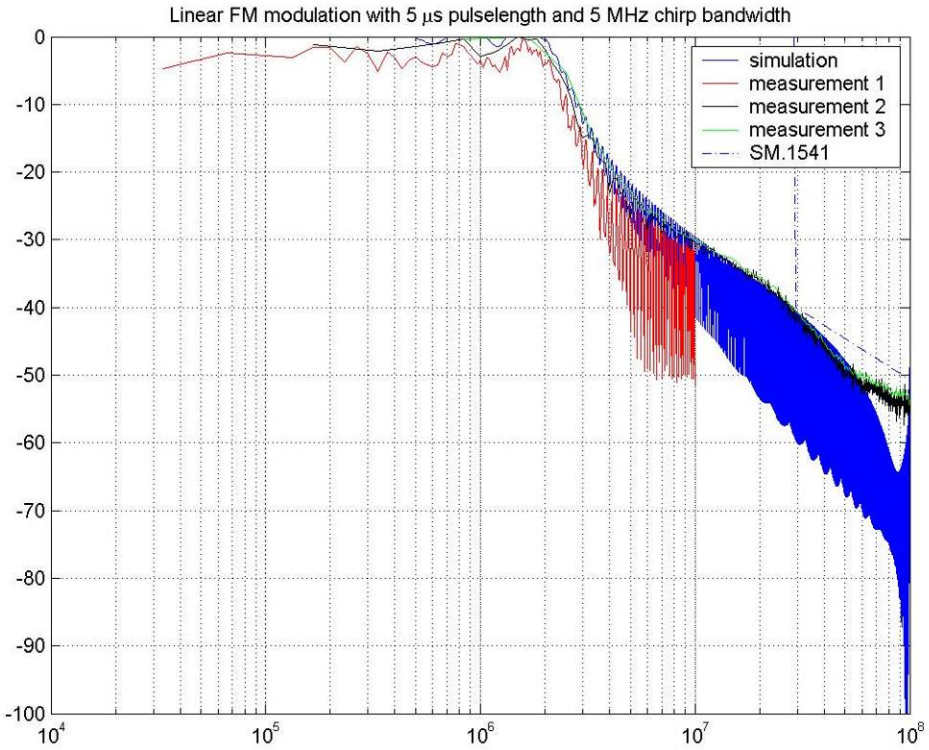
ANNEX 2: Results for trapezoidal linear FM pulses

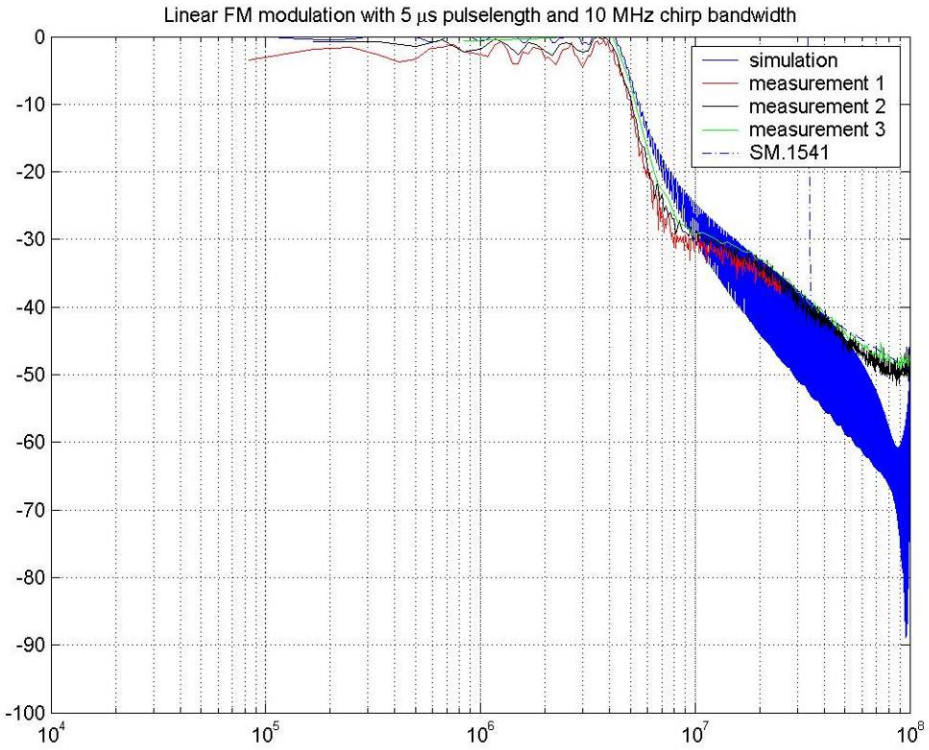





Linear FM modulation with 1 μs pulselength and 10 MHz chirp bandwidth
simulation
measurement 1
measurement 2
measurement 3
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^5
10^6
10^7
10^8
10^9


Linear FM modulation with 5 μs pulselength and 1 MHz chirp bandwidth
simulation
measurement 1
measurement 2
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^4
10^5
10^6
10^7
10^8


Linear FM modulation with 5 μs pulselength and 5 MHz chirp bandwidth
simulation
measurement 1
measurement 2
measurement 3
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^4
10^5
10^6
10^7
10^8


Linear FM modulation with 5 μs pulselength and 10 MHz chirp bandwidth
simulation
measurement 1
measurement 2
measurement 3
SM.1541
0
-10
-20
-30
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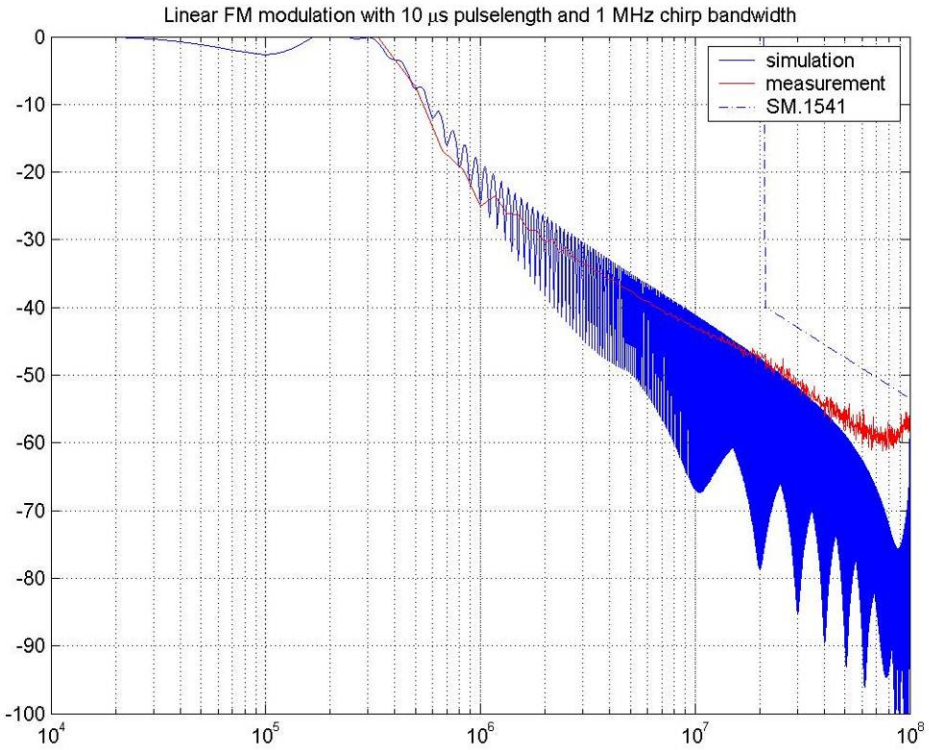
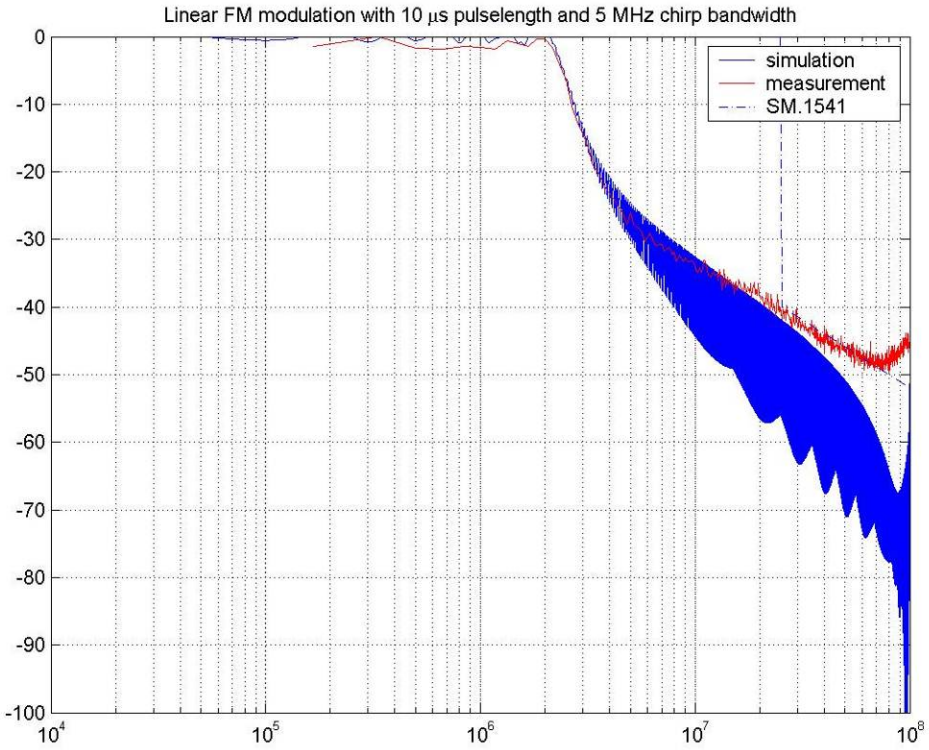
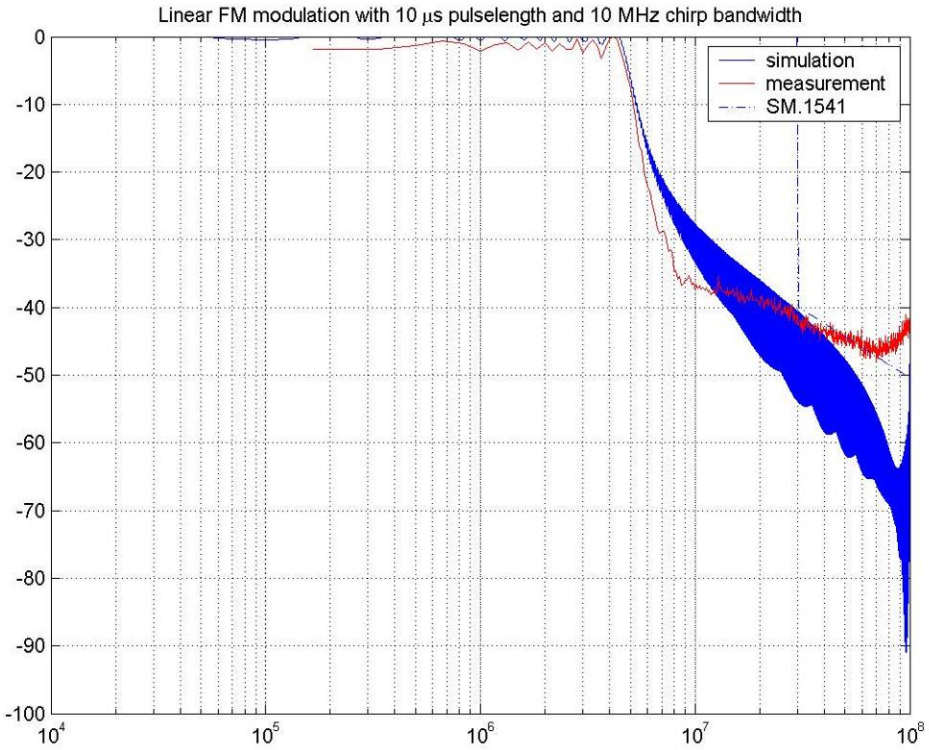
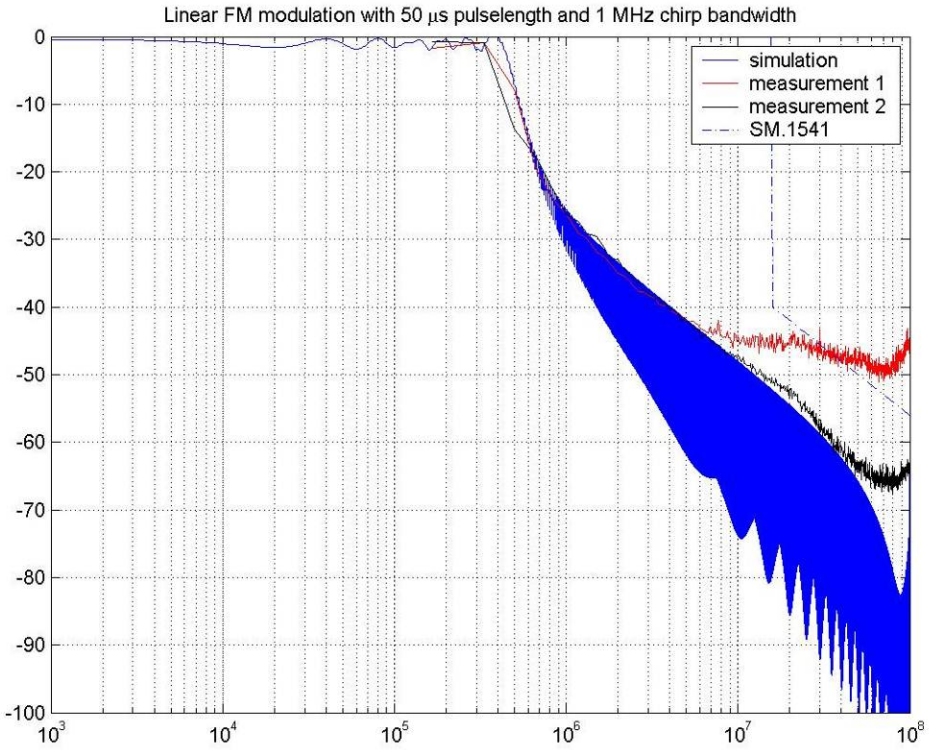
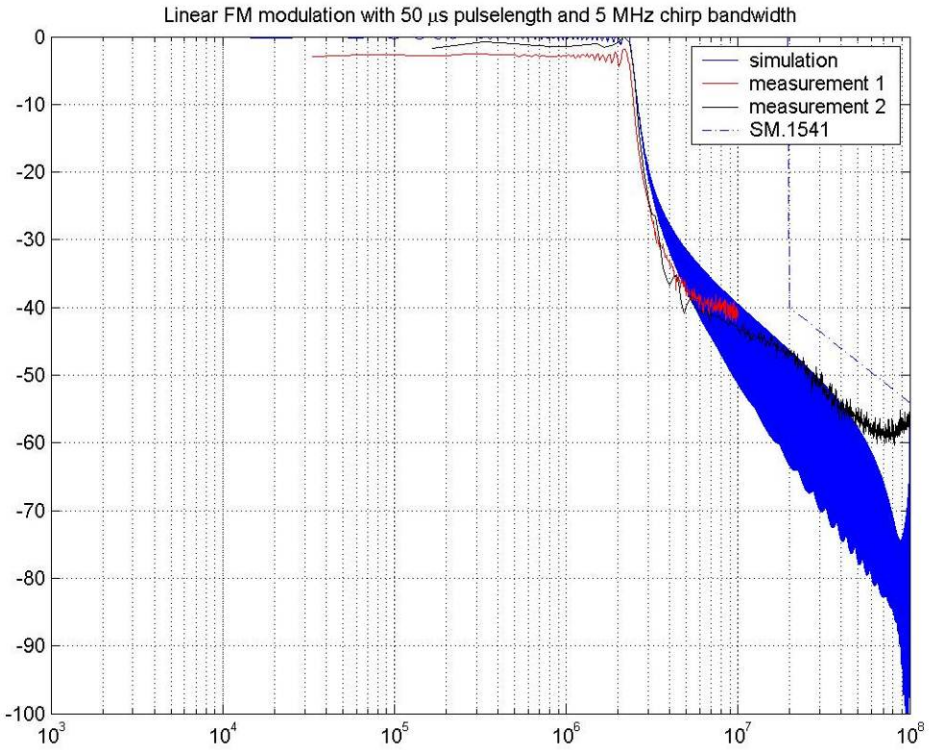
-50
-60
-70
-80
-90
-100
10^4
10^5
10^6
10^7
10^8

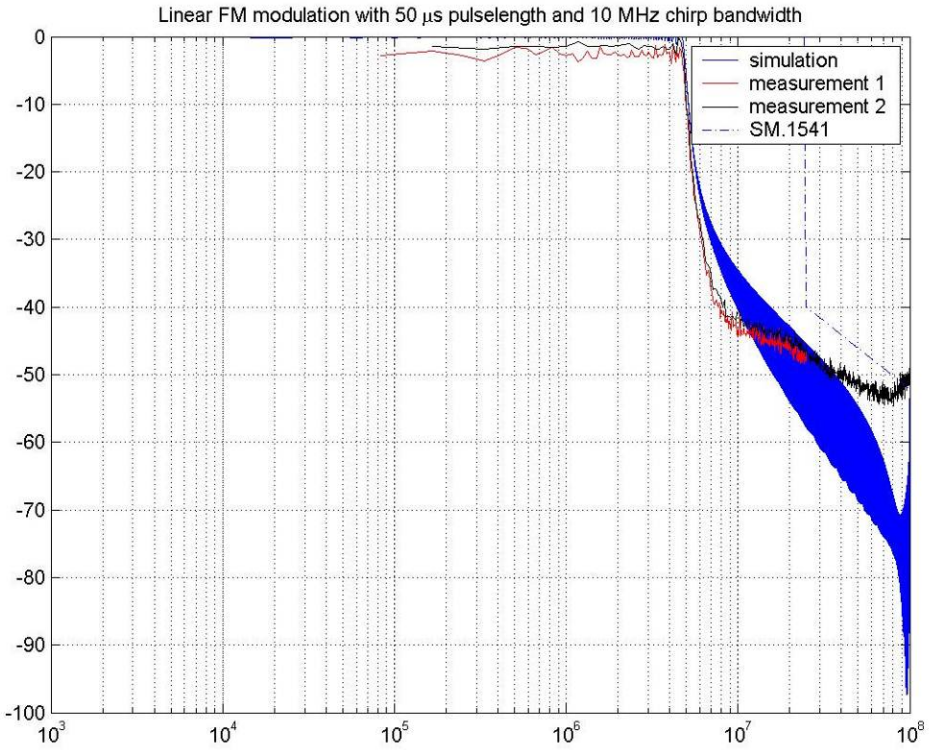

Linear FM modulation with 10 μs pulselength and 1 MHz chirp bandwidth
simulation
measurement
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^4
10^5
10^6
10^7
10^8

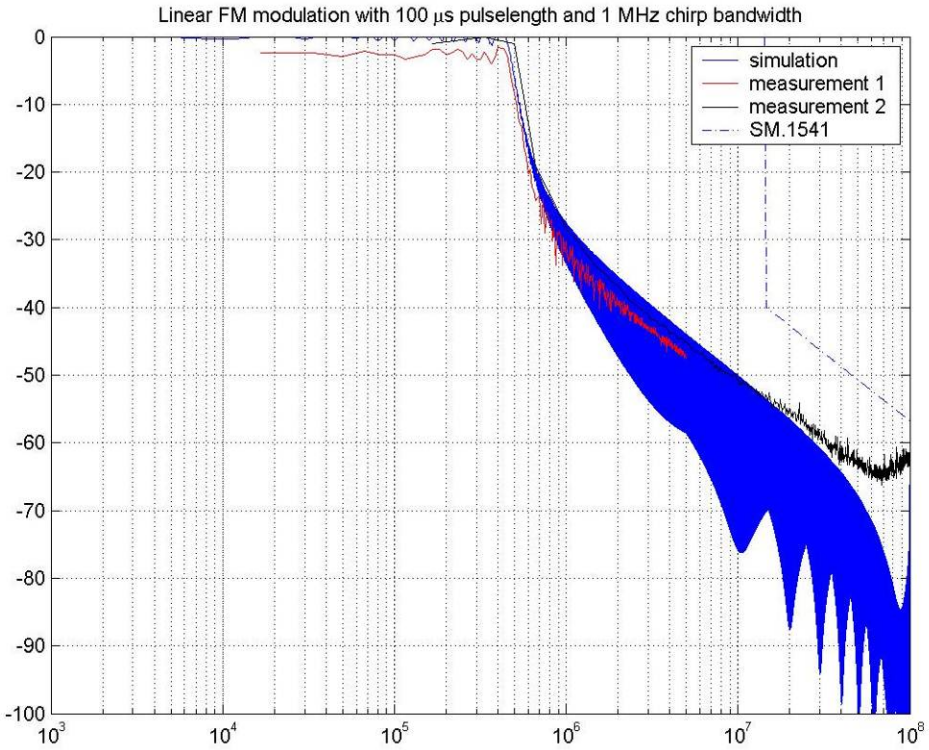

Linear FM modulation with 10 μs pulselength and 5 MHz chirp bandwidth
simulation
measurement
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^4
10^5
10^6
10^7
10^8

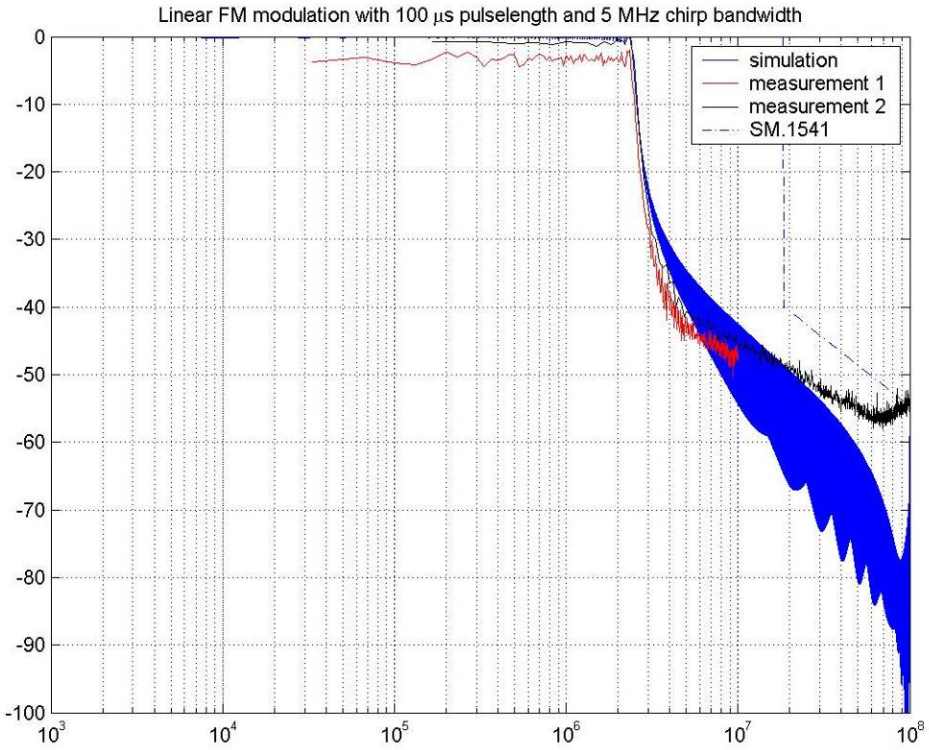

Linear FM modulation with 10 μs pulselength and 10 MHz chirp bandwidth
simulation
measurement
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^4
10^5
10^6
10^7
10^8


Linear FM modulation with 50 μs pulselength and 1 MHz chirp bandwidth
simulation
measurement 1
measurement 2
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^3
10^4
10^5
10^6
10^7
10^8


Linear FM modulation with 50 μs pulselength and 5 MHz chirp bandwidth
simulation
measurement 1
measurement 2
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^3
10^4
10^5
10^6
10^7
10^8


Linear FM modulation with 50 μs pulselength and 10 MHz chirp bandwidth
simulation
measurement 1
measurement 2
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^3
10^4
10^5
10^6
10^7
10^8


Linear FM modulation with 100 μs pulselength and 1 MHz chirp bandwidth
simulation
measurement 1
measurement 2
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^3
10^4
10^5
10^6
10^7
10^8


Linear FM modulation with 100 μs pulselength and 5 MHz chirp bandwidth
simulation
measurement 1
measurement 2
SM.1541
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10^3
10^4
10^5
10^6
10^7
10^8

Report SFCG 32-1R2

PASSIVE SENSOR FILTER CHARACTERISTICS

Editor's note: This Report will be further reviewed and complemented with additional filter characteristics as made available at future meetings.

1 INTRODUCTION

Passive sensors are nowadays keys to meteorological and other environmental activities and as such, protection of the sensors and related passive bands is one of the challenges for meteorological services, meteorological satellites operators and space agencies.

Unfortunately, despite huge efforts to ensure this protection, interferences have already been reported to some passive sensors (e.g. AMSR-E, SMOS, JASON). Interferences to passive sensors are usually caused by active services emissions (unwanted or in-band) within the passive band but one cannot exclude that such interferences could be produced by "regular" active services emissions within the sensor filter "side-lobes".

Providing detailed specifications and shape of passive sensor filters is hence key to both understanding and analyzing the causes of potential interference, and to persuade radiocommunications administrations to consider undertaking actions and finding solutions to solve these interference issues. Actually, these filter specifications are typically the first information requested by radiocommunications administrations prior to any action.

These specifications are normally not readily available and sometimes difficult to get in a relevant timeframe and SFCG agrees that compiling such information in this Report would ease the task of Members in future discussions with relevant radiocommunications administrations.

2 PASSIVE SENSORS FILTER CHARACTERISTICS

The annexes of the present SFCG Report provides relevant filter characteristics of the following sensors :

- Annex 1 : SMOS
- Annex 2 : MHS (on Metop)
- Annex 3 : MWR (on ENVISAT)
- Annex 4 : AMSU (on Metop)
- Annex 5: ATMS (on NPP)

- Annex 6 : MWR (on Sentinel-3)
- Annex 7 : GMI (on GPM)

Depending on the information available, these annexes present either specified or measured data for the filter itself or the overall receiving chain.

ANNEX 1 : Filter characteristics of the SMOS sensor (operated by ESA)

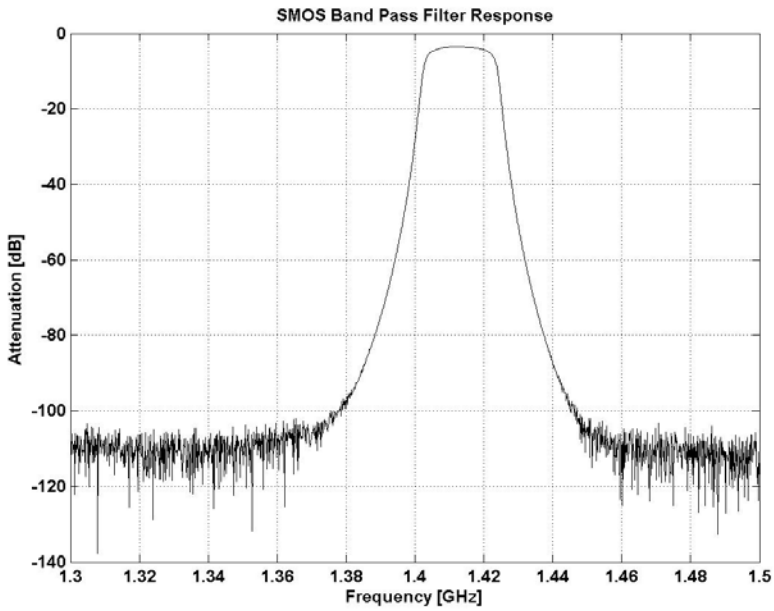


Figure 1-1: SMOS Band pass filter response (measured) (source ESA)

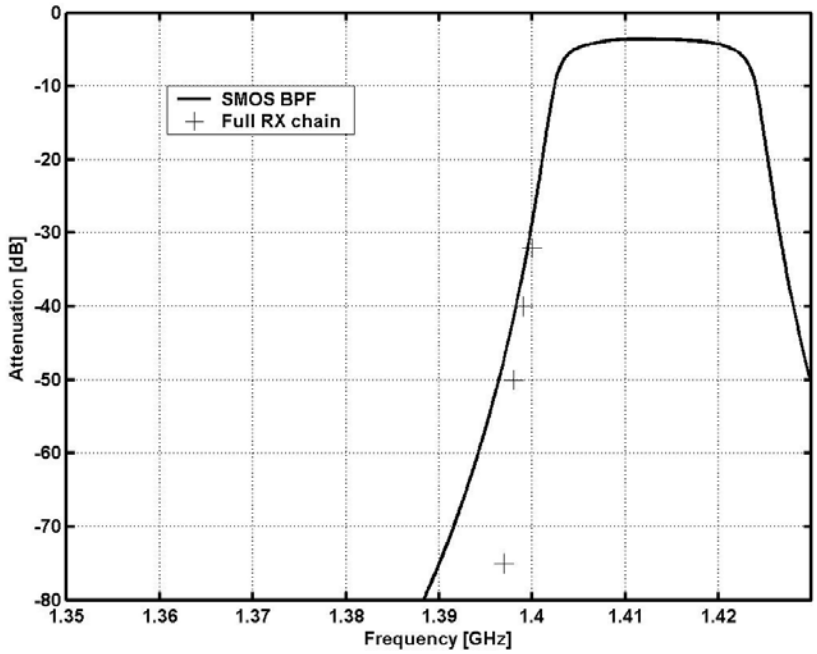


Figure 1-2: SMOS filtering pattern (measured), showing improvement of the overall response due to selectivity added by the full receiver chain (source ESA)

ANNEX 2 : Filter characteristics of MHS (operated by EUMETSAT)

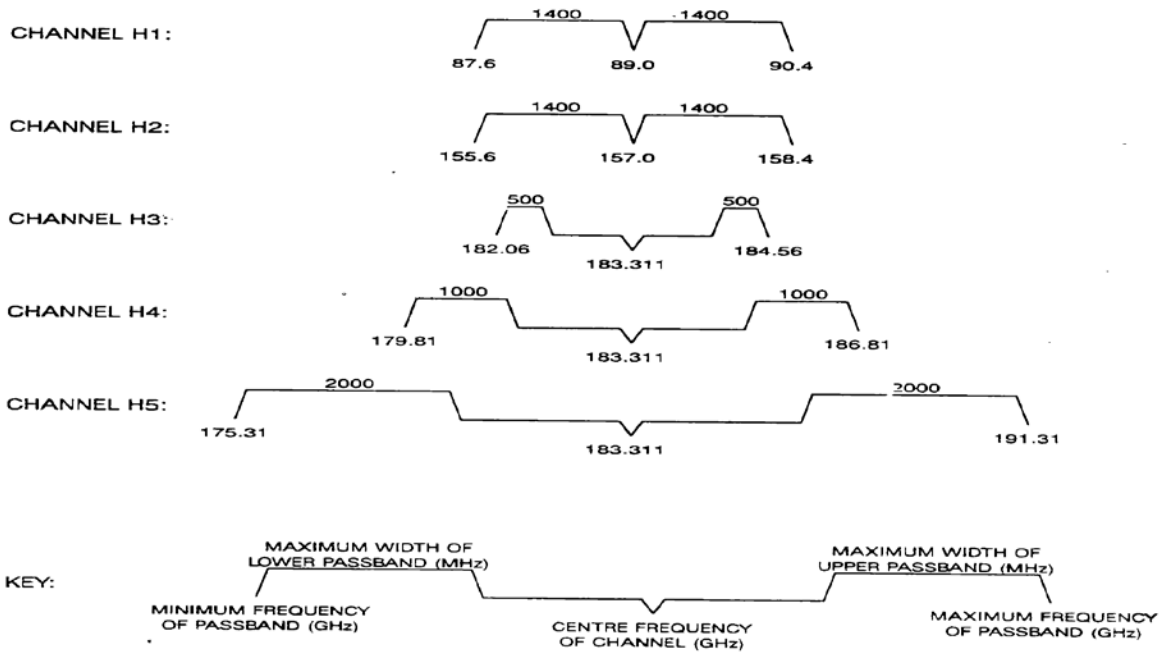


Figure 1: Centre frequencies and RF passbands of MHS channels.

Figure 2-1: Centre frequencies and RF passbands of MHS channels (source EUMETSAT)

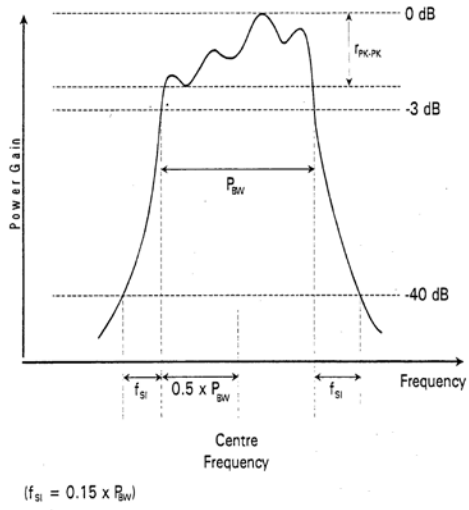


Figure 2-2: Generic pattern of the MHS Band pass filter response (specified) (source EUMETSAT)

Table 2-1 : Specific figures for the Band pass filter response (specified) for each MHS channel (source EUMETSAT)

Channel IF Characteristics

Channel	Nom. Centre Freq (GHz)	Lower LO Delta Freq (MHz)	Upper LO Delta Freq (MHz)	Lower IF -40 dB Freq (MHz)	Lower IF -3 dB Freq (MHz)	Upper IF -3 dB Freq (MHz)	Upper IF -40 dB Freq (MHz)	IF 3 dB Bandwidth (MHz)	In-Band Ripple (dB)
H1	89.000	1	5	91	112	1206	1292	1094	1.2
H2	157.000	-31	26	90	114	1211	1276	1097	1.3
H3	183.311	-28	6	708	750	1218	1276	468	0.6
H4	183.311	-28	6	2363	2500	3330	3643	830	1.9
H5	190.311	-17	20	91	111	1065	1132	954	0.8

Channel RF Characteristics

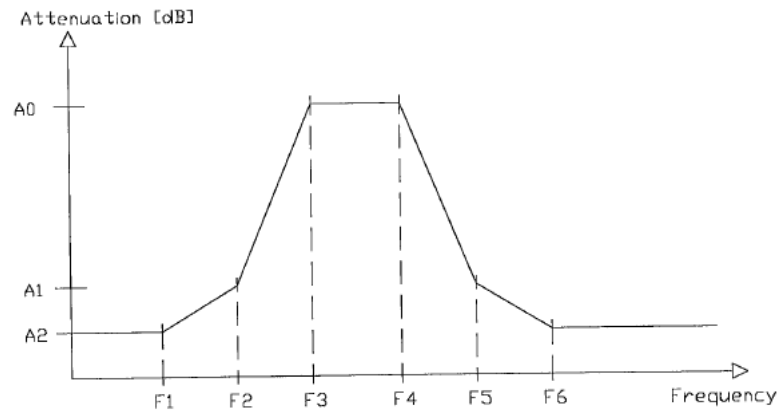
Channel	Lower Passband Lower -40 dB (GHz)	Lower Passband Lower -3 dB (GHz)	Lower Passband Upper -3 dB (GHz)	Lower Passband Upper -40 dB (GHz)	Centre Freq (GHz)	Upper Passband Lower -40 dB (GHz)	Upper Passband Lower -3 dB (GHz)	Upper Passband Upper -3 dB (GHz)	Upper Passband Upper -40 dB (GHz)
H1	87.708	87.794	88.888	88.909	89.000	89.091	89.112	90.206	90.292
H2	155.724	155.789	156.886	156.910	157.000	157.090	157.114	158.211	158.276
H3	182.035	182.093	182.561	182.603	183.311	184.019	184.061	184.529	184.587
H4	179.668	179.981	180.811	180.948	183.311	185.674	185.811	186.641	186.954
H5	189.179	189.246	190.200	190.220	190.311	190.402	190.422	191.376	191.443

ANNEX 3 : Filter characteristics of MWR (on ENVISAT operated by ESA)

Instrument name	MWR (MicroWave Radiometer)
Instrument type	Dual-channel, nadir-pointing, passive microwave radiometer based on the Dicke radiometer principle, operating at frequencies of 23.8 GHz and 36.5 GHz. The frequencies 23.8 GHz and 36.5 GHz are the result of a trade-off between instrument (reflector) size required to cover a horizontal area on the Earth surface comparable to the RA-2 beam, and the maximum sensitivity to water vapour change in the atmosphere. Envisat MWR is based on the radiometers used on the ERS-1 and ERS-2 satellites.
Objective	Measurement of atmospheric humidity as supplementary information for tropospheric path correction of the radar altimeter signal, which is influenced both by the integrated atmospheric water vapour content and by liquid water. In addition, MWR measurement data are useful for the determination of surface emissivity and soil moisture over land, for surface energy budget, investigations to support atmospheric studies, and for ice characterisation.
Website info	ESA: http://envisat.esa.int/earth/www/object/index.cfm?fobjectid=3775 CEOS database: http://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=185
Mission name	Envisat
Mission status	Decommissioned
Launch date	1 March 2001
Orbit altitude	764 km
Inclination	98.6 deg

MWR sensor characteristics (measured)

	K-Band	Ka-Band
RF centre frequency	23.8 GHz	36.5 GHz
Bandwidth	400 MHz	400 MHz
EESS-passive allocation	23.6-24 GHz (400MHz)	36-37 GHz (1000 MHz)
Antenna gain	41.8 dBi	42.1 dBi
Receiver type	Single conversion, DSB No LNA fitted	Single conversion, DSB No LNA fitted
1st RF bandpass filter characteristics	See Figure 1. B_{-20dB} = 600 MHz B_{-52dB} = 1300 MHz	See Figure 1. B_{-20dB} = 600 MHz B_{-40dB} = 1800 MHz
IF bandbass response	B_{-3dB} = 154.6 MHz B_{-40dB} = 324.8 MHz	B_{-3dB} = 153.8 MHz B_{-40dB} = 316.0 MHz
Overall Rx selectivity	See Figure 2	See Figure 3



MWR K-Band

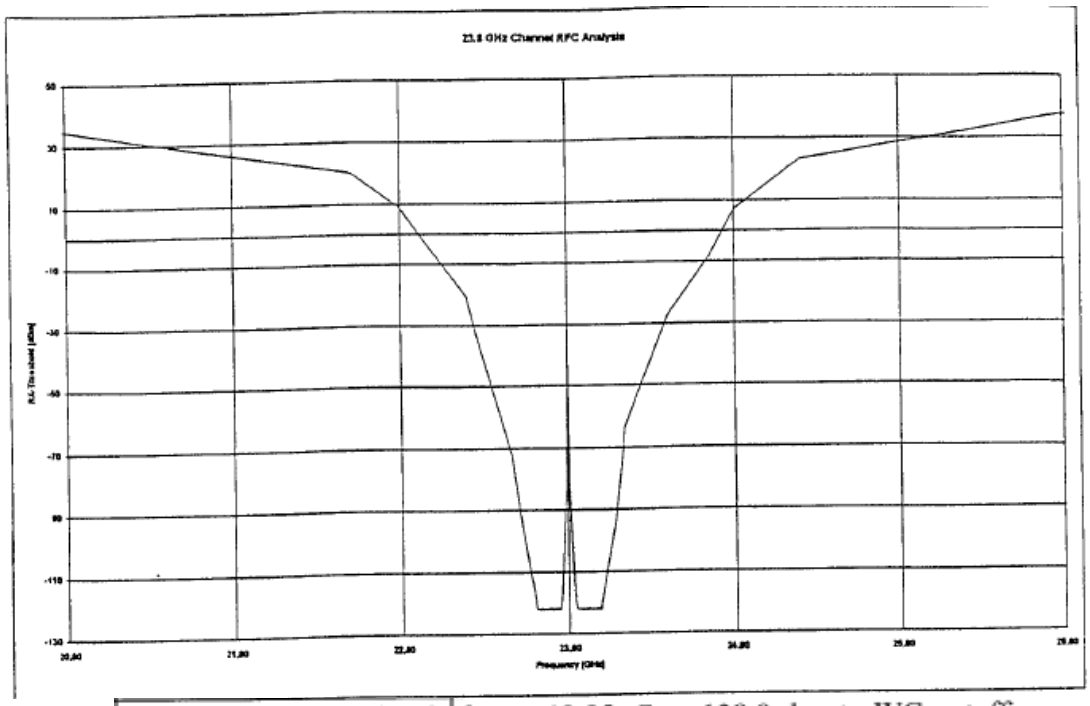
Description of 1st Rx Bandpass with its attenuation $A_{1,i}$ (dB) versus frequency $f_{1,i}$ (GHz) of SA (average values)	$f_1 = 18.0$	$A_1 = 80$
	$f_2 = 23.2$	$A_2 = 53.4$
	$f_3 = 23.5$	$A_3 = 20$
	$f_c = 23.8$	$A_c = 0.75$*
	$f_4 = 24.1$	$A_4 = 20$
	$f_5 = 24.5$	$A_5 = 52$
	$f_6 = 26.5$	$A_6 = 80$

MRW Ka-Band

Description of 1st Rx Bandpass with its attenuation $A_{1,i}$ (dB) versus frequency $f_{1,i}$ (GHz) of SA (average values)	$f_1 = 26.5$	$A_1 = 80$
	$f_2 = 35.6$	$A_2 = 40$
	$f_3 = 36.2$	$A_3 = 2$
	$f_c = 36.5$	$A_c = 0.9$*
	$f_4 = 36.8$	$A_4 = 2$
	$f_5 = 37.4$	$A_5 = 42$
	$f_6 = 40.0$	$A_6 = 70$

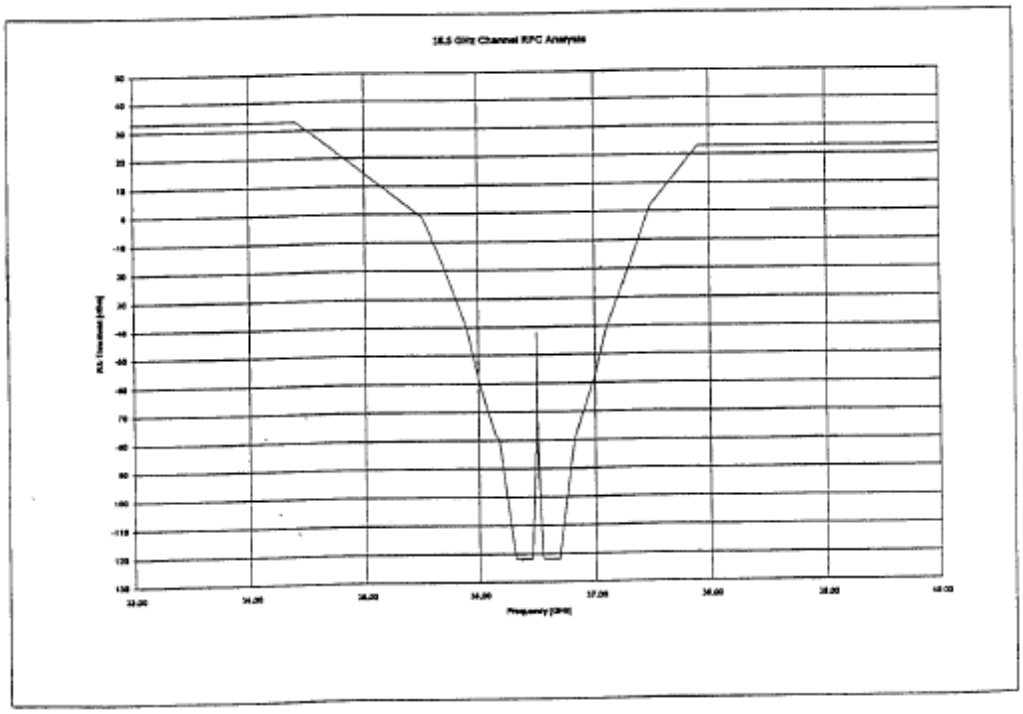
* in (0 to +30C) range, including losses of the whole switching assembly

Figure 3-1: Envisat MWR, 1st Receiver bandpass filter response with Attenuation A(dB) versus frequency f (average values). (source: ENVISAT/MWR Specific Interface Control Document, Jan 2000)



Overall Rx Sensitivity / Threshold Level S_i (dBm) at the Antenna Port versus Frequency f_i (GHz), including far off out of Band Frequencies) (2)	f_1 = < 13.95 S_1 = 138.0 due to WG cutoff f_2 = 14.050 S_2 = 88.0; f_3 = 14.150 S_3 = 38.0 f_4 = 18.000 S_4 = 38.0; f_5 = 20.800 S_5 = 34.9 f_6 = 22.500 S_6 = 20.3; f_7 = 22.800 S_7 = 8.8 f_8 = 22.950 S_8 = -2.8; f_9 = 23.200 S_9 = -20.5 f_{10} = 23.200 S_{10} = -20.5; f_{11} = 23.250 S_{11} = -31.6 f_{12} = 23.467 S_{12} = -72; f_{13} = 23.530 S_{13} = -95.8 f_{14} = 23.600 S_{14} = -117.4; f_{15} = 23.606 S_{15} = -119.0 f_{16} = 23.610 S_{16} = -122.0; f_{17} = 23.750 S_{17} = -122.0 f_{18} = 23.760 S_{18} = -119.0; f_{19} = 23.791 S_{19} = -82.0 f_{20} = 23.793 S_{20} = -77.0; f_{21} = 23.800 S_{21} = -32.0 f_{22} = 23.807 S_{22} = -77.0; f_{23} = 23.809 S_{23} = -82.0 f_{24} = 23.840 S_{24} = -119.0; f_{25} = 23.850 S_{25} = -122.0 f_{26} = 23.990 S_{26} = -122.0; f_{27} = 23.998 S_{27} = -119.0 f_{28} = 24.000 S_{28} = -118.5; f_{29} = 24.080 S_{29} = -93.5 f_{30} = 24.133 S_{30} = -69.5; f_{31} = 24.140 S_{31} = -63.6 f_{32} = 24.400 S_{32} = -26.9; f_{33} = 24.400 S_{33} = -26.9 f_{34} = 24.650 S_{34} = -8.2; f_{35} = 24.800 S_{35} = 7.1 f_{36} = 25.200 S_{36} = 23.4; f_{37} = 26.800 S_{37} = 37.4 f_{38} = 27.000 S_{38} = 38.0

Figure 3-2: Envisat MWR-K Band (24GHz), Overall sensitivity/threshold level S (dBm) at the antenna port versus frequency f (GHz), including far off out-of-band frequencies. (source: ENVISAT/MWR Specific Interface Control Document, Jan 2000)



Overall Rx Sensitivity / Threshold Level S_i (dBm) at the Antenna Port versus Frequency f_i (GHz), including far off out of Band Frequencies) (2)	f_1 = < 20.900 S_1 = 133.0 due to WG cutoff f_2 = 21.000 S_2 = 83.0; f_3 = 21.100 S_3 = 33.0 f_4 = 26.000 S_4 = 33.0; f_5 = 33.500 S_5 = 33.0 f_6 = 34.400 S_6 = 33.0; f_7 = 35.400 S_7 = 2.2 f_8 = 35.520 S_8 = -1.5; f_9 = 35.700 S_9 = -18.6 f_{10} = 35.900 S_{10} = -40.5; f_{11} = 36.000 S_{11} = -58.4 f_{12} = 36.145 S_{12} = -78.3; f_{13} = 36.175 S_{13} = -79.6 f_{14} = 36.300 S_{14} = -117.3; f_{15} = 36.306 S_{15} = -119.0 f_{16} = 36.310 S_{16} = -122.0; f_{17} = 36.450 S_{17} = -122.0 f_{18} = 36.460 S_{18} = -119.0; f_{19} = 36.491 S_{19} = -82.0 f_{20} =36.495 S_{20} = -68.0; f_{21} = 36.500 S_{21} = -42.0 f_{22} = 36.505 S_{22} = -68.0; f_{23} = 36.509 S_{23} = -82.0 f_{24} = 36.540 S_{24} = -119.0; f_{25} = 36.550 S_{25} = -122.0 f_{26} = 36.690 S_{26} = -122.0; f_{27} = 36.694 S_{27} = -119.0 f_{28} = 36.700 S_{28} = -117.3; f_{29} = 36.825 S_{29} = -79.1 f_{30} = 36.830 S_{30} = -78.8; f_{31} = 37.000 S_{31} = -57.4 f_{32} = 37.100 S_{32} = -40.5; f_{33} = 37.300 S_{33} = -18.6 f_{34} = 37.480 S_{34} = 2.0; f_{35} = 37.600 S_{35} =8.0 f_{36} = 37.900 S_{36} = 23.0; f_{37} = 38.600 S_{37} = 23.0 f_{38} = 39.500 S_{38} = 23.0; f_{39} = 40.000 S_{39} = 23.0

Figure 3-3: Envisat MWR-Ka Band (36GHz), Overall sensitivity/threshold level S (dBm) at the antenna port versus frequency f (GHz), including far off out-of-band frequencies. (source: ENVISAT/MWR Specific Interface Control Document, Jan 2000)

ANNEX 4 : Filter characteristics of AMSU (on Metop operated by EUMETSAT)

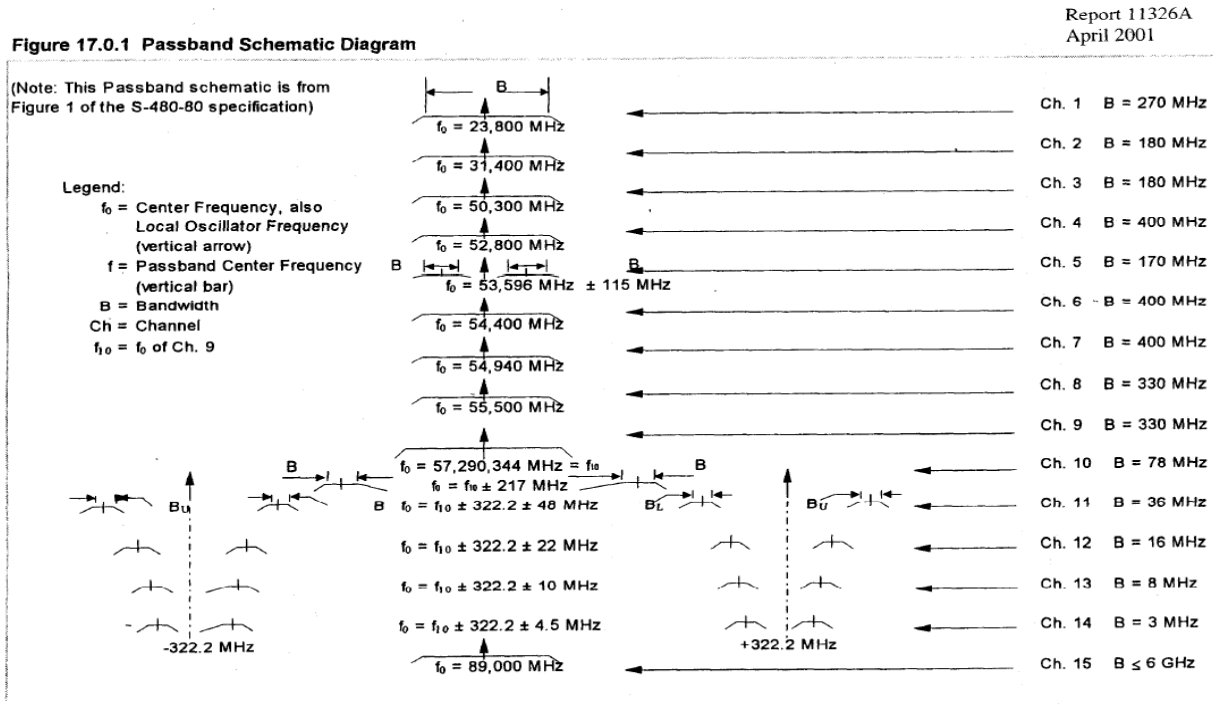


Figure 4-1: AMSU Passband schematic diagram (source EUMETSAT)

Relevant measured filter characteristics are provided as follows :

Ch 1 (23.8 GHz) : see appendix 4-1

Ch 2 (31.4 GHz) : see appendix 4-2

Ch 3 (50.3 GHz) : see appendix 4-3

Ch 4 (52.8GHz) : see appendix 4-4

Ch 5 (53.596 GHz) : see appendix 4-5

Ch 6 (53.596 GHz) : see appendix 4-6

Ch 7 (54.4 GHz) : see appendix 4-7

Ch 8 (54.94 GHz) : see appendix 4-8

Ch 9 (55.5 GHz) : see appendix 4-9

Ch 10 (57.29 GHz) : see appendix 4-10

Ch 11 (57.29 GHz) : see appendix 4-11

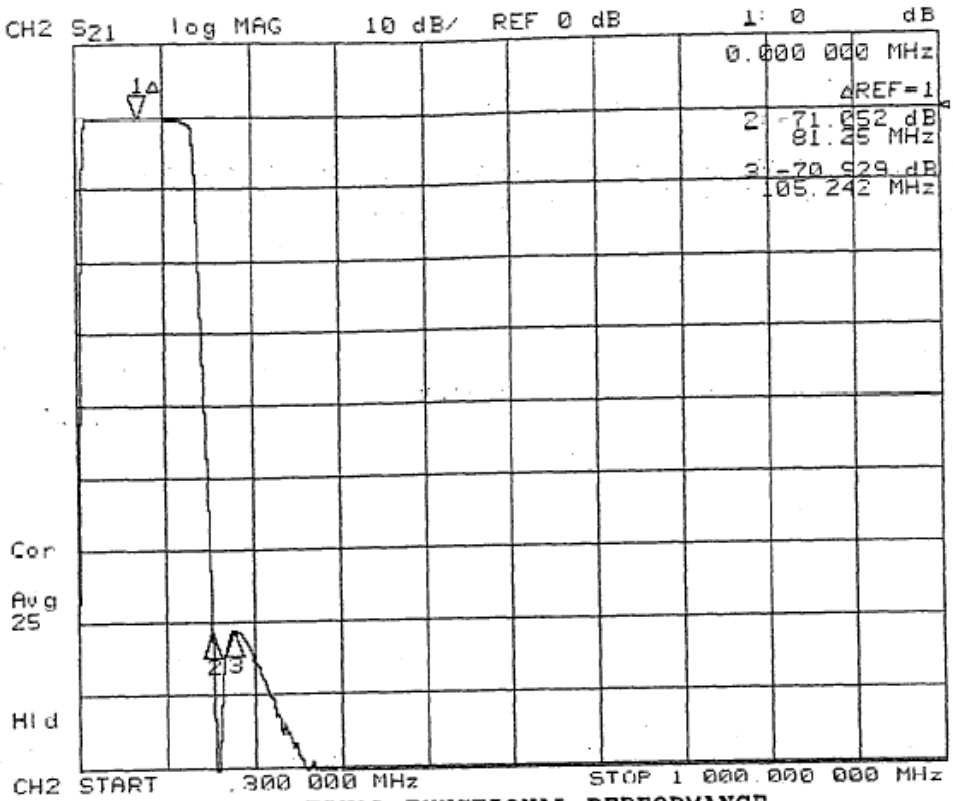
Ch 12 (57.29 GHz) : see appendix 4-12

Ch 13 (57.29 GHz) : see appendix 4-13

Ch 14 (57.29 GHz) : see appendix 4-14

Ch 15 (89 GHz) : see appendix 4-15

Appendix 4-1: Filter characteristics of AMSU (Channel 1 – 23.8 GHz)



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P232-007
+15C DATA
OPR: R. HOGGATT DATE 12/11/96

MARKER PARAMETERS	Channel 1	Channel 2
MARKER 1	1.000000 MHz OFF	72.500000 MHz 0 dB
MARKER 2	5.000000 MHz OFF	153.750000 MHz -71.052 dB
MARKER 3	5.000000 MHz OFF	177.742800 MHz -70.929 dB
MARKER 4	5.000000 MHz OFF	1000.000000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB
REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB	-3 dB
	OFF	OFF
MARKER TRACKING	OFF	OFF

BANDPASS FILTER MODEL HL72.5-125-10SS1 S/N P232-007
'EROJET 1331559-6 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE. +24.1 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

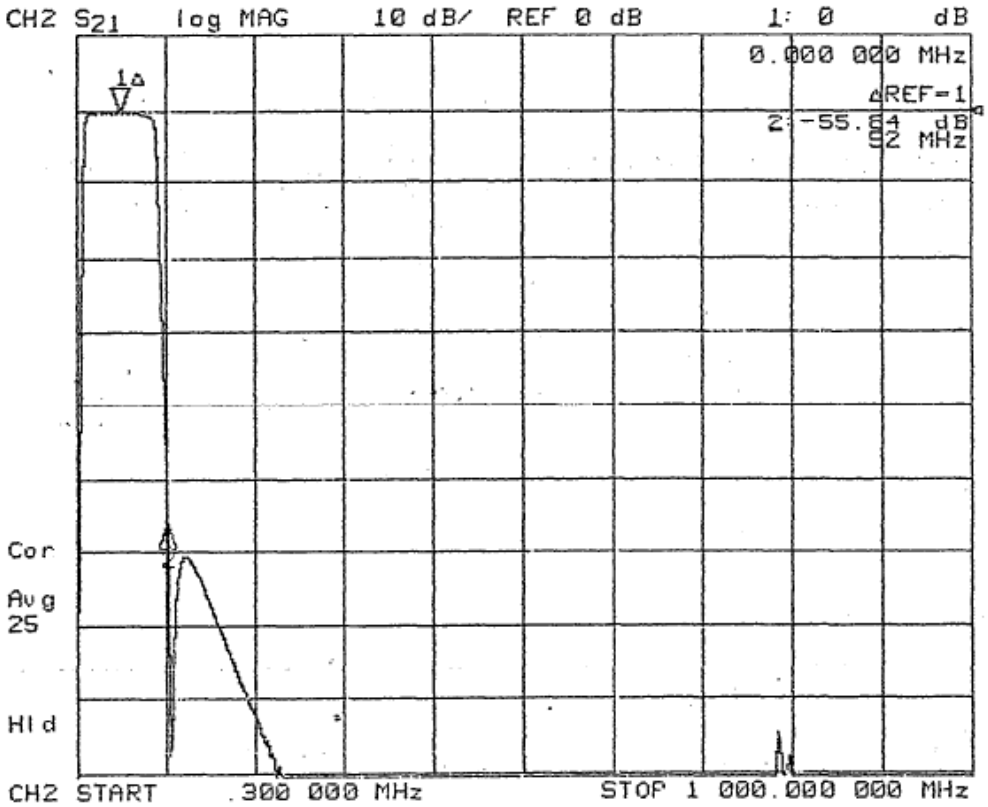
REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-98.7 dB	F11	(*) 80.0	MHz	-0.31 dB
F2	1.0	MHz	-92.1 dB	F12	(*) 100.0	MHz	-0.42 dB
F3	5.0	MHz	-30.6 dB	F13	120.0	MHz	-0.60 dB
F4	7.5	MHz	-9.60 dB	F14	130.0	MHz	-1.05 dB
F5	10.0	MHz	-0.90 dB	F15	135.0	MHz	-5.14 dB
F6	15.0	MHz	-0.29 dB	F16	140.0	MHz	-21.6 dB
F7	25.0	MHz	-0.21 dB	F17	150.0	MHz	-54.7 dB
F8	(*) 45.0	MHz	-0.18 dB	F18	200.0	MHz	-74.6 dB
F9	(*) 65.0	MHz	-0.27 dB	F19	500.0	MHz	-109.3 dB
F10	72.5	MHz	-0.36 dB	F20	1000.0	MHz	-99.4 dB

TEST PERFORMED BY: R. Hoggatt DA DATE 12/18/96

NOTE IF TEST WITNESSED BY AESD_____ GSI Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-2: Filter characteristics of AMSU (Channel 2 – 31.4 GHz)



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P229-010
+15C DATA
OPR: R. HOGGATT DATE DEC 18 1996

MARKER PARAMETERS	Channel 1	Channel 2
MARKER 1	1.000000 MHz OFF	50.000000 MHz 0 dB
MARKER 2	5.000000 MHz OFF	102.000000 MHz -55.84 dB
MARKER 3	5.000000 MHz OFF	102.000000 MHz OFF
MARKER 4	5.000000 MHz OFF	1000.000000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB
REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB	-3 dB
	OFF	OFF
MARKER TRACKING	OFF	OFF

BANDPASS FILTER MODEL HL50-80-10SS1 S/N P229-010
AEROJET 1331559-3 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE +24.4 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-99.6 dB	F11	(*) 60.0	MHz	-0.32 dB
F2	1.0	MHz	-94.9 dB	F12	(*) 70.0	MHz	-0.40 dB
F3	5.0	MHz	-31.4 dB	F13	80.0	MHz	-0.63 dB
F4	7.5	MHz	-10.5 dB	F14	85.0	MHz	-0.87 dB
F5	10.0	MHz	-1.38 dB	F15	90.0	MHz	-6.20 dB
F6	15.0	MHz	-0.28 dB	F16	100.0	MHz	-45.3 dB
F7	20.0	MHz	-0.21 dB	F17	200.0	MHz	-82.1 dB
F8	(*) 30.0	MHz	-0.18 dB	F18	300.0	MHz	-102.8 dB
F9	(*) 40.0	MHz	-0.21 dB	F19	500.0	MHz	-105.9 dB
F10	50.0	MHz	-0.25 dB	F20	1000.0	MHz	-106.1 dB

TEST PERFORMED BY: R. HOGGATT DA 6 DATE 12/18/96

NOTE IF TEST WITNESSED BY AESD Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-3: Filter characteristics of AMSU (Channel 3 – 50.3 GHz)

APPENDIX C **ACCEPTANCE TEST REPORT**

BANDPASS FILTER MODEL HL50-80-10SS1 S/N P229-014
AEROJET 1331559-3 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.5 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g} ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

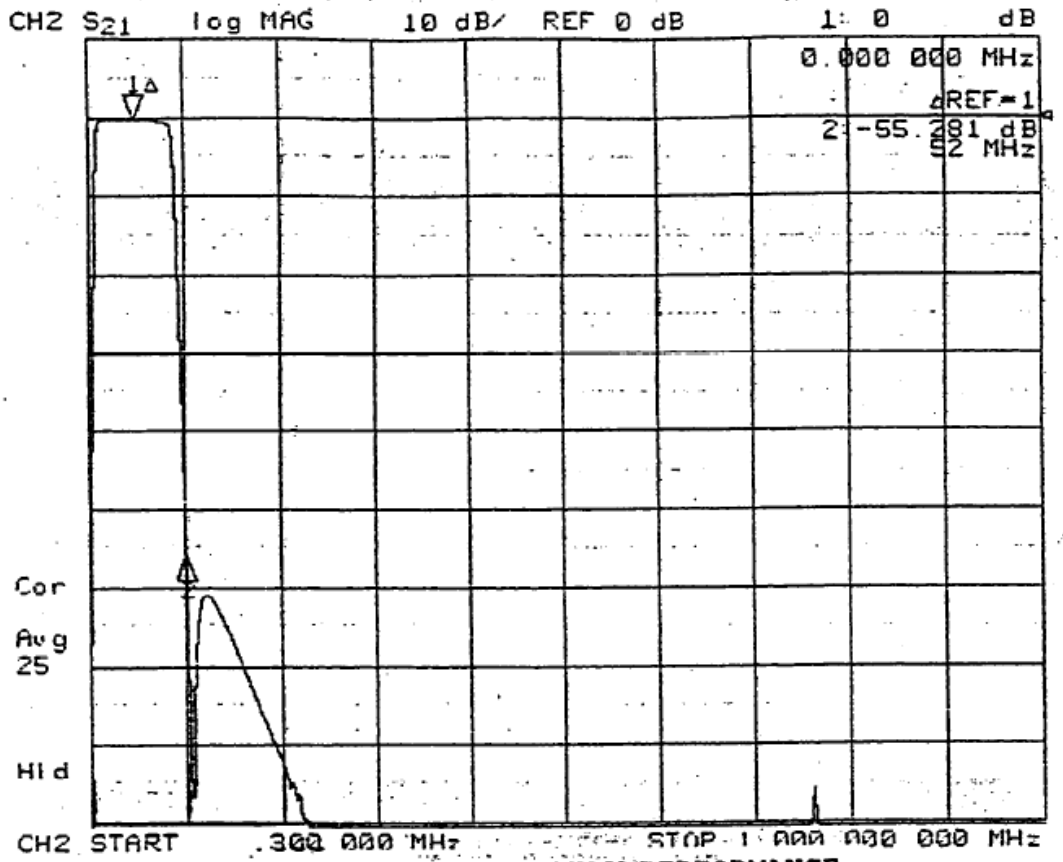
OUT-OF-BAND REJECTION

ACCEPTANCE TEST PROCEDURE 63-0005-02 PARA 4.5.5 Fc=50.0 MHz. REF {5A} FOR INSERTION LOSS @ Fc	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 1.0 MHz	>100 dB (40.0 dB MIN)	>100 dB (40.0 dB MIN)	>100 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 102.0 MHz TO 1000.0 MHz	-54.6 dB (40.0 dB MIN)	-55.3 dB (40.0 dB MIN)	-56.1 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-12.3 °C (-15.0 TO -10.0)	+14.2 °C (12.5 TO 17.5)	+43.7 °C (40.0 TO 45.0)
4} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√) ✓ (√)	✓ (√) ✓ (√)	✓ (√) ✓ (√)

TEST PERFORMED BY R. HOGGATT DATE 12/18/96

NOTE IF TEST WITNESSED BY AESD: Not witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P229-014
+15C DATA
OPR: R. HOGGATT DATE DEC 18 1996

MARKER PARAME...	Channel 1	Channel 2
MARKER 1	1.000000 MHz OFF	50.000000 MHz 0 dB
MARKER 2	5.000000 MHz OFF	102.000000 MHz -55.281 dB
MARKER 3	5.000000 MHz OFF	102.000000 MHz OFF
MARKER 4	5.000000 MHz OFF	1000.000000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB
REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB OFF	-3 dB OFF
MARKER TRACKING	OFF	OFF

BANDPASS FILTER MODEL HL50-80-10SS1 S/N P229-014
EROJET 1331559-3 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE +23.5 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-102.4 dB	F11	(*) 60.0	MHz	-0.32 dB
F2	1.0	MHz	-94.0 dB	F12	(*) 70.0	MHz	-0.39 dB
F3	5.0	MHz	-30.4 dB	F13	80.0	MHz	-0.60 dB
F4	7.5	MHz	-9.71 dB	F14	85.0	MHz	-0.85 dB
F5	10.0	MHz	-1.21 dB	F15	90.0	MHz	-5.79 dB
F6	15.0	MHz	-0.27 dB	F16	100.0	MHz	-45.1 dB
F7	20.0	MHz	-0.20 dB	F17	200.0	MHz	-82.3 dB
F8	(*) 30.0	MHz	-0.19 dB	F18	300.0	MHz	-102.3 dB
F9	(*) 40.0	MHz	-0.22 dB	F19	500.0	MHz	-104.5 dB
F10	50.0	MHz	-0.25 dB	F20	1000.0	MHz	-95.7 dB

DA 5

TEST PERFORMED BY: R. Hoggatt DATE 12/18/96

NOTE IF TEST WITNESSED BY AESD Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-4: Filter characteristics of AMSU (Channel 4 – 52.8 GHz)

APPENDIX B QUALIFICATION TEST REPORT

BANDPASS FILTER MODEL HL105-190-10SS1 S/N P228-002
\EROJET 1331559-2 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.5 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g) ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

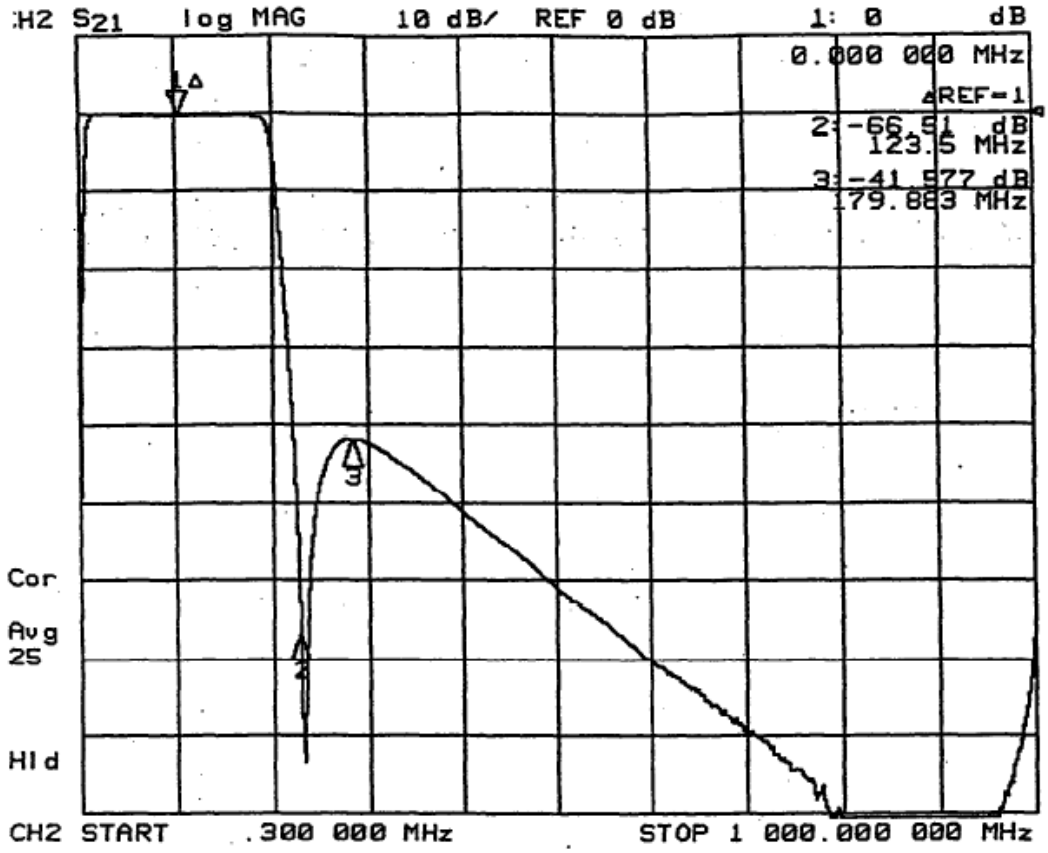
OUT-OF-BAND REJECTION
QUALIFICATION TEST PROCEDURE
63-0005-010 PARA 4.5.5
Fc=105.0 MHz.
REF {5A} FOR INSERTION LOSS @ Fc

	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 1.0 MHz	-59.1 dB (40.0 dB MIN)	-59.1 dB (40.0 dB MIN)	-59.1 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 228.5 MHz TO 1000.0 MHz	-41.5 dB (40.0 dB MIN)	-41.6 dB (40.0 dB MIN)	-41.6 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-13.6 °C (-15.0 TO -10.0)	+15.0°C (12.5 TO 17.5)	+43.7 °C (40.0 TO 45.0)
14} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√) ✓ (√)	✓ (√) ✓ (√)	✓ (√) ✓ (√)

TEST PERFORMED BY R. Hoggatt DATE 12/27/96

NOTE IF TEST WITNESSED BY AESD: _____ GSI: _____ Not witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P228-002
+15C DATA
OPR: R. HOGGATT DATE DEC 27 1996 annel 2

MARKER PARAMET		
MARKER 1	1.000000 MHz OFF	105.000000 MHz 0 dB
MARKER 2	5.000000 MHz OFF	228.500000 MHz -66.51 dB
MARKER 3	5.000000 MHz OFF	284.883082 MHz -41.577 dB
MARKER 4	5.000000 MHz OFF	.300000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB

REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB	-3 dB
	OFF	OFF
MARKER TRACKING	OFF	OFF

BANDPASS FILTER MODEL HL105-190-10SS1 S/N P228-002
AEROJET 1331559-2 REV. 6

BANDPASS CHARACTERISTICS MEASUREMENT
PER QTP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE +22.1 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-82.6 dB	F11	(*) 130.0	MHz	-0.19 dB
F2	1.0	MHz	-66.2 dB	F12	(*) 150.0	MHz	-0.27 dB
F3	5.0	MHz	-17.6 dB	F13	180.0	MHz	-0.42 dB
F4	7.5	MHz	-7.21 dB	F14	190.0	MHz	-0.61 dB
F5	10.0	MHz	-1.68 dB	F15	200.0	MHz	-4.21 dB
F6	20.0	MHz	-0.08 dB	F16	250.0	MHz	-47.4 dB
F7	40.0	MHz	-0.11 dB	F17	300.0	MHz	-42.3 dB
F8	(*) 60.0	MHz	-0.18 dB	F18	400.0	MHz	-51.2 dB
F9	(*) 80.0	MHz	-0.21 dB	F19	500.0	MHz	-61.1 dB
F10	105.0	MHz	-0.21 dB	F20	1000.0	MHz	-70.4 dB

DA 5

TEST PERFORMED BY: R. Hoggatt DATE 12/27/96

NOTE IF TEST WITNESSED BY AESD _____ GSI _____ Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-5: Filter characteristics of AMSU (Channel 5 – 53.596 GHz)

APPENDIX E **ACCEPTANCE TEST REPORT**

BANDPASS FILTER MODEL HL115-170-10SS1 S/N P231-006
AEROJET 1331559-5 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.5 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g) ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

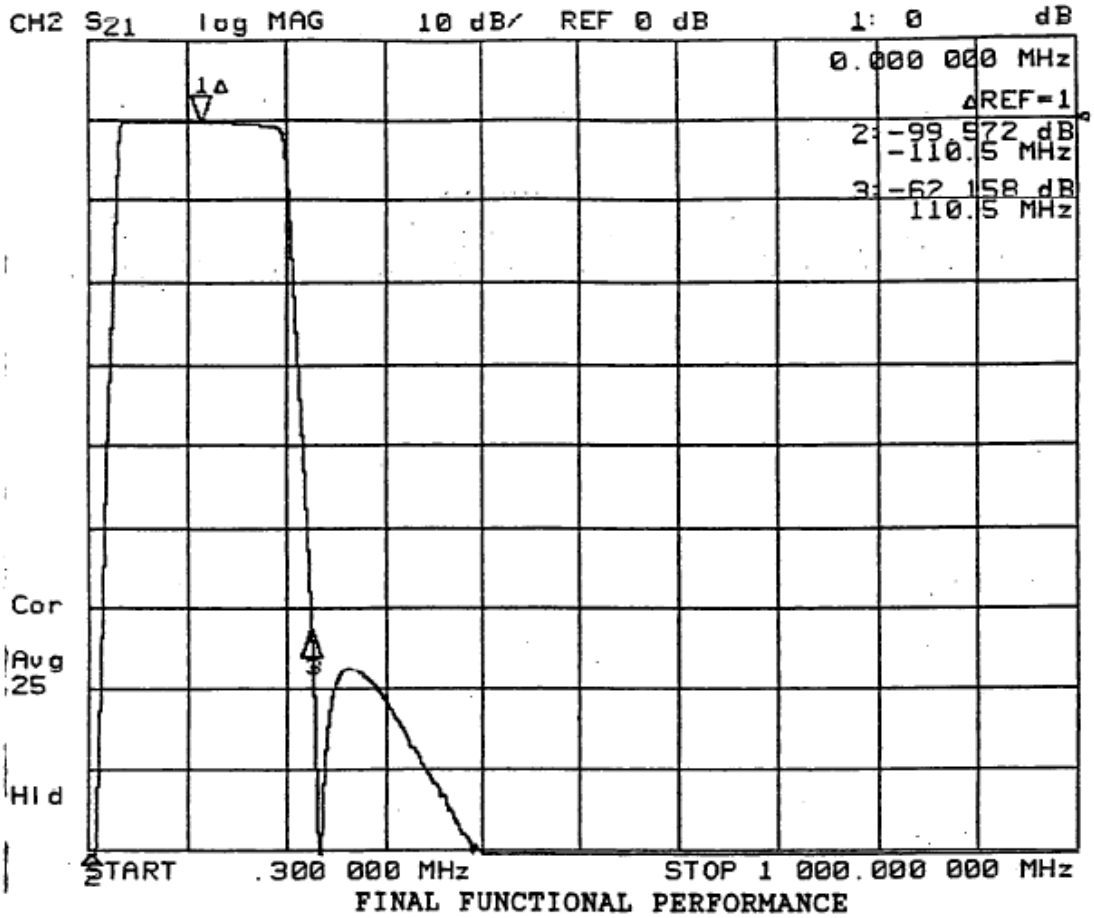
OUT-OF-BAND REJECTION

ACCEPTANCE TEST PROCEDURE 63-0005-010 PARA 4.5.5 Fc=115.0 MHz REF {5A} FOR INSERTION LOSS @ Fc	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 4.5 MHz	>90 dB (40.0 dB MIN)	>90 dB (40.0 dB MIN)	>90 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 225.5 MHz TO 1000.0 MHz	-61.1 dB (40.0 dB MIN)	-62.2 dB (40.0 dB MIN)	-63.1 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-12.2 °C (-15.0 TO -10.0)	+15.9 °C (12.5 TO 17.5)	+43.3 °C (40.0 TO 45.0)
{14} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

TEST PERFORMED BY R. Hoggatt DATE 12/27/96

NOTE IF TEST WITNESSED BY AESD: _____ GSI: Not witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P231-006
+15C DATA

MARKER PARAMET OPR: R. HOGGATT DATE DEC 27 1996 annel 2

MARKER 1	1000.000000 MHz OFF	115.000000 MHz 0 dB
MARKER 2	1000.000000 MHz OFF	4.500000 MHz -99.572 dB
MARKER 3	1000.000000 MHz OFF	225.500000 MHz -62.158 dB
MARKER 4	1000.000000 MHz OFF	1000.000000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB
REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB OFF	-3 dB OFF
MARKER TRACKING	OFF	OFF

APPENDIX E **ACCEPTANCE TEST REPORT**

BANDPASS FILTER MODEL HL115-170-10SS1 S/N P231-006
AEROJET 1331559-5 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687 PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE +22.5 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-101.2 dB	F11	(*) 130.0	MHz	-0.33 dB
F2	1.0	MHz	-102.4 dB	F12	(*) 155.0	MHz	-0.46 dB
F3	10.0	MHz	-82.6 dB	F13	180.0	MHz	-0.65 dB
F4	20.0	MHz	-39.5 dB	F14	190.0	MHz	-0.83 dB
F5	30.0	MHz	-6.75 dB	F15	200.0	MHz	-4.70 dB
F6	40.0	MHz	-0.31 dB	F16	210.0	MHz	-26.2 dB
F7	50.0	MHz	-0.24 dB	F17	300.0	MHz	-71.7 dB
F8	(*) 75.0	MHz	-0.28 dB	F18	400.0	MHz	-90.7 dB
F9	(*) 100.0	MHz	-0.26 dB	F19	500.0	MHz	-98.2 dB
F10	115.0	MHz	-0.29 dB	F20	1000.0	MHz	-104.5 dB

TEST PERFORMED BY: R. Hoggan DATE 12/21/96

NOTE IF TEST WITNESSED BY AESD_____ GSI Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-6: Filter characteristics of AMSU (Channel 6 – 53.596 GHz)

APPENDIX B ACCEPTANCE TEST REPORT

BANDPASS FILTER MODEL HL105-190-10SS1 S/N P228-009
AEROJET 1331559-2 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.5 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g) ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

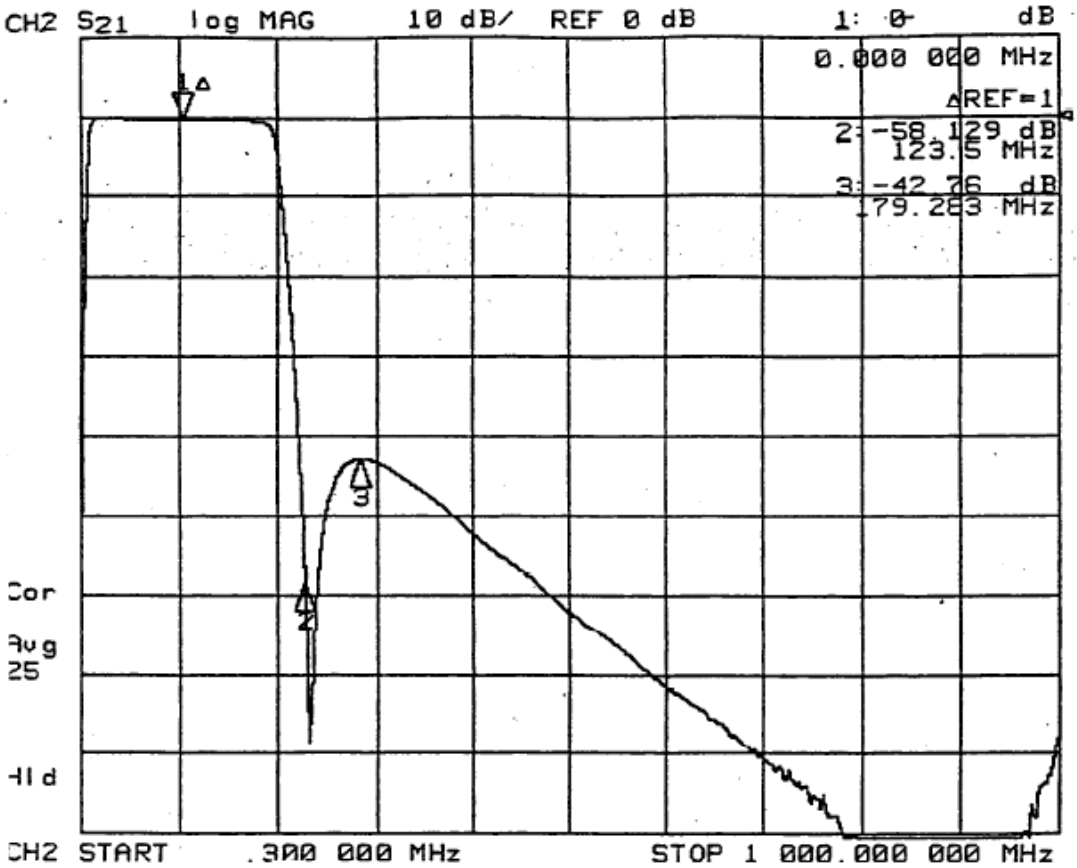
OUT-OF-BAND REJECTION
ACCEPTANCE TEST PROCEDURE
63-0005-02 PARA 4.5.5
Fc=105.0 MHz.
REF {5A} FOR INSERTION LOSS @ Fc

	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 1.0 MHz	-59.1 dB (40.0 dB MIN)	-59.1 dB (40.0 dB MIN)	-59.0 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 228.5 MHz TO 1000.0 MHz	-42.7 dB (40.0 dB MIN)	-42.8 dB (40.0 dB MIN)	-42.8 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-12.8 °C (-15.0 TO -10.0)	+15.4 °C (12.5 TO 17.5)	+42.9 °C (40.0 TO 45.0)
{} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√) ✓ (√)	✓ (√) ✓ (√)	✓ (√) ✓ (√)

TEST PERFORMED BY R. Hoggatt DATE 12/28/96

NOTE IF TEST WITNESSED BY AESD: _____ GSI: Not witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P228-009
+15C DATA

MARKER PARAMET OPR: R. HOGGATT DATE DEC 28 1996 annel 2

MARKER 1	1.000000 MHz OFF	105.000000 MHz 0 dB
MARKER 2	5.000000 MHz OFF	228.500000 MHz -58.129 dB
MARKER 3	5.000000 MHz OFF	284.283262 MHz -42.76 dB
MARKER 4	5.000000 MHz OFF	.300000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB
REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB	-3 dB
	OFF	OFF
MARKER TRACKING	OFF	OFF

APPENDIX B **ACCEPTANCE TEST REPORT**

BANDPASS FILTER MODEL HL105-190-10SS1 S/N P228-009
AEROJET 1331559-2 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE: +23.3 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-82.4 dB	F11	(*) 130.0	MHz	-0.21 dB
F2	1.0	MHz	-66.1 dB	F12	(*) 150.0	MHz	-0.30 dB
F3	5.0	MHz	-17.6 dB	F13	180.0	MHz	-0.45 dB
F4	7.5	MHz	-7.21 dB	F14	190.0	MHz	-0.65 dB
F5	10.0	MHz	-1.69 dB	F15	200.0	MHz	-3.85 dB
F6	20.0	MHz	-0.08 dB	F16	250.0	MHz	-49.2 dB
F7	40.0	MHz	-0.10 dB	F17	300.0	MHz	-43.4 dB
F8	(*) 60.0	MHz	-0.16 dB	F18	400.0	MHz	-52.2 dB
F9	(*) 80.0	MHz	-0.18 dB	F19	500.0	MHz	-62.1 dB
F10	105.0	MHz	-0.20 dB	F20	1000.0	MHz	-75.7 dB

DA 5

TEST PERFORMED BY: R. Hoggatt DATE 12/27/96

NOTE IF TEST WITNESSED BY AESD _____ GSI Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-7: Filter characteristics of AMSU (Channel 7 – 54.4 GHz)

APPENDIX B **ACCEPTANCE TEST REPORT**

BANDPASS FILTER MODEL HL105-190-10SS1 S/N P228-006
\EROJET 1331559-2 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.5 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g) ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	____ (√)

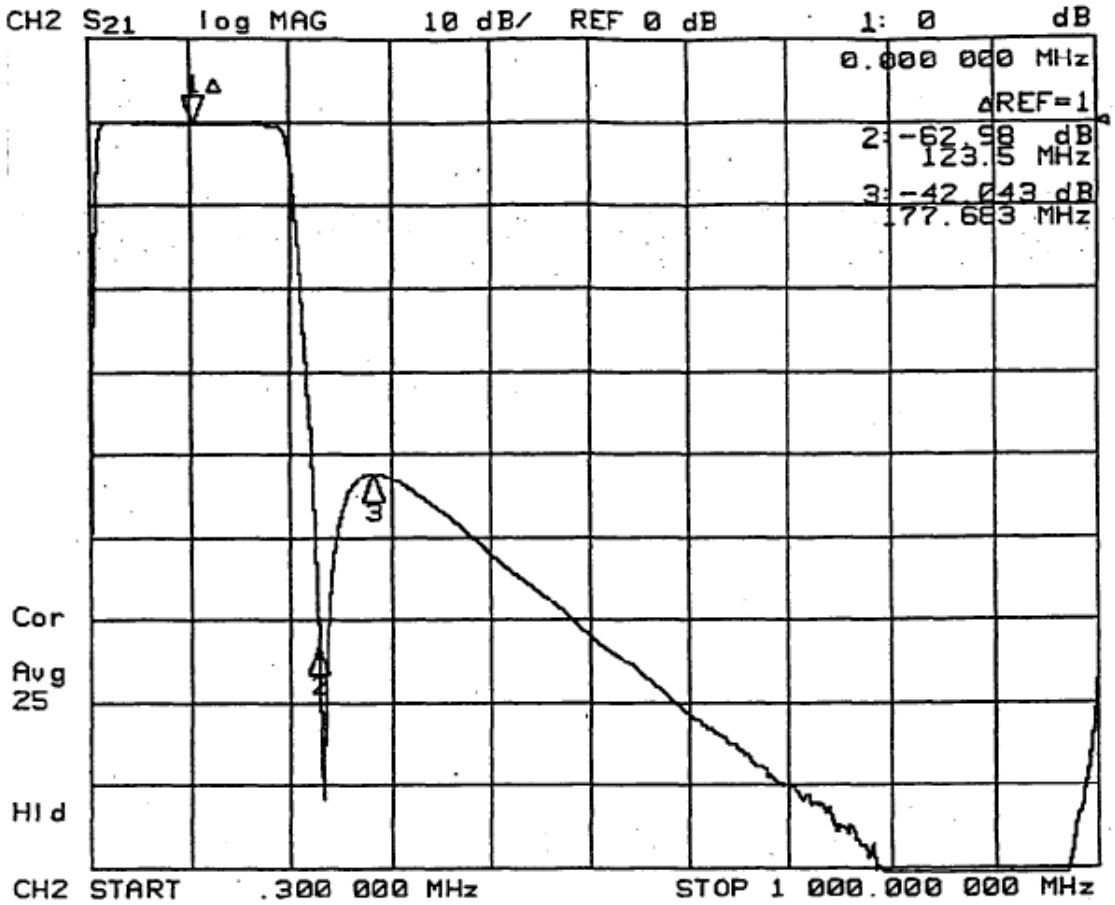
OUT-OF-BAND REJECTION

ACCEPTANCE TEST PROCEDURE 63-0005-02 PARA 4.5.5 Fc=105.0 MHz. REF {5A} FOR INSERTION LOSS @ Fc	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 1.0 MHz	-59.2 dB (40.0 dB MIN)	-59.2 dB (40.0 dB MIN)	-59.1 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 228.5 MHz TO 1000.0 MHz	-42.0 dB (40.0 dB MIN)	-42.0 dB (40.0 dB MIN)	-42.1 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-13.0 °C (-15.0 TO -10.0)	+15.7 °C (12.5 TO 17.5)	+42.9 °C (40.0 TO 45.0)
{14} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√) ✓ (√)	✓ (√) ✓ (√)	✓ (√) ✓ (√)

TEST PERFORMED BY R. Hoggatt DATE 12/23/96

NOTE IF TEST WITNESSED BY AESD: _____ GSI: Not witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P228-006
+15C DATA
MARKER PARAMET OPR: R. HOGGATT DATE DEC 28 1996 annel 2

MARKER 1	1.000000 MHz OFF	105.000000 MHz 0 dB
MARKER 2	5.000000 MHz OFF	228.500000 MHz -62.98 dB
MARKER 3	5.000000 MHz OFF	282.683742 MHz -42.043 dB
MARKER 4	5.000000 MHz OFF	.300000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB

REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB	-3 dB
	OFF	OFF
MARKER TRACKING	OFF	OFF

APPENDIX B **ACCEPTANCE TEST REPORT**

BANDPASS FILTER MODEL HL105-190-10SS1 S/N P228-006
EROJET 1331559-2 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE +22.9 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-82.4 dB	F11	(*) 130.0	MHz	-0.21 dB
F2	1.0	MHz	-66.1 dB	F12	(*) 150.0	MHz	-0.26 dB
F3	5.0	MHz	-17.7 dB	F13	180.0	MHz	-0.41 dB
F4	7.5	MHz	-7.36 dB	F14	190.0	MHz	-0.62 dB
F5	10.0	MHz	-1.78 dB	F15	200.0	MHz	-3.93 dB
F6	20.0	MHz	-0.07 dB	F16	250.0	MHz	-47.5 dB
F7	40.0	MHz	-0.10 dB	F17	300.0	MHz	-42.9 dB
F8	(*) 60.0	MHz	-0.16 dB	F18	400.0	MHz	-52.1 dB
F9	(*) 80.0	MHz	-0.19 dB	F19	500.0	MHz	-62.0 dB
F10	105.0	MHz	-0.23 dB	F20	1000.0	MHz	-70.7 dB

TEST PERFORMED BY: R. HOGGATT DATE 12/27/96

NOTE IF TEST WITNESSED BY AESD _____ GSI Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

APPENDIX D ACCEPTANCE TEST REPORT

BANDPASS FILTER MODEL HL87.5-155-10SS1 S/N P230-010
PROJET 1331559-4 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.5 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g) ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

OUT-OF-BAND REJECTION

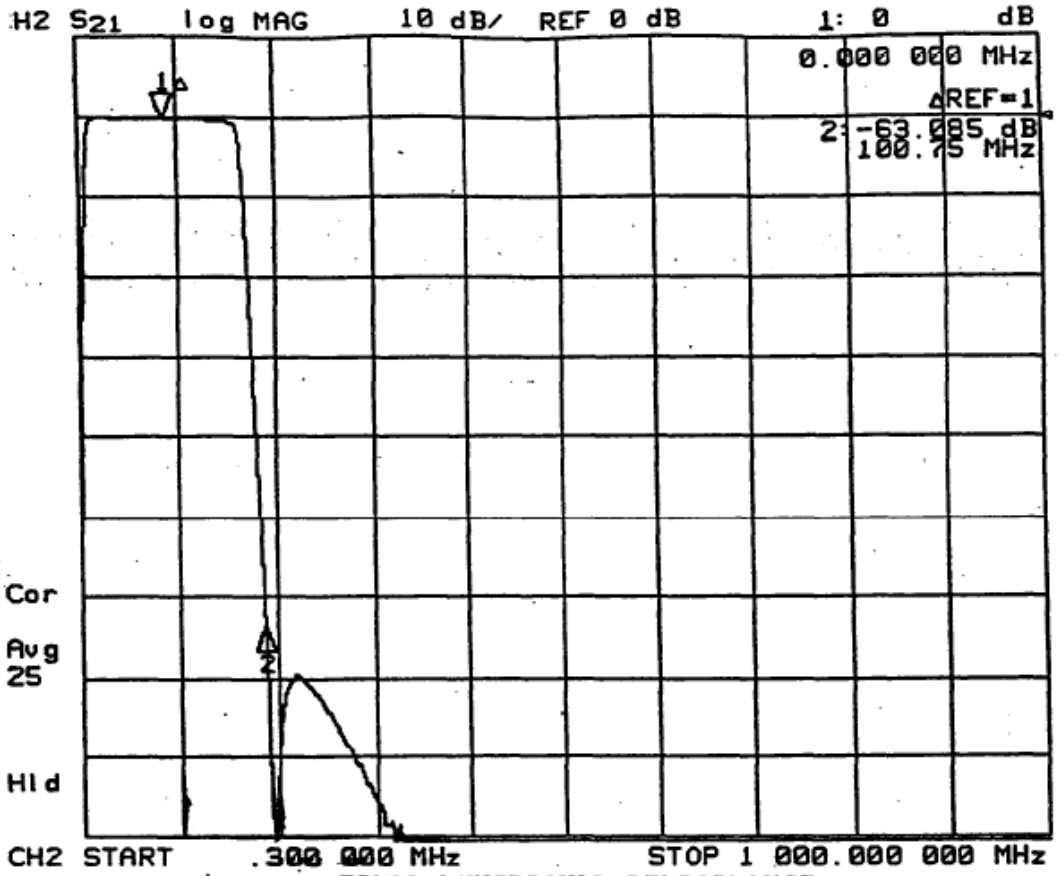
ACCEPTANCE TEST PROCEDURE 63-0005-02 PARA 4.5.5 Fc=87.5 MHz. REF {5A} FOR INSERTION LOSS @ Fc	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 1.0 MHz	-60.4 dB (40.0 dB MIN)	-60.4 dB (40.0 dB MIN)	-60.3 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 188.25 MHz TO 1000.0 MHz	-62.2 dB (40.0 dB MIN)	-63.1 dB (40.0 dB MIN)	-64.1 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-11.0 °C (-15.0 TO -10.0)	+12.5 °C (12.5 TO 17.5)	+43.5 °C (40.0 TO 45.0)
{14} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√) ✓ (√)	✓ (√) ✓ (√)	✓ (√) ✓ (√)

DA 5

TEST PERFORMED BY R. HOGGATT DATE 12/20/96

NOTE IF TEST WITNESSED BY AESD: _____ GSI Not witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P230-010
+15C DATA
MARKER PARAME OPR: R. HOGGATT DATE DEC 20 1996 annel 2

MARKER 1	1.000000 MHz OFF	87.500000 MHz 0 dB
MARKER 2	5.000000 MHz OFF	188.250000 MHz -63.085 dB
MARKER 3	5.000000 MHz OFF	188.250000 MHz OFF
MARKER 4	5.000000 MHz OFF	1000.000000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB

REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB	-3 dB
	OFF	OFF
MARKER TRACKING	OFF	OFF

BANDPASS FILTER MODEL HL87.5-155-10SS1 S/N P230-010
EROJET 1331559-4 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE. +22.4 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-83.6 dB	F11	(*) 100.0	MHz	-0.25 dB
F2	1.0	MHz	-67.3 dB	F12	(*) 125.0	MHz	-0.33 dB
F3	5.0	MHz	-18.5 dB	F13	150.0	MHz	-0.58 dB
F4	7.5	MHz	-7.59 dB	F14	160.0	MHz	-1.04 dB
F5	10.0	MHz	-1.78 dB	F15	165.0	MHz	-4.35 dB
F6	15.0	MHz	-0.21 dB	F16	170.0	MHz	-15.5 dB
F7	25.0	MHz	-0.11 dB	F17	200.0	MHz	-81.8 dB
F8	(*) 50.0	MHz	-0.15 dB	F18	300.0	MHz	-85.5 dB
F9	(*) 75.0	MHz	-0.20 dB	F19	500.0	MHz	-102.0 dB
F10	87.5	MHz	-0.25 dB	F20	1000.0	MHz	-99.7 dB

TEST PERFORMED BY: R. Hoggatt DA DATE 12/20/96

NOTE IF TEST WITNESSED BY AESD _____ GSI Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-9: Filter characteristics of AMSU (Channel 9 – 55.5 GHz)

APPENDIX D ACCEPTANCE TEST REPORT

BANDPASS FILTER MODEL HL87.5-155-10SS1 S/N P230-006
AEROJET 1331559-4 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.5 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g} ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

OUT-OF-BAND REJECTION

ACCEPTANCE TEST PROCEDURE
63-0005-02 PARA 4.5.5
Fc=87.5 MHz.
REF {5A} FOR INSERTION LOSS @ Fc

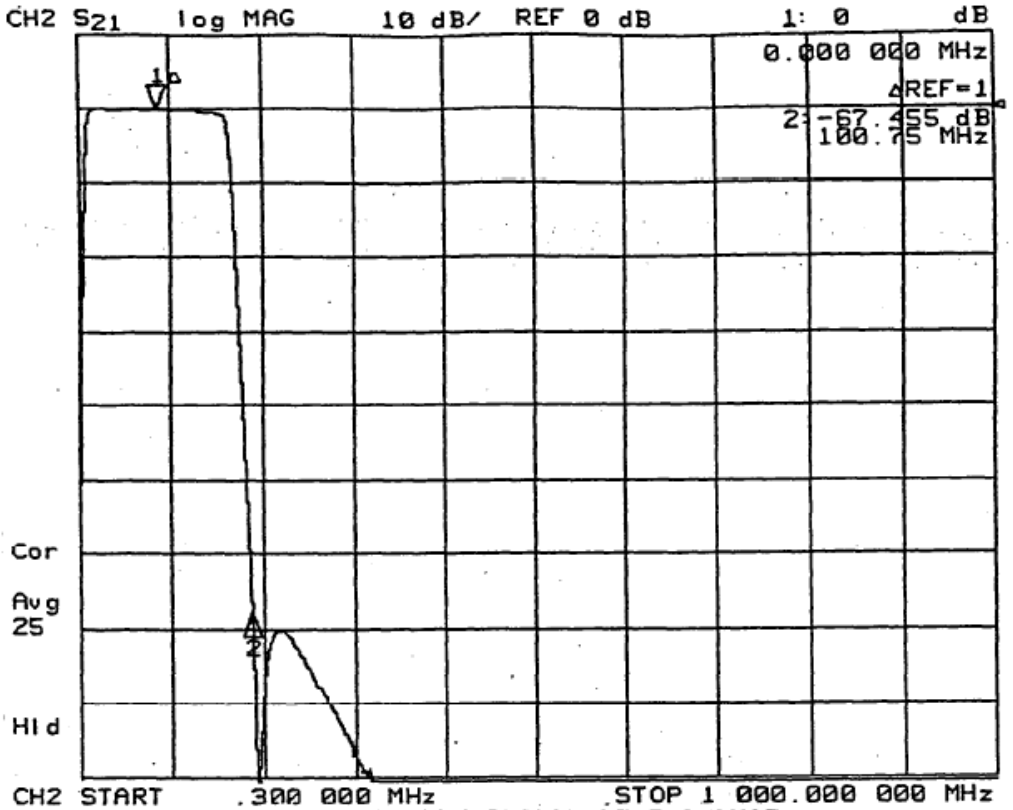
	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 1.0 MHz	-60.5 dB (40.0 dB MIN)	-60.4 dB (40.0 dB MIN)	-60.3 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 188.25 MHz TO 1000.0 MHz	-66.4 dB (40.0 dB MIN)	-67.5 dB (40.0 dB MIN)	-68.7 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-11.8 °C (-15.0 TO -10.0)	+13.7 °C (12.5 TO 17.5)	+42.7 °C (40.0 TO 45.0)
{14} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√) ✓ (√)	✓ (√) ✓ (√)	✓ (√) ✓ (√)

DA 5

TEST PERFORMED BY R. Hoggatt DATE 12/20/96

NOTE IF TEST WITNESSED BY AESD: _____ GSI: Not witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P230-006
+15C DATA
MARKER PARAMET OPR: R. HOGGATT DATE DEC 20 1996 annel 2

MARKER 1	1.000000 MHz OFF	87.500000 MHz 0 dB
MARKER 2	5.000000 MHz OFF	188.250000 MHz -67.455 dB
MARKER 3	5.000000 MHz OFF	188.250000 MHz OFF
MARKER 4	5.000000 MHz OFF	1000.000000 MHz OFF
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB

REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB OFF	-3 dB OFF
MARKER TRACKING	OFF	OFF

APPENDIX D **ACCEPTANCE TEST REPORT**

BANDPASS FILTER MODEL HL87.5-155-10SS1 S/N P230-006
EROJET 1331559-4 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE. +22.9 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	0.5	MHz	-84.2 dB	F11	(*) 100.0	MHz	-0.26 dB
F2	1.0	MHz	-67.6 dB	F12	(*) 125.0	MHz	-0.34 dB
F3	5.0	MHz	-18.5 dB	F13	150.0	MHz	-0.61 dB
F4	7.5	MHz	-7.62 dB	F14	160.0	MHz	-1.07 dB
F5	10.0	MHz	-1.80 dB	F15	165.0	MHz	-4.57 dB
F6	15.0	MHz	-0.22 dB	F16	170.0	MHz	-16.6 dB
F7	25.0	MHz	-0.11 dB	F17	200.0	MHz	-78.9 dB
F8	(*) 50.0	MHz	-0.16 dB	F18	300.0	MHz	-87.0 dB
F9	(*) 75.0	MHz	-0.20 dB	F19	500.0	MHz	-101.3 dB
F10	87.5	MHz	-0.23 dB	F20	1000.0	MHz	-106.8 dB

TEST PERFORMED BY: R. Hoggan (DA 5) DATE 12/20/96

NOTE IF TEST WITNESSED BY AESD_____ GSI Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-10: Filter characteristics of AMSU (Channel 10 – 57.29 GHz)

APPENDIX G ACCEPTANCE TEST REPORT

BANDPASS FILTER MODEL FX217-78-10SS1 S/N P233-008
AEROJET 1331559-7 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.7 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g} ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

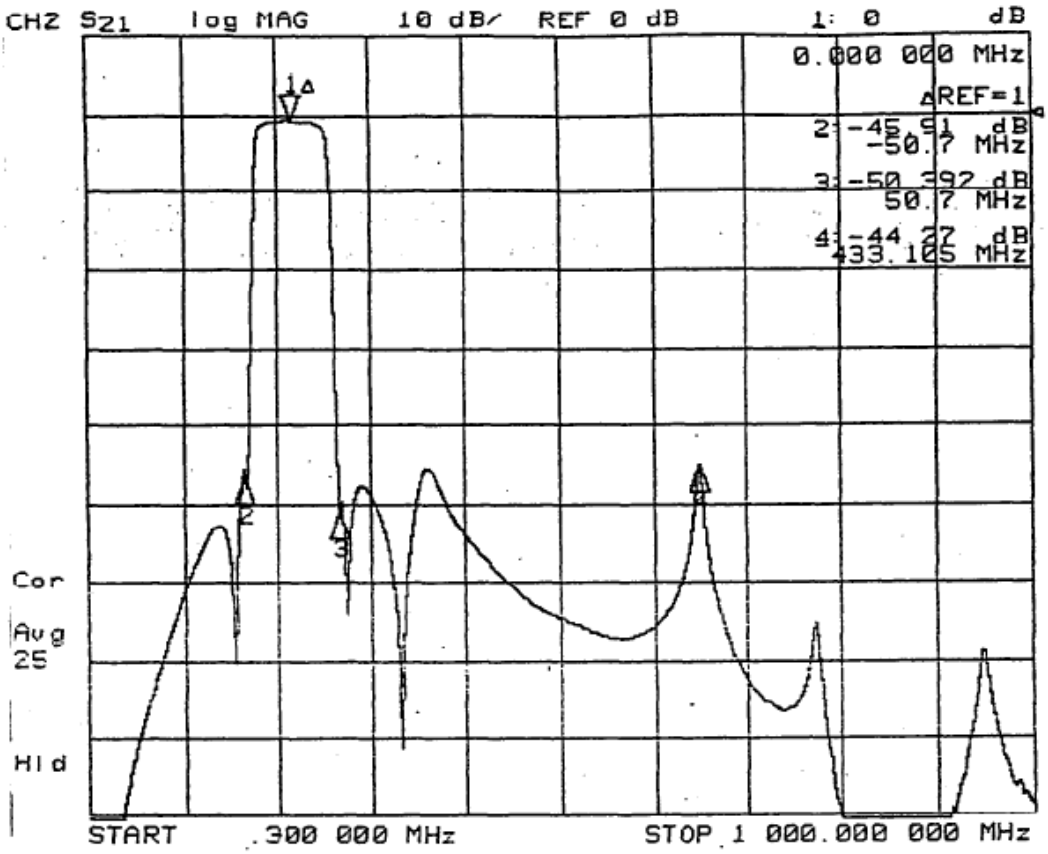
OUT-OF-BAND REJECTION
ACCEPTANCE TEST PROCEDURE
63-0005-02 PARA 4.5.5
Fc=217.0 MHz.
REF {5A} FOR INSERTION LOSS @ Fc

	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 166.3 MHz	-44.9 dB (40.0 dB MIN)	-44.9 dB (40.0 dB MIN)	-45.1 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 267.7 MHz TO 1000.0 MHz	-44.1 dB (40.0 dB MIN)	-44.3 dB (40.0 dB MIN)	-44.3 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-12.3 °C (-15.0 TO -10.0)	+16.0 °C (12.5 TO 17.5)	+41.7 °C (40.0 TO 45.0)
{14} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

TEST PERFORMED BY R. Hoggatt DATE 1/31/97 DA 5

NOTE IF TEST WITNESSED BY AESD: _____ GSI: _____ Not Witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P233-008
+15C DATA
OPR: R. HOGGATT DATE JAN 31 1997 Channel 2

MARKER PARAMET		
MARKER 1	1000.000000 MHz OFF	217.000000 MHz 0 dB
MARKER 2	1000.000000 MHz OFF	166.300000 MHz -45.91 dB
MARKER 3	1000.000000 MHz OFF	267.700000 MHz -50.392 dB
MARKER 4	1000.000000 MHz OFF	650.105029 MHz -44.27 dB
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB
REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB	-3 dB
	OFF	OFF
MARKER TRACKING	OFF	OFF

APPENDIX G ACCEPTANCE TEST REPORT

BANDPASS FILTER MODEL FX217-78-10SS1 S/N P233-008
AEROJET 1331559-7 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE +24.2 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	1.0	MHz	-100.6 dB	F11	217.0	MHz	-0.61 dB
F2	10.0	MHz	-104.5 dB	F12	(*) 224.0	MHz	-0.64 dB
F3	100.0	MHz	-61.3 dB	F13	(*) 230.0	MHz	-0.70 dB
F4	150.0	MHz	-58.0 dB	F14	240.0	MHz	-0.88 dB
F5	170.0	MHz	-45.7 dB	F15	250.0	MHz	-1.56 dB
F6	178.0	MHz	-6.79 dB	F16	256.0	MHz	-5.71 dB
F7	184.0	MHz	-1.32 dB	F17	264.0	MHz	-36.2 dB
F8	194.0	MHz	-0.80 dB	F18	300.0	MHz	-48.7 dB
F9	(*) 204.0	MHz	-0.63 dB	F19	500.0	MHz	-64.6 dB
F10	(*) 210.0	MHz	-0.60 dB	F20	1000.0	MHz	-87.9 dB

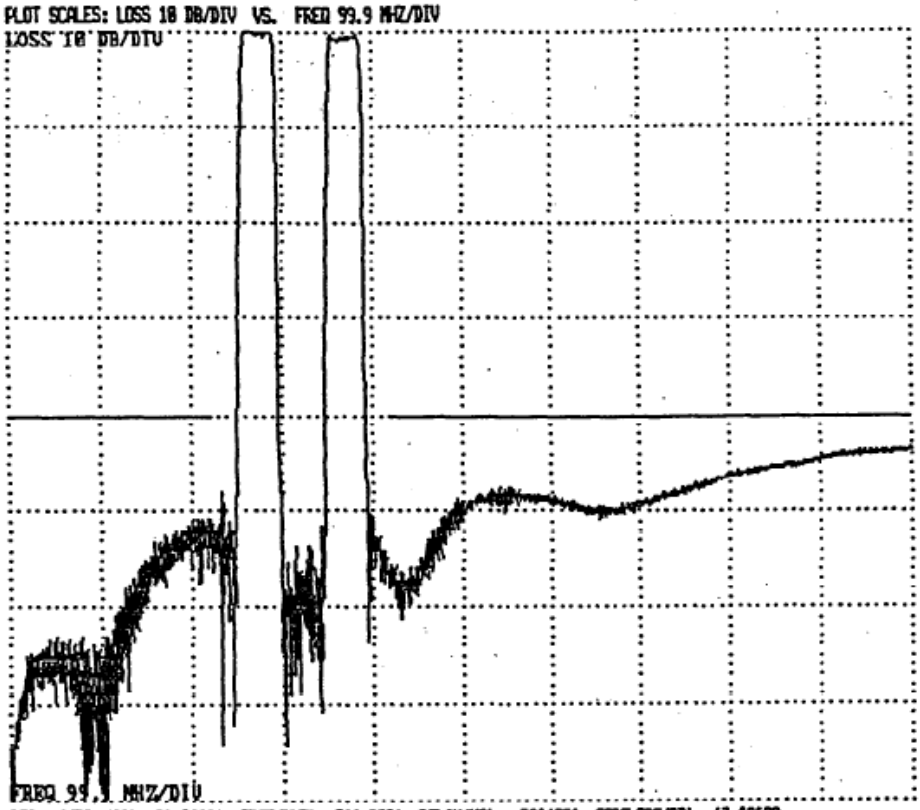
TEST PERFORMED BY: R. Hoggatt DATE 1/31/97 DA 5

NOTE IF TEST WITNESSED BY AESD _____ GSI _____ Not Witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

Appendix 4-11: Filter characteristics of AMSU (Channel 11 – 57.29 GHz)

PHONON CORPORATION
FILE=1ER8807A.DAT 18:31:09 06-16-1998
PN 100828_823 FINAL_FUNCTIONAL TEMP:R FLIGHT7_3FUNCT /N WIDE_S21
06-15-1998 HP8753,SSREF,SSREF
FREQUENCY(MHZ): CENTER= 300.5 WIDTH= 999 INCR.= .200125 SYSTEM BANDWIDTH= 999
REFERENCES: LOSS(DB)= 28.50072 PHASE(DEG)= 1955.791 DELAY(US)= 5.743086E-02 SLOPE(US/MHZ)= 0
RMS ERRORS: LOSS(DB)= 15.93412 PHASE(DEG)= 4727.23
PLOT SCALES: LOSS 10 DB/DIV VS. FREQ 99.9 MHZ/DIV



PEAK: LEVEL(DB)= 28.09281 FREQ(MHZ)= 288.9228 DELAY(US)=-.3064226 SIDELOBE(DB)=-43.03699
ENERGY: LEVEL(DB)= 28.9481 CENTER(MHZ)= 319.4828 WIDTH(MHZ)= 73.03752 SKEW(MHZ)= 15.66655

L(DB)	LO(MHZ)	HI(MHZ)	CTR(MHZ)	WID(MHZ)	AV-CTR(MHZ)	AV-WID(MHZ)	AV-SL(DB)	LOX(MHZ)	HIX(MHZ)
-0.41	288.92282	288.92282	288.92282	0.00000	288.92282	0.00000	0.00	288.92282	288.92282
0.50	258.98831	298.51443	274.75137	31.52612	274.63438	31.64143	-14.51	258.98831	385.04254
1.00	258.48527	298.88394	274.64459	32.47867	274.65848	32.33776	-14.60	258.48527	386.19038
2.00	257.56409	291.48700	274.52554	33.92291	274.58647	33.38663	-14.73	257.56409	387.18623
3.00	256.98694	291.88611	274.43652	34.89917	274.53427	33.97199	-14.80	256.98694	387.63568
4.00	256.55609	292.22675	274.39142	35.67065	274.53644	34.33684	-14.85	256.55609	388.06763
5.00	256.21457	292.58583	274.36828	36.29126	274.53595	34.48413	-14.87	256.21457	388.45888
6.00	255.91431	292.74774	274.33182	36.83344	274.58548	34.66296	-14.89	255.91431	388.76547
10.00	255.02587	293.54481	274.28455	38.51894	274.58967	34.94586	-14.92	255.02587	389.68882
20.00	253.57413	294.83798	274.23685	41.32385	274.58838	35.06581	-14.92	253.57413	391.11661
30.00	252.62759	295.91635	274.27197	43.28876	274.58889	35.07294	-14.92	252.62759	392.18068
40.00	251.77892	296.86423	274.31757	45.03331	274.58886	35.07365	-14.91	251.77892	392.76835

BAND(MHZ)	1.000	225.000	420.000 1000.000
LMIN(DB)	58.77	-0.48	43.49
LMAX(DB)	91.35	74.21	61.14
LDEL(DB)	40.59	74.61	17.65
PMIN(DEG)	3883.46	-4289.66	-3638.74
PMAX(DEG)	8127.31	8319.87	8278.94
PDEL(DEG)	4243.85	12528.73	11917.69

FILE: 1ER8807A.DAT Out-of-band Rejection: PEAK= 43.5 dB WIDTH= 0.000 MHz

Appendix 4-12: Filter characteristics of AMSU (Channel 12 – 57.29 GHz)

PHONON CORPORATION

FILE=2FR5B24B.DAT 09:39:38 02-24-1998

PN_100830_824 FINAL_FUNCTIONAL TEMP:R FLIGHT4_FUNCT3 /N DUPL_EXX

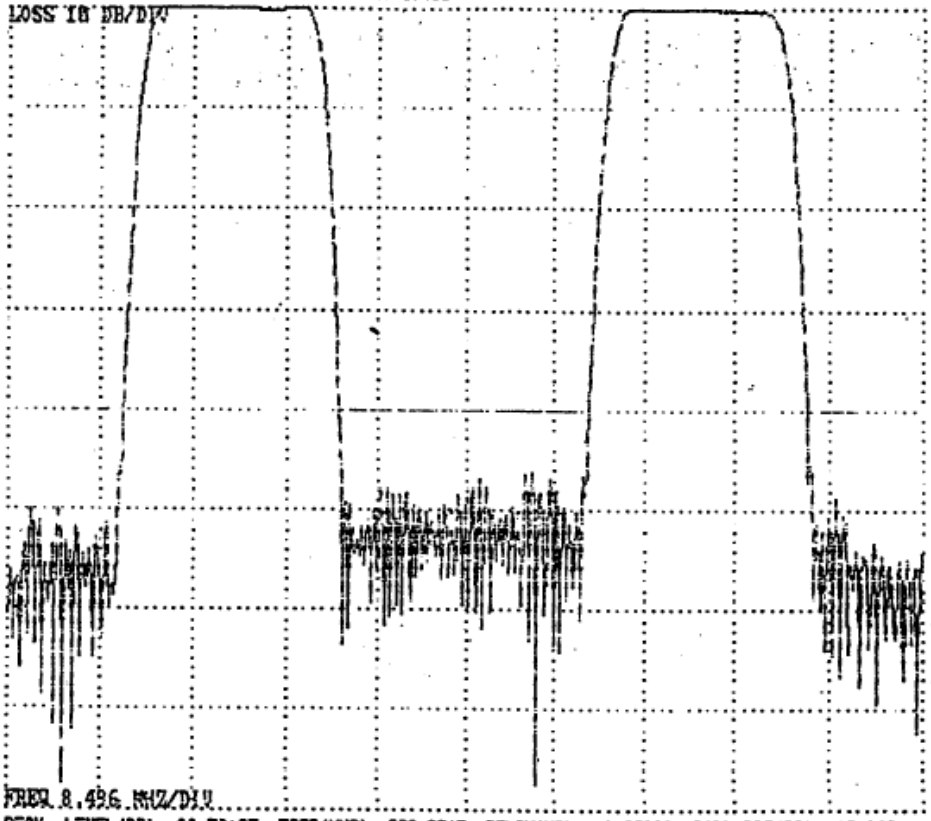
02-03-1998 HP8753,SSREF,SSREF

FREQUENCY(MHZ): CENTER= 322.2 WIDTH= 84.55 INCR.= .12 SYSTEM BANDWIDTH= 25

REFERENCES: LOSS(DB)= 28.54639 PHASE(DEG)=-4545.26 DELAY(US)= .7974963 SLOPE(US/MHZ)= 0

RMS ERRORS: LOSS(DB)= 26.20258 PHASE(DEG)= 1424.212

PLOT SCALES: LOSS 10 DB/DIV VS. FREQ 8.456 MHZ/DIV



PEAK: LEVEL(DB)= 28.58125 FREQ(MHZ)= 339.3715 DELAY(US)= .2177372 SIDELOBE(DB)=-45.9692

ENERGY: LEVEL(DB)= 29.13649 CENTER(MHZ)= 322.1914 WIDTH(MHZ)= 32.35246 SKEW(MHZ)=-.1963978

L(DB)	LO(MHZ)	HI(MHZ)	CTR(MHZ)	WID(MHZ)	AV-CTR(MHZ)	AV-WID(MHZ)	AV-SL(DB)	LOX(MHZ)	HIX(MHZ)
-0.45	339.37145	339.37145	339.37145	0.00000	339.37145	0.00000	0.00	339.37145	339.37145
0.50	337.08670	350.82782	342.95728	13.74112	343.82687	13.73486	-6.17	293.32324	350.82782
1.00	336.82261	351.18402	344.00330	14.35141	342.82441	14.33949	-5.28	293.09171	351.18402
2.00	336.54521	351.54565	344.04525	15.00254	343.88467	14.75168	-6.36	292.77762	351.54565
3.00	336.32581	351.79126	344.05353	15.46545	343.88818	15.03377	-5.40	292.57077	351.79126
4.00	336.15323	351.97778	344.06549	15.82455	343.91733	15.19371	-5.42	292.39962	351.97778
5.00	336.01459	352.12845	344.07153	16.11386	343.91589	15.28005	-5.43	292.25287	352.12845
6.00	335.89334	352.27005	344.08170	16.37671	343.91513	15.35123	-5.43	292.12778	352.27005
10.00	335.50308	352.68091	344.09149	17.17883	343.91428	15.51115	-5.42	291.75772	352.68091
20.00	334.86111	353.32974	344.09543	18.46863	343.91443	15.55567	-5.35	291.14139	353.32974
30.00	334.41412	353.73956	344.07684	19.32544	343.91428	15.55895	-5.30	290.67613	353.73956
40.00	333.92123	354.07397	343.99762	22.15274	343.91428	15.55932	-6.24	290.29178	354.07397

BAND(MHZ)	294.200	305.200	332.200	350.202
LMIN(DB)	-0.16	-0.25	-0.45	
LMAX(DB)	0.26	77.53	0.36	
LDEL(DB)	0.43	77.78	0.81	
PMIN(DEG)	-2175.54	-3095.60	-919.32	
PMAX(DEG)	313.30	2473.76	1496.28	
PDEL(DEG)	2489.83	5570.37	2415.60	

FILE: 2FR5B24B.DAT Out-of-band Rejection: PEAK= 45.9 dB WIDTH= 0.000 MHz

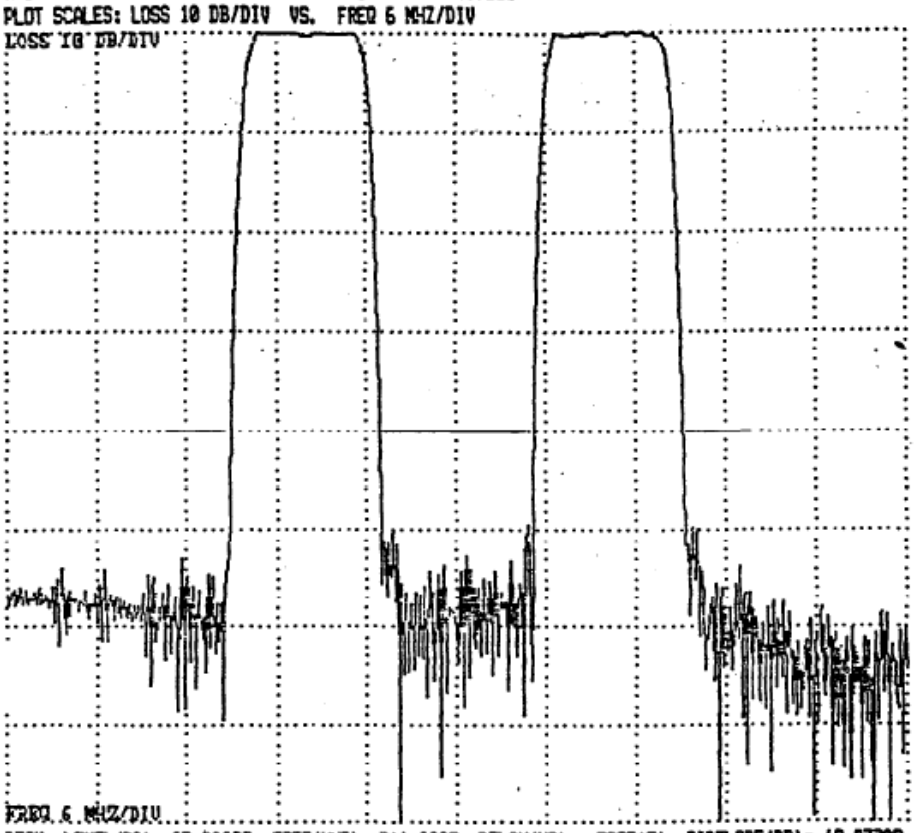
PHONON CORPORATION
FILE: 2FR8834B.DAT (+SSCF)
PN_100330_524 FINAL_FUNCTIONAL TEMP:R FLIGHT4_FUNCT3 /N DUAL_SXX
02-03-1998 HP8753,SSREF,SSREF,SSCF
REFERENCES: LOSS(DB)= 28.94838 PHASE(DEG)= -4546.18
DELAY(US)= .7974952 SLOPE(US/MHZ)= 0

BANDPASS CHARACTERISTICS MEASUREMENT

FREQUENCY(MHZ)	LOSS(DB)	PHASE(DEG)
285.400	54.65	-73.70
289.080	59.56	968.25
292.760	2.06	522.55
296.440	-0.05	-149.50
300.120	0.81	-921.22
303.800	0.24	-1592.22
307.480	0.36	-2462.58
311.160	49.24	-2780.73
314.840	52.53	-1776.66
318.520	53.03	-700.55
322.200	49.83	355.91
325.880	52.01	1430.49
329.560	51.93	1715.73
333.240	51.53	2455.04
336.920	0.88	1771.86
340.600	-0.22	1321.60
344.280	-0.01	277.55
347.960	0.32	-475.17
351.640	0.36	-1215.69
355.320	59.52	-2083.56
359.000	60.52	-1883.70

Appendix 4-13: Filter characteristics of AMSU (Channel 13 – 57.29 GHz)

PHONON CORPORATION
FILE=3FR8B03B.DAT 18:09:37 01-05-1998
PN 102832_825 FINAL_FUNCTIONAL TEMP:R REWORK TRAVELLER 06 /N DUAL_SXX
01-05-1998 HP8753,SSREF,SSREF,SSREF
FREQUENCY(MHZ): CENTER= 322.2 WIDTH= 60 INCR.= .1 SYSTEM BANDWIDTH= 60
REFERENCES: LOSS(DB)= 28.35454 PHASE(DEG)= 14073.33 DELAY(US)= 1.646077 SLOPE(US/MHZ)= 0
RMS ERRORS: LOSS(DB)= 27.2888 PHASE(DEG)= 1926.233
PLOT SCALES: LOSS 10 DB/DIV VS. FREQ 6 MHZ/DIV



PEAK: LEVEL(DB)= 27.98293 FREQ(MHZ)= 314.6287 DELAY(US)= .5997151 SIDELOBE(DB)=-49.87309
ENERGY: LEVEL(DB)= 28.5425 CENTER(MHZ)= 322.0052 WIDTH(MHZ)= 16.41336 SKEW(MHZ)= .462887

L(DB)	LO(MHZ)	HI(MHZ)	CTR(MHZ)	WID(MHZ)	AV-CTR(MHZ)	AV-WID(MHZ)	AV-SL(DB)	LOX(MHZ)	HIX(MHZ)
-0.37	314.62869	314.62869	314.62869	0.00000	314.62859	0.00000	0.00	314.62869	314.62869
0.50	308.69150	315.77643	312.23395	7.08493	312.21725	7.27263	-7.98	308.69150	335.71194
1.00	308.57230	315.88702	312.22968	7.31473	312.21930	7.44219	-8.05	308.57230	335.90530
2.00	308.41052	316.02921	312.21985	7.61858	312.25443	7.65928	-8.14	308.41052	336.09198
3.00	308.30109	316.13412	312.21759	7.83304	312.25082	7.77594	-8.18	308.30109	336.20514
4.00	308.21671	316.21832	312.21753	8.00162	312.24692	7.86816	-8.22	308.21671	336.29199
5.00	308.14212	316.28973	312.21594	8.14761	312.22745	7.90620	-8.23	308.14212	336.36697
6.00	308.07776	316.35339	312.21558	8.27563	312.22894	7.96407	-8.25	308.07776	336.43842
10.00	307.87988	316.55066	312.21527	8.67078	312.23102	8.02756	-8.25	307.87988	336.62180
20.00	307.55954	316.86282	312.21118	9.30328	312.23212	8.05149	-8.21	307.55954	336.93130
30.00	307.34348	317.05078	312.19714	9.70731	312.23218	8.05315	-8.18	307.34348	337.14755
40.00	307.15970	317.19391	312.17682	10.03421	312.23218	8.05328	-8.15	307.15970	337.31778

BAND(MHZ)	309.200	315.200	329.200	335.200
LMIN(DB)	-0.37	-0.33	-0.07	
LMAX(DB)	0.23	90.06	0.32	
LDEL(DB)	0.60	90.39	0.39	
PMIN(DEG)	-745.81	-2133.45	-1913.77	
PMAX(DEG)	1466.83	1451.68	226.62	
PDEL(DEG)	2212.65	3585.13	2140.39	

FILE: 3FR8B03B.DAT Out-of-band Rejection: PEAK= 49.7 dB WIDTH= 0.000 MHz

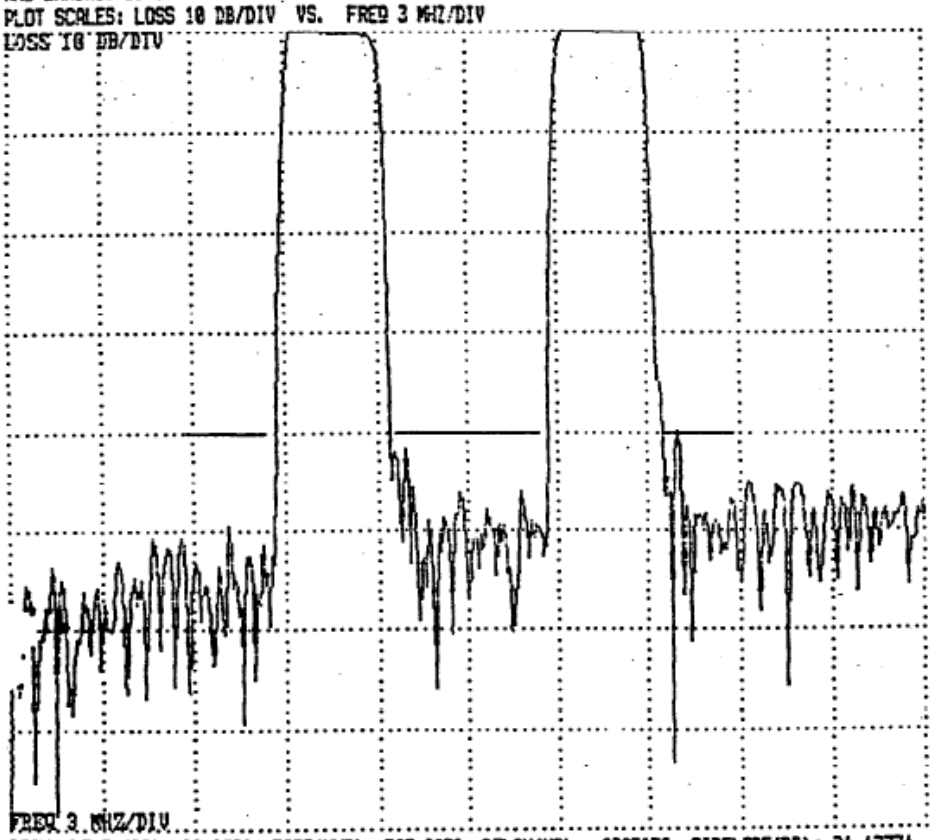
PHONON CORPORATION
FILE: 3FR8B03B.DAT (+SSCF)
PN_100832_825 FINAL_FUNCTIONAL TEMP:R REWORK TRAVELLER 05 /N DUAL_SXI
01-05-1998 HP8753,SSREF,SSREF,SSREF,SSCF
"SFERENCES: LOSS(DB)= 28.35454 PHASE(DEG)= 14073.33
DELAY(US)= 1.645077 SLOPE(US/MHZ)= 0

BANDPASS CHARACTERISTICS MEASUREMENT

FREQUENCY(MHZ)	LOSS(DB)	PHASE(DEG)
304.600	58.36	1433.23
306.360	59.74	2080.30
308.120	5.33	1908.83
309.880	-0.25	1247.87
311.640	0.06	588.17
313.400	0.02	-69.97
315.160	-0.33	-730.67
316.920	22.54	-1394.93
318.680	56.22	-2130.69
320.440	56.92	-1025.71
322.200	60.49	-406.08
323.960	56.30	-50.40
325.720	55.06	1011.77
327.480	29.85	866.22
329.240	0.13	212.10
331.000	0.08	-424.32
332.760	0.01	-1060.95
334.520	-0.01	-1701.67
336.280	3.84	-2342.32
338.040	53.89	-3046.24
339.800	57.13	-2550.07

Appendix 4-14: Filter characteristics of AMSU (Channel 14 – 57.29 GHz)

PHONON CORPORATION
FILE=4FR8B04A.DAT 09:34:12 10-28-1997
PN_100834_826 FINAL_FUNCTIONAL TEMP:R FLIGHT3_FUNCT3 /N DUAL_SXX
23-1997 HP8753,SSREF,SSREF
..QUENCY(MHZ): CENTER= 322.2 WIDTH= 30 INCR.= .05 SYSTEM BANDWIDTH= 30
SFERENCES: LOSS(DB)= 28.50952 PHASE(DEG)=-21423.51 DELAY(US)= 1.421155 SLOPE(US/MHZ)= 0
RMS ERRORS: LOSS(DB)= 22.30308 PHASE(DEG)= 937.2166
PLOT SCALES: LOSS 10 DB/DIV VS. FREQ 3 MHZ/DIV



PEAK: LEVEL(DB)= 28.0592 FREQ(MHZ)= 327.8558 DELAY(US)=-.2385675 SIDELOBE(DB)=-34.43774
ENERGY: LEVEL(DB)= 28.65869 CENTER(MHZ)= 322.2683 WIDTH(MHZ)= 6.117685 SKEW(MHZ)=-.1768197

L(DB)	LO(MHZ)	HI(MHZ)	CTR(MHZ)	WID(MHZ)	AV-CTR(MHZ)	AV-WID(MHZ)	AV-SL(DB)	LOX(MHZ)	HIX(MHZ)
-0.45	327.86584	327.86584	327.86584	0.00000	327.86584	0.00000	0.00000	327.86584	327.86584
0.50	325.32538	328.04370	326.68454	2.71832	326.68295	2.75519	-9.37657	316.38248	328.04370
1.00	325.28726	328.07068	326.67896	2.78342	326.68369	2.84115	-9.48477	316.35156	328.07068
2.00	325.23547	328.11115	326.67331	2.87567	326.68341	2.90897	-9.56706	316.31342	328.11115
3.00	325.19812	328.14255	326.67035	2.94443	326.67059	2.93437	-9.59295	316.28018	328.14255
4.00	325.16916	328.16806	326.66861	2.99890	326.68234	2.95789	-9.61867	316.25333	328.16806
5.00	325.14468	328.19009	326.66739	3.04541	326.67377	2.97456	-9.63578	316.23022	328.19009
6.00	325.12302	328.20950	326.66626	3.08649	326.68097	2.98867	-9.65007	316.20972	328.20950
10.00	325.05432	328.27176	326.66302	3.21744	326.67966	3.00534	-9.65378	316.14594	328.27176
20.00	324.94098	328.37140	326.65619	3.43042	326.67783	3.01642	-9.63576	316.04434	328.37140
30.00	324.86777	328.43344	326.65060	3.56567	326.67783	3.01677	-9.61416	315.98468	328.43344
40.00	324.82965	328.67844	326.75403	3.84879	326.67789	3.01688	-9.56765	315.93604	329.15921

BAND(MHZ)	316.575	318.825	325.575	327.825
LMIN(DB)	-0.34	-0.17	-0.33	
LMAX(DB)	0.43	65.73	0.12	
LDEL(DB)	0.77	65.90	0.45	
..N(DEG)	-3.42	-797.86	-1055.33	
..AX(DEG)	1391.69	1034.16	334.17	
EL(DEG)	1395.11	1832.02	1389.50	

FILE: 4FR8B04A.DAT Out-of-band Rejection: PEAK= 39.9 dB WIDTH= 0.011 MHz

PHONON CORPORATION
FILE: 4FR8804A.DAT (+SSCF)
PN_100834_B26 FINAL_FUNCTIONAL TEMP:R FLIGHT3_FUNCT3 /N DUAL_SXI
-23-1997 HP8753,SSREF,SSREF,SSCF
_FERENCES: LOSS(DB)= 28.50962 PHASE(DEG)= -21423.51
DELAY(US)= 1.421155 SLOPE(US/MHZ)= 0

BANDPASS CHARACTERISTICS MEASUREMENT

FREQUENCY(MHZ)	LOSS(DB)	PHASE(DEG)
315.000	53.11	1517.99
315.720	54.60	1921.18
316.440	-0.06	1492.62
317.160	-0.04	1032.51
317.880	0.20	575.75
318.600	0.14	120.59
319.320	7.44	-314.57
320.040	43.15	-545.92
320.760	55.17	-588.83
321.480	50.20	-246.06
322.200	57.01	-18.67
322.920	48.76	127.11
323.640	58.90	459.55
324.360	50.63	854.57
325.080	0.25	668.79
325.800	-0.28	203.13
326.520	0.05	-255.92
327.240	-0.04	-710.46
327.960	-0.28	-1150.00
328.680	40.11	-1353.71
329.400	48.97	-1603.45

Appendix 4-15: Filter characteristics of AMSU (Channel 15 – 89 GHz)

APPENDIX A **ACCEPTANCE TEST REPORT**

BANDPASS FILTER MODEL HL1000-1000-10SS1 S/N P227-003
AEROJET 1331559-1 REV. E

PASSBAND RIPPLE (CON'T)

{11f} RECORD PASS/FAIL (0.5 dB MAX)	PASS/FAIL	PASS/FAIL	PASS/FAIL
{11g) ATTACH PASSBAND RIPPLE PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

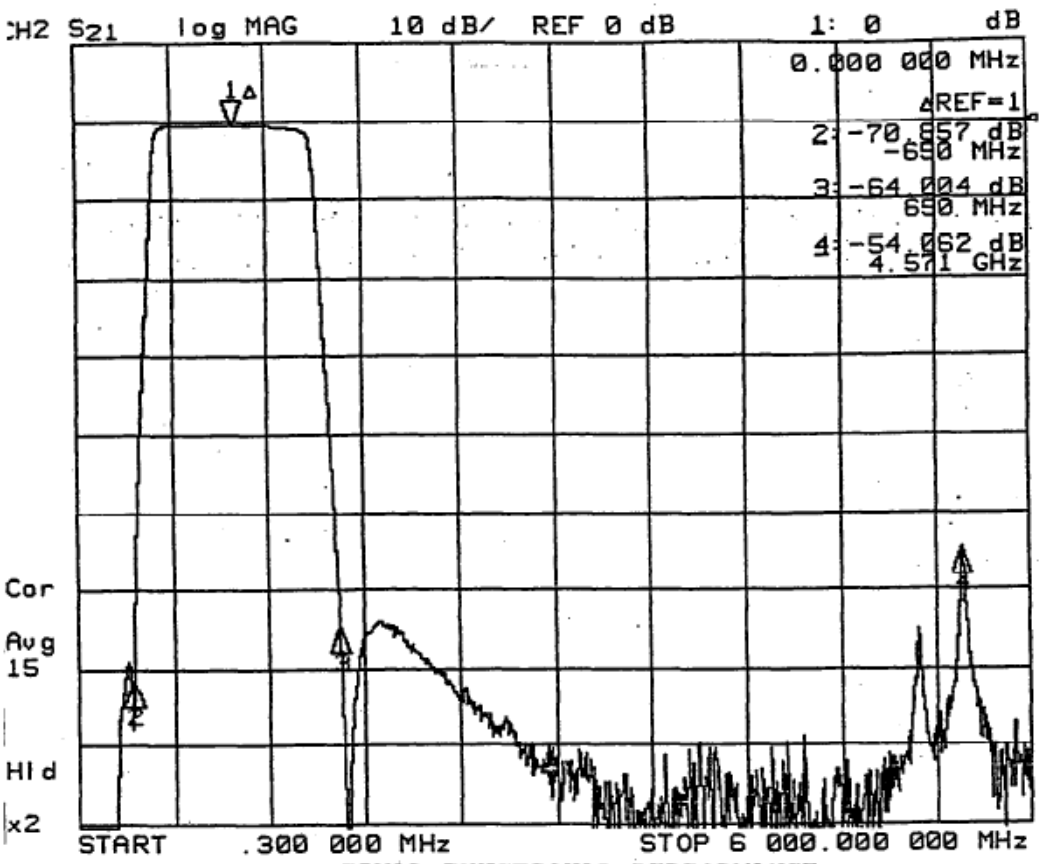
OUT-OF-BAND REJECTION
ACCEPTANCE TEST PROCEDURE
63-0005-02 PARA 4.5.5
Fc=1000.0 MHz.
REF {5A} FOR INSERTION LOSS @ Fc

	-10°C	+15°C	+40°C
{12} WORST CASE REJECTION FROM 0.300 MHz TO 350.0 MHz	-68.6 dB (40.0 dB MIN)	-68.9 dB (40.0 dB MIN)	-68.8 dB (40.0 dB MIN)
{13a} WORST CASE REJECTION FROM 1650.0 MHz TO 3000.0 MHz	-63.6 dB (40.0 dB MIN)	-63.6 dB (40.0 dB MIN)	-63.7 dB (40.0 dB MIN)
{13b} WORST CASE REJECTION FROM 3000.0 MHz TO 8000.0 MHz	-54.1 dB (40.0 dB MIN)	-54.2 dB (40.0 dB MIN)	-54.5 dB (40.0 dB MIN)
{13c} RECORD MEASURED TEMPERATURE	-11.5 °C (-15.0 TO -10.0)	+15.8 °C (12.5 TO 17.5)	+40.8 °C (40.0 TO 45.0)
{14} ATTACH REJECTION PERFORMANCE X-Y PLOT(S)	✓ (√)	✓ (√)	✓ (√)

TEST PERFORMED BY R. Hoggatt DATE 2/3/97 DA 5

NOTE IF TEST WITNESSED BY AESD: _____ GSI: ___ Not witnessed this time. DLD

***** END OF FUNCTIONAL PERFORMANCE TEST ****



FINAL FUNCTIONAL PERFORMANCE
REJECTION PERFORMANCE
SERIAL NO. P227-003
-10C DATA
OPR: R. HOGGATT DATE FEB 03 1997

MARKER PARAMET ... annel 2

MARKER 1	1000.000000 MHz OFF	1000.000000 MHz 0 dB
MARKER 2	1000.000000 MHz OFF	350.000000 MHz -70.857 dB
MARKER 3	1000.000000 MHz OFF	1650.000000 MHz -64.004 dB
MARKER 4	1000.000000 MHz OFF	5571.556164 MHz -54.062 dB
MKR STIMULUS OFFSET	0.000000 MHz 0 dB	0.000000 MHz 0 dB
REFERENCE MARKER	OFF	MARKER 1
PLACEMENT	CONTINUOUS	CONTINUOUS
MARKER SEARCH	OFF	OFF
TARGET VALUE	-3 dB	-3 dB
MARKER WIDTH VALUE	-3 dB	-3 dB
	OFF	OFF
MARKER TRACKING	OFF	OFF

APPENDIX A ACCEPTANCE TEST REPORT

BANDPASS FILTER MODEL HL1000-1000-10SS1 S/N P227-003
AEROJET 1331559-1 REV. E

BANDPASS CHARACTERISTICS MEASUREMENT
PER ATP PARA 4.6
(REF: AE-24687, PARA 4.8.2)

RECORD THE AMBIENT ROOM TEMPERATURE. +21.5 °C (+19°C TO +29.0°C)

{15} ATTACH PASSBAND PERFORMANCE X-Y PLOT ✓ (√)

{24} TEST POINT MATRIX

REF	FREQ	UNIT	VALUE	REF	FREQ	UNIT	VALUE
F1	1.0	MHz	-79.0 dB	F11	1000.0	MHz	-0.51 dB
F2	10.0	MHz	-92.7 dB	F12	(*) 1100.0	MHz	-0.57 dB
F3	100.0	MHz	-86.9 dB	F13	(*) 1200.0	MHz	-0.62 dB
F4	300.0	MHz	-71.3 dB	F14	1300.0	MHz	-0.81 dB
F5	400.0	MHz	-37.5 dB	F15	1400.0	MHz	-1.06 dB
F6	500.0	MHz	-2.18 dB	F16	1500.0	MHz	-6.72 dB
F7	600.0	MHz	-0.58 dB	F17	1600.0	MHz	-42.8 dB
F8	700.0	MHz	-0.48 dB	F18	1700.0	MHz	-82.1 dB
F9	(*) 800.0	MHz	-0.55 dB	F19	2000.0	MHz	-65.8 dB
F10	(*) 900.0	MHz	-0.58 dB	F20	5000.0	MHz	-87.6 dB

TEST PERFORMED BY: R. Hoggatt DATE 2/4/97 DA 5

NOTE IF TEST WITNESSED BY AESD _____ GSI _____ Not witnessed this time. DLD

***** END OF BANDPASS CHARACTERISTICS TEST *****

ANNEX 5 : Filter characteristics of ATMS (operated by NASA)

The filter characteristics provided in this annex are from specifications of the desired filter performance at the point of the sensor detector The filter performance was measured and found to meet these specifications.

ATMS Receive Sensitivity

ATMS Channel	Center Frequency	Max. Bandwidth	Frequency Range		EMI Sensitivity of ATMS Passbands			
	(MHz)	(MHz)	From (MHz)	To (MHz)	dBm	dBµV/m Boresight [1]	dBµV/m >15.5° [2]	dBµV/m >40° [3]
1	23800	270	21300	22000	-60	72.79	115.51	129.01
			22000	22800	-69	63.79	106.51	120.01
			22800	23567.25	-91	42.22	84.94	98.44
			23567.25	24032.75	-131	2.45	45.17	58.67
			24032.75	24800	-91	42.67	85.39	98.89
			24800	25900	-70	64.07	106.79	120.29
			25900	26300	-27	107.07	149.79	163.29
			26300	26550	-48.07	130.50	170.50	185.50
			26550	26850	-47.87	130.70	170.70	185.70
			26850	28900	-47.35	131.40	171.40	186.40
2	31400	180	28900	30400	-53	82.76	132.17	161.17
			30400	31241.5	-93	43.1	92.51	121.51
			31241.5	31558.5	-133	3.26	52.67	81.67
			31558.5	32400	-93	43.42	92.83	121.83
			32400	33900	-54	82.73	132.14	161.14
3	50300	180	47641.5	49300	-53	79.53	136.58	149.58
			49300	50141.5	-93	39.75	96.8	109.8
			50141.5	50458.5	-133	-0.15	56.9	69.9
			50458.5	51300	-93	39.95	97	110
			51300	52800	-53	80.15	137.2	150.2
4	51760	400	49260	50760	-53	79.8	136.85	149.85
			50760	51425	-93	39.99	97.04	110.04
			51425	52095	-133	0.1	57.15	70.15
			52095	52760	-93	40.21	97.26	110.26
			52760	54260	-53	80.39	137.44	150.44
5	52800	400	50300	51800	-49	83.98	141.03	154.03
			51800	52465	-89	44.16	101.21	114.21
			52465	53135	-129	4.27	61.32	74.32
			53135	53800	-89	44.38	101.43	114.43
			53800	55300	-49	84.56	141.61	154.61
6	53596 ± 115	170	51096	52596	-49	84.11	141.16	154.16

ATMS Channel	Center Frequency	Max. Bandwidth	Frequency Range		EMI Sensitivity of ATMS Passbands			
	(MHz)	(MHz)	From (MHz)	To (MHz)	dBm	dBµV/m Boresight [1]	dBµV/m >15.5° [2]	dBµV/m >40° [3]
			52596	53316	-89	44.3	101.35	114.35
			53316	53446	-129	4.45	61.5	74.5
			53446	53746	-89	44.4	101.45	114.45
			53746	53876	-129	4.44	61.49	74.49
			53876	54596	-89	44.51	101.56	114.56
			54596	56096	-49	84.68	141.73	154.73
7	54400	400	51900	53400	-49	84.25	141.3	154.3
			53400	54065	-89	44.42	101.47	114.47
			54065	54735	-129	4.53	61.58	74.58
			54735	55400	-89	44.64	101.69	114.69
			55400	56900	-49	84.81	141.86	154.86
8	54940	400	52440	53940	-49	84.34	141.39	154.39
			53940	54605	-89	44.51	101.56	114.56
			54605	55275	-129	4.62	61.67	74.67

[1] For susceptibility to an external source along the ATMS antenna boresight, the Boresight column should be used for worst-case analysis.

[2] For susceptibility to a SC source between 15.5 and 40 degrees relative to the ATMS antenna boresight, the 15.5 degree column should be used for worst-case analysis.

[3] For susceptibility to a SC source at a 40° or greater angle relative to the ATMS antenna boresight, the 40 degree column should be used for worst-case analysis.

ANNEX 6: Filter characteristics of MWR (on Sentinel-3 operated by ESA)

Instrument name	MWR (MicroWave Radiometer)
Instrument type	Dual frequency Noise Injection Radiometer (NIR). The channel at 23.8 GHz is used for tropospheric water vapour determination and the channel at 36.5 GHz provides information on non-precipitating clouds. Anticipated radiometric sensitivity is < 0.4 K with a stability< 0.6 K, and absolute accuracy < 3 K over a brightness temperature rangeof 150–313 K. Sentinel-3 MWR radiometer is developed based on heritage from the CryoSat and Jason MWR instruments.
Objective	The MWR instrument supports the SRAL altimeter to achieve the overall altimeter mission performance by providing the wet atmosphere correction derived from ENVISAT MWR heritage. The MWR is sensitive to the amount of water vapour and liquid water content in the atmosphere over a ~20 km footprint coincident with the SRAL nadir point. In addition, MWR measurements can also be used to determine surface emissivity, "soil moisture" over land, and in support of studies on surface energy budget, atmosphere and ice characterization.
Website info	ESA: http://www.esa.int/Our_Activities/Observing_the_Earth/GMES/Sentinel-3
Mission name	SENTINEL-3 (several satellites planned: 3A, 3B, 3C) It will be an operational mission, part of the Global Monitoring for Environment and Security (GMES) Programme. GMES is headed by the European Commission (EC) in partnership with the European Space Agency (ESA) and the European Environment Agency (EEA).
Mission status	Development
Launch date	Sentinel 3A (Nov 2014), Sentinel 3B (2015)
Orbit altitude	801 km
Inclination	98.6 deg

MWR sensor characteristics (Based on measurements during development)

	K-Band channel	Ka-Band channel
RF centre frequency	23.8 GHz	36.5 GHz
EESS-passive allocation	23.6-24 GHz (400MHz)	36-37 GHz (1000 MHz)
Antenna gain	38 dBi	43 dBi
Receiver type	Single conversion, DSB LNA fitted	Single conversion, DSB LNA fitted
RF bandpass filter response(*)	Image rejection filter after LNA $B_{-10dB} \approx 3$ GHz (See FIGURE 1)	Image rejection filter after LNA $B_{-10dB} \approx 5$ GHz FIGURE 2
IF bandbass response	$B_{-13dB} =$ 250 MHz $B_{-58dB} =$ 500 MHz (See FIGURE 3)	$B_{-13dB} =$ 250 MHz $B_{-58dB} =$ 500 MHz (See FIGURE 3)

Overall Rx selectivity	FIGURE 4	FIGURE 5

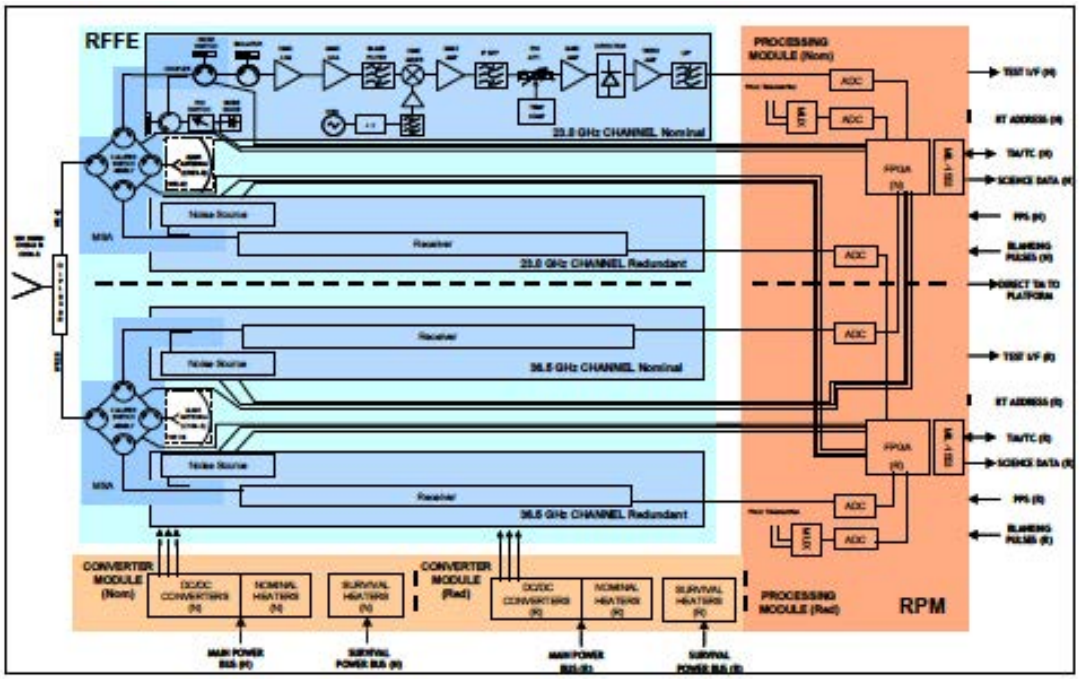


Figure 2. S-3 MWR functional architecture.

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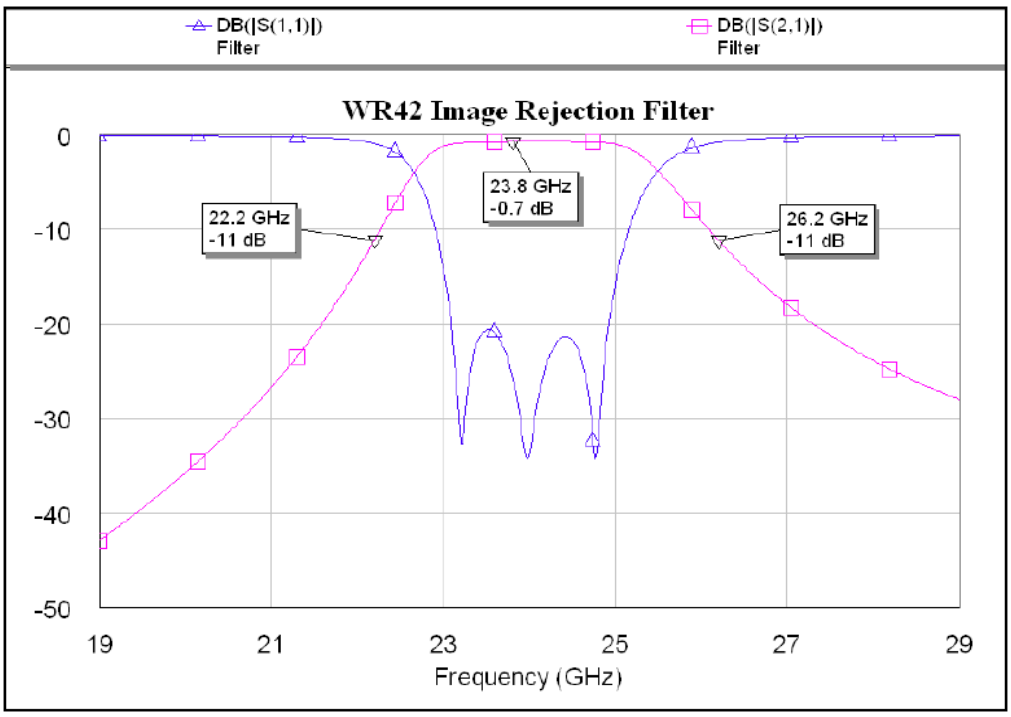

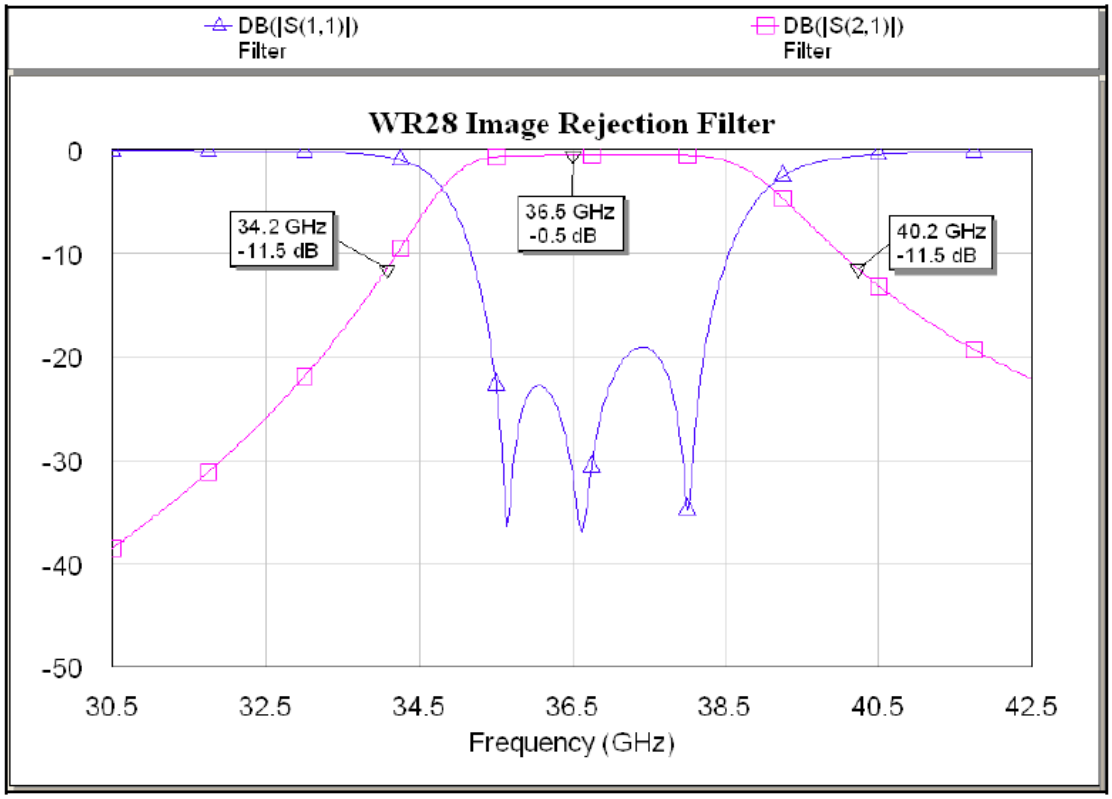

FIGURE 6-4: Sentinel-3 MWR RF Image Rejection Filter response (23.8 GHz channel)

FIGURE 6-5: Sentinel-3 MWR RF Image Rejection Filter response (36.5 GHz channel)

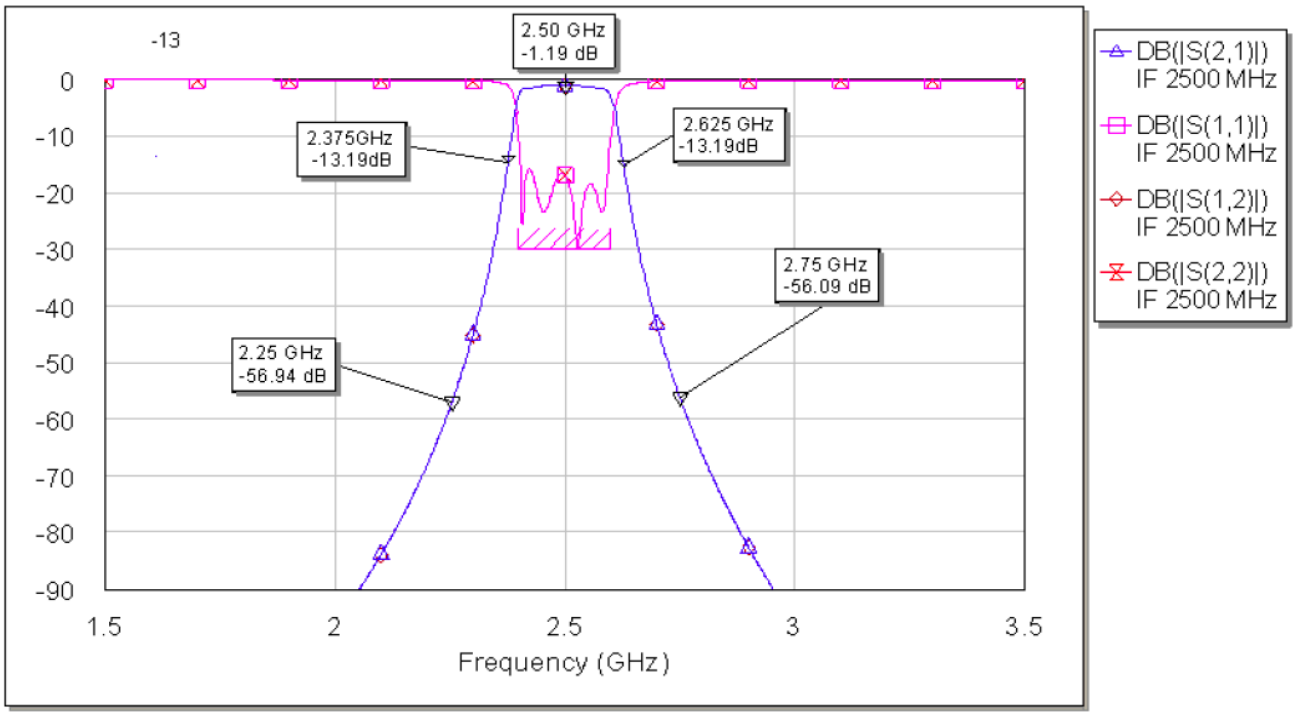

FIGURE 6-6: Sentinel-3 MWR IF Bandpass Filter response (common type for both channels)

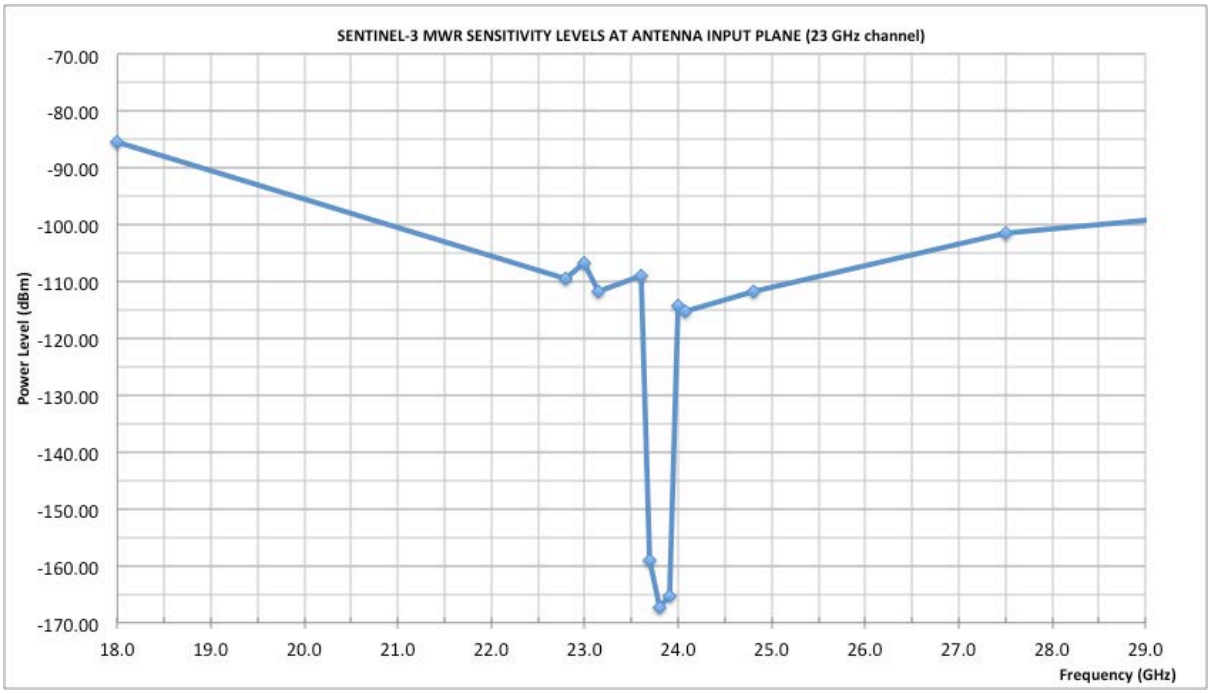

FIGURE 6-7: S3 MWR overall receiver sensitivity referred to antenna input plane (23 GHz channel)

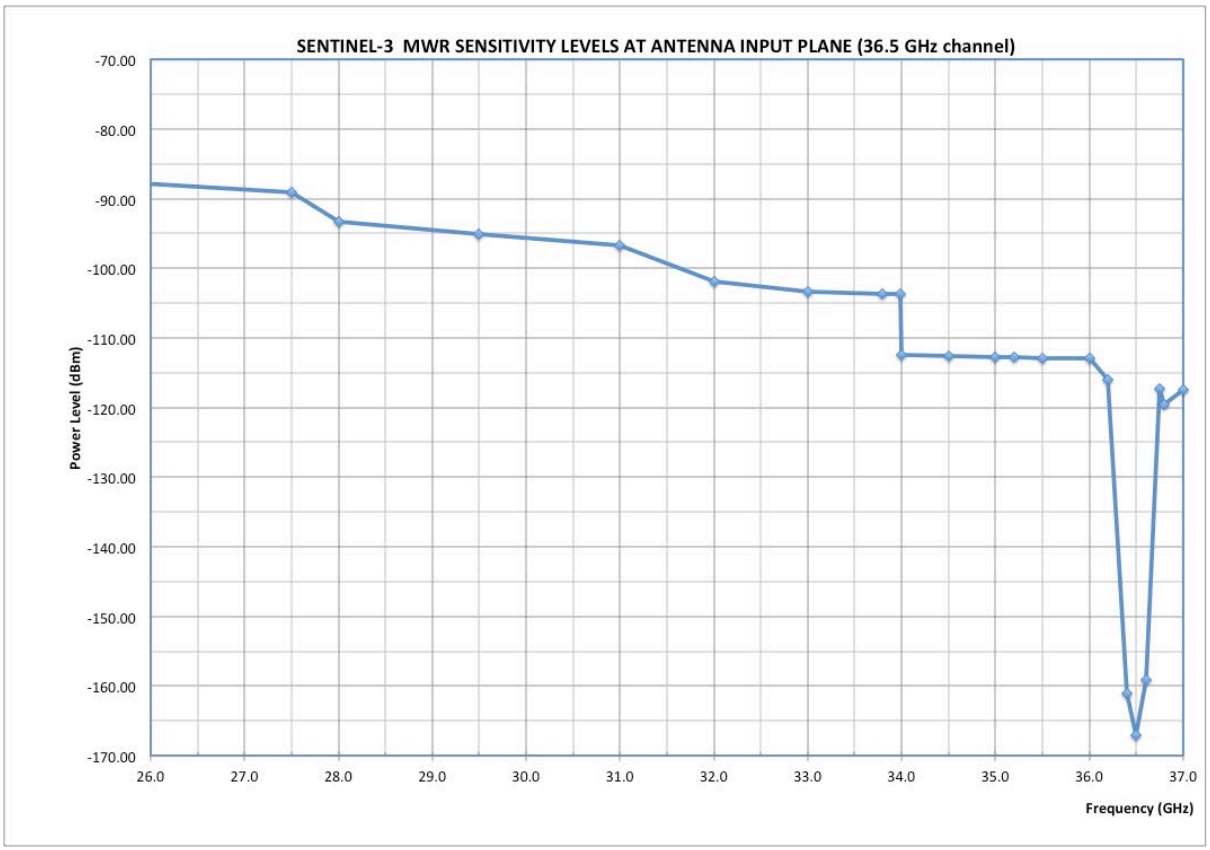

FIGURE 6-8: S3 MWR overall receiver sensitivity referred to antenna input plane (36 GHz channel)

ANNEX 7: Filter characteristics of GMI (on GPM operated by NASA)

The filter characteristics provided in this annex are from measured data at the point of the sensor detector.

1 Summary

This SER verifies the spectral requirements – bandpass width, gain variation, out-of-band rejection and frequency stability – for the GMI instrument.

Table 1 Summary of spectral requirements data for all GMI channels

Chan Num	Center Freq (GHz)	Passband (MHz)		Gain Variation (dB)		Out-of-Band Rejection (dB)		Frequency Stability (MHz)	
		Req't	Perf.	Req't.	Perf.	Req't	Perf.	Req't	Perf.
1	10.65	100	96.6	3	0.480	-40	-39.3*	10	0.17
2			95.1		0.422		-36.8*		-2.55
3	18.70	200	194.2		0.530		-40.3	20	-9.75
4			195.0		0.680		-40.1		-6.8
5	23.80	400	368.8		0.631		-42.1		-8.45
6	36.50	1000	700.0		1.820		-50.0	50	-5.77
7			708.0		1.450		-49.6		-5.75
8	89.00	6000	5880	4.6	3.170		< -50	200	-14
9			5923		3.250		-48.0		-15.7
10	166	4000	3855	3.5	2.090		-52.4		-15.2
11			3899		2.630		-54.5		-13.2
12	183.31 ± 3.0	2000	1498/1485	4.5	1.610/2.104	-35	-35.01**		-35.2
13	183.31 ± 7.0		1883/1882		2.665/1.891		-47.9		10.2

Table 2 Summary of Technical Requirements Document specifications

Channel Number	Center Freq (GHz)	Pol	Spec Passband (MHz)	Spec Gain Variation (dB)	Out of Band rejection (dB)	Frequency Stability (MHz)
1	10.65	V	100	3	-40	10
2		H				
3	18.70	V	200			20
4		H				
5	23.80	V	400			
6	36.50	V	1000			50
7		H				
8	89.00	V	6000	4.6		200
9		H				
10	166	V	4000	3.5		
11		H				
12	183.31 ± 3.0	V	2000	4.5	-35	
13	183.31 ± 7.0					

Table 3 GMI Instrument Specification for channels 1 through 11

Data Channel	Center Freq. f_c [GHz]	Pass-band Bandwidth B [MHz] (Max.)	CFS Maximum Deviation +/- (MHz)	Pol	Sample Time (msec)	Maximum NEDT (K)
1, 2	10.65	100	10	V, H	3.6	0.96
3, 4	18.70	200	20	V, H	3.6	0.84
5	23.80	400	20	V	3.6	1.05
6, 7	36.50	1000	50	V, H	3.6	0.65
8, 9	89.00	6000	200	V, H	3.6	0.57
10,11	166.0	4000	200	V,H	3.6	1.5
12	183.31 ± A *	2000	200	V	3.6	1.5
13	183.31 ± B *	2000	200	V	3.6	1.5

* The notation of (±) signifies that there are two (2) pass-bands for Channels 12 and 13, each with RF bandwidth as listed in the above column labeled Pass-band Bandwidth.

- For Channel 12, the acceptable range for setting the value of A is 2.9 to 3.1 GHz, with preference at 3.0 GHz
- For Channel 13, the acceptable range for setting the value of B is 6.9 to 7.1 GHz, with preference at 7.0 GHz

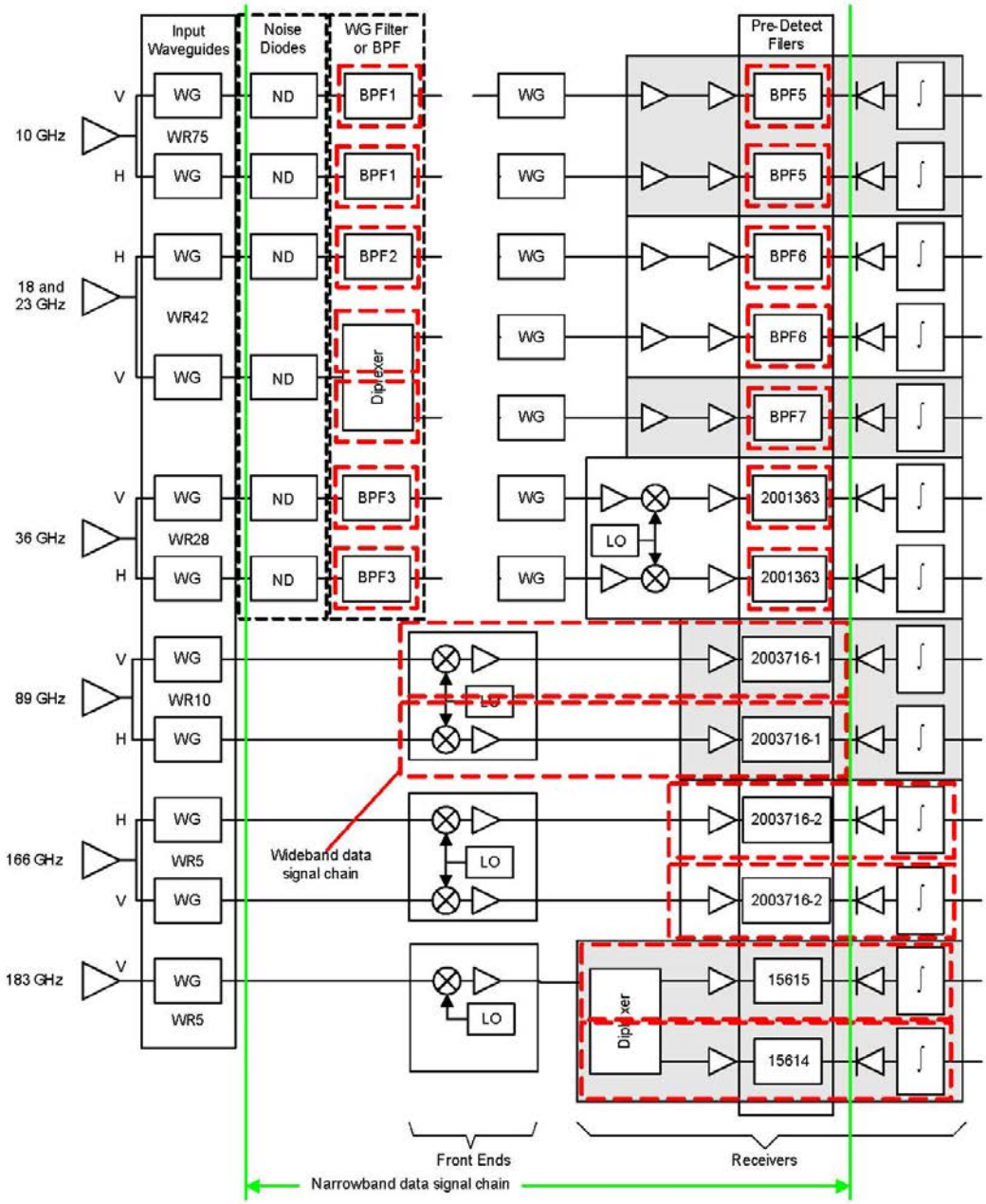

Figure 1. Block diagram of the RF portion of the GMI instrument. "WRXX" near waveguides indicates US designation. Text within blocks in "WG filter or BPF" or "Pre-Detect Filters" indicates dataset from ITT showing performance of that component. The red dashed-line boxes indicate components tested to verify OOB rejection requirements.

Space Frequency Coordination Group

Report SFCG 32-2R1

SHARING BETWEEN RNSS AND EESS (ACTIVE) IN THE 1215-1300 MHZ BAND

Abstract

This report presents an analysis of the sharing between RNSS and EESS (active) in the 1215-1300 MHz band. The report presents the results of compatibility measurements and possible compatibility measures between systems in the EESS (active) and systems in the RNSS in the band 1215-1300 MHz.

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1. Introduction

This report presents results of compatibility measurements and possible compatibility measures between systems in the EESS (active) and systems in the RNSS in the band 1215-1300 MHz.

2. Measurement of Degradation Ratio of GPS Receiver from Scatterometer2 and SAR3 Systems

2.1. Compatibility Measurement Approach

Parametric measurements were conducted for several SAR and scatterometer signal characteristics, pulse widths, PRFs and chirps. The SAR and scatterometer signals were hard-coupled into the RNSS receiver and the receiver performance was monitored and the SNR or C/N_0 was recorded as a function of the effective duty cycle at the receiver.

2.2. Synthetic Aperture radar (SAR3) and Scatterometer2 signals

The SAR3 system is a 1.26 GHz, synthetic aperture radar designed to acquire interferometric radar backscatter signals to monitor the Earth's deforming surfaces. The spaceborne radar is designed to operate at an altitude of 757 km and inclination of 98 deg to provide an average revisit time of 13 to 15 days. SAR3 has several modes with corresponding waveforms. One of the waveforms consists of a split spectrum with 20 MHz at one end of the 85 MHz allowed transmission and 5 MHz at the opposite end in order to mitigate the effects of the ionosphere on the interferometric phase. SAR3 has a reflector fed antenna with an active array feed. The active array feed consists of a single string set of 8-24 transmit/receive (T/R) modules that both transmit and receive both horizontal and vertical polarizations. Echoes received at the T/R modules are immediately digitized and digital beamforming techniques are employed to achieve the desired illumination while reducing downlink data rate. Table 1 summarizes the test characteristics of the SAR3 radar and antenna as simulated for the compatibility tests and analysis. The mode designations such as "SAR3-3" correspond to those test modes as shown in Table 3.

Table 1 Test characteristics of SAR3 Radar and Antenna

Parameters	SAR3-3	SAR3-4	SAR3-6	SAR3-8
Orbit altitude, km	757			
Orbit inclination, deg	98			
Local time of ascending node (LAN)	18:00			
Transmit (Xmt) pk pwr, W	3 200			
Antenna pk xmt gain, dBi	33.4			
e.i.r.p. pk, dBW	68.5			
Antenna pk rcv gain, dBi	41			
Antenna xmt elev. beamwidth, deg	15			
Antenna xmt az. beamwidth, deg	0.8			
Antenna rcv elev. beamwidth, deg	16.7			
Antenna rcv az. beamwidth, deg	0.8			
RF centre frequency, MHz	1 220.0 + 1 287.5	1 227.5 + 1 295.0	1 257.5	1 257.5
Polarization	Dual/quad, linear H and V			
RF bandwidth, MHz	5 + 20 (split spectrum)	20 + 5 (split spectrum)	40	78
RF pulsewidth, µsec	5 + 20	20 + 5	40	50
Pulse repetition frequency max, Hz	3 500			
Xmt Ave. pwr, W	240	240	448	560
e.i.r.p. ave, dBW	57.4	57.4	59.9	60.9
Chirp rate, MHz/µsec	1.0	1.0	1.0	1.56
Xmt duty cycle, %	8.75	8.75	14.0	17.5
Azimuth (Az) scan rate, rpm	0			
Antenna beam xmt look angle, deg	35			
Antenna beam rcv look angle, deg	35			
Antenna beam xmt az angle, deg	0			
Antenna beam rcv az angle, deg	0			
System noise temp, deg	420			

Scatterometer 2 is a 1.26 GHz radar designed to acquire radar backscatter signals to estimate surface soil moisture. The spaceborne radar is designed to operate at an altitude of 685 km and inclination of 98 deg to provide an average revisit time of 3 days for soil moisture globally. The orbit is dawn/dusk sun-synchronous. The radar will collect dual polarimetric returns (VV, HH,

and HV transmit-receive polarizations) at 3 km spatial resolution. In order to minimize range/Doppler ambiguities with the baseline antenna and viewing geometry, separate carrier frequencies are used for each polarization (e.g. 1260 MHz for H-pol and 1263 MHz for V-pol). The sub- band center frequencies are set 3 MHz apart, and the two frequencies can be selectively set within the 80 MHz range of 1217.5-1297.5 MHz to minimize RFI. The linearly FM pulses will have a pulse duration of 15 microseconds and bandwidth of 1 MHz. Table 2 summarizes the characteristics of the Scatterometer 2 radar and antenna as simulated for the compatibility tests and analysis. The mode designations such as "SCAT2-1" correspond to those test modes as shown in Table 3.

Table 2 Test characteristics of Scatterometer 2 Radar and Antenna

Parameters	SCAT2-1	SCAT2-2
Orbit altitude, km	685	
Orbit inclination, deg	98	
Local time of ascending node (LAN)	18:00	
Xmt pk pwr, W	320 maximum (230-300 typical) per polarization	
Antenna pk xmt gain, dBi	36	
e.i.r.p. peak, dBW	61.0	
Antenna xmt elev. beamwidth, deg	2.6	
Antenna xmt az. beamwidth, deg	2.6	
RF centre frequency, MHz	1 227.6 MHz	1 295.5
Polarization	Dual, linear H and V	
RF bandwidth, MHz	2 x 1	
RF pulsewidth, µsec	2 x 15	
Pulse repetition frequency max, Hz	1750	
Xmt Ave. pwr, W	16.8	
e.i.r.p. ave, dBW	48.25	
Chirp rate, MHz/µsec	0.35	
Xmt duty cycle, %	5.25	
Azimuth (Az) scan rate, rpm	14.6	
Antenna beam xmt look angle, deg	35.5	
Antenna beam xmt az angle, deg	0-360	

A SAR and scatterometer signal simulator used different combinations of the following waveform characteristics:

Pulse width:	5 µs, 15 µs, 20 µs, 40 µs and 50 µs
Chirp bandwidth:	1 MHz, 5 MHz, 20 MHz, 40 MHz and 78 MHz
Pulse Repetition Rate (PRR):	1750 Hz and 3500 Hz
Signal levels:	-125 dBW, -105 dBW, -85 dBW, and -75 dBW

Figure 1 shows a block diagram of the equipment to generate the SAR and scatterometer waveforms. For the scatterometer waveforms, there was a gating circuit to turn the signal on for 100 – 200 msec to simulate the transit of the scatterometer antenna beam rotating through the RNSS antenna beam pattern and to turn the signal off for 4 seconds to simulate the antenna rotation period of 4.1 seconds. The spaceborne SAR looks off to the side of the spacecraft at a fixed angle

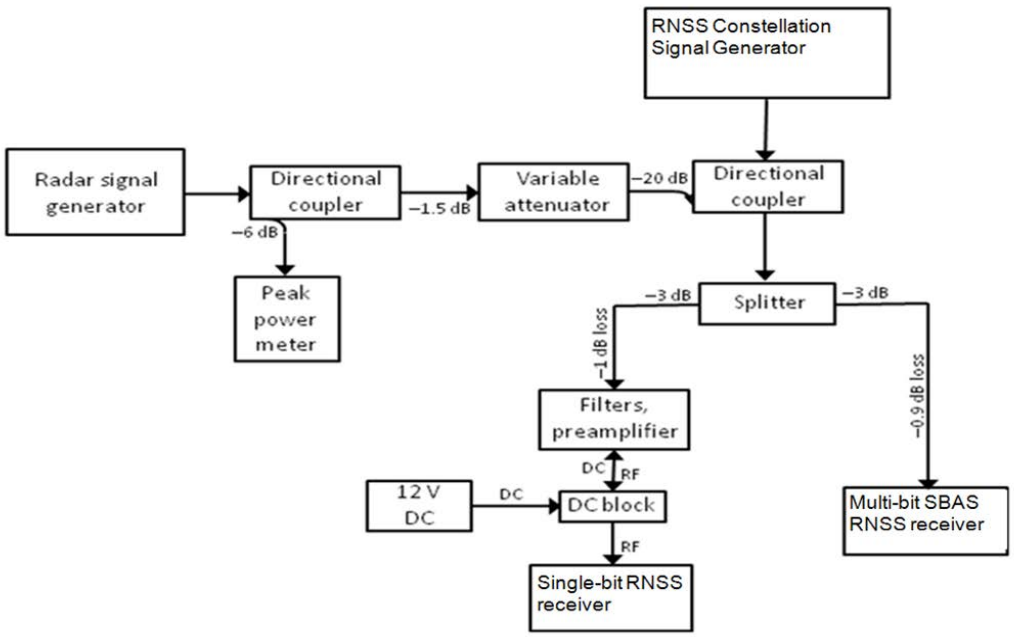


Figure 1a Test Setup with RNSS Simulator in Laboratory

The SAR and scatterometer signals were hard-coupled into the RF front-end of the RNSS receiver just after the antenna. SAR and scatterometer waveforms were monitored with a spectrum analyzer, oscilloscope and peak power meter at the input to the RNSS receiver RF stage.

The peak interfering signal levels to the RNSS ground receiver are calculated from the Scatterometer 2 at nominal altitude of 685 km. In Figure 2a, there are "spikes" of RFI occurring every 4.1 seconds as the Scatterometer 2 antenna beam rotates in azimuth toward the RNSS receiver. Figure 2a also shows below a span of 8 seconds in the orbit for two of the maximum 'spikes', and the temporal half-power width of the spikes are about 30 milliseconds. The shapes of the spikes are the modulation by the Scatterometer 2 antenna pattern in azimuth as the beam

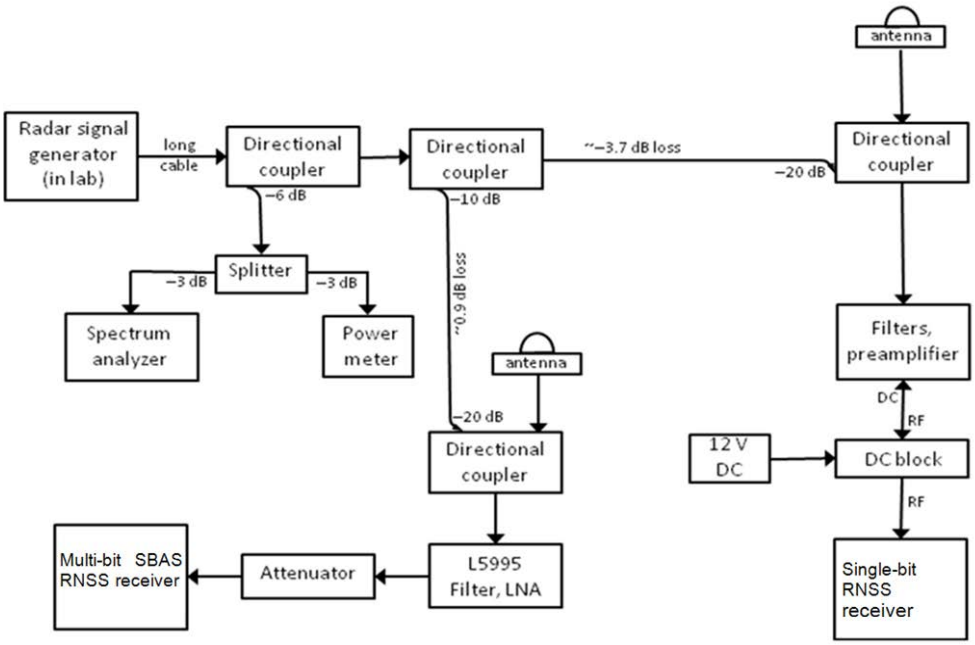
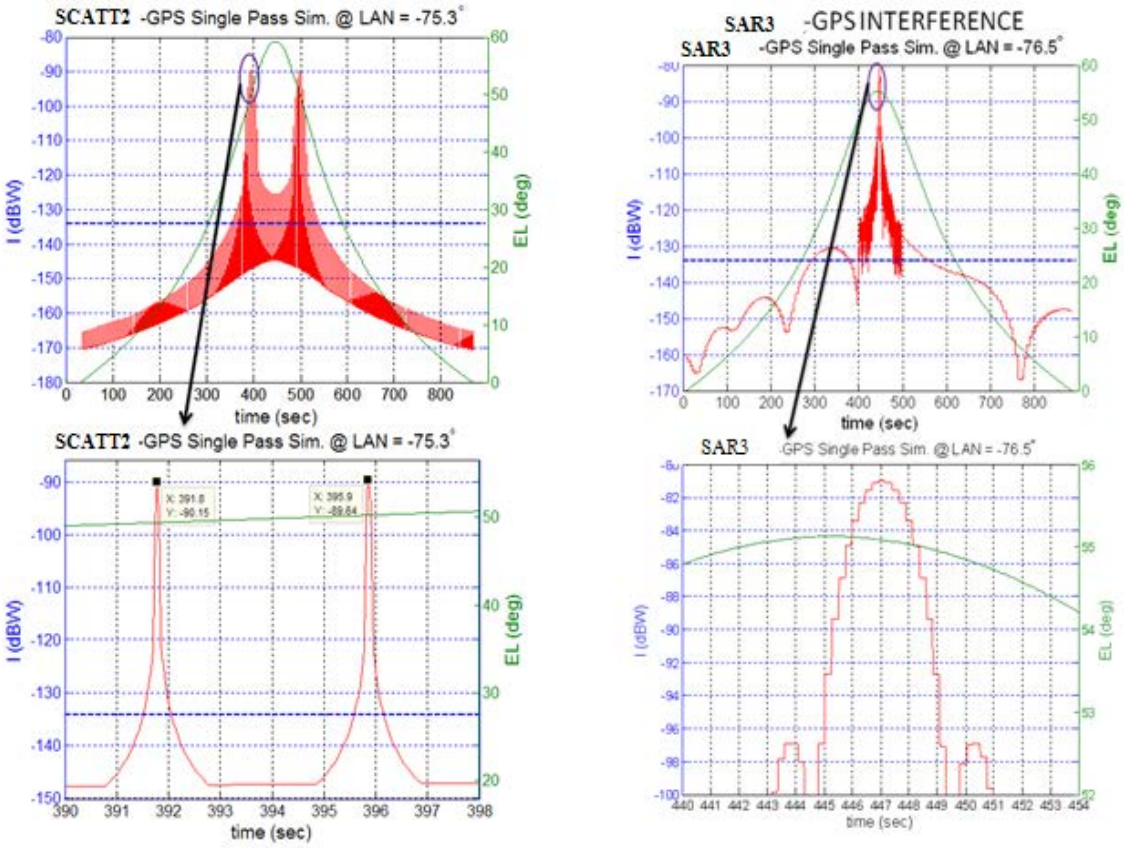


Figure 1b Test Setup with RNSS Satellite Transmissions on Roof of Building

rotates at 14.6 rpm. The peak RFI levels vary from -170 dBW at the low elevation angles at the beginning and end of the pass to about -90 dBW at 50 deg elevation angle when the Scatterometer 2 antenna beam center aligns with the RNSS receiver.

Figure 2b shows the RFI levels from SAR3 into a terrestrial RNSS receiver as a function of time during a typical pass. There is a single "spike" at the maximum elevation angle as the SAR3 antenna is pointed starboard and perpendicular to the ground nadir track toward the RNSS receiver. SAR3's antenna beamwidth in azimuth is 0.8 deg resulting in a duration of the RFI "spike" of about 2 seconds in the footprint and has a peak RFI level -82 dBW RFI levels vary from -216 dBW at the low elevation angles at the beginning of the pass and increase to above -135 dBW, a typical receiver noise level for a RNSS receiver, and sustain that level or higher for more than 250 seconds.



(a) Scatterometer 2 **(b) SAR 3**

Figure 2 Scatterometer 2 and SAR3 RFI Levels into RNSS Receiver over Typical Pass

2.3. SAR and Scatterometer Signal Calibration

The SAR and scatterometer signal simulator was calibrated to establish a prescribed signal level at the RNSS receiver input. The interference level of the generated waveform was measured at the input to the coupler using a peak power meter and monitored on a spectrum analyzer. Known values of attenuators were inserted to attain the desired interference level into the RNSS receiver. Interference signals were split to both RNSS receivers under test to allow parallel testing of both receivers.

2.4. RNSS receiver characteristics and performance criteria

Recommendation ITU-R M.1902 has the characteristics and protection criteria for RNSS receivers. Table 1-1 of Annex 1 lists seven RNSS receivers, two of which were included in the compatibility tests: the SBAS ground reference receiver RNSS1, and high precision semi-codeless RNSS2.

The following RNSS receiver performance parameters were monitored during the measurements to evaluate the effects of active spaceborne radar pulsed emissions on the system performance:

a. Decrease in SNR

b. Decrease in C/N_0

The objective of the data analysis was to determine the amount of degradation of the signal-to-noise ratio (SNR) or C/N_0 observed by the RNSS receiver in the presence of the interfering radar signal.

2.5. Measurement procedure

Several parameters of the interfering signal are varied in the different tests, including the radar type (SAR and scatterometer), power level, frequency, and gating so that the degradation varies accordingly. Each test consists of a number (ranging from two to ten) of 100-s intervals in which the interfering signal is alternately off and on. Within each 100-second interval there are ten 10-second measurements of the voltage SNR of the L2P signal for as many as twelve RNSS satellites.

2.6. Measurement results

2.6.1 Receiver Selectivity and Antenna Filter

The portion of the received interference power contained with the RNSS pre-correlator band can be calculated by multiplying the interference waveform spectrum by the combined filter response of the receiver sensitivity and the antenna filter/pre-amplifier. The combined filter response of the receiver sensitivity and the antenna filter/pre-amplifier is shown in Figure 3. The interference waveform spectra are shown in Figure 4 for the nine configurations. The product of the interference waveform spectra and the combined filter response are shown in Figure 5 for the nine configurations. Table 3 shows the pulse-width, PRF, bandwidth, and center RF frequency for the different scatterometer and SAR configurations.

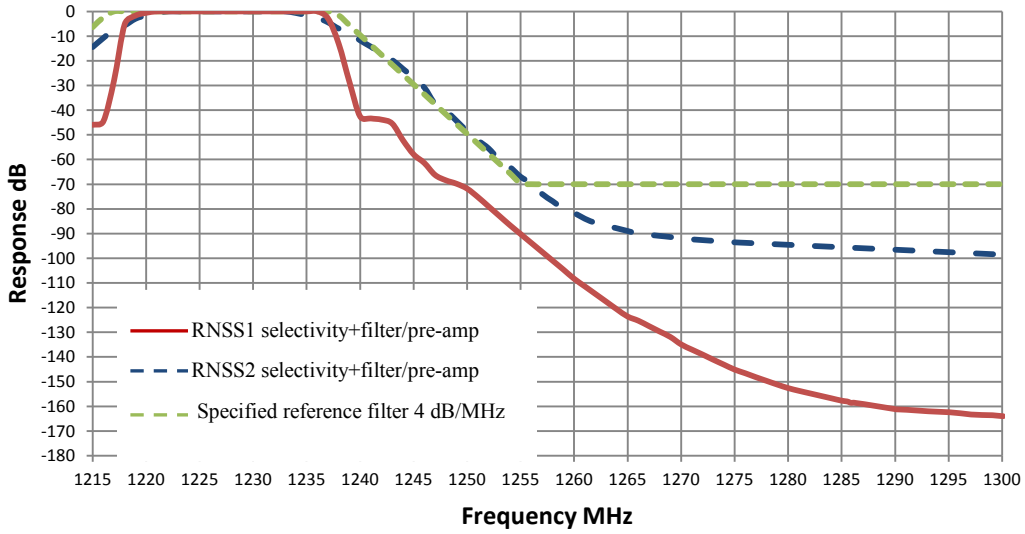
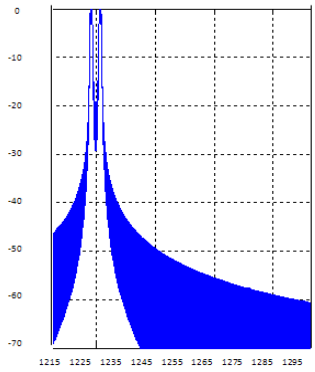
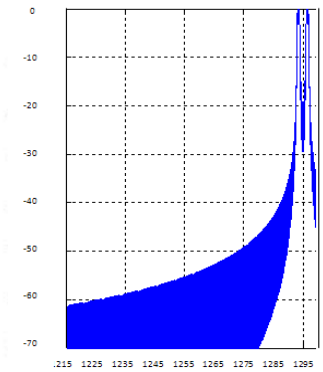


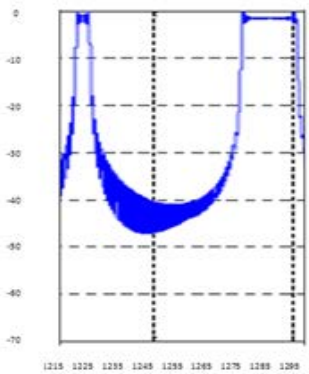
Figure 3 Total Filter Response for RNSS1 and RNSS2 Receivers



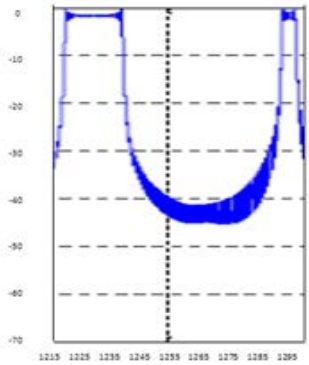
a) SCAT2-1



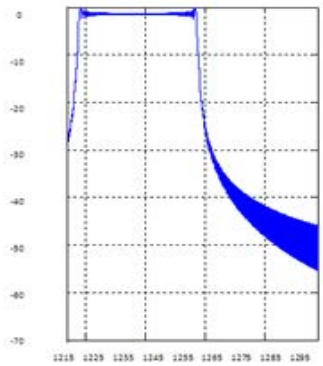
b) SCAT2-2



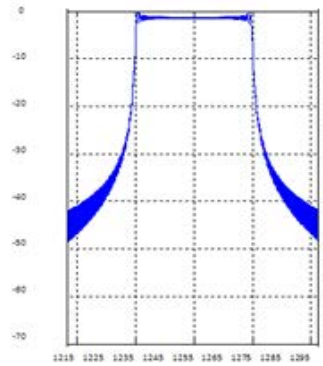
c) SAR3-3



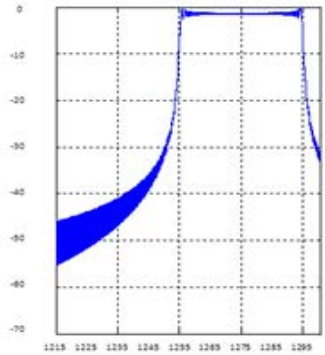
d) SAR3-4



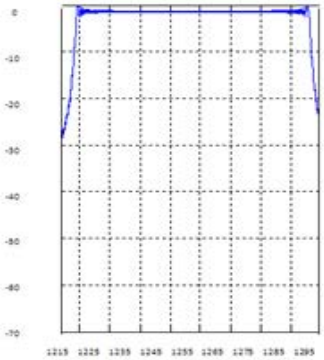
e) SAR3-5



f) SAR3-6

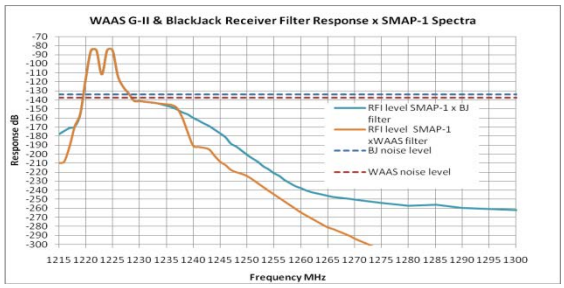


g) SAR3-7

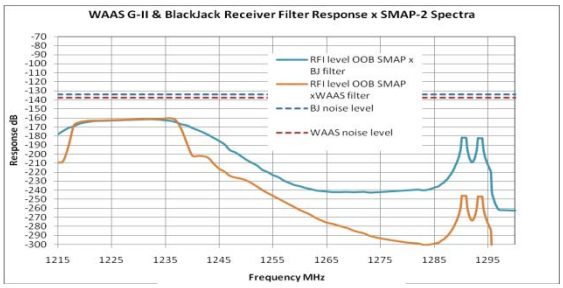


h) SAR3-8

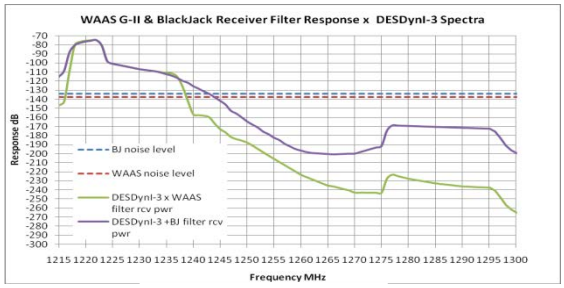
Figure 4 Relative Spectral Power over 1215-1300 MHz Band for Interference Waveforms



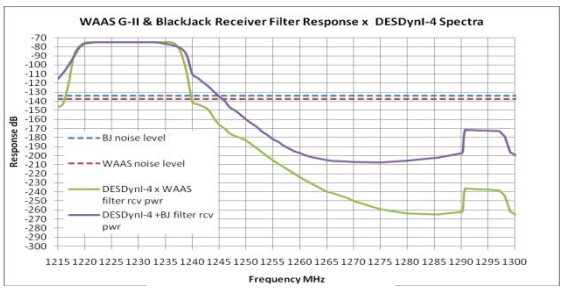
a) SCAT2-1



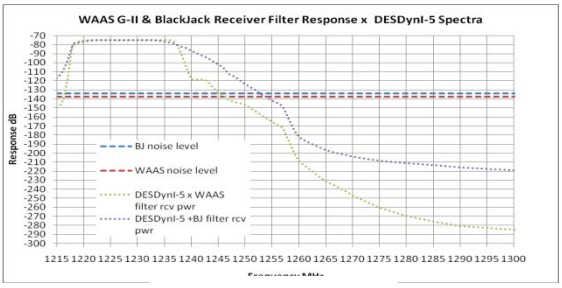
b) SCAT2-2



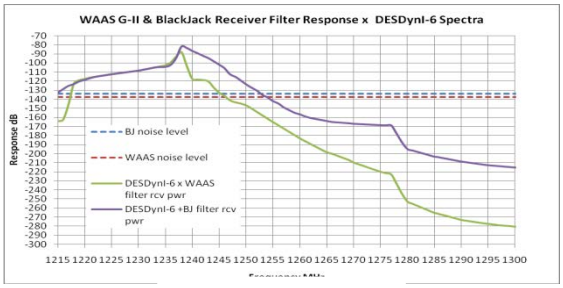
c) SAR3-3



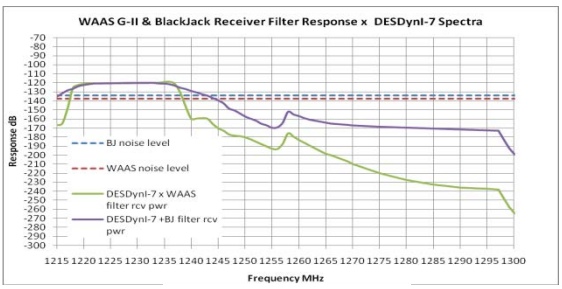
d) SAR3-4



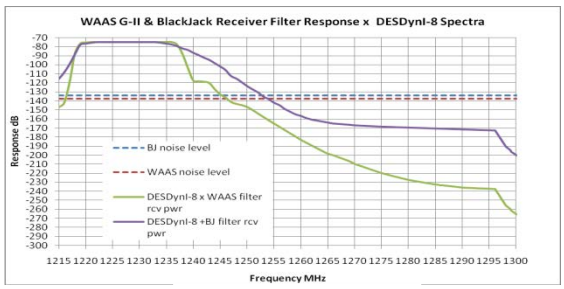
e) SAR3-5



f) SAR3-6



g) SAR3-7



h) SAR3-8

Figure 5 Received Spectral Power over 1215-1300 MHz Band for Interference Waveforms

2.6.2 C/N_0 or SNR Degradation Equation

For some EESS (active) scatterometers operating in sun-synchronous orbit, the degradation to the SNR or carrier-to-noise density can be approximated by the following equation:

$$\Delta SNR = 20\log(1 - PDC_{LIM}) \tag{1}$$

$$PDC_{LIM} = (\tau_{PW,EFF} + \tau_{RT})PRF_{EFF} \tag{2}$$

$$\tau_{PW,EFF} = \tau_{PW}\frac{BW_{overlap}}{BW} \tag{3}$$

$$PRF_{EFF} = PRF\frac{\tau_{obs}}{T_{TC}} \tag{4}$$

where:

PDC_{LIM} : fractional duty cycle of the saturating pulses (unitless ratio);

$\tau_{PW,EFF}$: the effective pulse width ,

τ_{RT} : the RNSS recovery time (0.6 µsec for RNSS1),

PRF_{EFF} : the effective pulse repetition frequency,

τ_{obs} : the observation time per cycle that the received peak power is above the RNSS input compression point (100-300 millisec for SCATTEROMETER 2), and

T_{TC} : the cycle time or time constant (4.1 sec rotation period for SCATTEROMETER 2),

τ_{PW}: the transmit pulse width (µsec)

PRF: the transmit pulse repetition frequency (e.g. PRF= 3500 Hz) ,

$BW_{overlap}$: the portion of the bandwidth which overlaps the RNSS L2 pre-correlator RF/IF band centered at 1227.6 MHz (MHz);

BW: the pre-correlator RF/IF bandwidth (MHz);

2.6.3 Measured SNR or C/N_0 Degradation versus Effective Duty Cycle

Using the equations above for the effective duty cycle, dc_{eff}, or the fractional duty cycle PDC_{LIM} as in equation (2) above, the measured SNR or C/N_0 degradation is plotted versus the dc_{eff} as shown in Figure 3. Regions of measured values of degradation can be distinguished between that for gating "ON" and gating "OFF". The measured degradation values are clustered around the trendline curve of 20 log (1-dc_{eff}).

Test results for all the tests conducted are listed in Table 3. This table represents as-run test parameters and test results. Explanation of the entries in Table 3 is as follows:

Col. 1 Contains the test number in the format (day number)-(sequence number). Day 1 is June 22, 2010, and day 4 is June 25. Also, 'roof" or "sim" indicates whether the test was conducted using signals from an antenna on the roof or from the RNSS constellation simulator.

Col. 2 Gives the type of radar signal (SCAT2 or SAR3) and a configuration number (from 1 to 8). The configuration number is intended to refer to a specific set of the parameters in columns 3 through 6.

Col. 3 Gives the pulse repetition frequency (PRF) in Hz and the pulse length or duration of each pulse in µs. SAR3 waveforms often consist of split spectrum signals that are generated as "sequential chirps" whereby the first chirp bandwidth centered on a first frequency uses a pulse length of τ_1 and the second chirp bandwidth centered at the second frequency uses a pulse length τ_2The two numbers (e.g., "10 + 40"), that are the pulse lengths of the chirps at the two frequencies in col. 4, respectively. Therefore the total transmission time is the sum of the two numbers $\tau_1 + \tau_2$. Chirp rate is kept the same on the two segments to insure a uniform power spectral density in the waveform.

Col. 4 Gives the bandwidth and the RF center frequency. The waveform consists of a signal whose frequency changes linearly in time (a "chirp"). If there is a single number in this column, it is the bandwidth or the difference in frequency between the end and the beginning of the pulse. Using the pulse length (col. 3), frequency rate or chirp rate can be computed.

In some cases radar system specific designations are used. For the SCAT2 tests, this column always says "2 x 1," to designate that two 1 MHz bandwidth signal separated by 3 MHz were generated. Two implementations were employed. Most SCAT2 testing was conducted is the so called "sequential chirp" mode where the waveform consisted of two contiguous 15 µs wide segments having bandwidths of 1 MHz and a 3 MHz separation pulsed at a PRF of 1750 Hz. A second waveform consisted of two simultaneously generated pulses, both with a 15 µs pulse length and a PRF of 3500 Hz.

For the SAR3 tests there are several entries like "5 + 20." This means a 5-MHz chirp bandwidth centered on the first frequency in col. 4 followed by a 20-MHz chirp bandwidth at the second frequency in col. 4.

Also given is the center frequency of the pulses. For some systems, i.e., SAR3, where there are two numbers, they correspond to the center frequencies of the two sequential chirps. For SCAT2 tests, the single number is the middle of the total frequency range spanned by the two pulses—that is, the mean of the lowest frequency transmitted in the lower-frequency pulse and the highest frequency transmitted in the higher-frequency pulse.

Col. 5 Gives the power coupled into the receiver preamplifier during a pulse with the "gate" open and also indicates whether gating was on.

Col. 6 Provides the timing parameters for the gating circuit. It is specified by two numbers with the format: (time interval during which gate is open in seconds)/(total gating period in seconds). For example, "0.1/4.1" means that in a 4.1-second interval, the gate is open, and pulses are being transmitted, for 0.1 second. Then during the remaining 4.0 seconds the gate is closed, and the pulses are transmitted with 60 dB of attenuation.

Col. 7 Contains the observed Δ_{SNRP} estimated for the RNSS1 (SBAS) receiver.

Col. 8 Contains the observed $\Delta C/N_0$ estimated for the RNSS2 (high precision semi-codeless) receiver.

Col 9 Contains the model estimates of Δ_{SNRP}, the power SNR loss caused by radar interference. The lower end of the range is the estimate based on the assumption that only interference within 10 MHz of the L2 center frequency, 1227.6 MHz, is effective. It is an approximate lower bound on Δ_{SNRP}. The higher end of the range assumes that all interferenceinterference impacts the RNSS receiver'seffective noise floor. It is a hard upper bound on Δ_{SNRP}.

Using the equations (1) to (4) above the effective duty cycle, dc_{eff}, or the fractional duty cycle PDC_{LIM} as in equation (2) above, is estimated for each test run in Table 4.

2.7. Possible Mitigation Measures

In the previous section on "Measurement Results", the degradation to the SNR, ΔSNR, or degradation to the carrier-to-noise density, $\Delta C/N_0$, can be approximated by equations 1-4. There are possible mitigation measures that would reduce the degradation by adjusting the parameter values in the equations 1-4.

2.7.1 Reduction of the Ratio of Chirp Bandwidth Overlapping the Pre-Correlator Band

In equation 3, the effective pulsewidth is reduced by the factor of the ratio of the chirp bandwidth which overlaps the pre-correlator band to the pre-correlator bandwidth. As an example, SAR3 has the wideband mode where only 20 MHz of the 78 MHz wide (-3 dB bandwidth) overlaps the 20 MHz wide GPS L2 pre-correlator bandwidth, such that the effective pulsewidth is reduced by a factor of 0.26 (20 MHz / 78 MHz). As a second example, SAR3 has a split-spectrum mode where there is a 5 MHz bandwidth with 5 usec pulsewidth component and a 20 MHz bandwidth with 20 usec pulsewidth component; the components are separated by the maximum possible within the 1215-1300 MHz band for optimum InSAR height accuracy. By placing the component with the lowest duty cycle (5 usec x 1955 Hz) within the GPS L2 pre-correlator band, the degradation is reduced by a factor of 0.25 (5 usec/ 20 usec). As a third example, SAR3 has two additional modes whereby a single chirp with either 5 MHz bandwidth with 20 usec pulsewidth or 20 MHz bandwidth with 40 usec pulsewidth is placed within the 1215-1300 MHz band. By placing the single chirp outside of the GPS L2 pre-correlator band to eliminate any overlap, the SNR degradation is reduced greatly.

2.7.2 Reduction of the Ratio of Observation Time per Cycle

In equation 4, the effective pulse repetition frequency is reduced by the factor of the ratio of the observation time per cycle to the cycle time period. As an example, Scatterometer2 rotates its

antenna beam in azimuth 360 deg each 4.1 seconds with a 14.6 rpm rate. The azimuth beam footprint is observed at the ground receiver only a maximum of 300 millisec each 4.1 second period, for a reduction to the PRF by a factor of 0.073 (0.3 sec/ 4.1 sec). As a second example, Scatterometer1 switches among its three non-overlapping beams every 60 millisec, and then repeats the switching during the next 180 millisec period, for a reduction to the PRF by a factor of 0.33 (60 millisec/ 180 millisec).

2.8. Conclusions related to the GPS receiver protection

In conclusion, the overall results of the GPS/EESS (active) study are:

1) The effect of pulsed RF interference from the two spaceborne radars Scatterometer 2 and SAR3 upon the two RNSS receivers is a change in SNR or C/N_0 of less than 0.1 dB for Scatterometer 2 and less than -1.4 dB for SAR3 for maximum RFI levels at the RNSS receivers. With mitigation measures, the SAR3 degradation to SNR can be reduced from -1.4 dB to -0.1 dB.
2) Accounting for the dynamics and temporal aspects of the radar antenna beam coupling with the RNSS antenna beam by gating in the test setup reduces the effective duty cycle that the RFI levels are above the RNSS receiver noise level from the transmit pulse-to-pulse duty cycle by a factor of about 40 for Scatterometer 2.
3) Accounting for the overlap of the radar transmit spectrum with the 20 MHz wide RNSS band reduces the effective pulse-to-pulse duty cycle as well. The Scatterometer 2 signal with dual 1 MHz wide frequencies is tunable and can be positioned within the 80 MHz band from 1217.5 MHz to 1297.5 MHz. The 4 MHz wide envelope of the dual spectra would then overlap the RNSS band when close to the center of the RNSS band at 1227.6 MHz.
4) Accounting for the overlap of the SAR3 transmit spectrum with the 20 MHz wide RNSS band also reduces its effective pulse-to-pulse duty cycle as well. The SAR3 split spectrum signal with “20 MHz + 5 MHz” has the lower duty cycle 5 MHz, 5 usec component located at the lower end of the 1215-1300 band centered around 1220 MHz such that the higher duty cycle 20 MHz, 20 usec component does not overlap with the GPS L2 band. The SAR3 20 MHz wide signal can be centered at 1275.5 MHz again with no overlap with the RNSS band. The SAR3 78 MHz wide signal is centered at 1257.5 MHz with about one-fourth of its bandwidth overlapping the RNSS band.

Table 3 Summary of L2 C/N_0 and SNR Degradation

1	2	3	4	5	6	7	8	9
Run No.	**Configuration**	**Pulsewidth (µsec) / PRF (Hz)**	**Bandwidth (MHz) / Centre RF Frequency (MHz)**	**Power (dBW) / Gating**	**Gating Timing (sec/sec)**	**RNSS1 L2 (SBAS/WAAS) C/No µ (dB)**	**RNSS2 L2 (High Precision Semi-codeless) SNR [3] µ (dB)**	**Model SNR Loss[4] (dB)**
2-2 (Roof)	SCAT2-1	(2 x 15)/1 750	(1 x 2)/ 1 227.6	−85/OFF		−0.61	−0.43	−0.47
3-6 (Sim.)						−0.36	−0.51	−0.47
4-1 (Sim.)						−0.38	N/A	−0.47
4-8 (Roof)						−0.41	−0.65	−0.47
3-3 (Sim.)				−105/OFF		−0.32	N/A	−0.47
4-5 (Sim.)				−125/OFF		−0.73	−0.32	−0.47
3-5 (Sim.)				−85/ON	0.1/4.1	0.03	−0.05	−0.01
4-2 (Sim.)[1]					0.1/4.1	0.03	N/A	−0.01
4-9 (Roof)					0.1/4.1	0.04	−0.05	−0.01
3-2 (Sim.)				−105/ON	0.1/4.1	−0.02	N/A	−0.01
3-4 (Sim.)[2]					0.2/4.1	−0.02	−0.04	−0.02
3-7 (Sim)	SCAT2-2	(2 x 15)/1 750	(1 x 2)/ 1 295.5	−85/OFF		N/A	−0.05	0 to −0.01
4-3 (Sim.)						0.00	N/A	0 to −0.47
4-4 (Sim.)				−85/ON	0.1/4.1	0.01	N/A	0.01
4-10 (Roof)					0.1/4.1	−0.01	−0.10	0.01
3-9 (Sim.)	SAR3-3	(10 + 40)/ 3 500	(5 + 20)/ (1 220.0 + 1 287.5)	−75/OFF		−0.53	−1.17	−0.28 to −1.4
3-11 (Sim.)	SAR3-4	(40 + 10)/ 3 500	(20 + 5)/ (1 227.5 + 1 295.0)	−75/OFF		−1.41	−1.43	−1.3 to −1.67
3-13 (Sim.)[1]	SAR3-6	40/3 500	40/1 257.5	−75/OFF		−0.10	−0.74	0 to −1.31
3-15 (Sim.)	SAR3-8	50/3 500	78/1 257.5	−75/OFF		−0.56	−1.05	−0.38 to −1.67

NOTE 1 – Only two ON cycles available for processing

NOTE 2 – 200 ms/4.1 s instead of 100 ms/4.1 s for all other SCAT2 tests

NOTE 3 – Visual Partition results used when available, otherwise Matched Filter results used

NOTE 4 – Range of values for effect of only in-band signal or both in-band and out-of-band signals

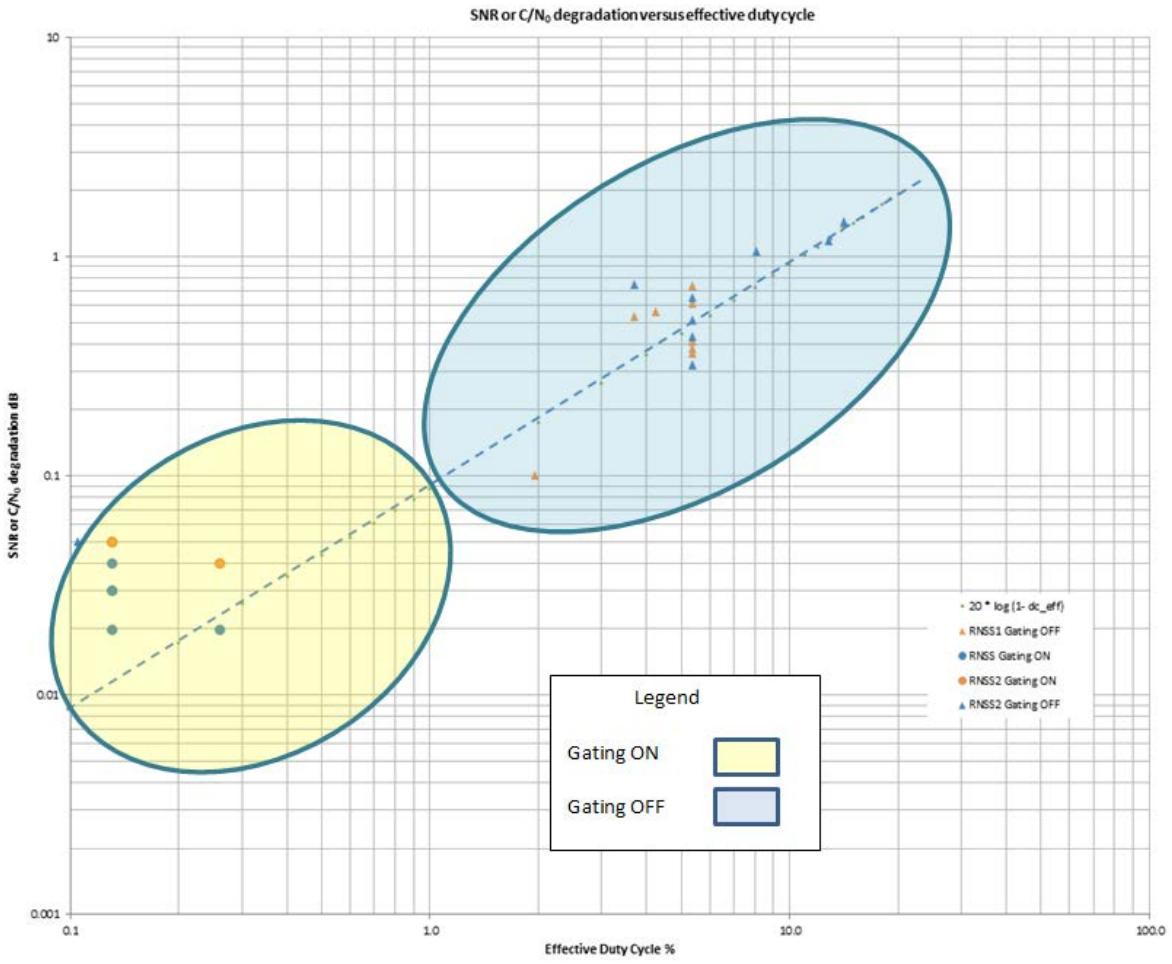


Figure 3 Measured SNR or C/N_0 Degradation versus Effective Duty Cycle

Table 4

Calculation of fractional duty cycle PDC_{LIM}

Run No.	$\tau_{PW,EFF}$ (usec) [eq (3)]		PRF_{EFF} (Hz) [eq (4)]		PDC_{LIM} (%) [eq (2)]	
	RNSS1	RNSS2	RNSS1	RNSS2	RNSS1	RNSS2
2-2	30.000	30.000	1 750.000	1 750.000	5.355	5.268
3-6	30.000	30.000	1 750.000	1 750.000	5.355	5.268
4-1	30.000	30.000	1 750.000	1 750.000	5.355	5.268
4-8	30.000	30.000	1 750.000	1 750.000	5.355	5.268
3-3	30.000	30.000	1 750.000	1 750.000	5.355	5.268
4-5	30.000	30.000	1 750.000	1 750.000	5.355	5.268
3-5	30.000	30.000	42.683	42.683	0.131	0.128
4-2	30.000	30.000	42.683	42.683	0.131	0.128
4-9	30.000	30.000	42.683	42.683	0.131	0.128
3-2	30.000	30.000	42.683	42.683	0.131	0.128
3-4	30.000	30.000	85.366	85.366	0.261	0.257
3-7	0.000	0.000	1 750.000	1 750.000	0.105	0.018
4-3	0.000	0.000	1 750.000	1 750.000	0.105	0.018
4-4	0.000	0.000	42.683	42.683	0.003	0.000
4-10	0.000	0.000	42.683	42.683	0.003	0.000
3-9	10.000	36.000	3 500.000	3 500.000	3.710	12.635
3-11	40.000	40.000	3 500.000	3 500.000	14.210	14.035
3-13	5.000	10.000	3 500.000	3 500.000	1.960	3.535
3-15	11.538	22.436	3 500.000	3 500.000	4.248	7.888

3 Measurement of Degradation Ratio of QZSS Receivers from ALOS-2 SAR System

To confirm the degradation of QZSS LEX signal affected by ALOS-2 signals, JAXA had the compatibility test in 2011. Figure 4 shows the configuration of the compatibility test.

The QZSS signal transmitted from the satellite was received at GPS antenna on the roof of the facility in Tsukuba Space Center, and mixed with the ALOS-2 signals generated by ALOS-2 Engineering Models (EM) at the hybrid. The characteristics of ALOS-2 signals included the pulse width, PRF, bandwidth, and the RF duty cycle were worst case in each observation modes of ALOS-2.

The test case and results of the compatibility tests shows the Table 5. The SNR degradation typically ranges from -0.23 dB to -0.88 dB.

FIGURE 4

The configuration of compatibility test between QZSS receiver and ALOS-2

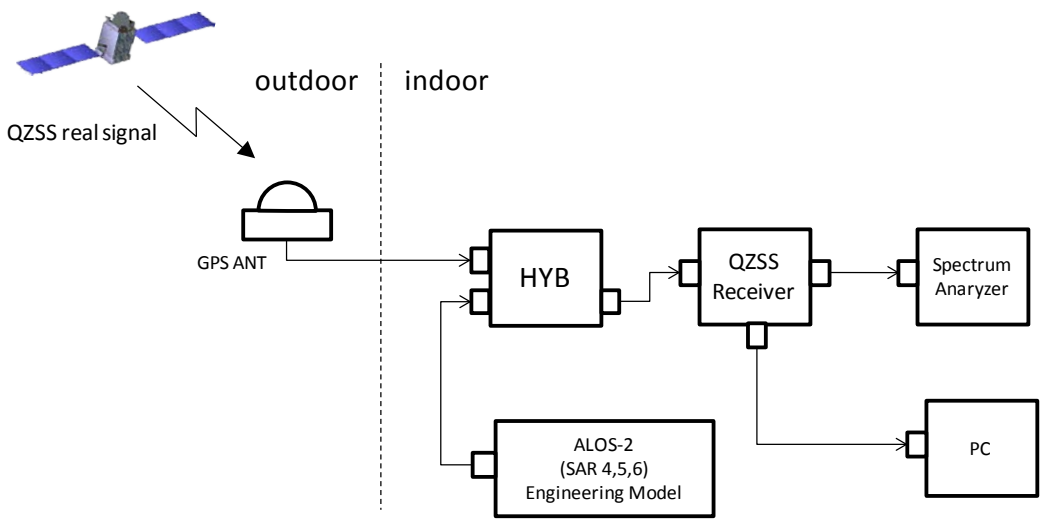


TABLE 5

Static Degradation measurements in QZSS/ALOS-2 compatibility demonstration test

Demonstration test step configuration The level into the QZSS receiver is the maximum level: -71.48 dBW for the worst case test	**Lock/ No lock**	**LEX SNR change (dB)**	**L2C SNR change (dB)**
84 MHz bandwidth, PRF=1 960 Hz, Pulsewidth=51 µs Center frequency: 1257.5 MHz (SAR4)	Lock	-0.88	-0.66
42 MHz bandwidth, PRF=1 477 Hz, Pulsewidth=46 µs Center frequency: 1257.5 MHz	Lock	-0.72	-0.35
28 MHz bandwidth, PRF=2 637 Hz, Pulsewidth=25 µs Center frequency: 1257.5 MHz (SAR6)	Lock	-0.58	-0.32
14 MHz bandwidth, PRF=1 915 Hz, Pulsewidth=36.6 µs Center frequency: 1257.5 MHz(SAR5)	Lock	-0.67	-0.32
42 MHz bandwidth, PRF=2 900 Hz Pulsewidth=23.4 µs Center frequency: 1257.5 MHz	Lock	-0.60	-0.27
28 MHz bandwidth, PRF=4 400 Hz, Pulsewidth=15 µs Center frequency: 1257.5 MHz(SAR6)	Lock	-0.47	-0.23
14 MHz bandwidth, PRF=1 915 Hz Pulsewidth=36.6 µs Center frequency : 1236.5 MHz(SAR5)	Lock	-0.34	-0.50
28 MHz bandwidth, PRF=2 637 Hz, Pulsewidth=25 µs Center frequency: 1278.5 MHz(SAR6)	Lock	-0.65	-0.40

4 Conclusion

This document analyzes the sharing between RNSS (GPS and QZSS) and EESS (active) in the 1215-1300 MHz band and presents results of compatibility measurements and possible compatibility measures between systems in the EESS (active) and systems in the RNSS in the band 1215-1300 MHz.

The effect of pulsed RF interference from the two spaceborne radars Scatterometer 2 and SAR3 upon the two GPS receivers is a change in SNR or C/N_0 of less than 0.1 dB for Scatterometer 2 and less than -1.4 dB for SAR3 for maximum RFI levels at the RNSS receivers. With mitigation measures, the SAR3 degradation to SNR can be reduced from -1.4 dB to -0.1 dB.

For the QZSS receivers, the SNR degradation from ALOS-2 SAR typically ranges from -0.23 dB to -0.88 dB.

Report SFCG 33-1

ASSESSMENT OF TECHNIQUES TO MITIGATE INTERFERENCE POTENTIAL FROM EESS (ACTIVE) SCATTEROMETER INTO ARNS SYSTEMS IN 1215-1300 MHZ BAND

Abstract

This draft SFCG report assesses the techniques to mitigate interference potential from one Earth exploration-satellite service (EESS) (active) scatterometer system into three ARNS systems in the 1 215-1 300 MHz frequency band, and shows how the mitigation techniques lower the interference levels.

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7. Summary 12

1. Introduction

This document analyzes the potential interference from one Earth exploration-satellite service (EESS) (active) system into three ARNS systems in the 1 215-1 300 MHz frequency band, and possible mitigation techniques to lower the interference levels.

2. Description of EESS (active) Scatterometer2

The Scatterometer 2 is a 1.26 GHz, radar scatterometer designed to acquire radar backscatter signals to estimate surface soil moisture. The spaceborne radar is designed to operate at an altitude of 685 km and inclination of 98 degrees to provide an average revisit time of 3 days for soil moisture globally. The orbit is dawn/dusk sun-synchronous. The radar will collect dual polarimetric returns (VV, HH, and HV transmit-receive polarizations) at 3 km spatial resolution. In order to minimize range/Doppler ambiguities with the baseline antenna and viewing geometry, separate carrier frequencies are used for each polarization (e.g., 1260 MHz for H-pol and 1263 MHz for V-pol). The sub- band center frequencies are set 3 MHz apart, and the two frequencies can be selectively set within the 80 MHz range of 1217.5-1297.5 MHz to minimize RFI. The linearly FM pulses will have a pulse duration of 15 microseconds and bandwidth of 1 MHz. Table 1 shows the characteristics of the Scatterometer 2 radar and antenna. Figure 1a illustrates the Scatterometer2 in orbit and Figure 1b illustrates the measurement geometry with the rotating antenna.

Table 1 - Characteristics of Scatterometer 2 Radar and Antenna

Parameters	Scatterometer 2
Orbit altitude, km	685
Orbit inclination, degrees	98
Transmit Pk pwr,W	320 W maximum (230 – 300 W typical) per polarization
Antenna Pk Xmt Gain, dBi	36
EIRP peak, dBW	61.0 maximum
Antenna xmt elev. beamwidth, degrees	2.6
Antenna xmt az. beamwidth,degrees	2.6
RF center frequency, MHz	Tunable from 1217.25 MHz to 1297.75 MHz
Polarization	Dual, linear H and V
RF bandwidth, MHz	1
RF pulsewidth, usec	2 x 15
Pulse Repetition frequency max, Hz	3200
Transmit Ave. pwr,W	15 W max per polarization
EIRP ave, dBW	50.7
Chirp rate, MHz/usec	0.067
Transmit duty cycle, %	2 x 4.8
Azimuth scan rate, rpm	14.6
Antenna beam xmt look angle, degrees	35.5
Antenna beam xmt azimuth angle, degrees	0-360

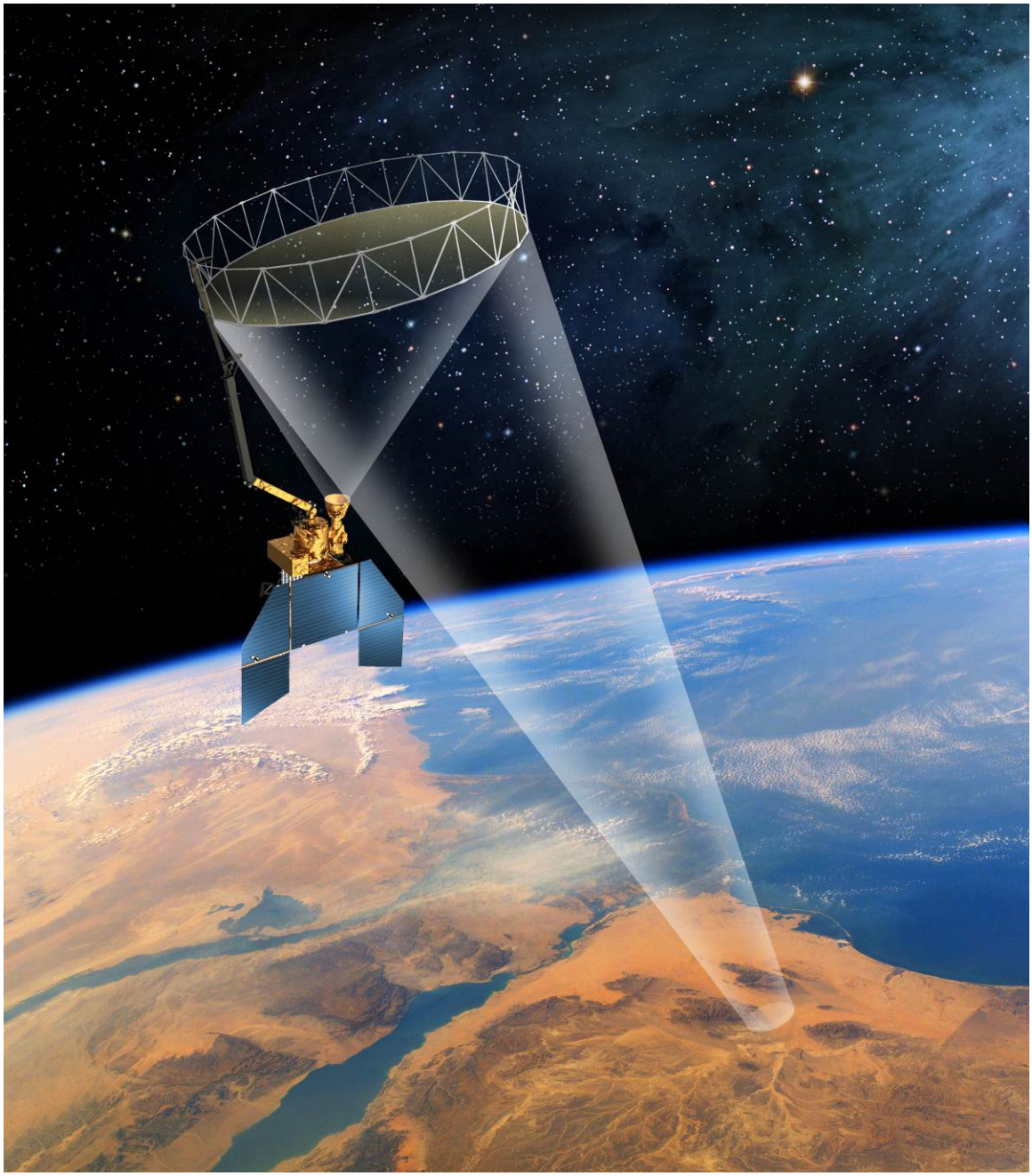

Figure 1a. Illustration of Scatterometer2 in Orbit

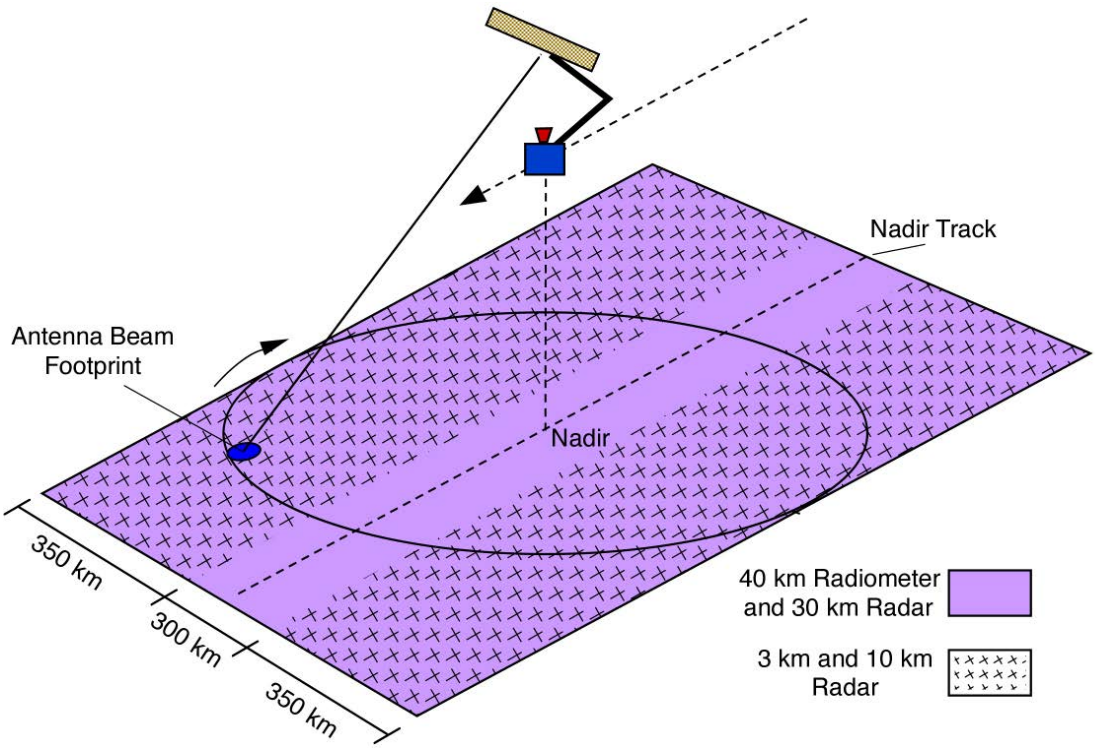

Figure 1b – Scatterometer2 measurement geometry showing the rotating antenna and the 1000 km ground swath that is swept out as the spacecraft moves in a 680 km orbit. The beam footprint is shown in blue.

3. Description of the Three ARNS Systems

The three ARNS systems being considered in the simulations are shown in Table 1. The system characteristics of Systems 1,2, and 8 are taken from Table 1 of Preliminary Draft Revision of Recommendation ITU-R M.1463 "Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz".

Table 2. 1 215-1 400 MHz radiodetermination system characteristics of Systems 1,2 and 8

Parameter	System 1	System 2	System 8
Peak power into antenna (dBm)	97	80	78.8
Frequency range (MHz)			1 240-1 350
Pulse duration (µs)	2	88.8; 58.8 (Note 1)	120 ; 22 (NOTE 4)
Pulse repetition rate (pps)	310-380 staggered	291.5 or 312.5 average	319average
Chirp bandwidth for frequency modulated (chirped) pulses	Not applicable	770 kHz for both pulse widths	1.2 MHz; 1.0 MHz;
Phase-coded sub-pulse width (µs)	Not applicable	Not applicable	Not applicable
Compression ratio	Not applicable	68.3:1 and 45.2:1	144 :1 and 22 :1
RF emission bandwidth (3 dB) (MHz)	0.5	1.09	1.2
Output device	Klystron	Transistor	Transistor
Antenna type	Horn-fed reflector	Stack beam reflector	Horn-fed reflector
Antenna polarization	Horizontal, vertical, LHCP, RHCP	Vertical, circular	Vertical ;RHCP
Antenna maximum gain (dBi)	34.5, transmit 33.5, receive	32.4-34.2, transmit 31.7-38.9, receive	34
Antenna elevation beamwidth (degrees)	3.6 shaped to 44	3.63-5.61, transmit 2.02-8.79, receive	3.7 shaped to 44 (cosecant squared)
Antenna azimuthal beamwidth (degrees)	1.2	1.4	1.2
Antenna horizontal scan characteristics (rpm)	360ºmechanical at 5 rpm	360ºmechanical at 5 rpm	360ºmechanical at 5 rpm
Antenna vertical scan characteristics (degrees)	Not applicable	–7 to +30 in 12.8 or 13.7 ms	Not applicable
Receiver IF bandwidth	780 kHz	0.69 MHz	1.2 MHz
Receiver noise figure (dB)	2	2	3.2
Platform type	Fixed	Fixed	Fixed
Time system operates (%)	100	100	100

LHCP: left-hand circularly polarized

RHCP: right-hand circularly polarized

NOTE 1 – The radar has 44 RF channel pairs with one of 44 RF channel pairs selected in normal mode. The transmitted waveform consists of an 88.8 µs pulse at frequency f_1 followed by a 58.8 µs pulse at frequency f_2. Separation of f_1 and f_2 is 82.854 MHz.

NOTE 4 –This radar utilizes two fundamental carriers, F1 and F2, with two sub-pulses each, one for medium range detection and one for long range detection. The carriers are tunable in 0.1 MHz increments with a minimum separation of 26 MHz between F1 and F2. The carrier sub-pulses are separated by a fixed value of 5.18 MHz. The pulse sequence is as follows: 120 µs pulse at F1 + 2.59 MHz, then a 120 µs pulse at F2 + 2.59 MHz, then a 22 µs pulse at F2 – 2.59 MHz, then a 22 µs pulse at F1 – 2.59 MHz. All four pulses are transmitted within a single pulse repetition interval.

4. I/N Curves of Single Pass of Spacecraft over ARNS sites

Short duration single pass simulations that only included orbits within the visibility circle of the ARNS radar site obtain assessments of I/N levels under conditions with different antenna beam couplings. The longitude of the ascending node (LAN) of the orbits were generally selected to test "stressing" conditions, where all three coupling levels occurred in the same orbit (Scatterometer main-lobe to ARNS side-lobe, Scatterometer2 side-lobe to ARNS main-lobe, and side-lobe to side-lobe) to assess the interference levels and how long the interference persisted during the orbit. These simulations used 20 ms time steps and 15 minutes orbit duration. The short term single pass simulations were used mainly to optimize the interference mitigation strategy and to study the dependence of the interference on the Scatterometer2 transmission frequency.

The calculated values of the I/N level in System 2 are shown below in Figures 2 as a function of time during a single pass of Scatterometer 2 satellite (with no frequency hopping) using a dynamic simulation of the systems.

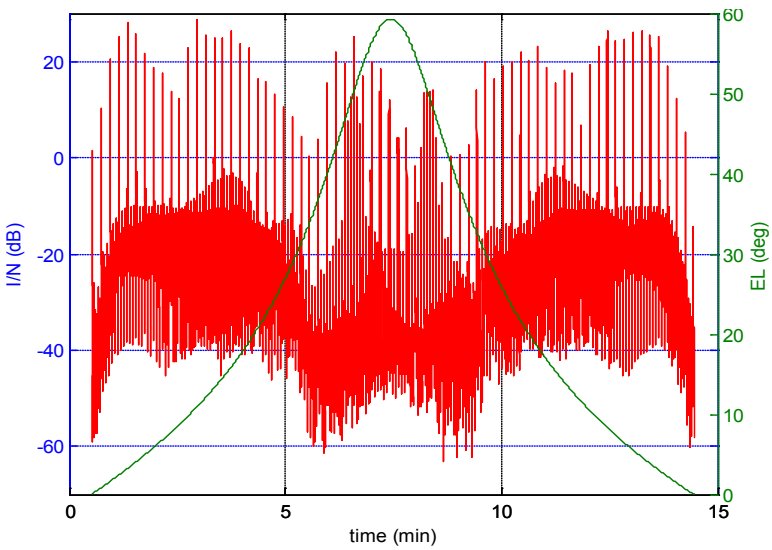

Figure 2 – Calculated values of the I/N level in System 2 receiver as a function of time during on overpass of the Scatterometer 2 satellite using a dynamic simulation of the systems.

5. Mitigation Techniques of Duty Cycle Reduction, ARNS Band Reduction, Frequency Hopping

5.1. Duty Cycle Reduction

Standard theory coupled with quantitative measurements showed that the target detection probability of the ARNS processors depends upon the duty cycle of the interfering signal, with higher interference level tolerance for lower duty cycles. It is known that the interference caused by spaceborne active sensors into ARNS radars is directly related to the effective duty cycle, which is the product of the true transmit duty cycle and the ratio of the tracking radar detection bandwidth to the active sensor transmit bandwidth. The effective duty cycle, and hence the degree of interference, is reduced when the true transmit duty cycle

is lowered or the transmit bandwidth is increased relative to the tracking radar detection bandwidth.

The Scatterometer2 lowered its effective duty cycle to minimize the potential impact on ARNS radars. The original pulse length of 40 microseconds coupled with the 3200 Hz PRF yielded an effective duty cycle of approximately 8% for the ARNS. By increasing the peak transmit power from 250 W to 500 W and decreasing the pulse length to 15 microseconds, the effective duty cycle was reduced to approximately 3%). These parameters give the lowest effective duty cycle that can be accommodated within the science and technology constraints for the active sensor.

5.2 ARNS Band Reduction

There is the option of changing the operating frequency of the Scatterometer2 active sensor to not overlap the band of the ARNS radars from 1240-1300 MHz.

Science and technology constraints preclude transmitting in a different band or with an appreciably different waveform.

5.3. Frequency Hopping

Frequency hopping involves changing the Scatterometer 2 transmission frequency fast enough that a single ARNS radar, which operates at fixed frequency, does not experience interference from Scatterometer2 a duration that could adversely impact their performance.

A significant reduction in the number of interference events and the average I/N level at given ARNS radar site can be achieved through implementation of a frequency hopping strategy during Scatterometer2 mission operations. In particular, the number of interference events occurring in consecutive scans of the ARNS radar is dramatically reduced through appropriate selection of the time between frequency hops and the frequency step size.

The essence of the approach would be to never operate a Scatterometer2 signal on a single frequency for as long as one scan cycle of a ARNS radar (that is, to always operate for less than 12 seconds at a time on any given frequency). Hopping from one frequency to the next for less than 12 seconds at a time, and not revisiting any given frequency in intervals of less than several ARNS scan cycles, no target could be impacted for more than one scan cycle at a time, and the affected ARNS receivers would have 2 or more scan cycles to then observe all targets before the Scatterometer2 could revisit their frequencies. The I/N levels over a single pass are shown in Figure 3 below for Scatterometer2 both without and with frequency hopping.

Frequency hopping reduces interference in three ways:

1) The number of times where interference levels from the Scatterometer2 radar exceed higher levels of I/N that causes target detection degradation is significantly reduced.
2) The minimum time interval between interference events increases, so one target is never continuously subject to a loss of detection.
3) The average I/N is significantly reduced.

Frequency hopping will not reduce the maximum possible interference power seen at a given ARSR site. However, by reducing the probability that the two radars operate near the same frequency, it reduces the number of times that high interference powers will occur. For example, power levels seen once per month without frequency hopping will be seen once per year when hopping between 12 different frequencies in a cycle. The most significant effect, though, is the change in the persistence of the interference during a Scatterometer2 orbit.

The three interference mitigating effects of frequency hopping listed above are shown graphically in Figure 3 where the I/N levels as a function of time during an orbital overpass of the Scatterometer2 satellite are plotted with and without frequency hopping. This figure clearly shows the following major

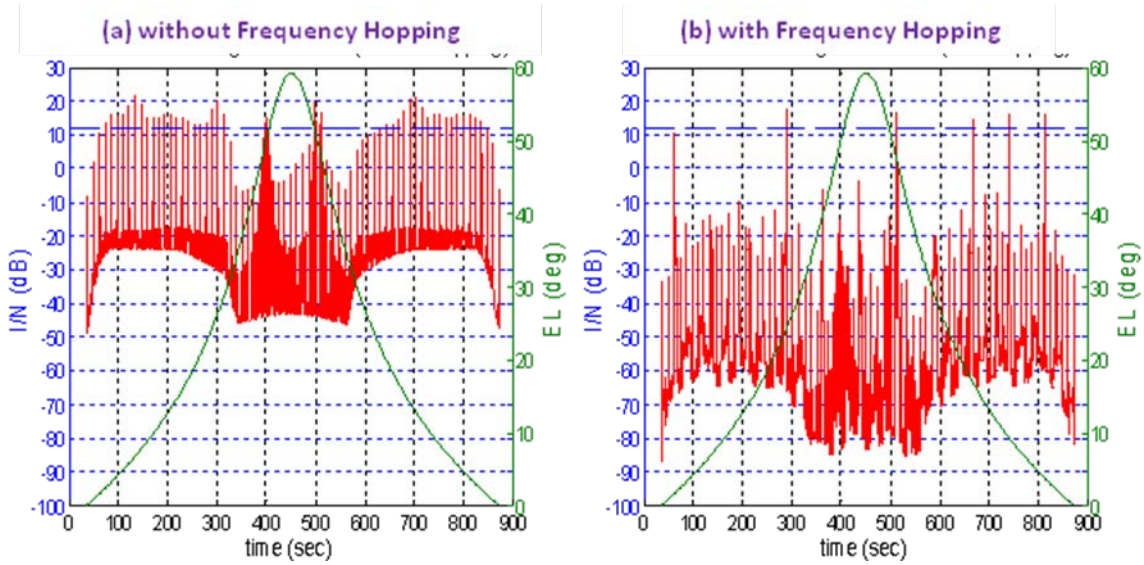

Figure 3 – I/N levels as a function of time at an ARNS receiver during a Scatterometer 2 orbital overpass (a) at fixed Scatterometer2 frequency and (b) with frequency hopping. The red curve shows the I/N levels and the green curve the elevation angle of the satellite relative to the ARNS radar.

mitigating effects: (1) the number of times where the I/N level exceeds -6 dB and the I/N value during the spikes are both significantly reduced; and (2) large I/N spikes are always separated by more than one ARNS radar scan unlike the case without frequency hopping where interference spikes separated by 12 seconds occur during a significant fraction of the time that Scatterometer2 is within the visibility circle. The I/N level is generally much lower and the maximum I/N level during this single orbit is smaller with frequency hopping implemented.

6. Frequency Hopping Mitigation Technique and Curves of I/N over Single Pass of Spacecraft over ARNS sites

Single pass simulations at all possible Scatterometer2 transmission frequencies in sequences with 7.5 MHz frequency spacing and 1.25 MHz tuning resolution (63 orbits total) were repeated for five different ARNS frequencies (1241.47 MHz, 1254.42 MHz, 1260.0 MHz, 1272.54 MHz, 1285.49 MHz). The ARNS site is located at 38°N, 80° W in the simulations. A typical frequency sequence for the single pass orbit is shown in Figure 4. The single pass simulations with the Systems 1, 2 and 8 are shown in Figures 5, 6 and 7, respectively.

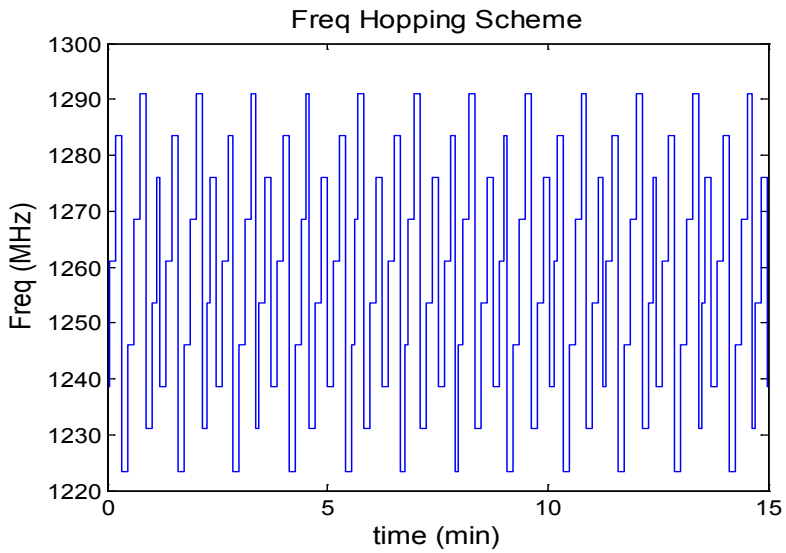

Figure 4 – Typical frequency hopping sequence during Scatterometer2 orbit simulated.

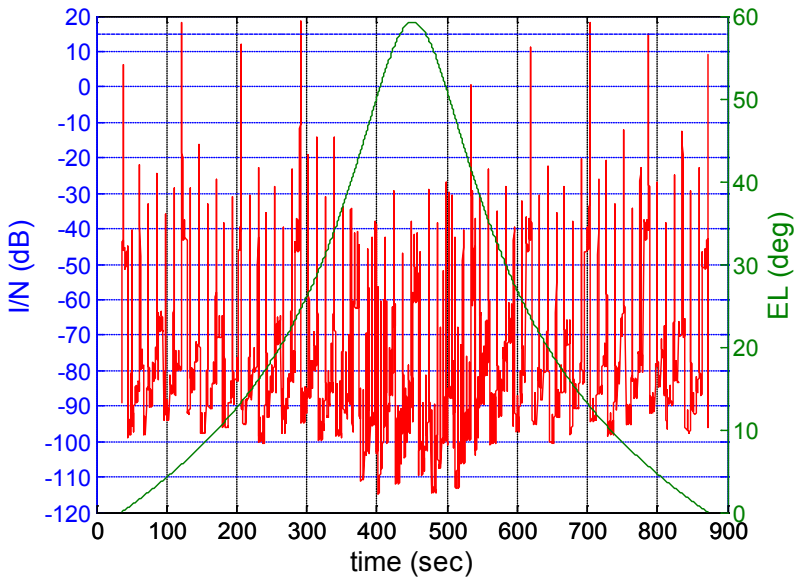

Figure 5 – Calculated values of the I/N level in System 1 receiver as a function of time during on overpass of the Scatterometer 2 satellite using a dynamic simulation of the systems.

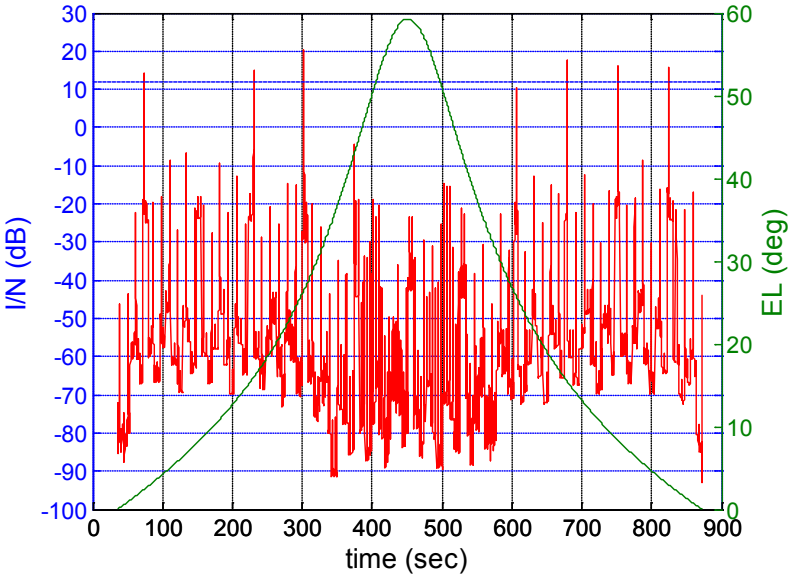

Figure 6 – Calculated values of the I/N level in System 2 receiver as a function of time during on overpass of the Scatterometer 2 satellite using a dynamic simulation of the systems.

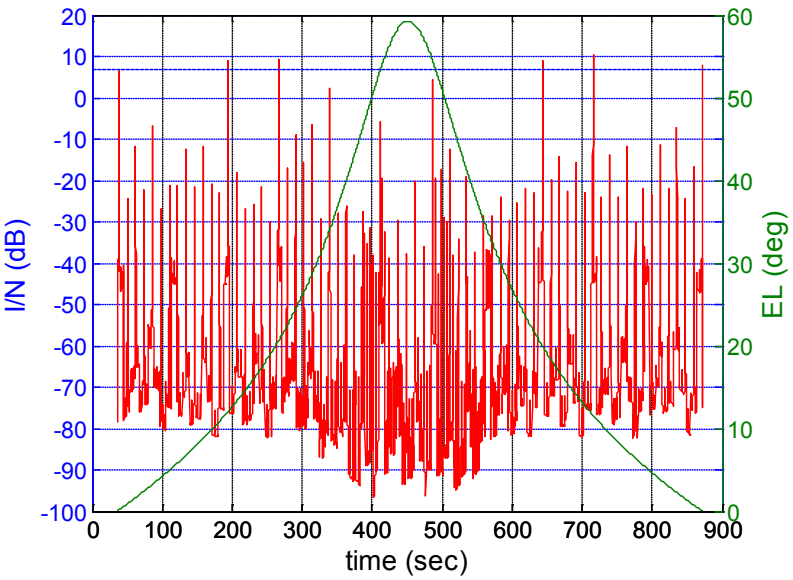

Figure 7 – Calculated values of the I/N level in System 8 receiver as a function of time during on overpass of the Scatterometer 2 satellite using a dynamic simulation of the systems.

Typically, the spikes where the I/N value exceeds +8 to +12 dB are separated by more than a minute. Otherwise, the I/N values are typically at levels below -6 dB.

Analysis of the potential interference from the Scatterometer2 radar sensor into ground-based ARNS surveillance and tracking radars yielded the following results:

1) The satellite geometry precludes main-beam to main-beam coupling between the two radars.

2) Given the effective duty cycle of the Scatterometer2 radar, interference-to-noise levels that exceed a high level of I/N can arise from either Scatterometer2 main-lobe to ARNS side-lobe or ARNS main-lobe to Scatterometer2 side-lobe coupling.
3) Maximum interference levels occur when both of the following conditions are met: (a) The two radars are azimuthally aligned so that the radars point at each other; and (b) the Scatterometer2 transmit frequency of either the H-polarization or V-polarization chirp is within the 3-dB processing bandwidth of the ARNS receiver.
4) Dynamic simulations of interference-to-noise levels during Scatterometer2 orbits show that with frequency hopping to mitigate interference, the Scatterometer2 interference power level is typically less than -6 dB and is very unlikely to exceed high levels of I/N on two consecutive scans of the ARNS radar.
5) Both short duration (single orbits within visibility circle of ARNS radar) and long duration (28-day ARNS operation) simulations confirm that a frequency hopping algorithm that works for the ARNS System 8 receivers, which have the lowest interference threshold, works for the Systems 1 and 2 receivers also.
6) Interference-to-noise (I/N) levels above +25 dB occur very infrequently (10 cases in 2500 simulated orbits, or less than once in two weeks).
7) Interference-to-noise levels that exceed the critical threshold usually occur between one and six times during the ~14 minutes of an orbit when the Scatterometer2 radar is within the visibility circle of the ARNS radar.
8) With frequency hopping implemented, six or more clean scans separate events where the Scatterometer2 interference level exceeds the critical threshold for all three ARNR radar types and for the Scatterometer frequency in the full allocated band of 1215-1300 MHz. Exceptional events where the Scatterometer2 interference power level exceeds the interference threshold on two consecutive scans of the ARNS radar are very rare (1 case in 2500 simulated orbits, or less than once in six months).
9) Analysis of a contingency case where the Scatterometer2 operational band is reduced by 24 MHz (for ARNS band reduction) shows a potential reduction to 3 or more clean scans separating any event where the Scatterometer2 interference level exceeds high levels of I/N (+8 to +12 dB).

7. Summary

This document analyzes the potential interference from one EESS (active) system into ARNS systems in the 1215-1300 MHz band. Three mitigation techniques of duty cycle reduction, ARNS band reduction, and frequency hopping are discussed.

The document presents the single pass interference to noise ratio (I/N) of RFI from one EESS (active) system, the Scatterometer2, into ARNS systems, in particular ARNS Systems 1,2,and 8 in the 1215-1300 MHz band. The I/N curves are presented for representative single passes of the spacecraft over three types of ARNS systems. Mitigation of the RFI persistence is studied using a frequency hopping technique whereby the frequency of the EESS (active) system is changed on a smaller timescale (8.2 seconds) than the 360 deg azimuthal scan time of the ARNS systems (12 seconds). The I/N curves with the frequency hopping show lower values of I/N over the single passes.

Report SFCG 33-2

TYPICAL TECHNICAL AND OPERATING CHARACTERISTICS FOR SPACEBORNE RADAR SOUNDER SYSTEMS USING THE 40-50 MHZ BAND

Abstract

The purpose of draft report is to present frequency band selection rationale and the typical technical and operating characteristics of a spaceborne radar sounder for operation in the 40-50 MHz band.

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1 Introduction

There is an interest in remote sensing in the vicinity of 40-50 MHz for remote measurements of the Earth's subsurface providing radar maps of subsurface scattering layers with the intent to locate water/ice/deposits using active spaceborne sensors. This document provides the preferred frequency band selection rationale, and typical technical and operating characteristics.

The technical and operating characteristics of an active sensor at 40-50 MHz are described and the sharing situation with other services allocated in this frequency range is examined. The 40-50 MHz band is currently allocated to the fixed, mobile and broadcasting services. The uses of the 40.98-41.015 MHz frequency band by space research service are on secondary basis.

2 Frequency band selection rationale

The reason for an allocation between 40 MHz and 50 MHz for a spaceborne sounding radar is based upon the following selection criteria: surface penetration, length scale of observation, region of electromagnetic scattering model, and previous work.

2.1 Surface penetration

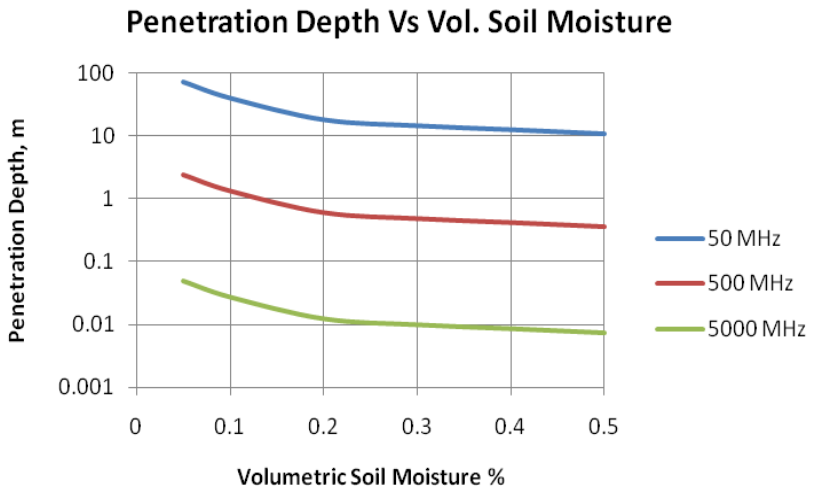
Penetration of an incident radar wave is normally many tens of wavelengths. Under the proper conditions of wavelength and composition of the scattering medium, radio waves can readily penetrate the dielectric materials comprising the Earth's surface and cover. A quantitative estimate of this depth δ_p is as follows:

$$\delta_p = \frac{\lambda_0 \sqrt{e'}}{2\pi e''} \tag{1}$$

where λ_o is the wavelength, and e' and e'' are the real and imaginary parts of the surface dielectric constant. Using this expression with the soil dielectric constants, Fig. 1 shows the surface penetration depths for 50 MHz, 500 MHz, and 5 000 MHz. From the figure, it is evident that surface penetration at 50 MHz is deeper than for 500 MHz by a factor of 20 to 30, and is thus most favourable for Earth penetration studies. The objectives would be to provide radar maps of subsurface scattering layers with the intent to locate water/ice/deposits using active spaceborne sensors.

FIGURE 1

Surface penetration depth



2.2 Length scale of observations

The addition of 50 MHz to the exiting 435 MHz and 1 250 MHz bands would extend the range of length scales at which the roughness of the surface is observed. For many geologic surfaces, backscatter is dominated by that harmonic component of the surface whose wavelength is near the projected radar wavelength and longer, whereas, other components of the surface contribute only through second order effects. Thus, radar measurements at as many frequencies as possible over as wide a range of incidence angles as possible increase the ability to accurately describe the surface.

2.3 Region of electromagnetic scattering model

The addition of 50 MHz to the existing 435 MHz and 1 250 MHz bands would expand the region of validity of electromagnetic scattering models. The 50 MHz radar would be more sensitive to subsurface morphology because the rms height of the surface is a smaller fraction of the wavelength, resulting in a lower measured radar backscatter. The greater sensitivity of 50 MHz to subsurface morphology combined with the fact that the 50 MHz signals penetrate deeper into the soil, increases the subsurface volume in which scattering occurs, resulting in a much greater ratio of power received from the subsurface relative to that received from the surface than that a shorter wavelengths. Also, scatterers embedded in the alluvial cover will be smaller relative to 50 MHz than either 435 MHz or 1 250 MHz.

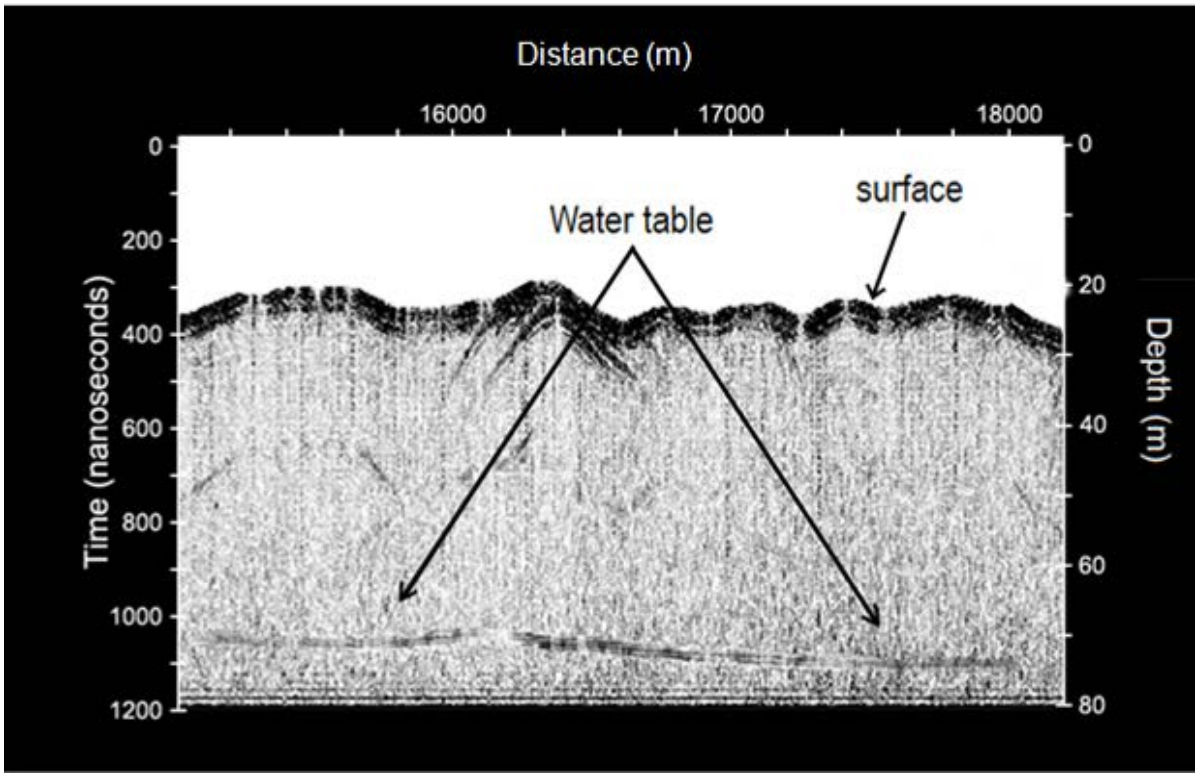
2.4 Previous work and regulatory status between 40-44 MHz band

A considerable amount of work in the form of ground-based and airborne radar systems development and data collection has already been done at 3-50 MHz. Along with this hardware development has been computational work aimed at studying the surface penetration depth versus soil moisture content at 3-50 MHz and analysis of measuring ocean returns by oceanographic radars.

Airborne radars have made measurements around 50 MHz in the desertic areas in the Arabian peninsula and Antarctica. Figure 2 shows a radargram with variations in the depth of the water table from 49 to 52 meters with data taken from an airborne VHF radar in Kuwait in 2011.

FIGURE 2

Radargram taken from airborne VHF radar in Kuwait in 2011



The frequency band 3-50 MHz was considered for the oceanographic radars along the coast (in the radiolocation service (RLS)) under WRC-07 Agenda item 1.15 and the sharing studies were documented in Report ITU-R M.2234. WRC-12 agreed to allocate RLS through a combination of secondary and primary allocations on a regional and country basis with footnotes in sub-bands between 4-44 MHz (43.35-44 MHz was the highest frequency range allocating radiolocation service with a country footnote (two countries)) with footnotes to protect the incumbent fixed and mobile services. Applications in the RLS are limited to oceanographic radars operating in accordance with Resolution 612 (Rev.WRC-12). Resolution 612 (Rev.WRC-12) also contains additional limitations to the oceanographic radars such as maximum EIRP of 25 dBW and a station identification (call sign) on the assigned frequency. In the radio regulations, there is no allocation to EESS (active) in the 3-50 MHz range. If the frequency were chosen for the spaceborne system at higher or lower frequency bands, the hardware and computational work reference would need to be repeated for the airborne radar campaigns in the desertic areas.

3 Technical characteristics of a 40-50 MHz spaceborne sounding radar

The spaceborne sounding radar will operate at 40-50 MHz and the resulting radar data will be used in the study of the Earth's subsurface with radar mapping of subsurface scattering layers with the intent to locate water/ice/deposits. The characteristics of the 40-50 MHz spaceborne sounding radar are shown in Table 1.

3.1 Mission objectives

The spaceborne active sensor will produce data with a vertical resolution of 5-7 m, and will have a surface SNR of 66 dB. It is expected to be a 9-16 month orbital mapping campaign. The mission scientific objectives are 1) to understand the global thickness, inner structure, and the thermal stability of the Earth's ice sheets of Greenland and Antarctica as an observable parameter of earth climate evolution, and 2) to understand the occurrence, distribution and dynamics of the earth fossil aquifers in desertic environments such as northern Africa and the Arabian peninsula as key elements in understanding recent paleoclimatic changes.

3.2 Orbital parameters

The spaceborne active sensor is carried on a low-Earth orbiting satellite at an altitude of 400 km, an inclination optimized for a sun synchronous orbit and an eccentricity less than 0.001.

3.3 Design parameters

The postulated system for the Earth orbiting sounding radar is an earth enhanced duplicate of the Shallow Radar Sounder (SHARAD) which was a Mars orbiting sounding radar in the SRS (active). The spaceborne sounding radar transmits an FM modulated pulse centred at 45 MHz with 10 MHz bandwidth at a pulse repetition frequency of 1200 Hz. Each pulse has a duration of 85 µsec. The peak RF power is 100 W, and the transmitted signal is circularly polarized. These design parameters are shown in Table 1.

TABLE 1

50 MHz spaceborne sounding radar characteristics

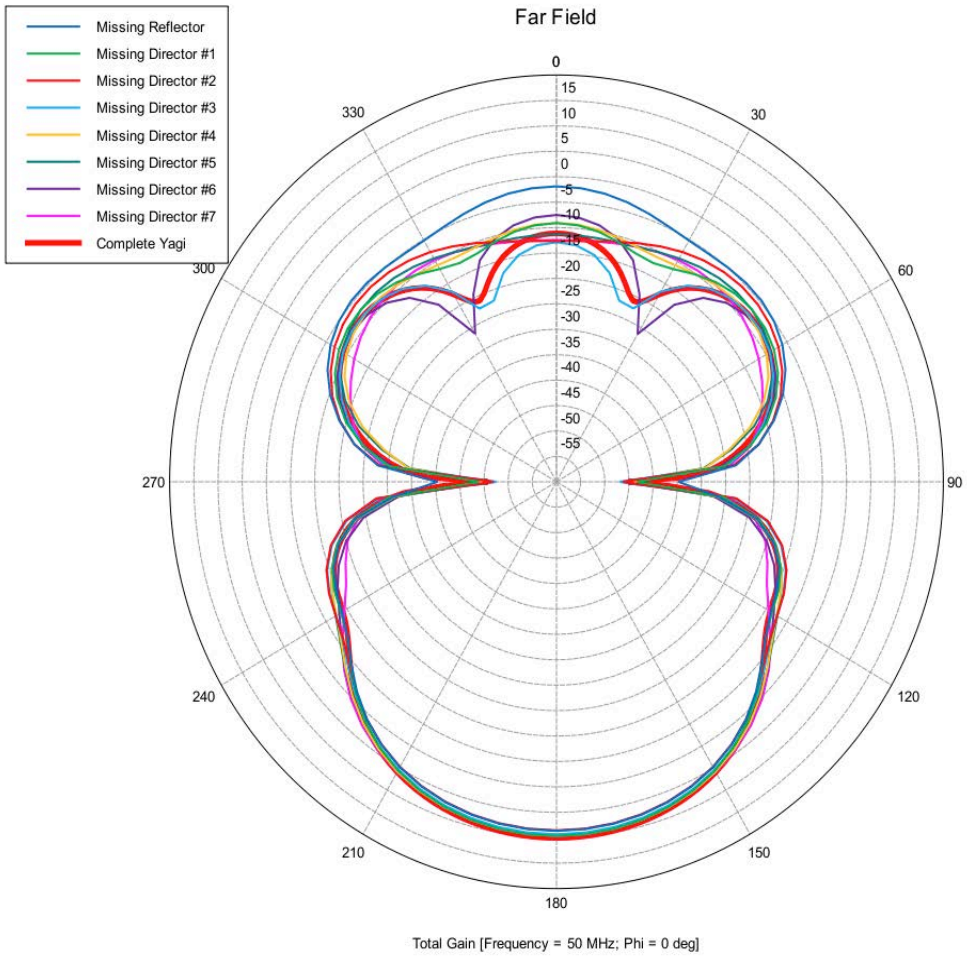
Parameter	Value
Orbital altitude	400 km
Orbital inclination	97º
RF centre frequency	45 MHz
Peak RF output power	100 Watts
Polarization	Circular (LHC on transmit, RHC on receive)
Pulse modulation	Linear FM chirp
Pulse bandwidth (-20 dB)	6-10 MHz
Pulse width	85 µsec
Pulse repetition rate	1220 Hz
Parameter	**Value**
Compression ratio	510-850
Antenna type	Cross Yagi (9 elements)
Antenna peak gain	10 dBi
Antenna orientation	nadir
Antenna beamwidth	40 deg (El), 40 deg (Az)

3.4 Antenna gain pattern

The spaceborne sounding radar antenna is a 9 element cross Yagi antenna, with antenna gain of 10 dBi, and beamwidth of 40° in range and azimuth as shown in Figure 3.

FIGURE 3

9-Element Yagi antenna pattern



3.5 Operational limitations

The sounding radar is to be operated only in either uninhabited or sparsely populated areas of the ice sheets of Greenland and Antarctica and deserts of northern Africa and the Arabian peninsula. The radar is to be operated at night-time only from 3 a.m. to 6 a.m. locally when the ionospheric perturbations to the radar signal is at a minimum and man-made RFI is expected to be lightest.

4 PFD and spectral PFD levels at Earth's surface

For the parameters of the sounding radar in Table 1, the power flux-density (pfd) level is calculated to be −93.3 dB (W/m^2) at 45 MHz, corresponding to spectral pfd levels of −163.3 dB (W/m^2-Hz) at 45 MHz assuming 10 MHz bandwidth.

5 Conclusions

There is an interest in remote sensing in the vicinity of 40-50 MHz for remote measurements of the Earth's subsurface providing radar maps of subsurface scattering layers with the intent to locate water/ice/deposits using active spaceborne sensors. This document provides the preferred frequency band selection rationale, and typical technical and operating characteristics for a possible instrument.

Characteristics of a spaceborne radar sounder that would operate in the frequency range 40-50 MHz have been developed.

Space Frequency Coordination Group

Report SFCG 34-1

WORST CASE INTERFERENCE LEVELS FROM MAINLOBE-TO-MAINLOBE ANTENNA COUPLING OF SYSTEMS OPERATING IN THE RADIOLOCATION SERVICE INTO ACTIVE SENSOR RECEIVERS OPERATING IN THE EARTH EXPLORATION-SATELLITE (ACTIVE) IN THE 35.5 -36.0 GHZ BAND

Abstract

This SFCG report presents the worst case interference levels from antenna mainlobe-to-mainlobe coupling of radiolocation service systems into the Earth Exploration-Satellite (active) Service receivers in the 35.5-36.0 GHz band. Presented are the characteristics of a typical spaceborne active sensor in the EESS (active) and of a typical RLS system. The potential worse case interference from mainlobe to mainlobe coupling into the EESS (active) receiver from the RLS system is analyzed using both a static analysis and a dynamic analysis.

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1. Introduction

This document presents the worst case interference levels from antenna mainlobe-to-mainlobe coupling of radiolocation service systems into the Earth Exploration-Satellite (active) Service receivers in the 35.5-36.0 GHz band. Presented are the characteristics of a typical spaceborne active sensor in the EESS (active) and of a typical RLS system and the potential worse case interference from mainlobe coupling into the EESS (active) receiver from the RLS system is analyzed.

The 35.5-36 GHz band is allocated on a primary status to both spaceborne active sensors in the EESS (active) and RLS systems.

In this study herein, a SAR with 200 MHz bandwidth is introduced and it has an allocation in the 35.5-36 GHz band. This is a current design for a 200 MHz bandwidth interferometric SAR.

2. Technical Characteristics of a Typical 35.5-36.0 GHz Interferometric SAR

The postulated high resolution interferometric synthetic aperture radar (InSAR) is an active sensor with sufficient capability for Earth science, commercial, and civil applications. The resolution of a 1300 MHz bandwidth signal at 3 deg look angle is about 3.25 m with 4 looks.

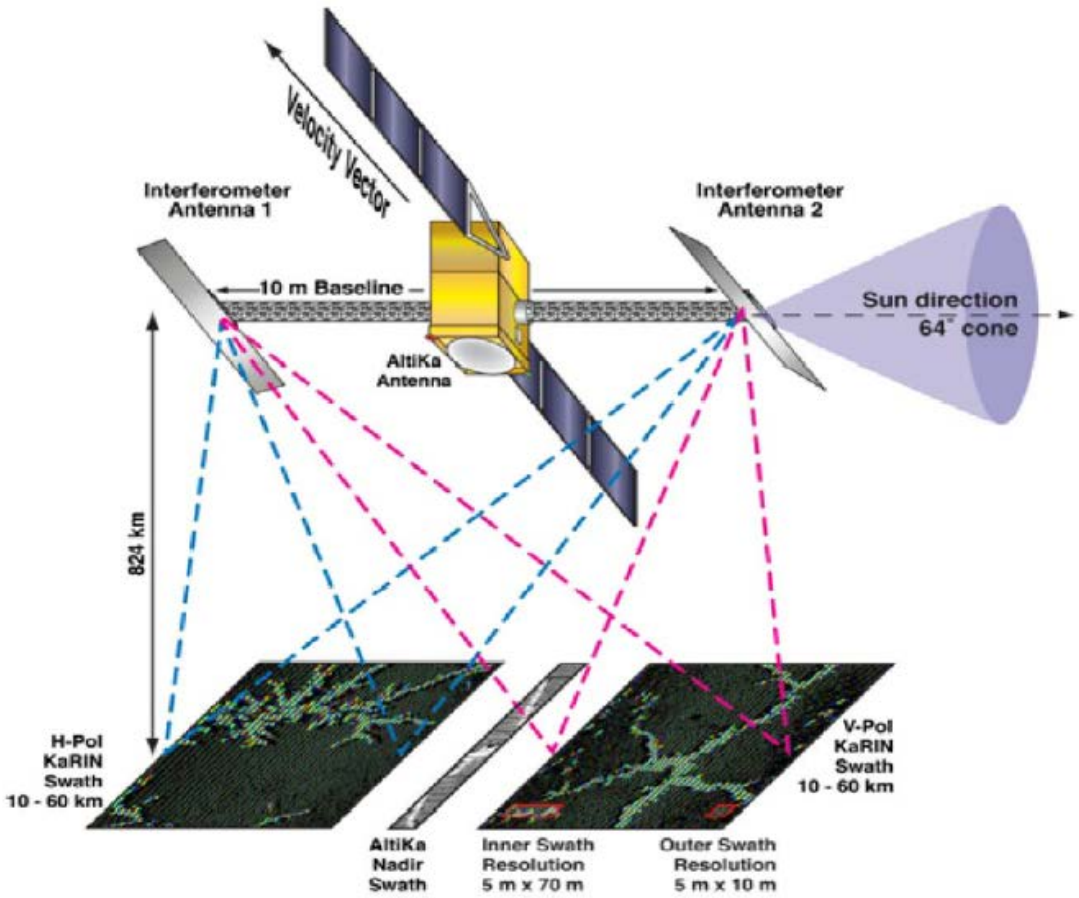
The InSAR is an interferometric synthetic aperture radar with which operates in the 35.5-36 GHz.

The primary objective of the InSAR would be to make interferometric measurements of the Earth's surface using single pass interferometry measurements from two antennas on the single satellite.

The 35.5-36.0 GHz InSAR will orbit the Earth at an altitude of 824 km in a near circular orbit with an inclination of 98.7 degrees. The repeat period is 16 days. Each interferometer antennas look off from nadir at 0.7 deg in near range (NR) and at 4.3 deg in far range (FR).

FIGURE 1

Illustration of 35.5-36.0 GHz SWOT KaRin /AltiKa Illumination Geometry (200 MHz bandwidth)



The 35.5-36.0 GHz InSAR transmits linear FM pulses with 1300 MHz bandwidth centered at 35.35 GHz with a pulse repetition rate approximately at 4400 Hz per antenna. The signal is horizontally and vertically polarized at both transmission and reception. The significant parameters for the InSAR are given in Table 1.

The InSAR uses two reflectarray antennas. Each of the 3.8m x 0.17 m reflectarray antennas has about 33.4 dBi gain. The antenna beamwidth is 2.9 deg in elevation and 0.13 deg in azimuth. The antenna gain patterns in elevation and azimuth are shown in Figures 1a and 1b, respectively.

Figure 2

35.5-36.0 GHz InSAR antenna elevation and azimuth gain pattern in band 34.7-36 GHz (a) Elevation pattern from -10 deg to +10 deg, (b) Azimuth pattern from -1 deg to +1 deg (Calculated pattern in blue, equation fit in red)

(a) Antenna Elevation Gain pattern **(b) Antenna Azimuth Gain pattern**

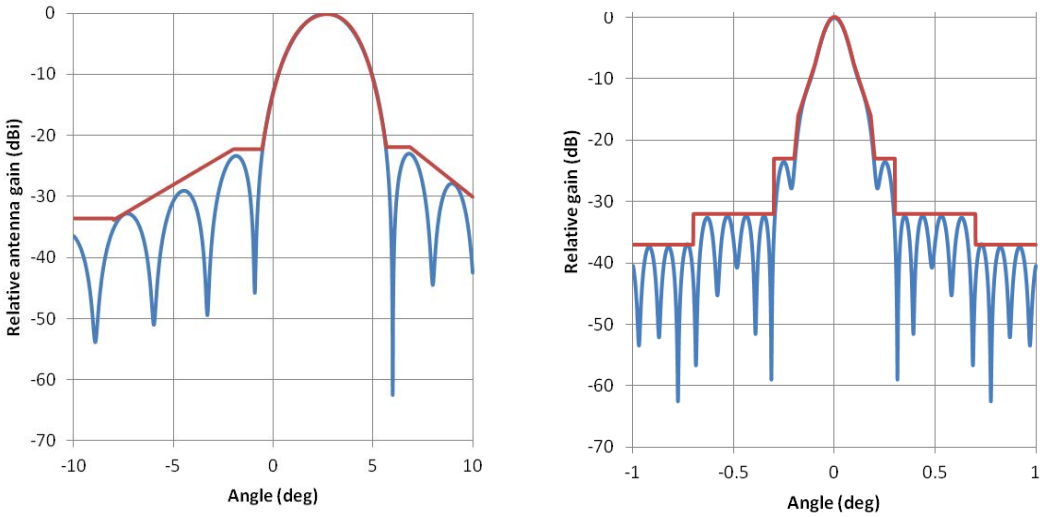


TABLE 1

35.5-36 GHz InSAR Interferometric Synthetic Aperture Radar Characteristics

PARAMETER	VALUE
Altitude	824 km
Inclination	98.7 deg
Repeat cycle	16 days
RF Center Frequency	35.7 GHz
Peak RF output power	300 Watts
Pulse Modulation	Linear FM chirp
Pulse -3dB Bandwidth	200 MHz
Pulse Duration	18 µsec
Pulse Repetition Rate per antenna	4400 Hz
Duty Cycle	15.8 %
Antenna Type	Reflectarray 3.8 m x 0.17 m
Antenna Gain	49.29 dBi
Antenna Orientation	0.7 deg (NR) and 4.3 deg (FR) from nadir
Antenna Beamwidth	2.9 deg x 0.13 deg
Antenna Polarization	Linear horizontal/vertical
System Noise Temperature	438 K

3. Technical Characteristics of a Typical 35.5-36.0 GHz Terrestrial Radar

For the EESS (active) spaceborne 35.5-36.0 GHz InSAR, it has a look angle, that angle between nadir and the beam center, of 0.7 deg (NR) and 4.3 deg (FR). Recommendation ITU-R M.1640, " Characteristics of, and protection criteria for sharing studies for radars operating in the radiodetermination service in the frequency band 33.4-36 GHz" shows the characteristics of five terrestrial radars operating in the 33.4-36 GHz band. The metric radar with 135 kW transmit peak power is the highest power radar in Table 1 of the Annex to the Recommendation.

TABLE 2

Characteristics of Terrestrial Radars in Radiolocation Service

Parameter	**Imaging**	**Imaging**	**Metric**	**Metric**	**Seeker**
Sensor type	Passive	Active	Active	Active	Active
Modulation	–	Pulse	Pulse	Pulse	Linear FM
Compression ratio	–	–	–	–	200
Pulse width	–	0.05	0.25	0.05	10
Tx peak power (kW)	–	0.5	135	1	0.001
PRF (kHz)	–	30	1	50	10
RF bandwidth (MHz)	–	80	10	101	12
Antenna gain (dBi)	35	30	52	51	28.7
Beamwidth (degrees)	0.5 × 3.0	0.75 × 10	0.25 × 0.25	0.5 × 0.5	4.4 × 4.4
Rx IF bandwidth (GHz)	2	0.040	0.006	0.185	0.100
Noise temperature (K)	850	–	–	–	–
Noise figure (dB)	–	4.5	10	10	5
Rx sensitivity (dBm)	–	–81	–95	–78	–93
Tuning	Fixed	Fixed	Fixed	Frequency hop	Fixed

PRF: pulse repetition frequency

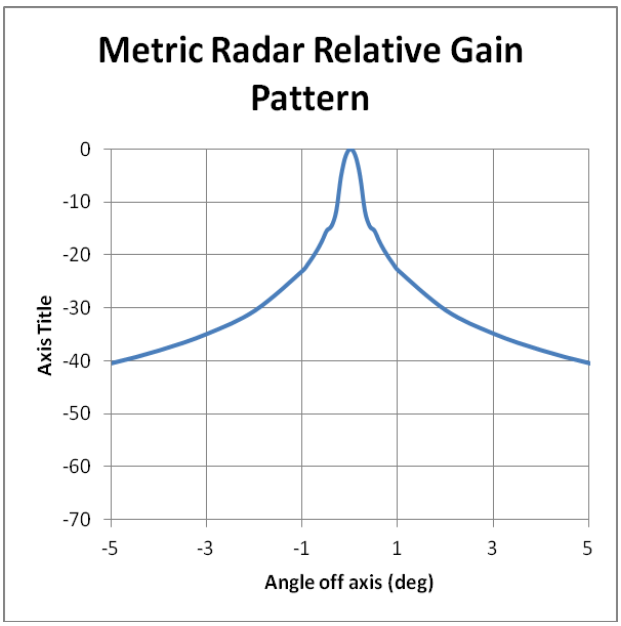
Typical terrestrial tracking radars cover elevation angles from 0 deg to 90 deg during the track, and can have mainlobe-to-mainlobe coupling in elevation. The 35.5-36.0 GHz InSAR sensor beams which point near nadir move past the terrestrial systems as the spacecraft proceeds in its orbit. For a sensor azimuth beamwidth of 0.13 deg, the beam scans past the terrestrial system in about 0.2 second. The InSAR looks down to the side of the nadir track at a fixed look angle.

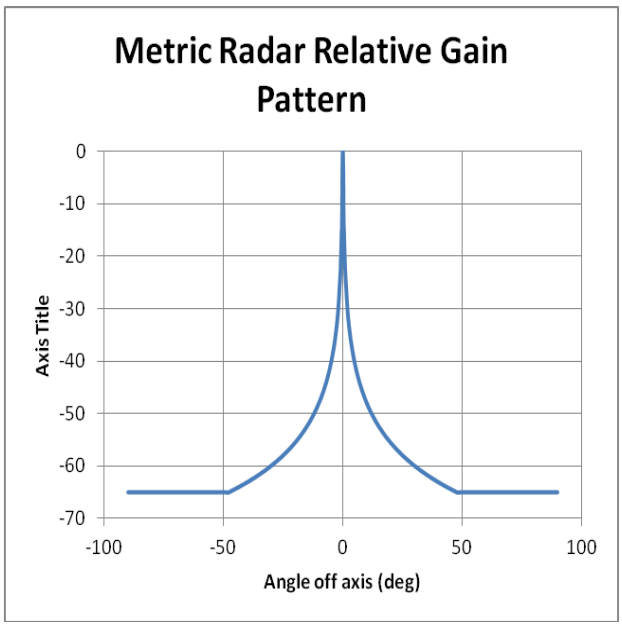
Recommendation ITU-R F.1245, " Mathematical Model of Average and Related Radiation Patterns for Line-of-Sight Point-to-Point Radio-Relay System Antennas for Use in Certain Coordination Studies and Interference Assessment in the Frequency Range from 1 GHz to About 70 GHz" gives the antenna gain equations for the 35 GHz antenna pattern.

FIGURE 2

35.5-36.0 GHz Terrestrial antenna elevation and azimuth gain pattern in band 35 GHz (a) Elevation pattern from -5 deg to +5 deg, (b) Azimuth pattern from -90 deg to +90 deg

(a) Antenna Elevation Gain pattern **(b) Antenna Azimuth Gain pattern**





4. Potential Interference between EESS (active) and Radiolocation Service

4.1 Static Analysis of Mainlobe-to-Mainlobe Coupling of RFI in InSAR

In Figures 3 and 4 below, the single pass simulation of the InSAR over 800 seconds, 20 seconds and 0.2 second shows the received power into the Ka-band InSAR peaks above +0 dBm in the middle of the pass. The InSAR receiver must be protected up to + 0 dBm, or +6 dBm if a 6 dB margin is imposed. The duration of the RFI above -10 dBm is about 20 milliseconds and above 0 dBm is about 5 milliseconds.

FIGURE 3

Single Pass Simulation of Received Power in 35.5-36.0 GHz InSAR from Terrestrial Metric Radar (a) 800 seconds in orbit (b) 2 seconds in middle of orbit

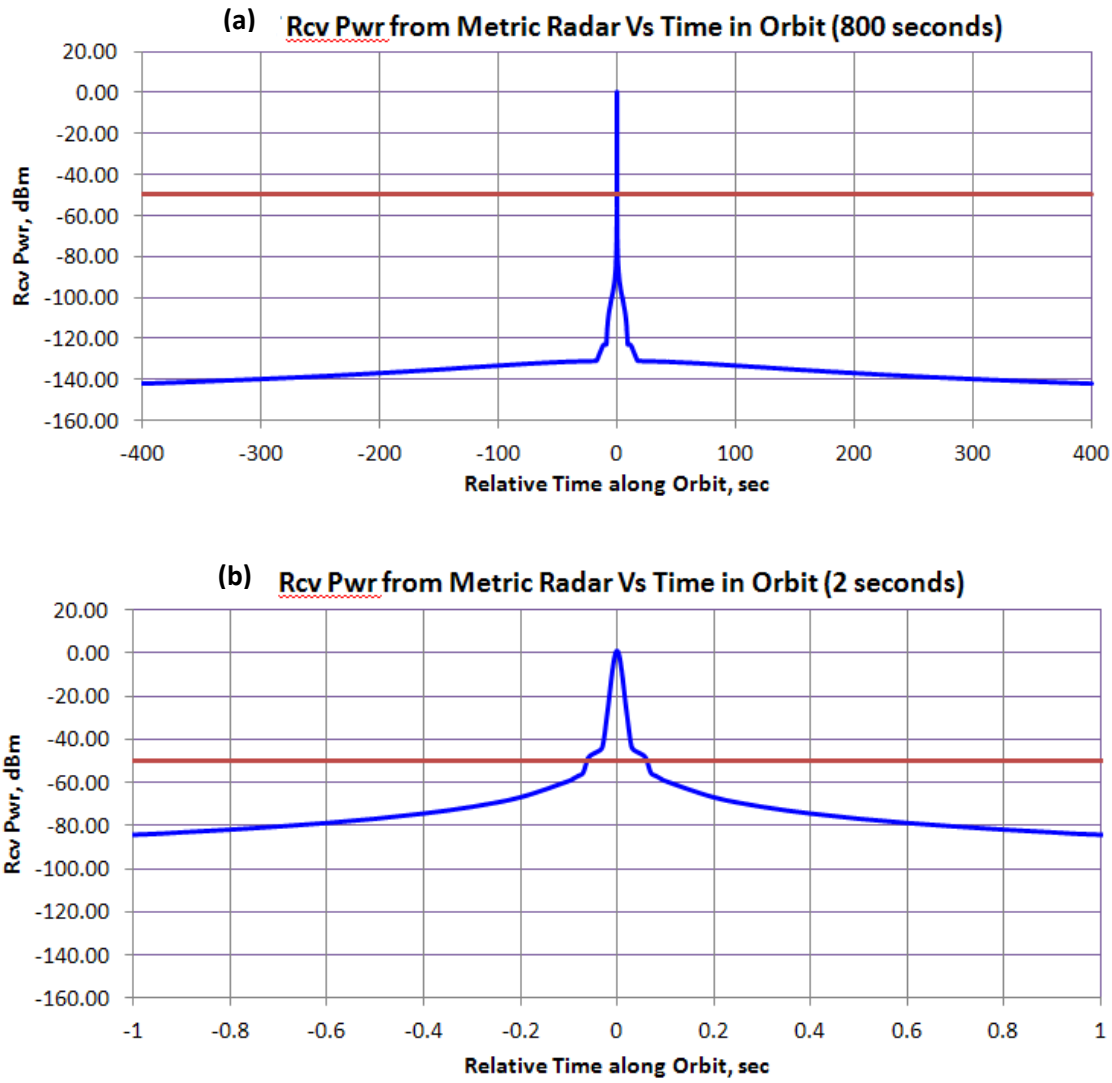
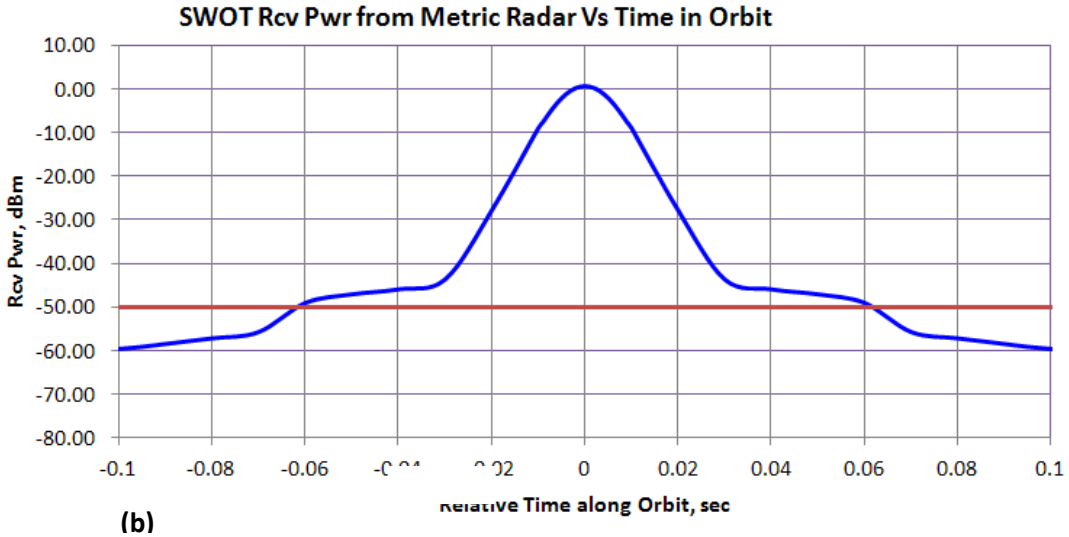


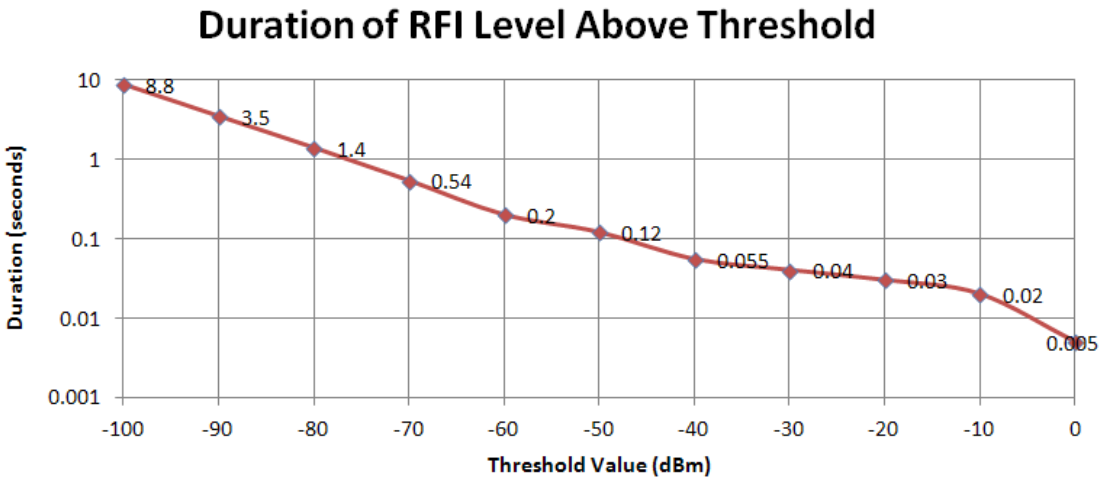
FIGURE 4

(a) Single Pass Simulation of Received Power in 35.5-36.0 GHz InSAR from Terrestrial Metric Radar over 0.2 seconds in middle of orbit (b) duration of RFI level above threshold

(a)



(b)



4.2 Dynamic Analysis of Mainlobe-to-Mainlobe Coupling of RFI in InSAR

Several dynamic simulations were performed to look at the temporal aspects of the RFI levels from the terrestrial radars into the EESS (active) receivers.

In dynamic analysis 1 simulations, for simplicity, the terrestrial radar was assumed to be pointed at zenith and the EESS (active) receive antenna pattern in elevation was a composite of the pair of interferometric SAR antenna patterns on each side of nadir and the nadir

looking altimeter antenna pattern. This would represent the situation of where the highest probability of main beam to main beam interaction between the radar and the spacecraft exist.

In dynamic analysis 2 simulations, terrestrial radars were spaced by about 500 km separation over the world land masses, and the terrestrial radars were assumed to track the spacecraft. Although the tracking of the EESS (active) spacecraft by all of the radars is not a realistic scenario the simulation provides the means for identifying situations where coupling between the radar and the EESS (active) receive beam could produce a situation where harm to the RF frontend of the EESS (active) spacecraft could occur. The EESS (active) receive antenna patterns were assumed to a pair of separate antenna beams on each side of nadir for a total of four antenna beams.

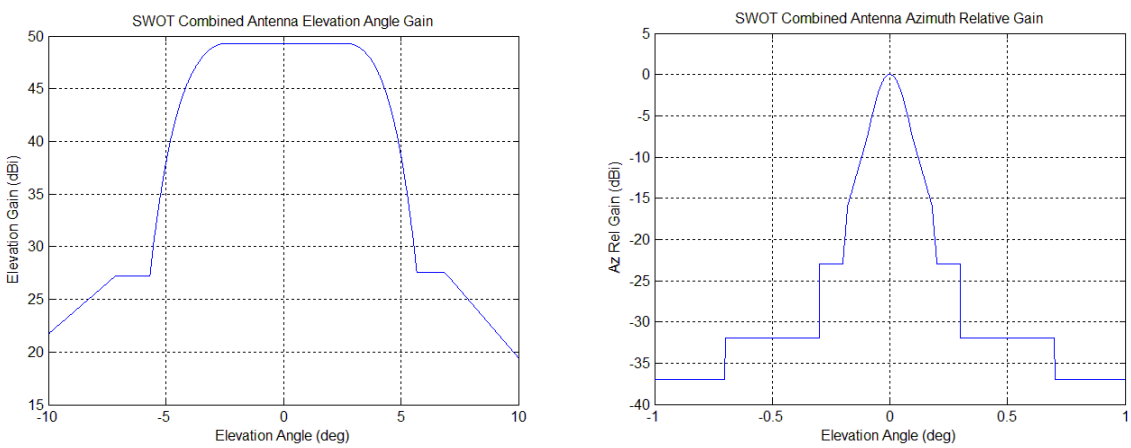
4.2.1 Dynamic analysis 1: Use of Combined InSAR Receive Antenna Pattern

4.2.1.1 EESS (active) receive antenna patterns

The combined antenna pattern in elevation of the two interferometric SAR beams on each side of nadir and the nadir looking altimeter beam is shown in Figure 6(a). The combined antenna pattern in azimuth is shown in Figure 6(b).

FIGURE 6

Combined Antenna Patterns of EESS (active) system in Elevation and Azimuth



4.2.1.2 Terrestrial radar characteristics

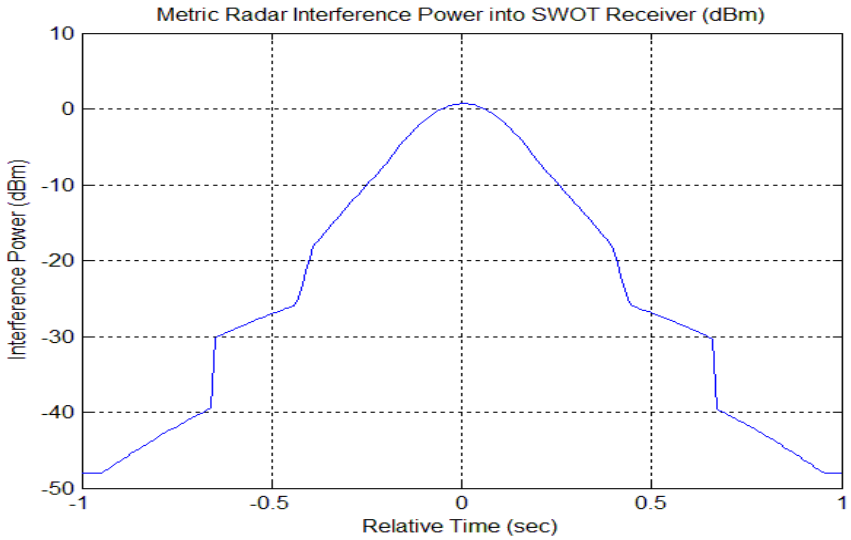
The terrestrial radar was modeled to be pointed in a fixed zenith-looking position. Its characteristics were assumed to be those of the "metric radar" in Table 2. The peak transmit power is 135 kW, the peak antenna gain is 52 dBi, and the frequency is 35.7 GHz. The antenna patterns were modeled as in Recommendation ITU-R F.1245-2 for a 1.4 m dish antenna with 52 dBi gain.

4.2.1.3 Orbit simulations

The EESS (active) orbit was assumed to have a sun synchronous orbit at 824 km altitude, and 98.7 deg inclination with a repeat orbit of 16 days. The STK simulation had a 10 millisecond time tic with the EESS (active) initial orbit assumed flying over the metric radar as worst case. Figure 7 shows the peak received worst case interference power into the EESS (active) receiver.

FIGURE 7

Metric radar RFI Level into EESS (active) Receiver (worst case)



In Figure 7, the absolute worst case peak interference power is +0.67 dBm. The duration for the -3 dB power points is 0.24 seconds and the duration of the -10 dB power points is 0.5 seconds.

4.2.2 Dynamic analysis 2: Use of four InSAR receive antenna patterns

4.2.2.1 EESS (active) receive antenna patterns

The antenna pattern in elevation of the four interferometric SAR beams, two on each side of nadir, and the nadir looking altimeter beam are as shown previously in Figure 2. There are four beams since the InSAR alternatively transmits on different sides of nadir and receives on both sides of nadir, both co-nadir and cross-nadir beams.

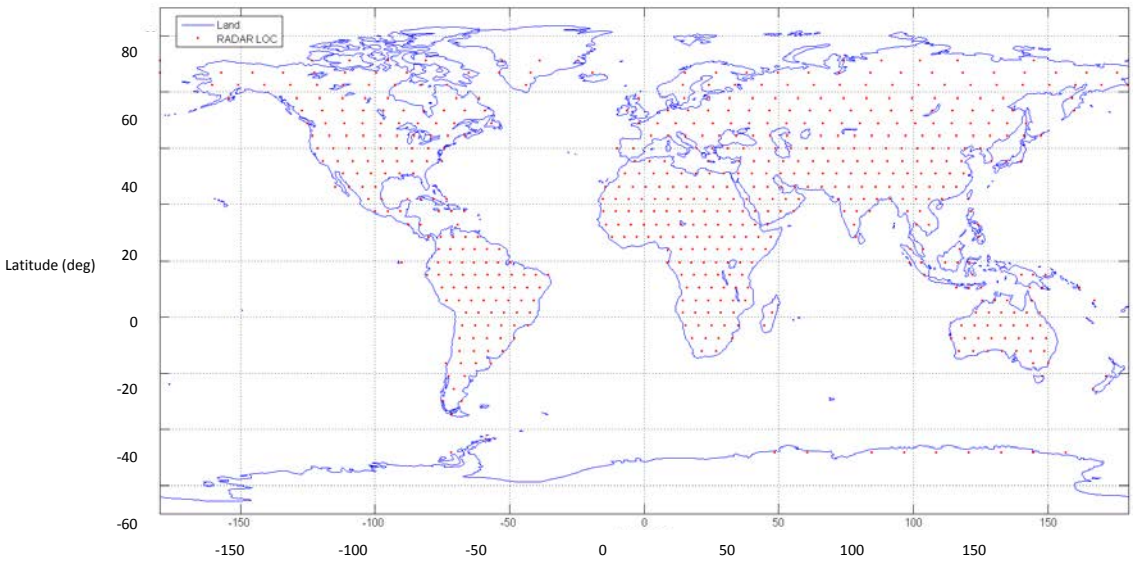
4.2.2.2 Terrestrial radar characteristics

The terrestrial radars were modeled to be tracking the spacecraft whenever a direct line of sight between the radar and spacecraft was possible. Its characteristics were assumed to be those of the "metric radar" in Table 2. The peak transmit power is 135 kW, the peak antenna gain is 52 dBi, and the frequency is 35.7 GHz. The antenna patterns are as shown in Figure 3 for a 1.4 m dish antenna with 52 dBi gain.

The terrestrial radars were spaced about 500 km apart worldwide on the land masses as shown in Figure 8.

FIGURE 8

Worldwide distribution of terrestrial tracking radars

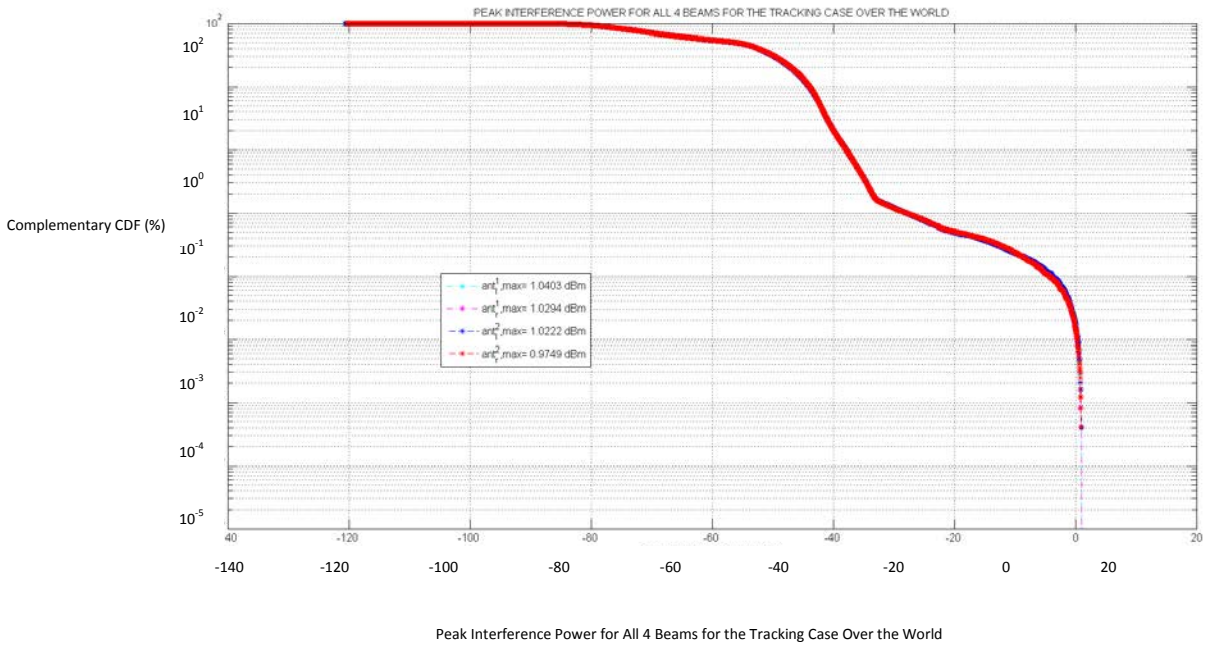


4.2.2.3 Orbit simulations

The EESS (active) orbit was assumed to have a sun synchronous orbit at 824 km altitude, and 98.7 inclination with a repeat orbit of 16 days. The 30 day simulation had a one second time tic with the EESS (active) initial orbit assumed directly over the metric radar as worst case. Figure 9 shows the complementary CDF of the peak received interference power into the EESS (active) four receiver channels. There is one receiver channel for each of the four receive antenna beams. The peak received RFI level as shown in Figure 9 is about +1 dBm.

FIGURE 9

1-CDF of RFI into Four EESS (active) Receiver Channels from Terrestrial Radars



5. Conclusions

The analysis herein provides designers of EESS (active) systems with worst case, mainlobe antenna coupling levels, against which the receiver must be protected. For the spaceborne InSAR operating in the 35.5-36 GHz band, assuming a bandwidth of 200 MHz, the received power into the InSAR peaks above +0 dBm in the middle of the pass. The InSAR receiver should be protected up to + 0 dBm with no margin or up to +6 dBm if a 6 dB margin is imposed. The duration of the RFI above -10 dBm is about 20 milliseconds and above 0 dBm is about 5 milliseconds.

In this document, the worst case RFI levels into the EESS (active) receiver systems from the radiolocation service in the 35.5-36 GHz band were analyzed for the case of antenna mainlobe-to-mainlobe coupling.

REPORT SFCG 34-2

GLOBAL RFI SURVEY ON EARTH EXPLORATION-SATELLITE SERVICE L-BAND SENSORS (ACTIVE AND PASSIVE)

Abstract

This SFCG report presents global surveys of RFI levels observed by operational L-band sensors in the Earth exploration-satellite service (EESS) (active) band 1215-1300 MHz and the EESS (passive) band 1400-1427 MHz.

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1. Introduction

This SFCG report describes the radio frequency (RF) environment experienced by one spaceborne active sensor, the Aquarius scatterometer, operating around 1 260 MHz in the Earth exploration-satellite service EESS (active) allocation in the 1 215-1 300 MHz band, and two spaceborne passive sensors, the SMOS and Aquarius radiometers, operating in the EEE (passive) allocation in the 1 400-1 427 MHz band.

The band 1 215-1 300 MHz is allocated on a primary basis to the radiolocation service and the band 1 240-1 300 MHz is also allocated on a primary basis to the aeronautical radionavigation service. Systems operating under the EESS (active) allocation cannot claim protection from systems operating in the radiolocation or aeronautical radionavigation services in these bands. However, from the perspective of the active sensors operating in the EESS (active), emissions from the terrestrial radars operating in the radiolocation and aeronautical radionavigation services are RF interference to these sensors. Also presented for comparison is the RF environment for the Aquarius radiometer in a 7 day global map of brightness temperature for the 7 day period as for the scatterometer.

The band 1 400-1 427 MHz is allocated on a primary basis to the EESS(passive), SRS passive and to the Radio-astronomy services. All emissions are prohibited in this band according to the ITU-R Radio Regulations (RR) footnote 5.340. In addition, the WRC-07 adopted Resolution 750 on the compatibility between the EESS-passive and relevant active services. As concerns the 1400–1427-MHz band, **ITU-R Resolution 750** contains recommended levels of unwanted emissions applicable to the whole range of ITU-R services allocated in the adjacent bands (Fig. 1-1) and resolves to urge administrations to take all reasonable steps to ensure that unwanted emissions of active services do not exceed the specific recommended maximum levels, noting that EESS passive sensors provide worldwide measurements that benefit all countries.

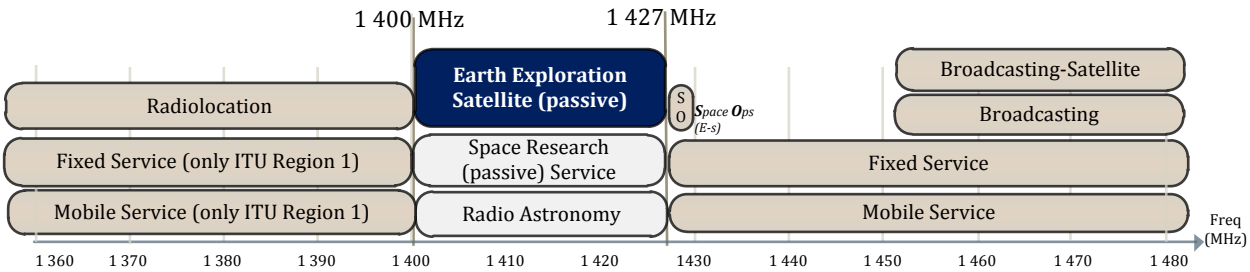


Figure 1: ITU-R Frequency allocations in the 1 400-1427 MHz range and adjacent frequency bands

This document describes that RFI as measured by spaceborne active and passive sensors operating in their allocated EESS frequencies in L-Band. Such information may be useful for the design of future spaceborne sensors in this band.

2. EESS (active) Sensor-Observed RFI

2.1 Aquarius Scatterometer Observed RFI

2.1.1 Description of Aquarius Scatterometer

Aquarius is a microwave remote sensing instrument designed to obtain global maps of the surface salinity field of the oceans from space, and it is flown on the Aquarius/ Satélite de Aplicaciones Científicas-D (SAC-D) mission, a partnership between the USA National Aeronautics and Space Administration (NASA) and Argentina Comisión Nacional de Actividades Espaciales (CONAE). Aquarius successfully launched in June 2011. The Aquarius instrument is a combination scatterometer and radiometer operating at 1.26 GHz for the scatterometer (active sensor) and at 1.413 GHz for the radiometer (passive sensor). Even though the primary instrument for measuring salinity is the radiometer which responds to salinity because of the modulation salinity produces on thermal emission from sea water, the scatterometer provides a correction for surface roughness (waves) which is one of the greatest unknowns in the retrieval.

The Aquarius scatterometer maps the world every 7 days. The Aquarius scatterometer is a 1.26 GHz, total power scatterometer designed to acquire radar backscatter signals to estimate ocean-surface roughness. The spaceborne scatterometer operates at an altitude of 657 km and inclination of 98 deg. The Aquarius scatterometer, co-points with the primary radiometer subsystem, to actively estimate ocean roughness and enable this temperature correction. The radar scatterometer collects fully polarimetric returns and they are summed to represent the total ocean backscatter. The range bandwidth is 4 MHz. The linearly frequency modulated (FM) pulses have a pulse duration of 1 millisec and bandwidth of 4 MHz. Three beams from an offset –parabolic reflector provide a 280 km width swath. The 2.9m x 2.5m offset parabolic reflector with three feeds produces inner, middle and outer 3 dB beam widths of 6.5 deg, 6.7 deg, and 7.1 deg, respectively. An illustration of the three beams of the Aquarius scatterometer and the three footprints on the Earth is shown in Figure 2.1-1. Each of the three beams is pointed at different nadir angles in order for the footprints to cover 390 km across track on the ground. The radar cycles among the three beams every 60 milliseconds.

Following the June 2011 launch and activation of the Aquarius instrument, RF interference (RFI) was observed to be present globally in the Aquarius scatterometer band 1258-1262 MHz. Onboard RFI flagging was available but is not sufficient for removing RFI effects for further processing, so an RFI detection and filtering algorithm was developed for ground data processing. Most RFI over the ocean has been effectively removed, and a substantial amount of RFI has been removed over most land areas. The global survey maps of observed RFI at 1260 MHz herein shows that certain land areas are contaminated with RFI.

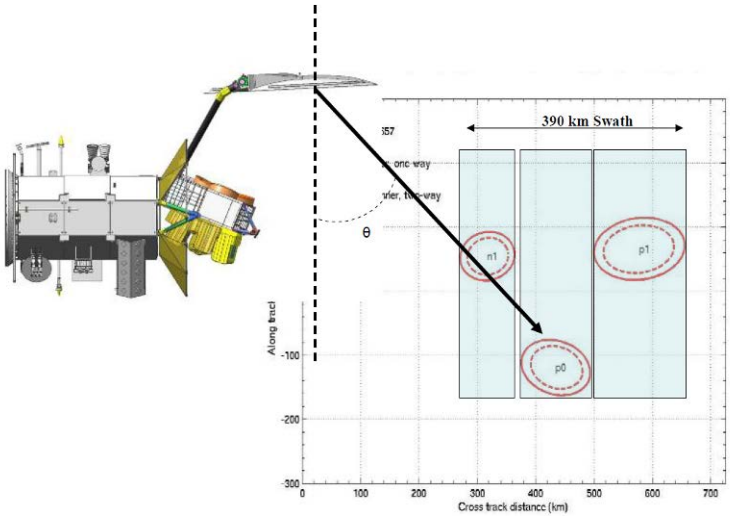


Figure 2.1-1. Illustration of Three Footprints of Three Antenna Beams of Aquarius Scatterometer

2.1.2 Observation of RFI by the Aquarius Scatterometer at 1260 MHz

The Aquarius scatterometer radar alternates horizontal (H) and vertical (V) transmit and receive polarized pulses, and interleaves noise-only measurements on each polarization. The echo data has HH, VV, HV, and VH transmit-receive polarizations, and nH and nV noise-only receive polarizations. During every other nV measurement, a noise diode injects a signal into the receive path which raises the apparent nV noise floor. Figure 2.1-2 shows the timing sequence of the Aquarius instrument. Figure 2.1-3 is a map of the V-pol and H-pol noise-only receive channels over a 7-day global mapping period. There are regions of high RFI in eastern North America, Europe, and East Asia, with numerous other high RFI regions in other land areas.

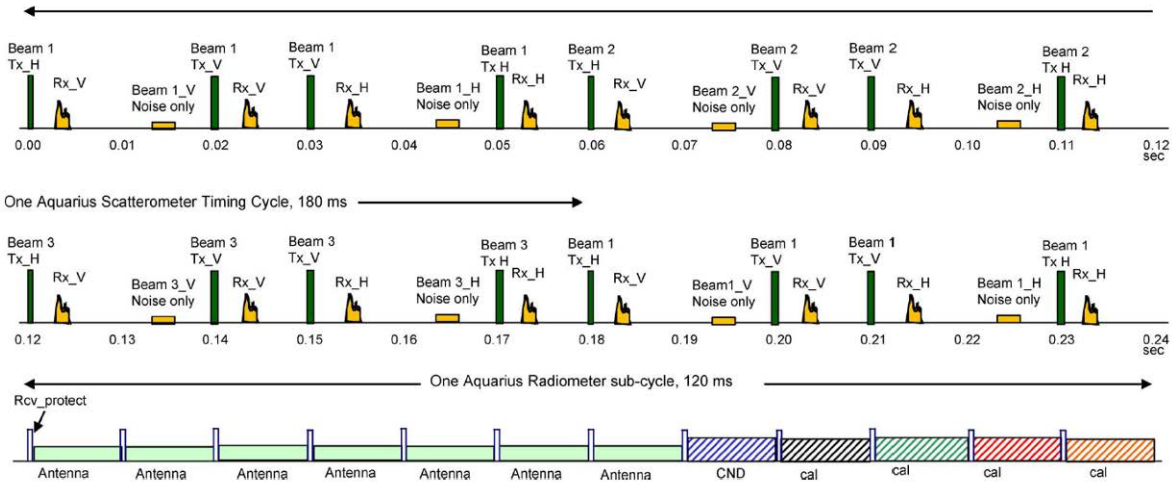


Figure 2.1-2. Timing Sequence of Aquarius Instrument

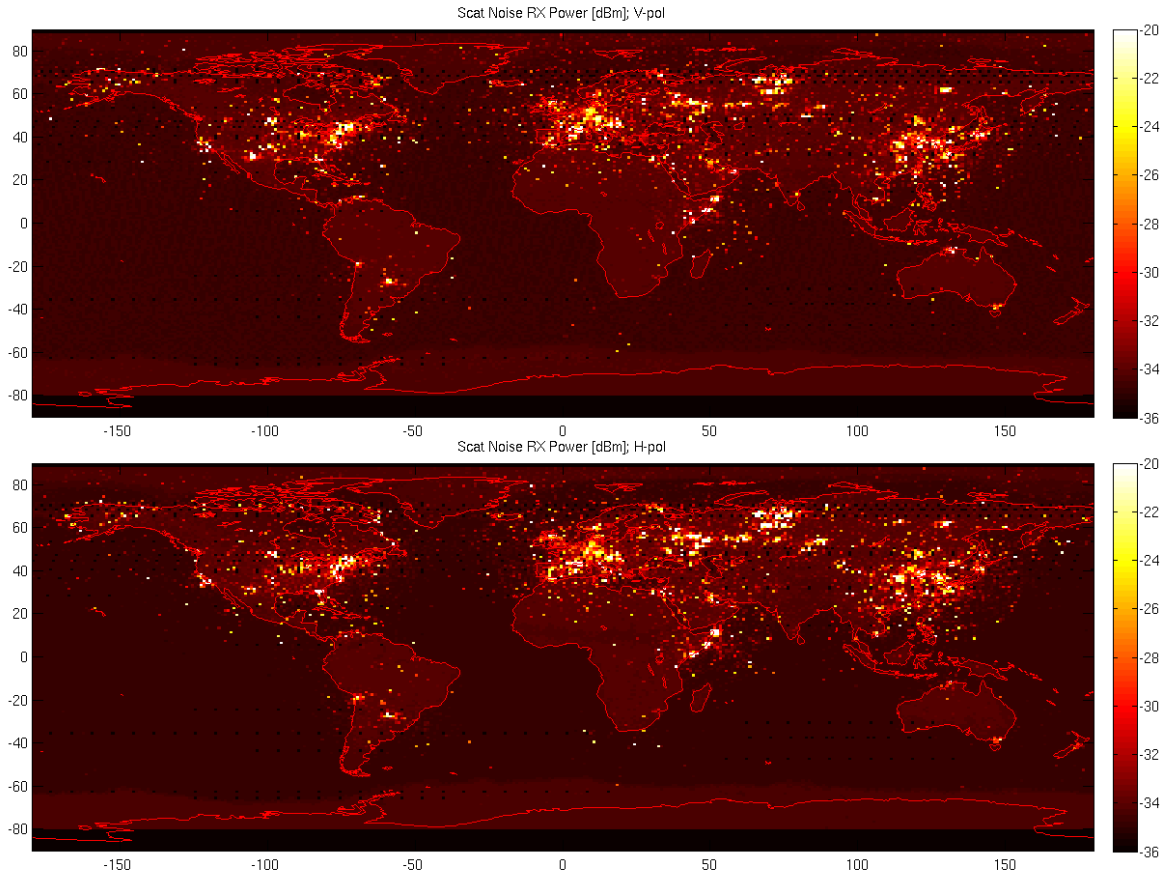


Figure 2.1-3. Global map of RFI into Aquarius Scatterometer at 1260 MHz

These global RFI maps show several types of RFI coupling: 1) the main beam of ground radar entering the sidelobes of the Aquarius scatterometer, and 2) ground radar sidelobes entering one of the Aquarius radar main beams. The first type of RFI coupling is apparent as far as 3000 km from the RFI source and into the nearby oceans. This coupling type usually appears simultaneously in all 3 radar beams. The second type of RFI coupling appears at the location of the RFI source and usually shows up in only one of the three beams at one time.

2.1.3 RFI Detection

The onboard RFI detection algorithm uses a threshold level of the high-rate 16-MHz digital sampling. Any pulsed RFI from ground sources are integrated over the Aquarius 2 ms receive windows. The scatterometer has thresholds at the RF front-end and at the ADC input.

2.1.4 RFI Source Analysis

Individual RFI sources can be identified from the Aquarius scatterometer RFI data using the spatial and temporal resolution. The observed RFI effects can be compared with the predicted RFI effects.

Figure 2.1-4 shows RFI power values over North America when the cumulative distribution function (CDF) equals to 90.0 to 100%, using histograms of noise received power in every 1x1 deg grid cell, and from histograms, the probability distribution functions (PDFs) and CDFs for

every 1x1 deg grid cell. The RFI maps are shown for H-pol in the top row and for V-pol in the bottom row. For example, in the top left is a map of the H-pol receive noise power value such that for each cell, 90.0% of the data in the cell is less than this value (color coded using values from color bar). It seems to be easier to identify the location of sources of RFI for lower CDF values around 99.5 %. Figure 2.1-5 shows an example of identifying the locations of Aquarius high localized RFI areas with nearby ATC radars over North America. Figure 2.1-6 shows a complementary cumulative distribution curve (1-CDF) of RFI levels observed Jan-Mar 2013 for the continental U.S. The receiver gain from the antenna feeds to the ADC input is about 67 dB, so for example if the RFI level is -10 dBm at the ADC input, then the signal level at the antenna feeds is -76 dBm, or -106 dBW. Figures 2.1-7, 8 and 9 show the RFI maps of the maximum observed noise in Regions 1, 2, and 3, respectively. Figures 2.1-10, 11 and 12 show the RFI maps of the observed noise for CDF value 99.9 % in Regions 1, 2, and 3, respectively, for observations in the first quarter of year 2014. By comparing the weekly RFI maps of the maximum observed noise, it is possible to see new sources of RFI as in Figure 2.1-13 for the northern part of Region 2. It is also possible to see RFI sources disappear by comparing the weekly RFI maps of the maximum observed noise, as in Figure 2.1-14 for the southern part of Region 1.

The expected RFI signal levels generated from RFI and source/receiver modeling can be compared to the RFI levels Aquarius actually observes. Analyses like these can aid in studies of RFI effects on future L-band satellite missions, and in studying the terrestrial L-band RFI environment as it evolves in the near future. Because of the reciprocity of the antenna gains, the observed RFI levels into the Aquarius scatterometer can be used to estimate the RFI levels into the ground radars from the spaceborne radar.

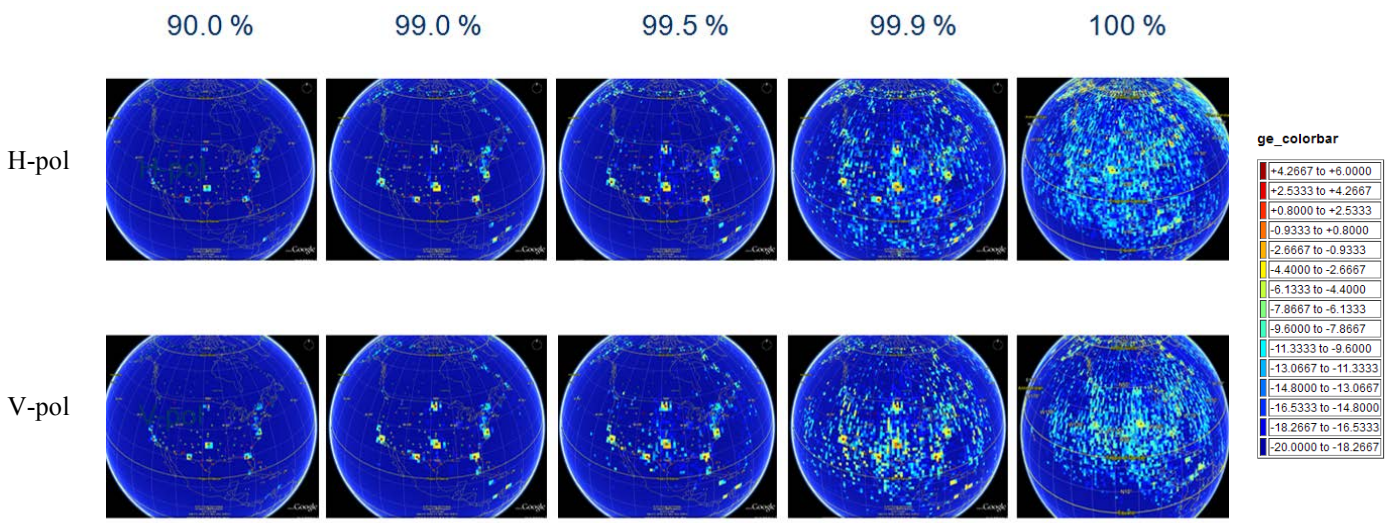


Figure 2.1-4. Maps of RFI into Aquarius Scatterometer over North America for H-pol and V-pol Data for 90 % to 100 %

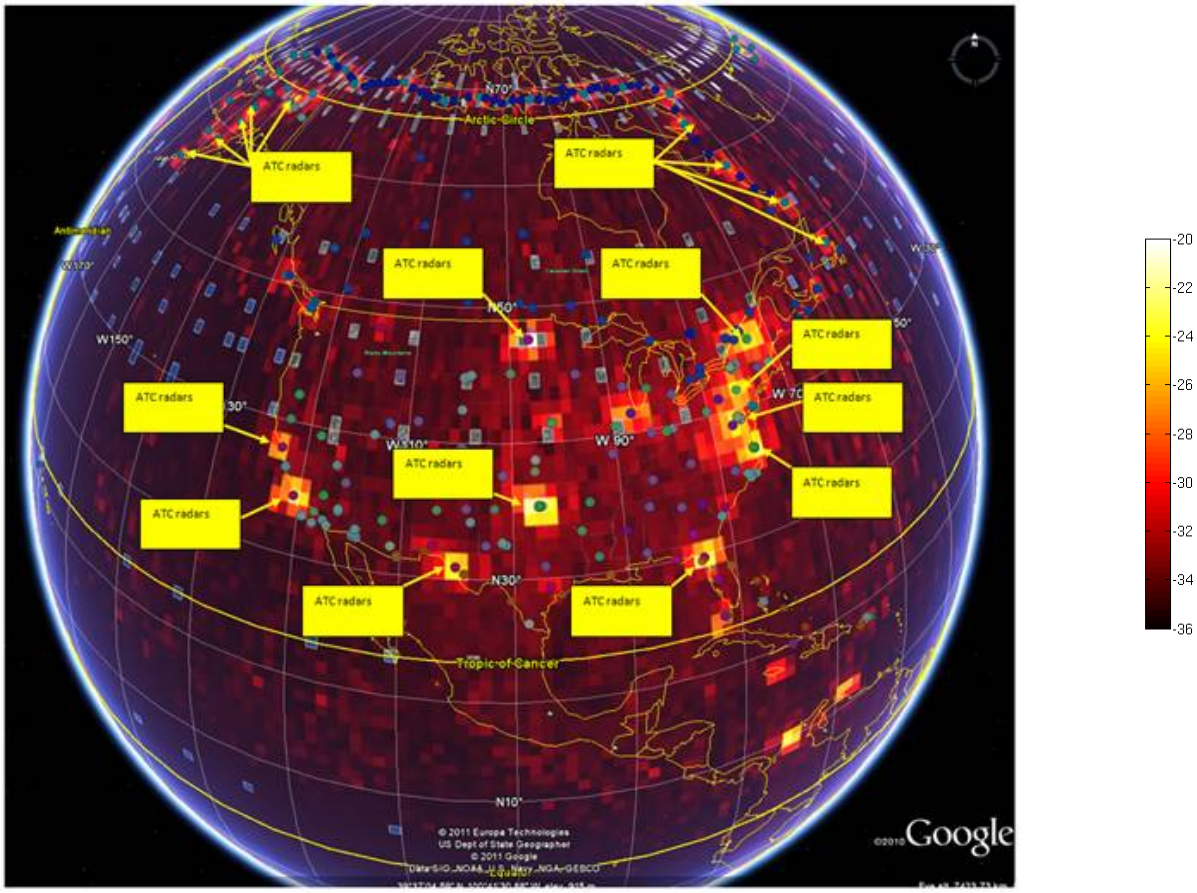


Figure 2.1-5. Aquarius-determined high RFI localized areas in North American identified with ATC radars

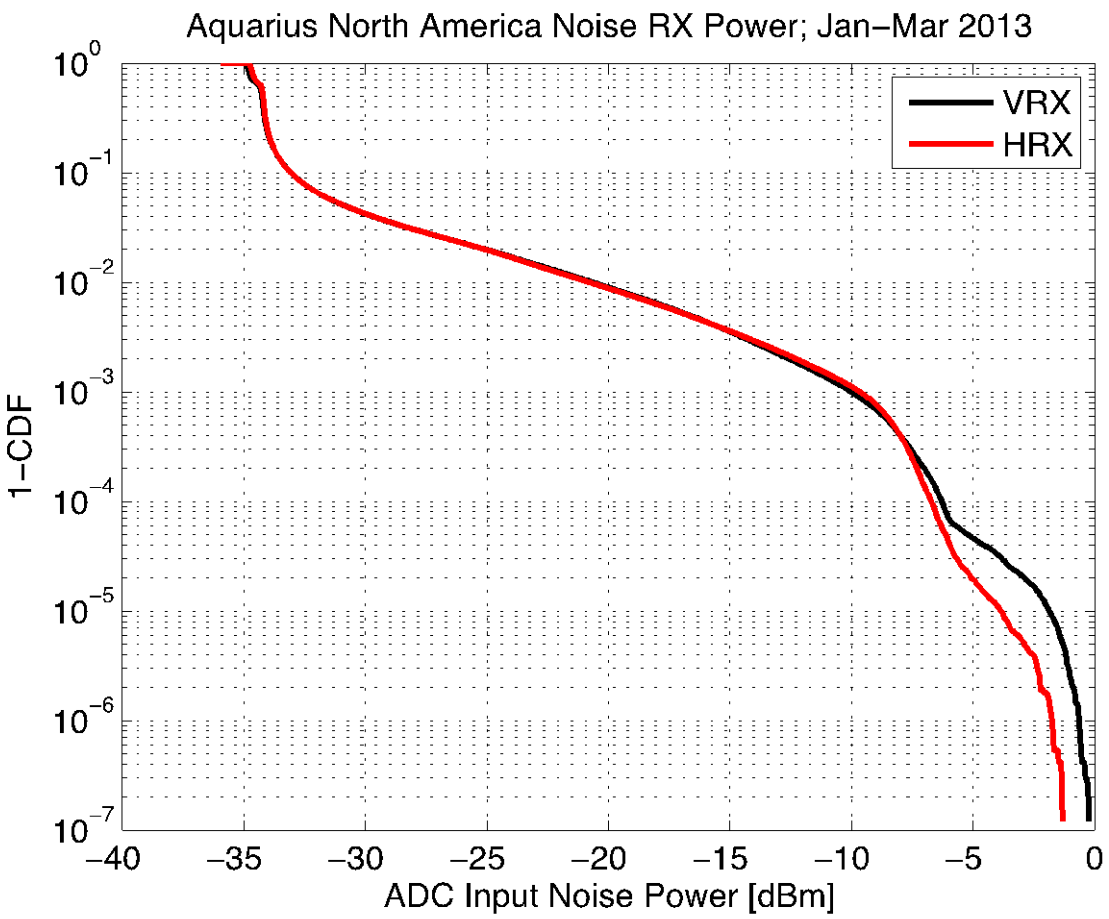


Figure 2.1-6. 1-CDF Distribution of observed noise power at scatterometer ADC input for North America (Jan-Mar 2013)

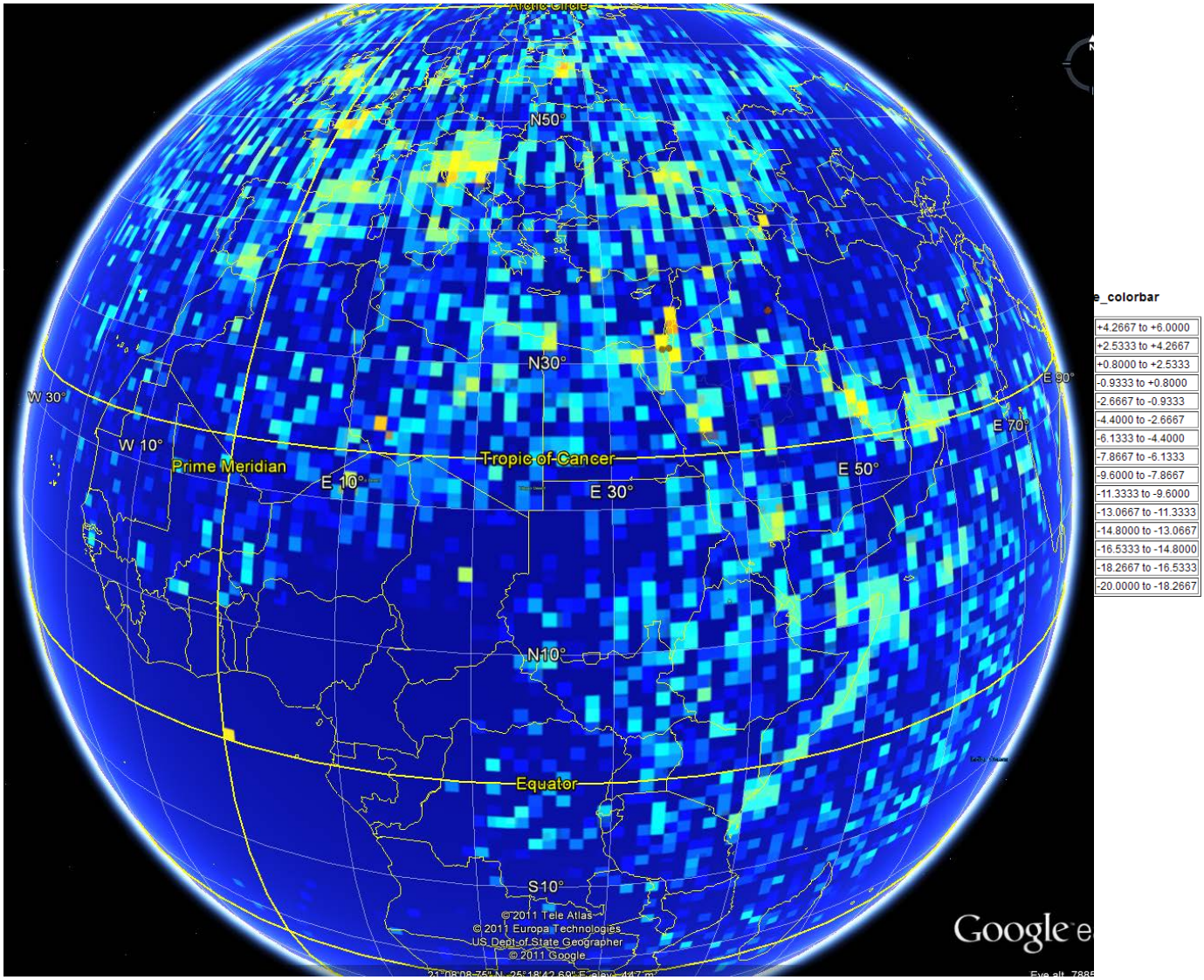


Figure 2.1-7. Map of observed maximum noise power at ADC input for Europe and Northern Africa (Region 1)

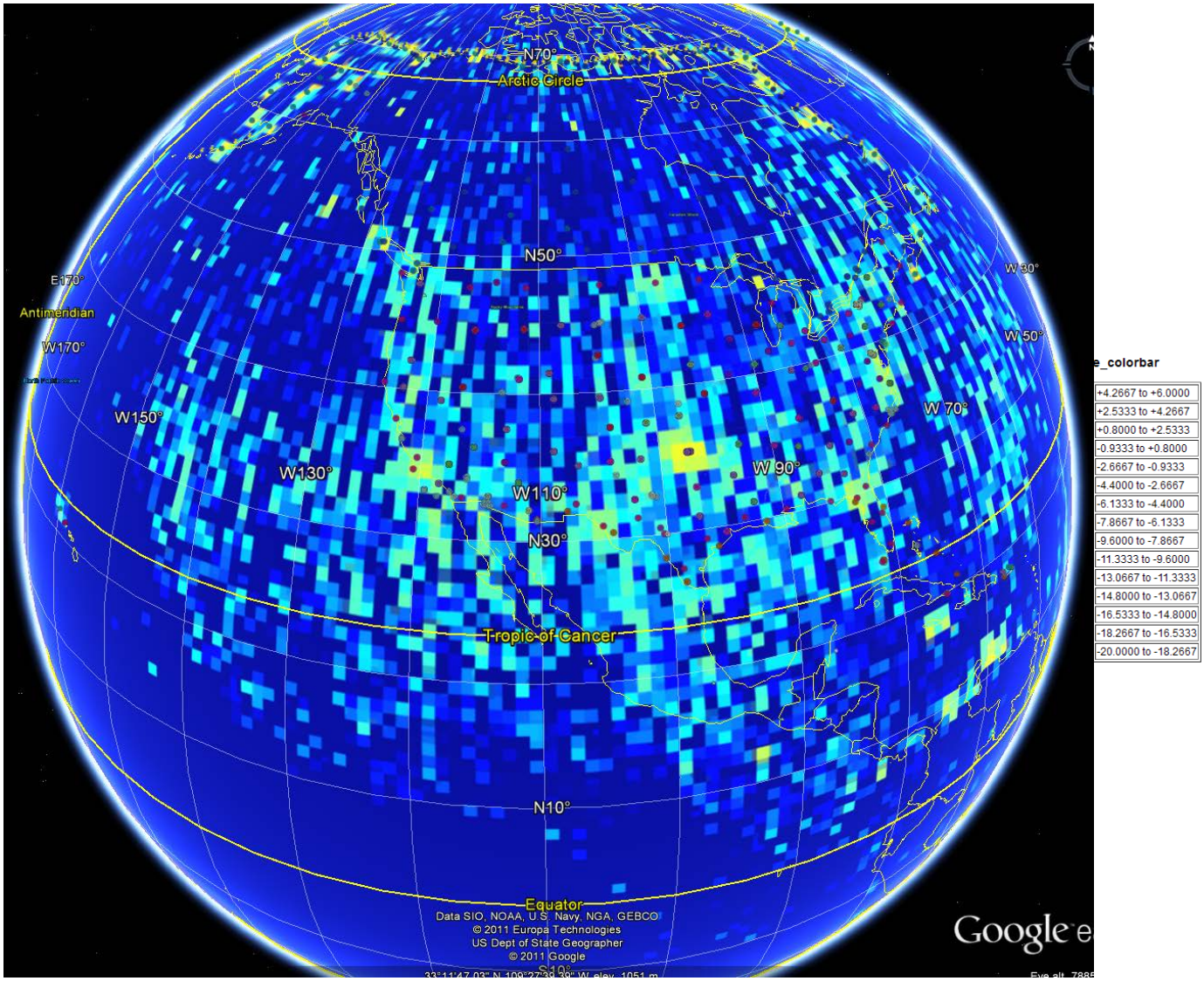


Figure 2.1-8. Map of observed maximum noise power at ADC input for North America (Region 2)

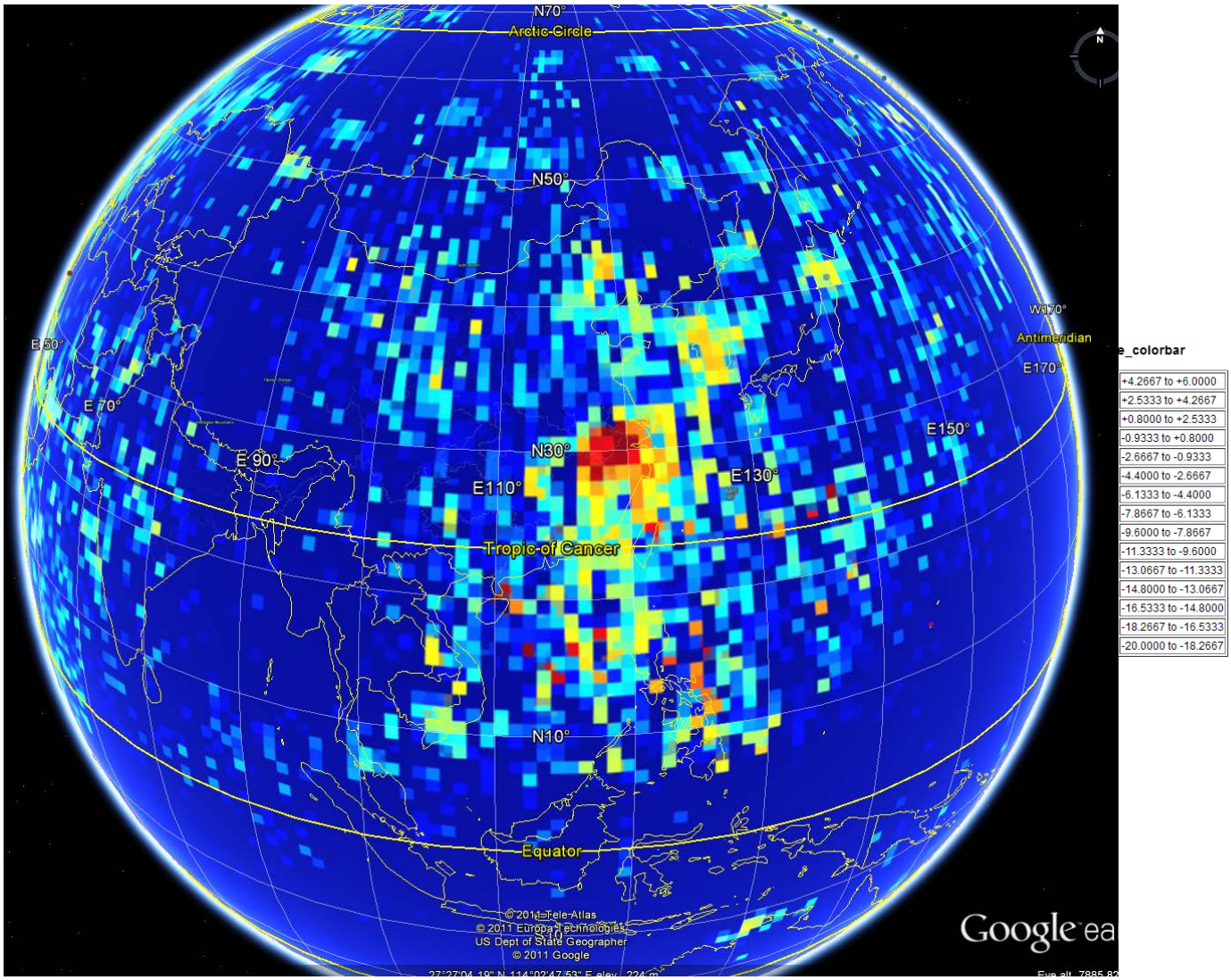


Figure 2.1-9. Map of observed maximum noise power at ADC input for Pacific Asia (Region 3)

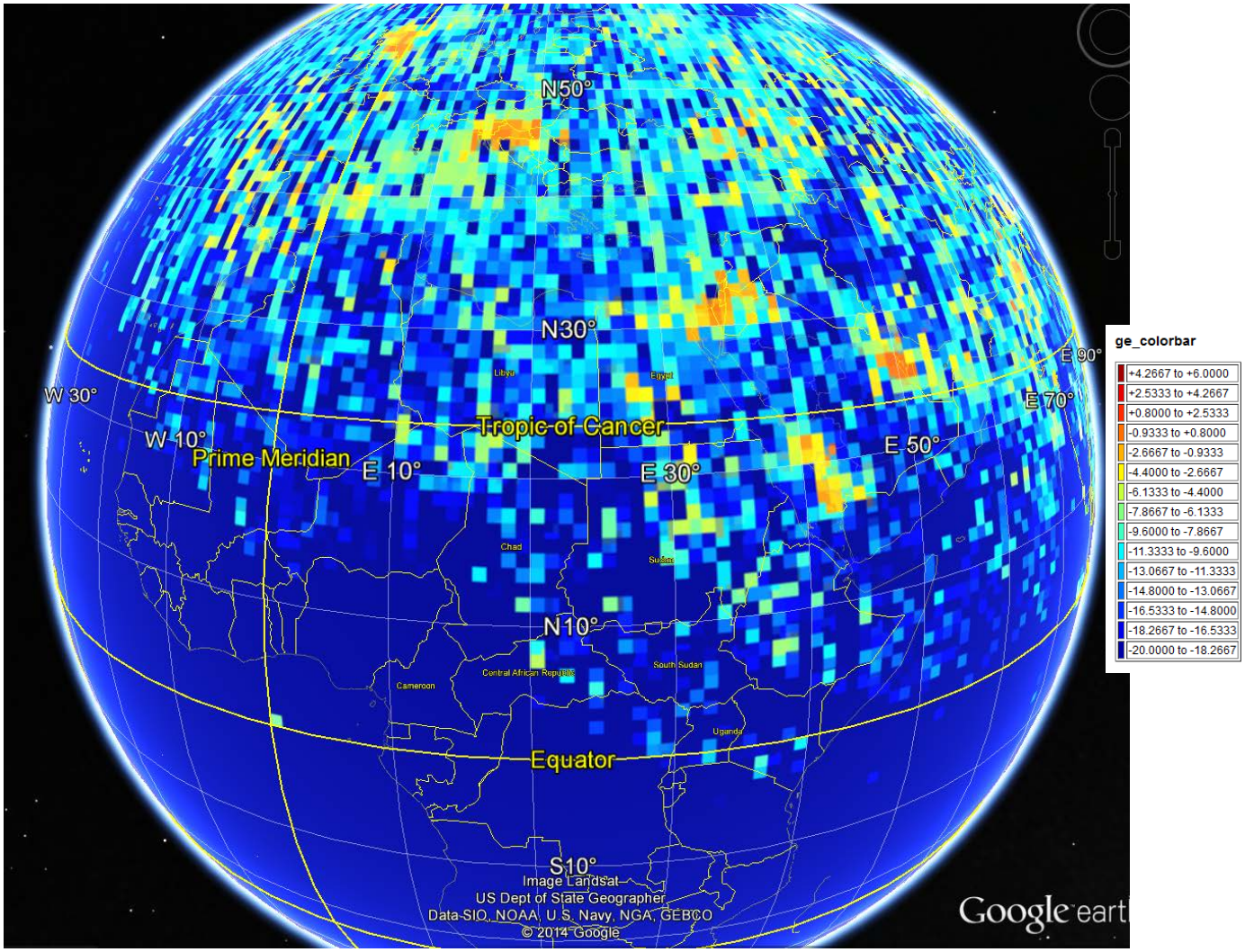


Figure 2.1-10. Map of observed noise power (99.9 %) at ADC input for Europe and Northern Africa (Region 1) (1st Quarter of Year 2014)

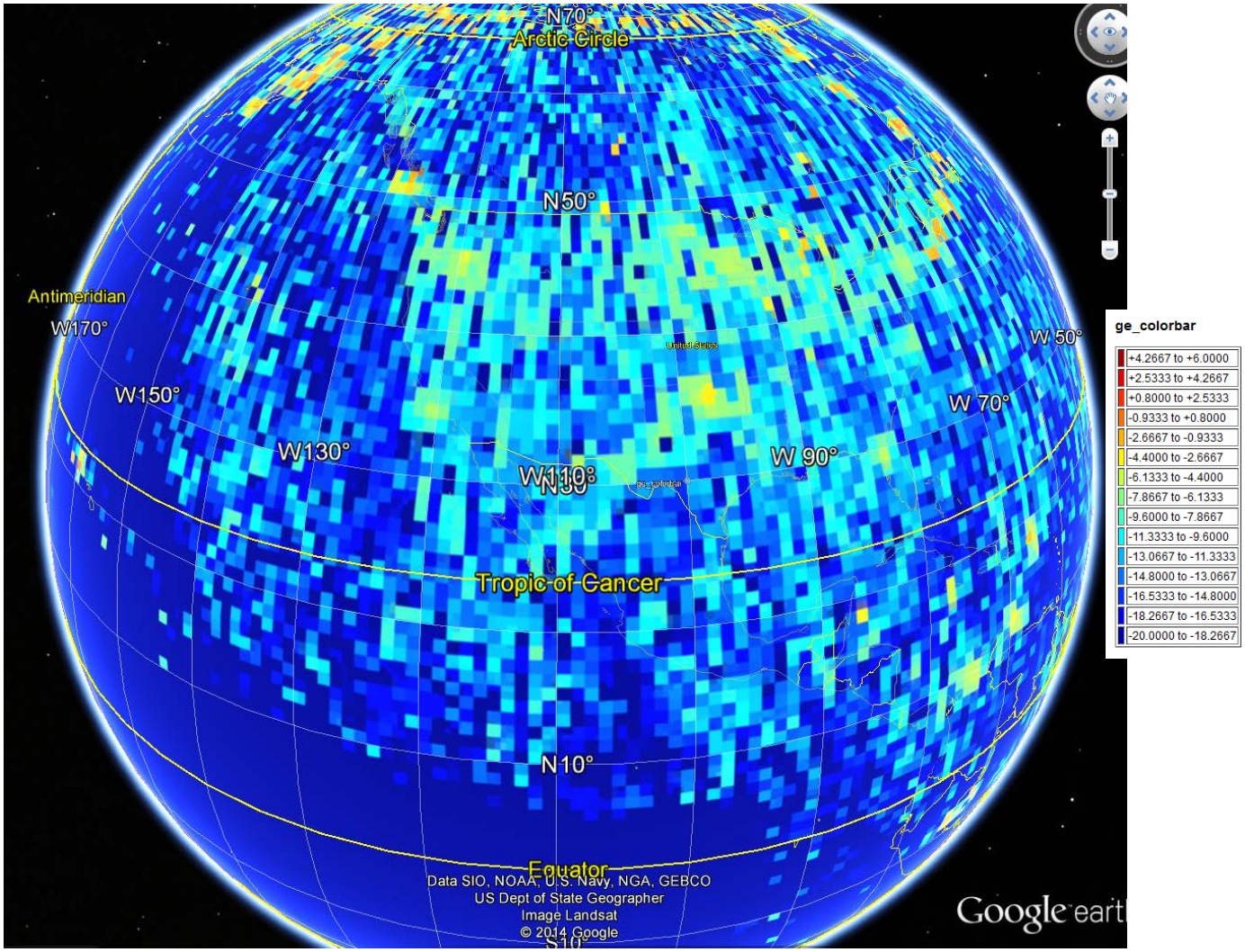


Figure 2.1-11. Map of observed noise power (99.9 %) at ADC input for North America (Region 2) (1st Quarter of Year 2014)

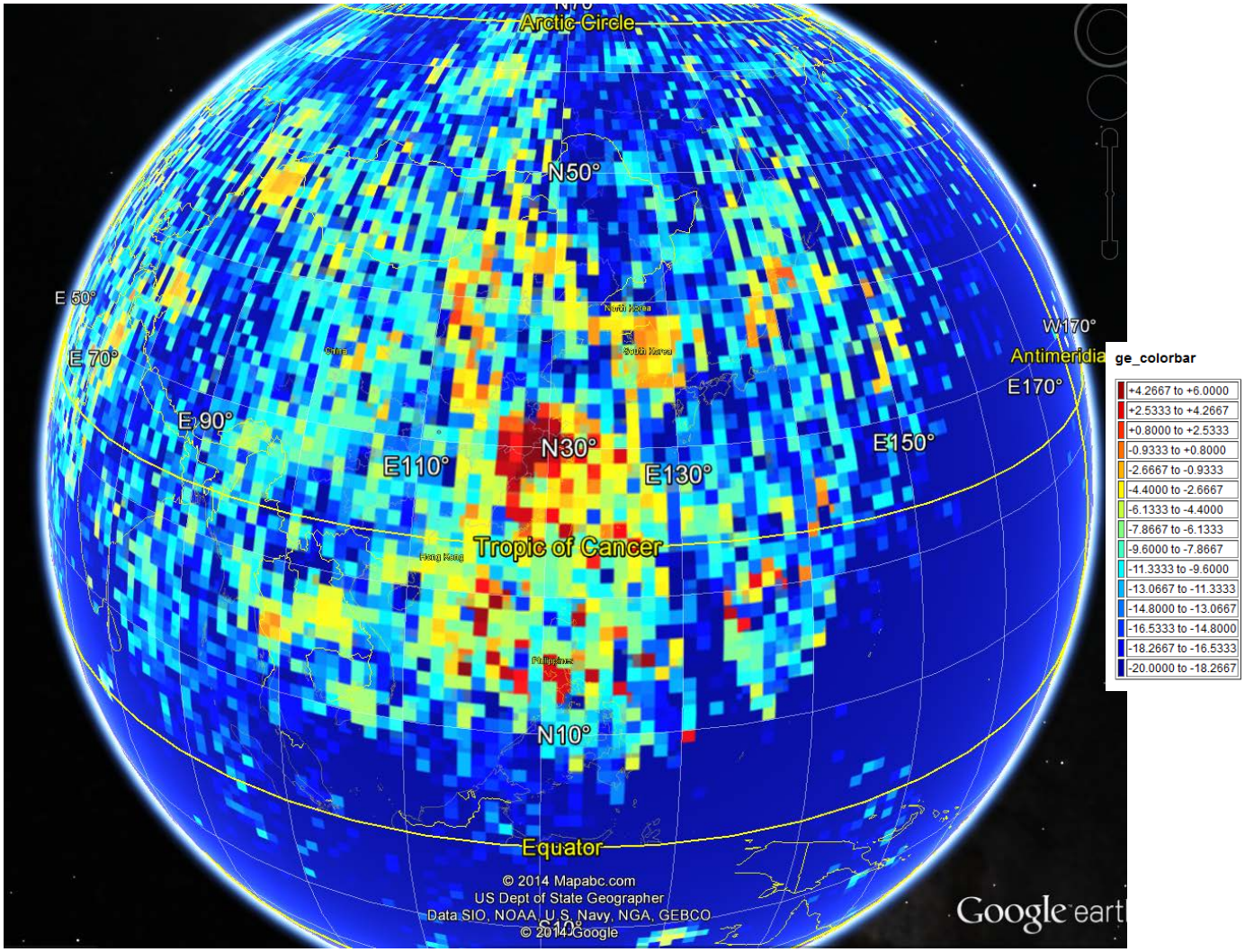
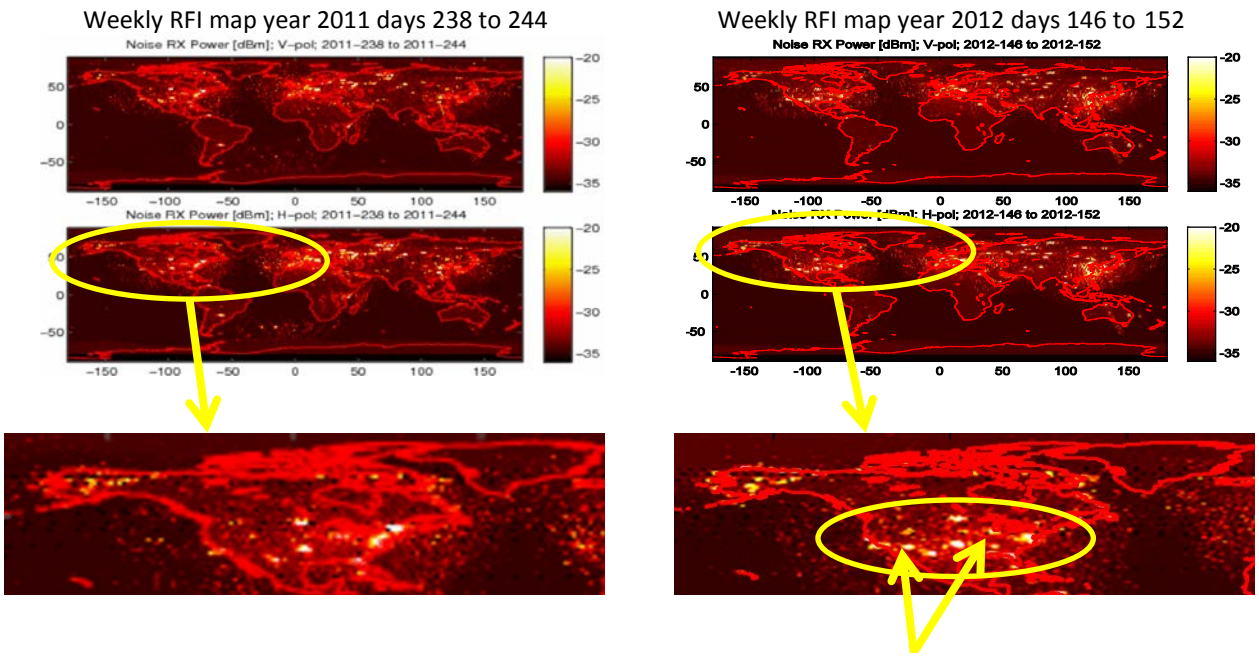


Figure 2.1-12. Map of observed noise power (99.9 %) at ADC input for Pacific Asia (Region 3) (1st Quarter of Year 2014)



Note: Weekly RFI map shows additional RFI sources by comparing observed RFI in northern part of Region 2 in maps about nine months apart

Figure 2.1-13. Comparison of observed weekly maximum noise power at ADC input in 2011 and 2012 for northern part of Region 2

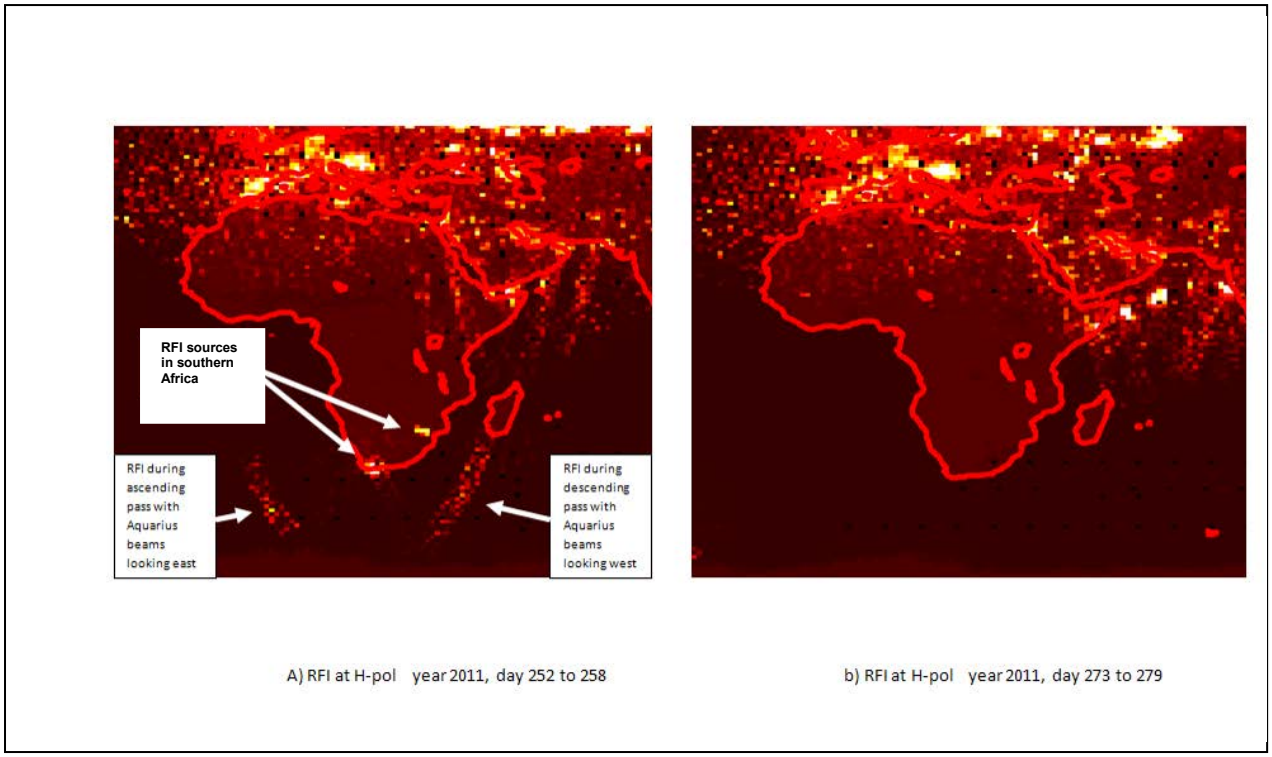


Figure 2.1-14. Comparison of observed weekly maximum noise power at ADC input in 2011 two weeks apart for southern part of Region 1

3. EESS (passive) Sensor-Observed RFI

3.1 SMOS Radiometer Observed RFI

ESA's Soil Moisture and Ocean Salinity (SMOS) mission was launched on November 2, 2009 and became operational in May 2010. The main scientific objective of SMOS is to observe soil moisture over land and sea surface salinity over oceans. As soon as SMOS data analysis began, it became clear that there were Radio Frequency Interferences (RFI) distributed worldwide, in particular over large parts of Europe, China, Southern Asia, and the Middle East.

Figure 3.1-1 shows a graphic representation of the EESS (passive) allocation and neighboring services in L-Band.

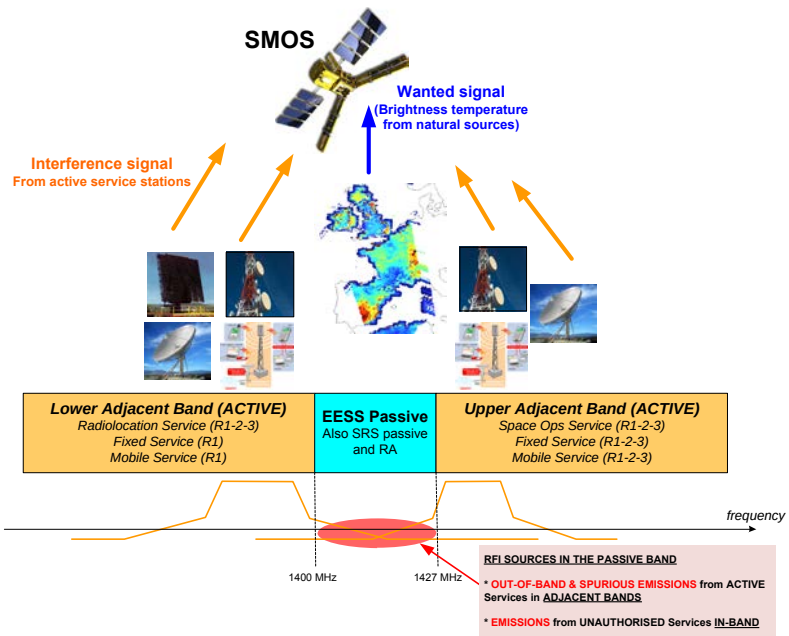


Figure 3.1-1: Graphic representation of EESS(passive) allocation and neighboring services in L-Band

3.1.1 Description of SMOS Radiometer

SMOS has a single payload on board, which consists on a Microwave Imaging Radiometer using Aperture Synthesis (MIRAS). MIRAS is a passive microwave 2-D interferometric radiometer comprising a central structure, the hub (1.3 m diameter), and 3 deployable arms extending up to 8 m in diameter. Each arm comprises eighteen L-Band receivers, complemented by a further twelve receivers, and three Noise Injection Radiometers (NIR) in the central hub. In total, the MIRAS payload comprises 69 antenna elements. SMOS measures the brightness temperature emitted from the Earth at L-band over a range of incidence angles (0 to 55º) across a swath of approximately 1000 km with a spatial resolution of 35 to 50 km. The SMOS brightness temperatures are the so-called Level 1 data products, based on which two level 2 data products are retrieved, namely the Level 2 soil moisture and Level 2 ocean salinity. A key requirement in the design of the receivers was the rejection of signals outside the 1400-1427 MHz passive band. The

SMOS radio frequency (RF) band pass filter response actually implemented on board the satellite is shown in **Fig. 3.1-2**. The center frequency of the filter is 1413.5 MHz with a -3dB bandwidth of 20 MHz. Furthermore, additional rejection is achieved due to the overall receiver selectivity response (complete receive chain): 32dB at 1400MHz and 77dB at 1397 MHz.

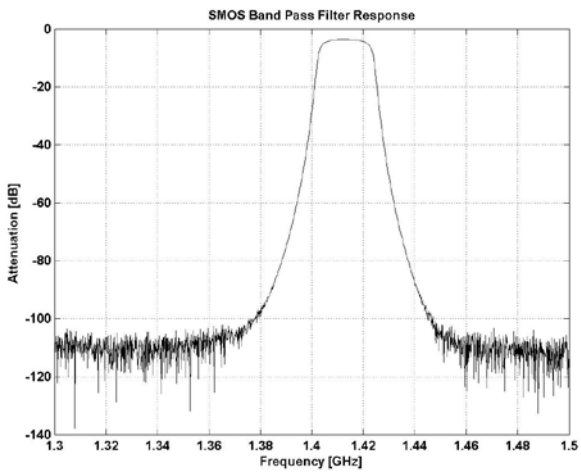


Figure 3.1-2. SMOS RF filter response

The instrument topology and imaging geometry for nominal measurement mode is shown in **Fig. 3.1-3a.** The satellite control utilises local normal pointing and yaw steering. The normal to the face of the instrument (the $+x_A$ axis) is offset from the nadir direction by a 32 degree tilt in the orbital plane (i.e., a pitch rotation). Yaw steering ensures that the trajectory of all targets is parallel to the ground track velocity vector.

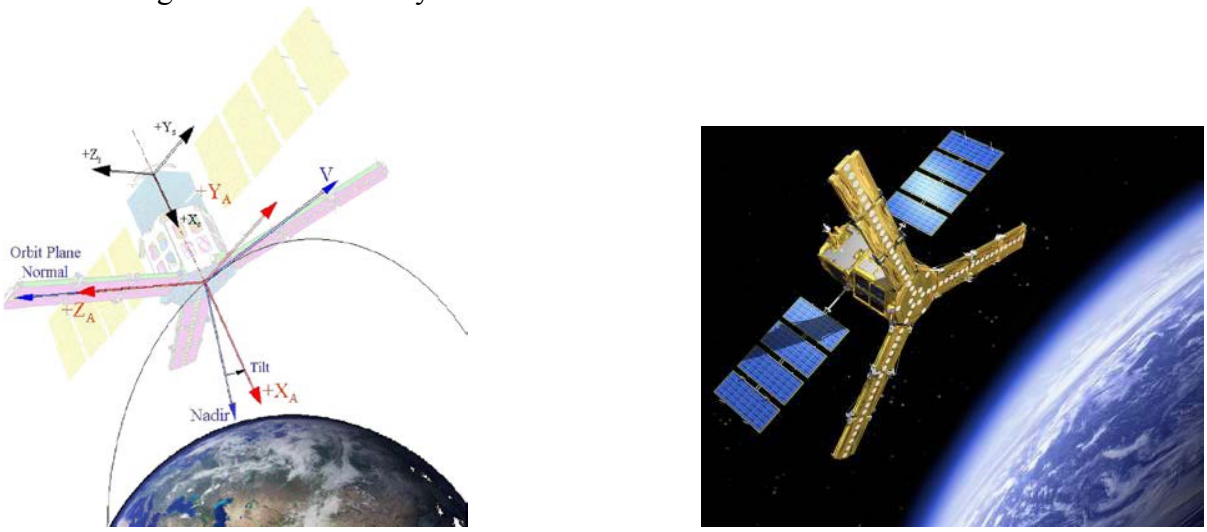


Figure 3.1-3a. SMOS observation mode geometry

Strong RFI can affect measurements thousands of Km away form the antenna source, as can be shown in **Fig. 3.1-3b.**

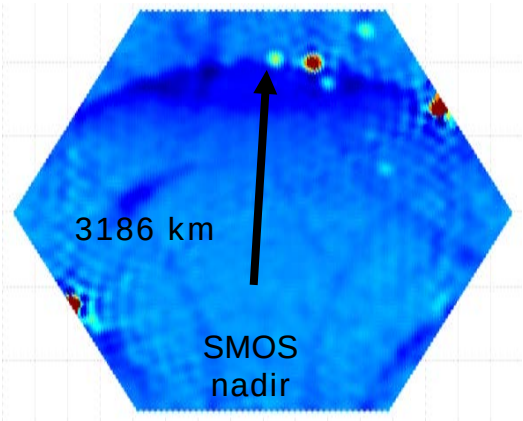


Figure 3.1-3b. SMOS field of view

3.1.2 Global Survey of SMOS Radiometer Brightness Temperature

The Level-2 soil moisture processor allows retrieving statistical information of the SMOS pixels affected by RFI and this data can be presented as **probability maps of RFI occurrences** during a certain period of time. The RFI detection included in soil moisture retrieval algorithms allows detecting strong emitters but also weaker sources. Strong sources are detected when their BTs are outside of the geophysical expectation range. This range uses variable thresholds dependent of the minimum/ maximum physical earth surface temperature within the antenna footprints. The basis of probability maps is to count the number of BTs considered as contaminated per pixel and orbit and to accumulate counters from the beginning of the mission in daily global files maps. SMOS RFI probability maps are prepared regularly by the SMOS team at CESBIO (CNES, France). CESBIO maintains a database with RFI observations since the beginning of the mission. The color bar ranges from red (100%), indicating that RFIs are always present and means that no BT measurements were kept at all during 15 days, to deep blue, indicating none to very low probability and thus almost all BT measurements were kept as usable for retrieval. Intermediate values indicate a high proportion of RFI presence but do not tell when the occurrences appeared within the time window considered. For the 15 days time window illustrated in these maps, a probability of 50% (green) is equally obtained by 7.5 days of continuous strong emissions followed by 7.5 days of no emission at all or by alternating one day with strong RFI followed by one day RFI off or any other combinations. Figures **3.1-4a and 4b** show the RFI probability maps in January 2010 and April 2014.

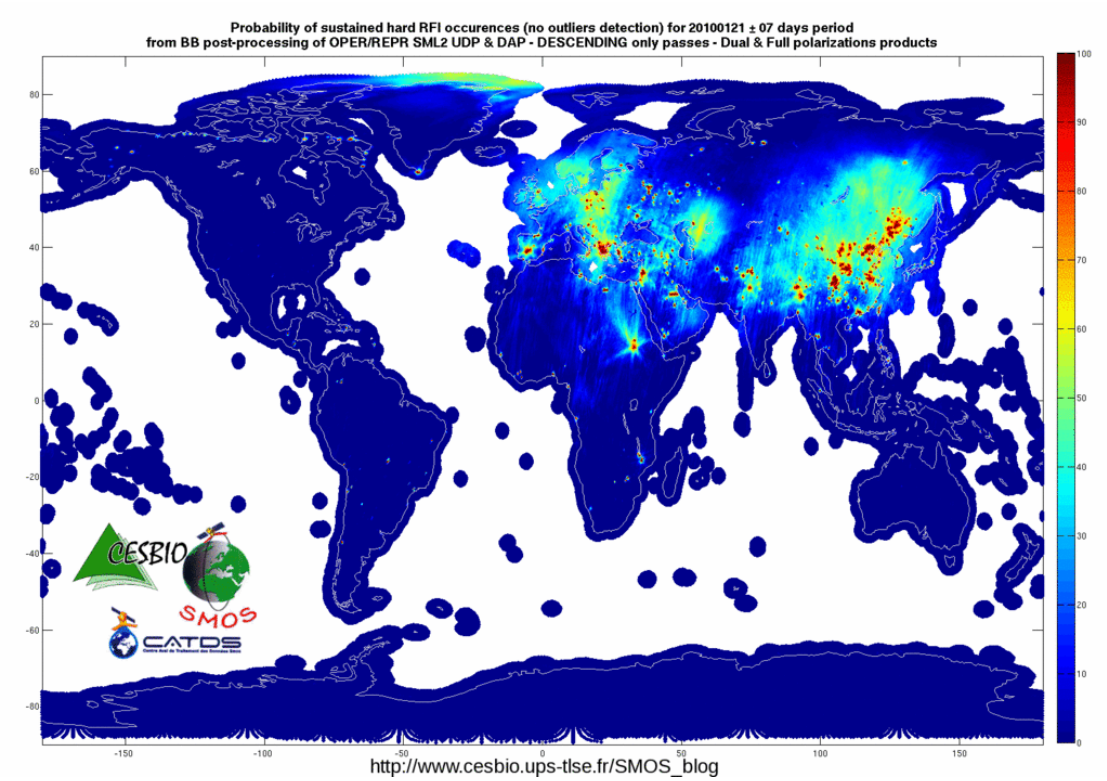


Figure 3.1-4a: Probability Map of sustained RFI occurrence in January 2010 (source: @ CESBIO CNES)

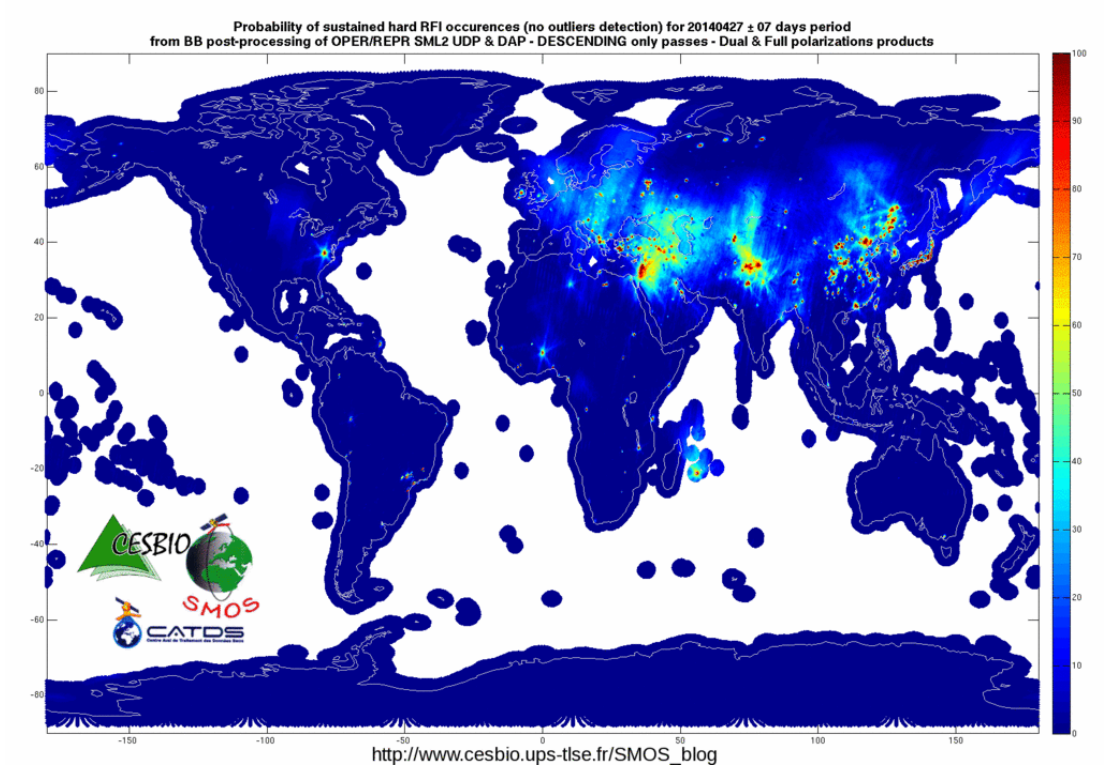


Figure 3.1-4b: Probability Map of sustained RFI occurrence in April 2014 (source: @ CESBIO CNES)

Figure **3.1-5a** shows a worldwide inventory of RFIs, with indication of the strength (brightness temperature) for the sources.

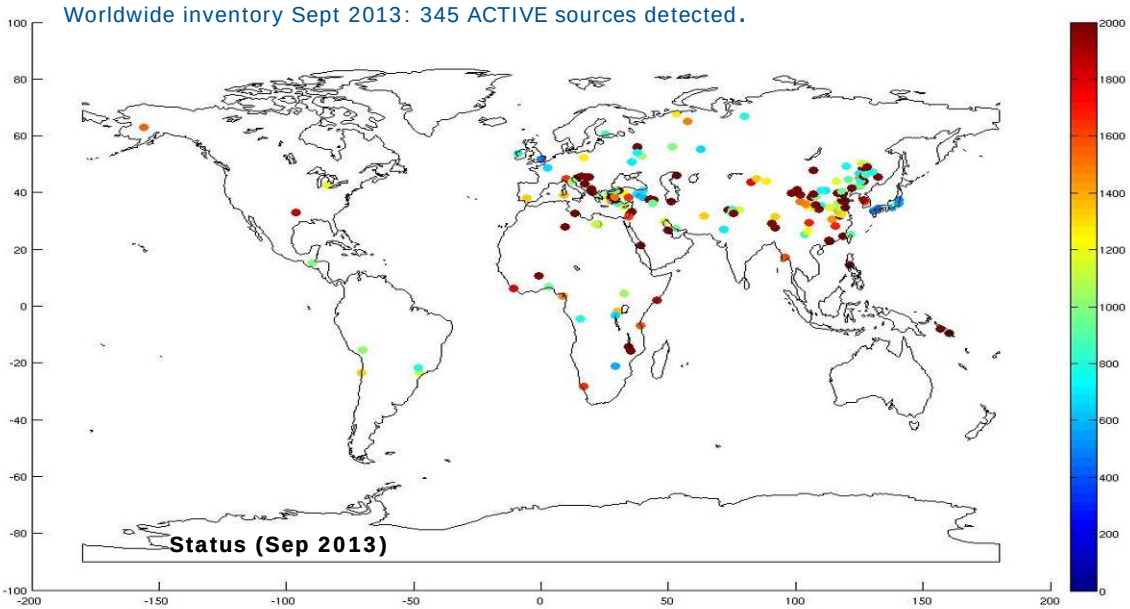


Figure 3.1-5a: Worldwide brightness temperature map in September 2013 (source: @ CESBIO CNES)

As of May 2013, up to 570 RFI have been detected and 261 RFI's (45 %) have been identified and cancelled. So far ESA has contacted 44 administrations. The RFIs are distributed worldwide (fig. **3.1-5b**), although most sources are detected over Asia (49%) and Middle-East (17 %).

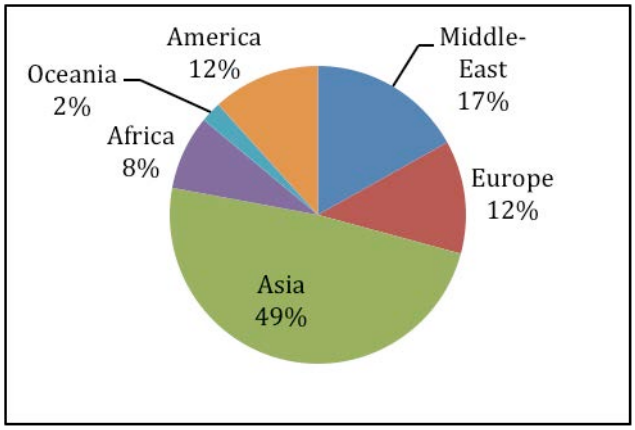


Figure 3.1-5b: **Distribution of SMOS RFI per Areas (May 2013)**

The overall situation is slowly improving as can be seen in Fig**. 3.1-6a and 6b**. However, strong RFIs are masking in some cases other RFI sources underneath and the total number of RFIs detected is increasing.

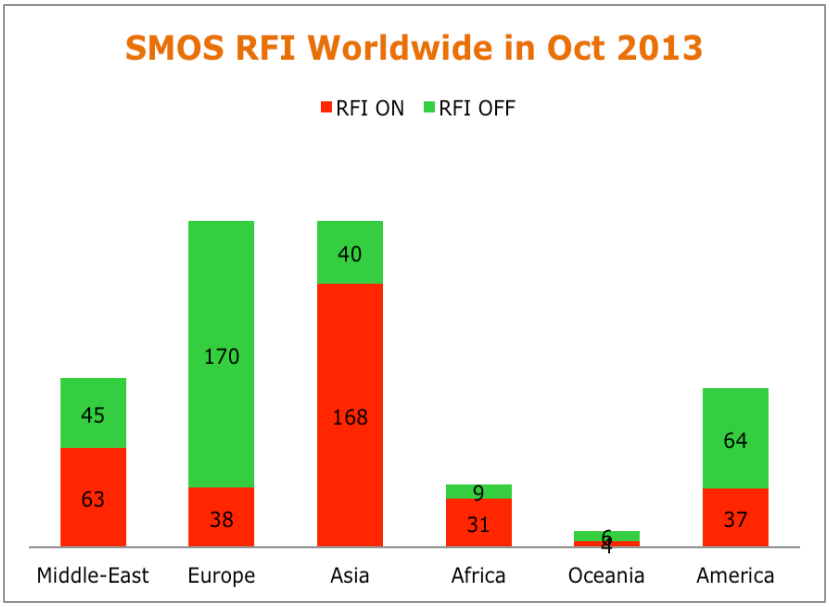


Figure 3.1-6a: Improvement in SMOS RFI worldwide (Oct 2013)

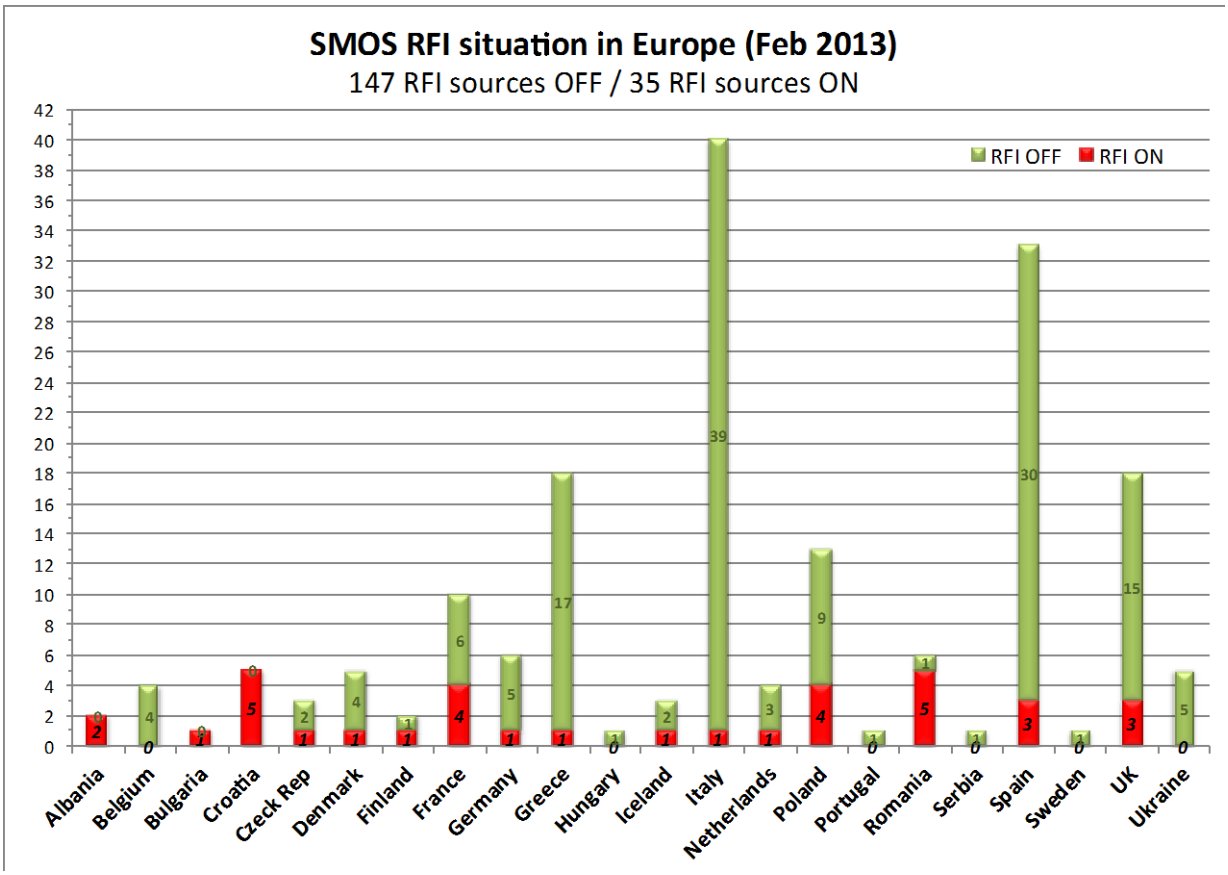


Figure 3.1-6b: Improvement in SMOS RFI in Europe (Feb 2013)

3.1.2.1 Examples of RFI situation in several areas

There has been a significant improvement in North America in part after the upgrade of the radar network in Canada (Fig. 3.1-7a). The levels of unwanted emissions were reduced significantly.

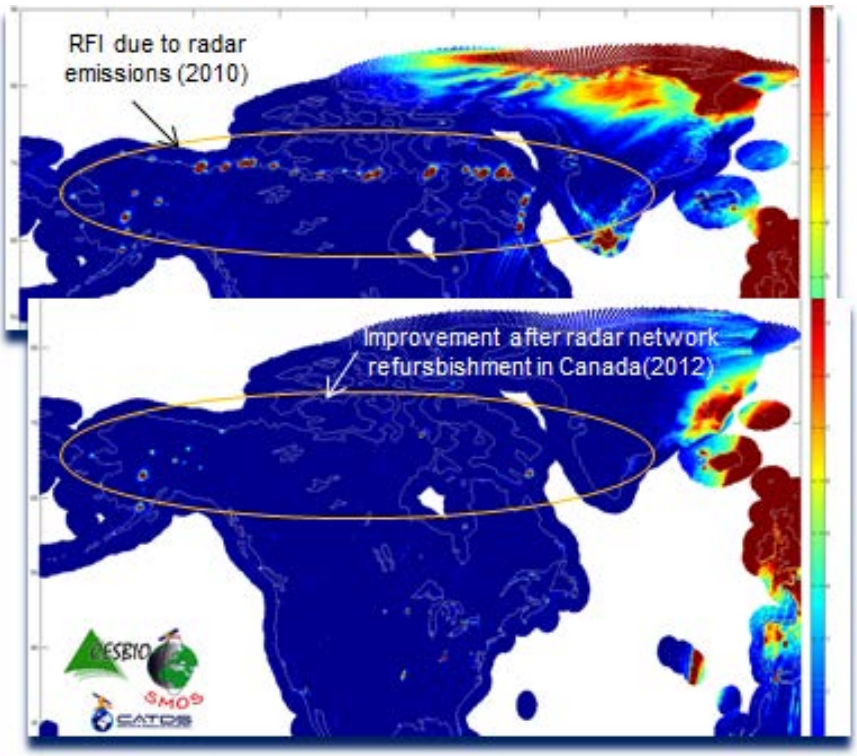


Figure 3.1-7a: Evolution of SMOS RFI in North America after refurbishment of L-Band radar systems in Canada (2012)

There have been some cases in which a single RFI source could blind the instrument and caused the loss of data over central Europe for several months. The cause was due to an old radar operating very close to 1400 MHz and transmitting very high power.

October 2012 February 2013

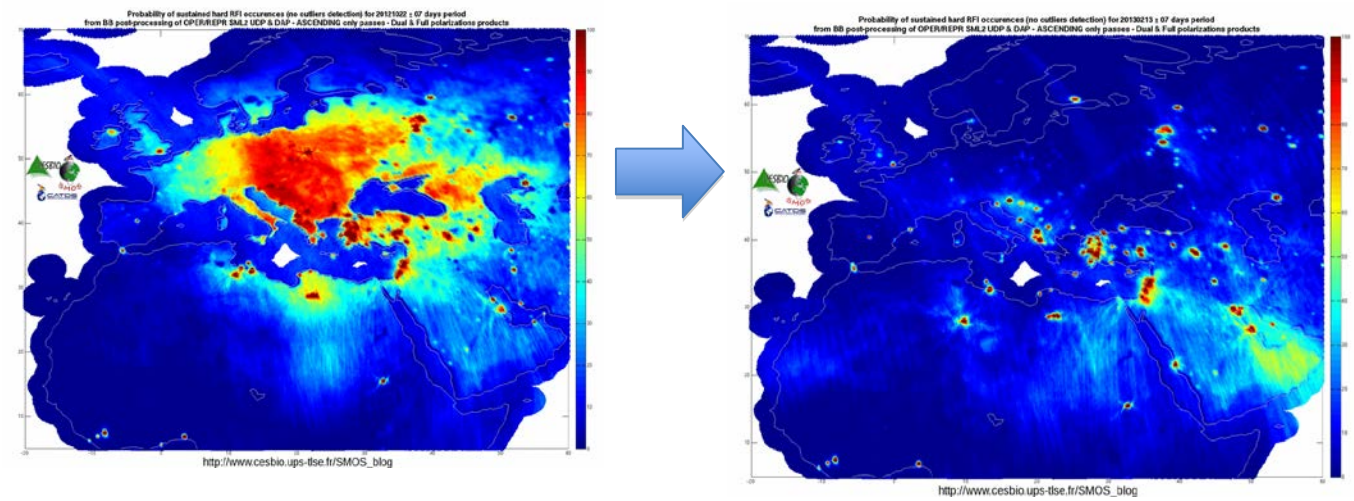


Figure 3.1-7b: SMOS RFI in Central Europe showing a very strong RFI detected in Oct '12
Several examples of the RFI situation before and after the intervention of the National Spectrum Management Authorities are presented in the following figures (UK, Spain)

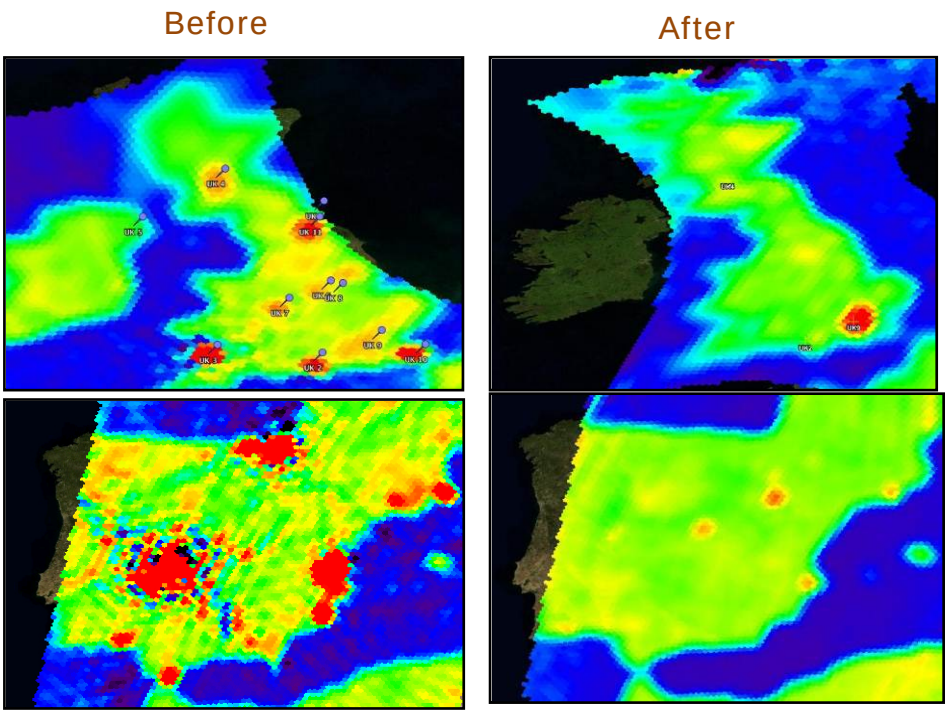


Figure 3.1-8a: Cases of RFI improvement after cooperation of the National Spectrum Management authorities (United Kingdom and Spain)

In some cases it has been observed sudden increase in RFIs in areas that before were free of RFI. This is the case of several RFI new cases that have been detected in Africa and South America. An important increase in RFIs has been observed over Japan and the authorities have already initiated investigations about the cause.

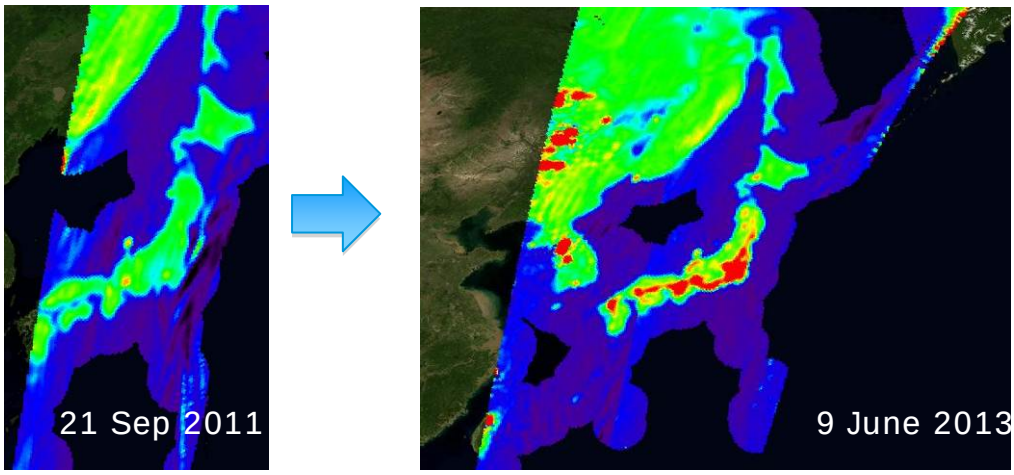


Figure 3.1-8b: Cases of RFI degradation over Japan (RFI case is under investigation)

3.1.3 RFI detection

SMOS L1c products provide geolocated measurements of BT. These measurements integrate the radiation received at the satellite every 1.2 s. The SMOS team at ESAC (ESA facilities in Spain)

regularly scans these SMOS images and the probability maps presented in the previous section for new RFI sources. Whenever a RFI is detected, a semiautomatic algorithm analyzes several SMOS passes over that area. The objective of the algorithm is to estimate, as best as possible, the on-ground location of the RFI and its BT intensity.

Even though SMOS spatial resolution (35–55 km) is not very adequate for this purpose, the algorithm relies on the large amount of observations to improve the accuracy of the geographical co-ordinates of the antenna emitter. Considering that during one pass, each point on-ground is measured several times under different incidence angles (as the satellite moves forward) and that at least two weeks of measurements over that region (i.e., ~10 passes) are used to infer the RFI position, the final accuracy of this technique is better than 5 km in the majority of the cases. (See Figure 3.1.9)

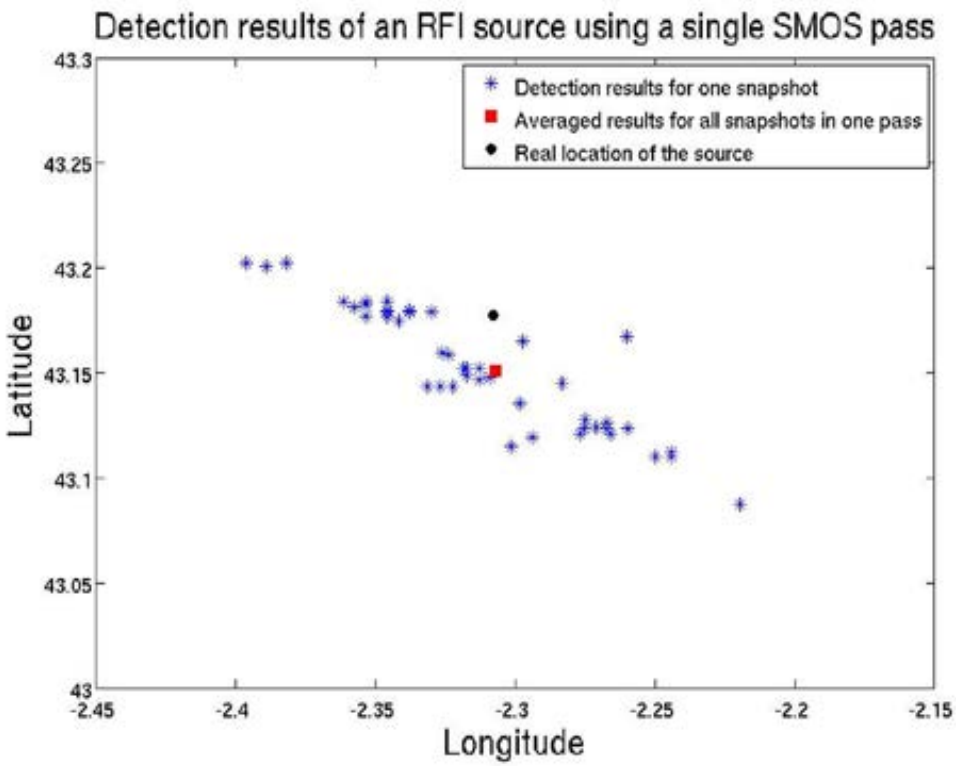


Figure 3.1-9: Example of SMOS RFI detection (source: R. Oliva @ ESA ESAC)

3.1.4 RFI source analysis

Man-made emissions within the passive band are observed by SMOS as strong point source emissions. The RFI is observed as a brightness temperature (BT) intensity that exceeds the emission radiated by natural sources. The maximum BT due to natural sources is the physical temperature of the source and the maximum ground temperature ever recorded so far is ~338 K (65 °C). Therefore, BTs values >340 K indicate that there is a man-made transmitter in the band without any doubt. RFI emissions can be categorized as low, moderate, strong or very strong as follows.

- **Low RFI emissions** have levels similar to natural sources and are difficult to detect, leading to incorrect physical retrieval.

- **Moderate RFI emissions** are easily detectable but their effects are circumscribed to the on-ground emitter's location. The quality of the data will be negatively affected, with less data available for the retrieval leading to less accuracy.
- **Strong RFI emissions** influence larger areas through the secondary lobes tails, which need to be discarded for scientific retrieval, thus leading to a significant data loss.
- **Very strong RFI emissions** essentially hide the full SMOS field-of-view and can blank out any natural signal over a range of several hundreds of kilometers, causing significant loss of data for scientific retrievals. In this respect, there are observed occasional but RFI recurrent flares in Europe that are able to saturate some of SMOS receivers.

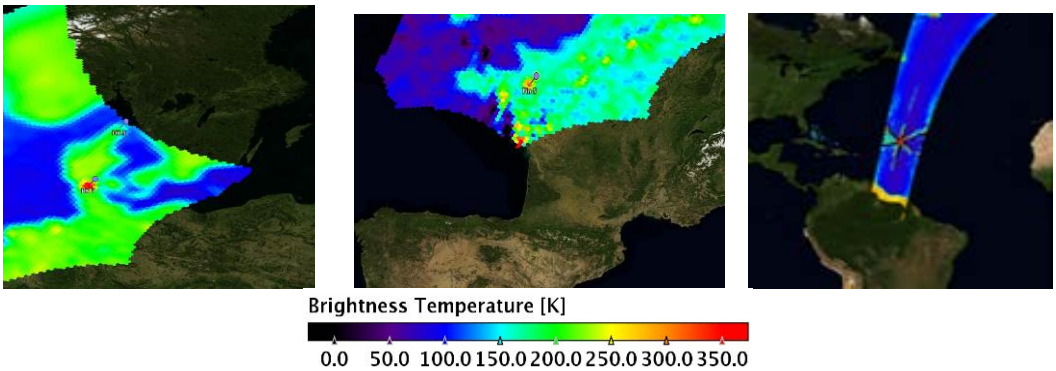


Figure 3.1-10: SMOS images showing detection of moderate RFI point source emissions

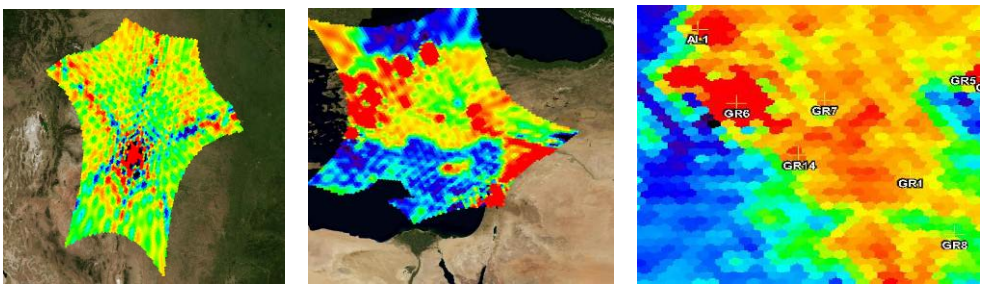


Figure 3.1-11: SMOS images showing detection of strong RFI emissions

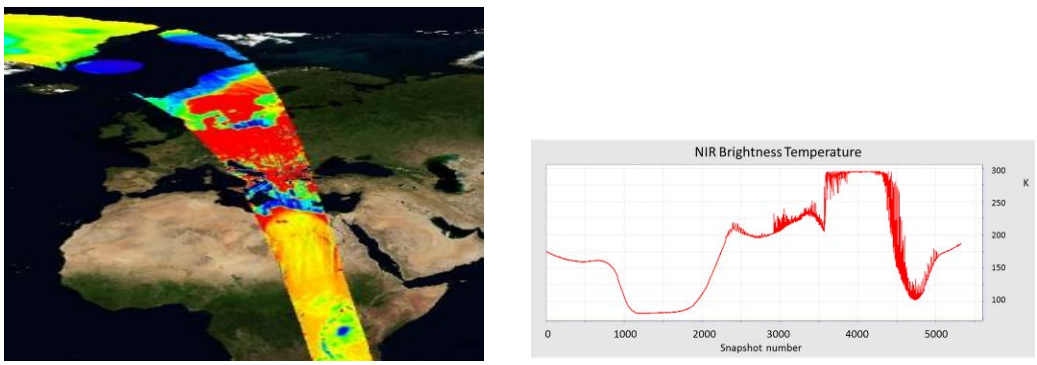


Figure 3.1-12: SMOS images showing the impact of very strong RFI emissions

3.1.4.1 Type of RFI sources

The RFI sources observed by SMOS can be grouped into two main categories:

- **Illegal in-band emissions in the protected band.** These are caused by unauthorized radiolinks, TV and FM broadcast stations, wireless monitoring cameras, malfunctioning DECT phone terminals, and more.
- **Excessive unwanted emissions from systems operating in the adjacent bands**. So far most of these RFIs are caused by out- of- band emissions of radar systems. The spurious emissions from systems operating in adjacent bands are also a common source of interference.

The type of emission causing the interferences cannot be confirmed based on the SMOS data alone. The feedback received from the national authorities is key to being able to better characterise the RFI source and establish some statistics and to further improve the interference detection, mitigation, and cancellation techniques.

ESA's and the scientists' actions to reduce the impact of RFI in SMOS data products have significantly improved the overall RFI situation. SMOS scientists have been investigating different methods for the RFI detection in close collaboration with the Expert Support Laboratories Future versions of the Level 1 and Level 2 data will result in an improved RFI flagging and monitoring. In parallel, ESA has been in contact with the National Frequency Management Authorities of those countries with RFI sources over their territory, and investigations and on-site measurements have allowed the elimination of many RFI sources. There has been significant improvement of the RFI scenario over Europe, where ESA member states are making great efforts to reduce the number of RFI sources that are contaminating SMOS observations. A good cooperation to reduce or mitigate the RFI situation has been also provided by other administrations, such as Canada and United States, and a general improvement has been observed over China.

3.2 Aquarius Radiometer Observed RFI

3.2.1 Description of Aquarius Radiometer

The Aquarius radiometer is a 1.413 GHz Dicke radiometers that uses noise injection for calibration. Long-term (days) stability is critical because significant averaging must be done to achieve the Aquarius goal for an accuracy of 0.2 psu (global rms on a monthly basis). Since it takes 7 days to map the globe, the radiometers must be stable over at least 7 days. The radiometers must be stable to within 0.13 K over 7 days.

The Aquarius radiometer maps the world every 7 days. The radiometer has adequate internal calibration and good thermal control. It uses two internal reference sources (noise diode and Dicke load). The primary amplification is done in the RFEs. There is a separate RFE for each feed assembly. In the RFE, the two signals from the OMT (one for vertical polarization and one for horizontal polarization) are amplified and then combined to form four channels (vertical, horizontal, and the sum and difference). The sum and difference signal are used to compute the third Stokes parameter (i.e., detected with a square-law detector in the RBE and later subtracted during the ground processing). The first elements at the input of the RFE are the Dicke switch and

its reference load followed by a coupler to a noise diode that provides the hot load. Together, these are the references used for internal calibration. The radiometric temperature of the Dicke load must be known with an uncertainty of <50 mK and the coupled noise temperature must be stable to < 300 ppm, adequate to achieve the required radiometric stability (0.13 K over 7 days). In addition, this radiometer architecture is largely implemented using microstrip-based technology, which is a tradeoff made to reduce size and improve thermal control at the expense of increased loss. As with the scatterometer which shares the antennas with the radiometer, the three beams from an offset –parabolic reflector provide a 390 km width swath. The 2.9m x 2.5m offset parabolic reflector with three feeds produces inner, middle and outer 3 dB beam widths of 6.1 deg, 6.2 deg, and 6.4 deg, respectively.

The Aquarius radiometer returns brightness measurements over most of the Earth, including land and ice as well as ocean areas. As far as timing for the hardware, the fundamental timing unit is 10 ms (approximately 1 ms for the scatterometer transmit pulse and 9 ms of observation time for the radiometer). The radiometer and scatterometer operations are alternated so that the two sensors look at the same piece of ocean nearly simultaneously. The three radiometers (one for each beam) operate in parallel. During 120 ms, each radiometer collects seven samples (9 ms long and repeated each 10 ms) looking into the antenna followed by five samples devoted to the calibration sources (two noise diodes and Dicke load). This 120-ms sequence is then repeated. However, because of limitations with the onboard data storage, the radiometer cannot download all of these data. The first and second 10 ms antenna looks are averaged together, as are the third and fourth. The next three antenna looks are left at the 10-ms resolution. The samples of the calibration references transmitted to the ground are the average of ten samples.

3.2.2 Global Survey of Aquarius Radiometer Brightness Temperature

The Aquarius radiometer operations are alternated so that the two sensors look at the same piece of ocean nearly simultaneously as illustrated in Figure 2.1-2 which shows the timing sequence of the Aquarius instrument. Figure 3.2-1 is a complementary CDF plot (1-CDF) of the radiometer brightness temperature in dB K, as observed over North America during Jan-Mar 2013. Figure 3.2-2 is a global map of the radiometer brightness temperature over a 7-day global mapping period. The white patches indicate missing data. The scatterometer RFI levels are shown in a global map over the same 7-day mapping period. Figure 3.2-3 shows 7-day global maps of observed RFI by the scatterometer and radiometer with three months intervals. Both radiometer brightness temperature map and scatterometer RFI level map show that there are regions of high RFI in eastern North America, Europe, and East Asia, with numerous other high RFI regions in other land areas. Figure 3.2-4 shows 7-day global maps of observed RFI by the radiometer with a two year interval from the beginning of year 2012 to the beginning of year 2014.

4. Summary of Observed RFI and RFI Source Analysis

Within this document, RFI measurements as observed globally by L-band sensors in the EESS (active) band 1215-1300 MHz and the EESS (passive) band 1400-1427 MHz have been presented. Global maps of observed RFI levels in dBm are shown for the EESS (active) Aquarius scatterometer at 1260 MHz and global maps of observed RFI brightness temperature in dB-K are shown for the SMOS radiometer and the Aquarius radiometer at 1413 MHz. Comparisons of observations for the active and passive sensors are given for a 7 day period in global maps for the Aquarius scatterometer and radiometer. Examples are given of how these scatterometer data can be used for RFI source analysis.

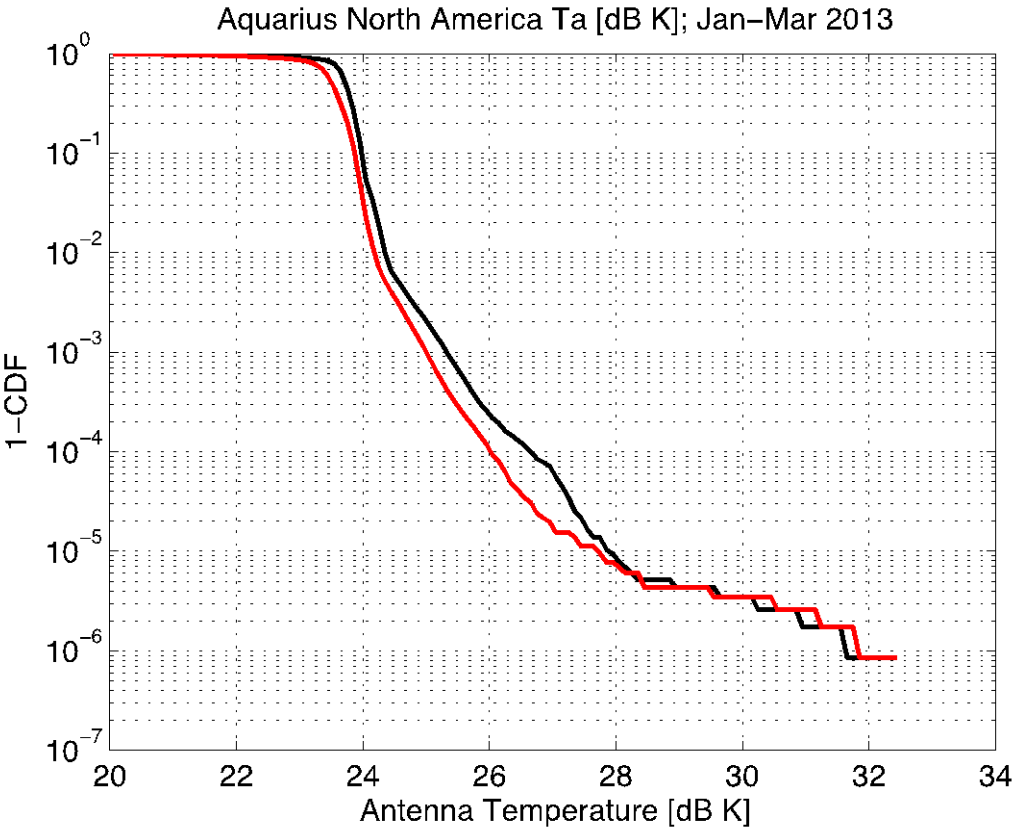
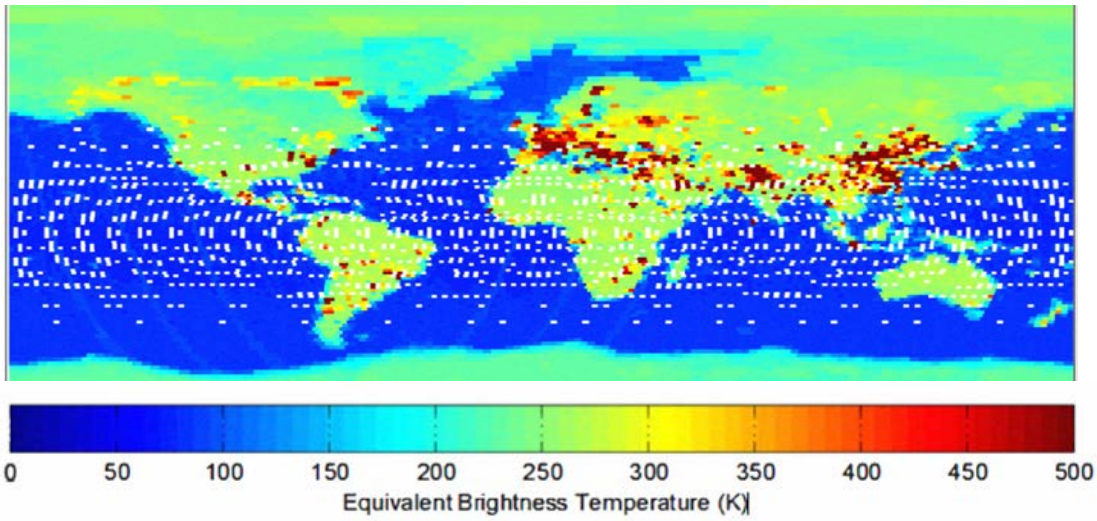
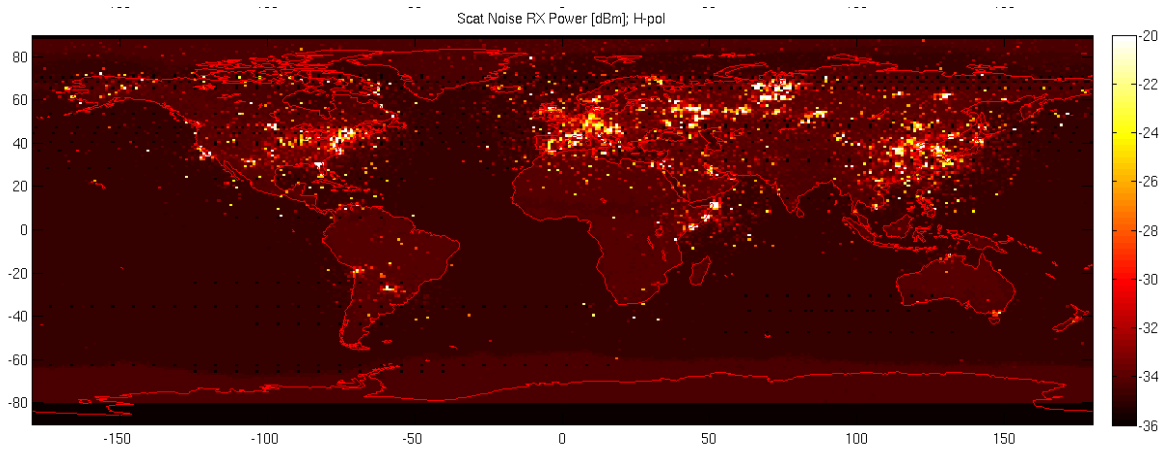


Figure 3.2-1. 1-CDF Distribution of observed brightness temperature at radiometer input for North America (Jan-Mar 2013)

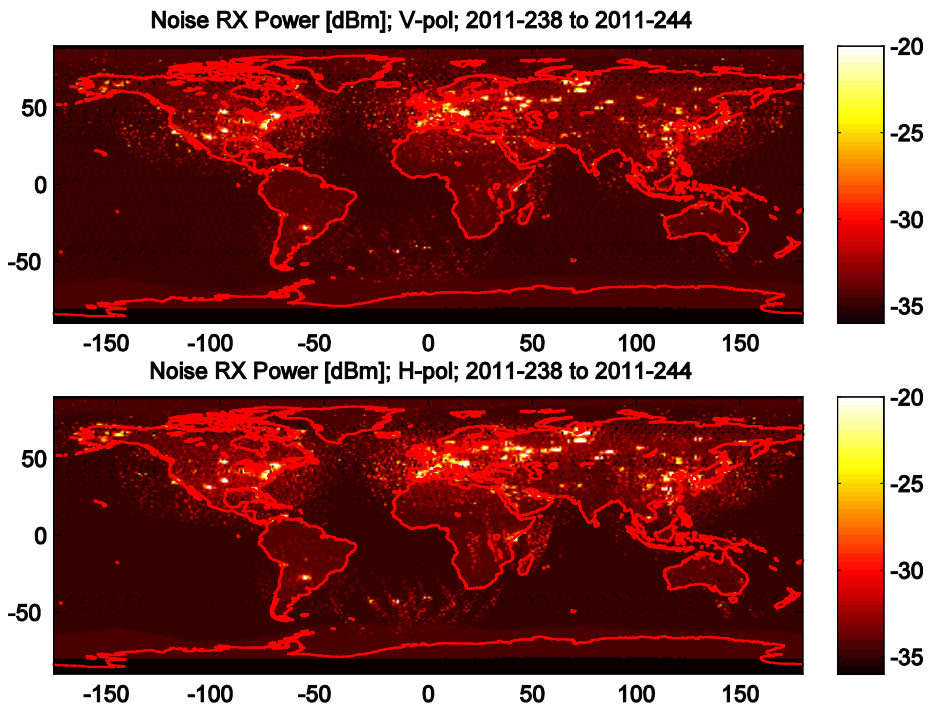


a) Observed 7-day radiometer brightness temperature

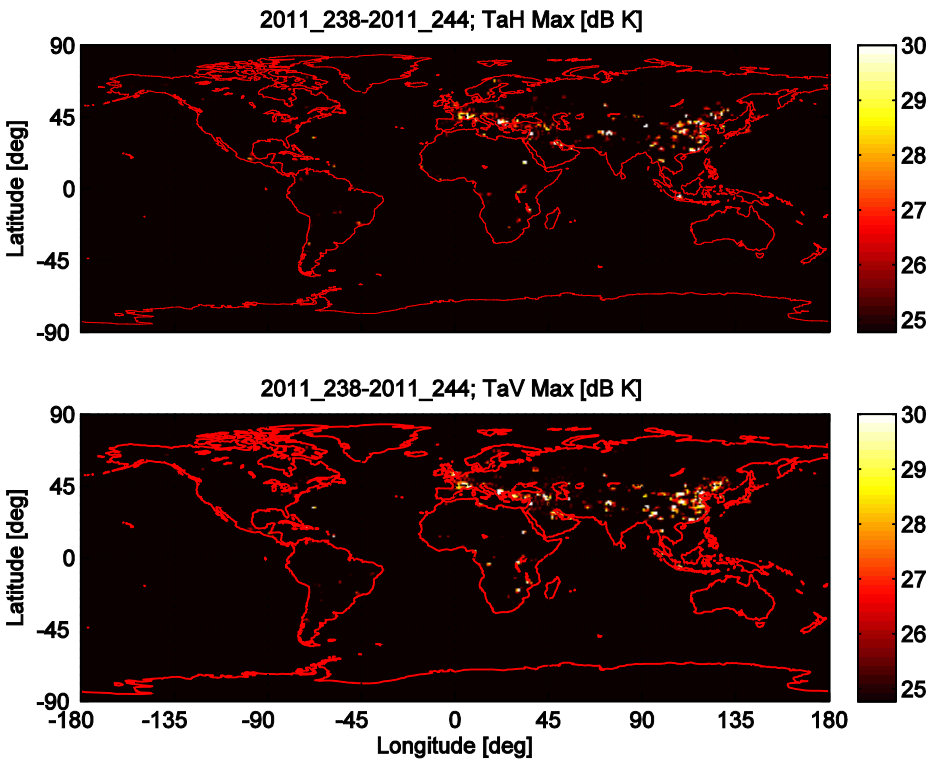


b) Observed 7-day scatterometer maximum noise power

Figure 3.2-2. Comparison of Aquarius instrument observed weekly radiometer brightness temperature and scatterometer maximum noise power at ADC input for same one week period

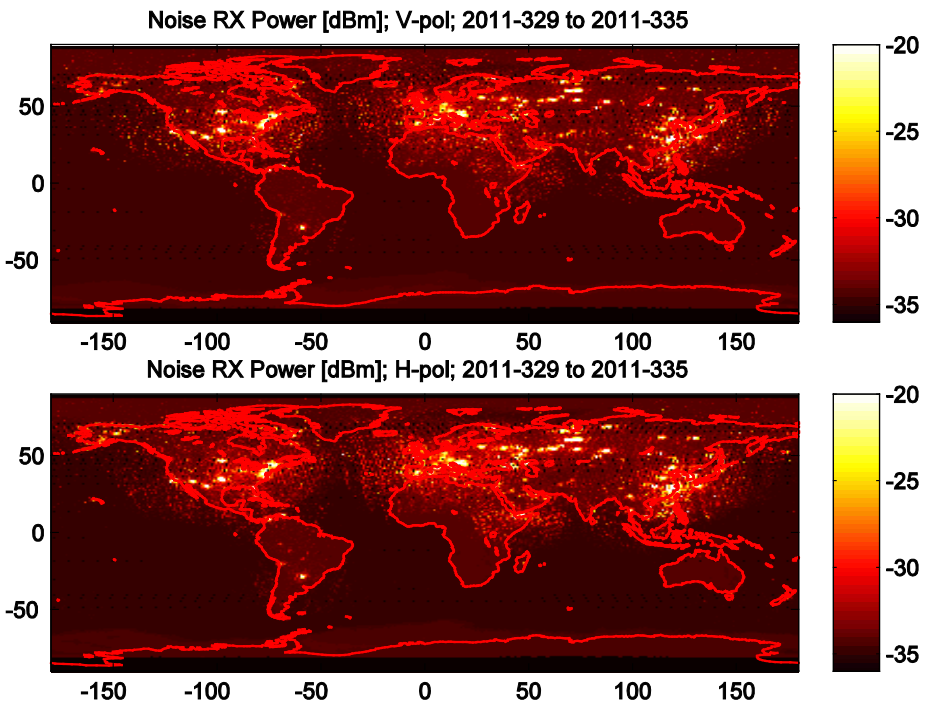


a) Aquarius Scatterometer Receiver Noise Power 2011-238 to 244

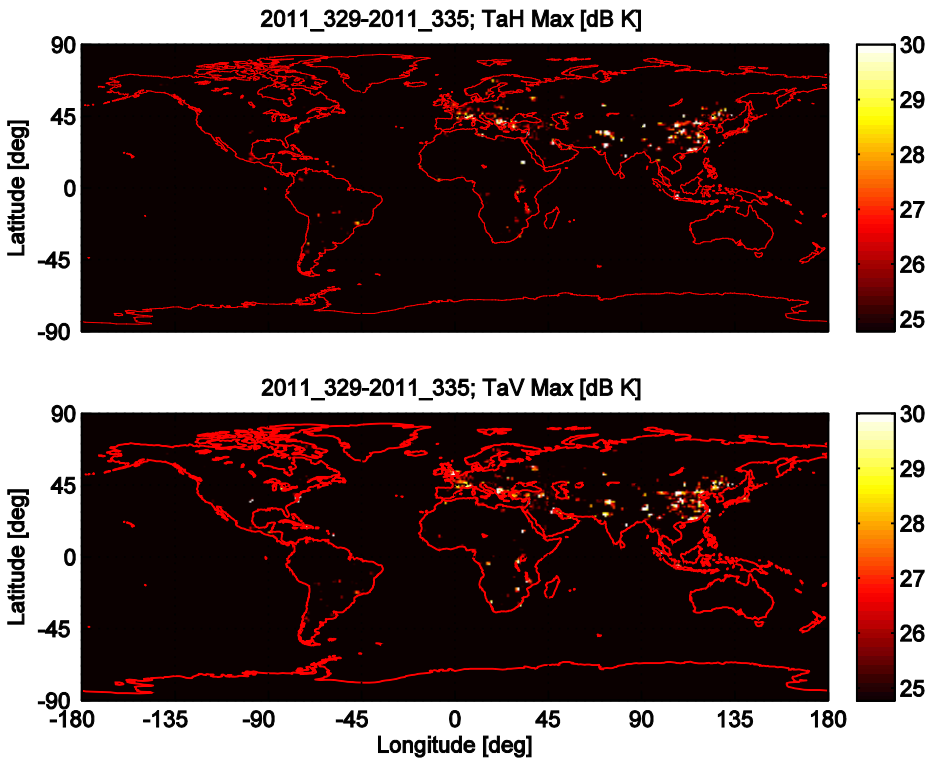


b) Aquarius Radiometer Brightness Temperature 2011-238 to 244

Figure 3.2-3. Global Maps of Aquarius Scatterometer and Radiometer RFI

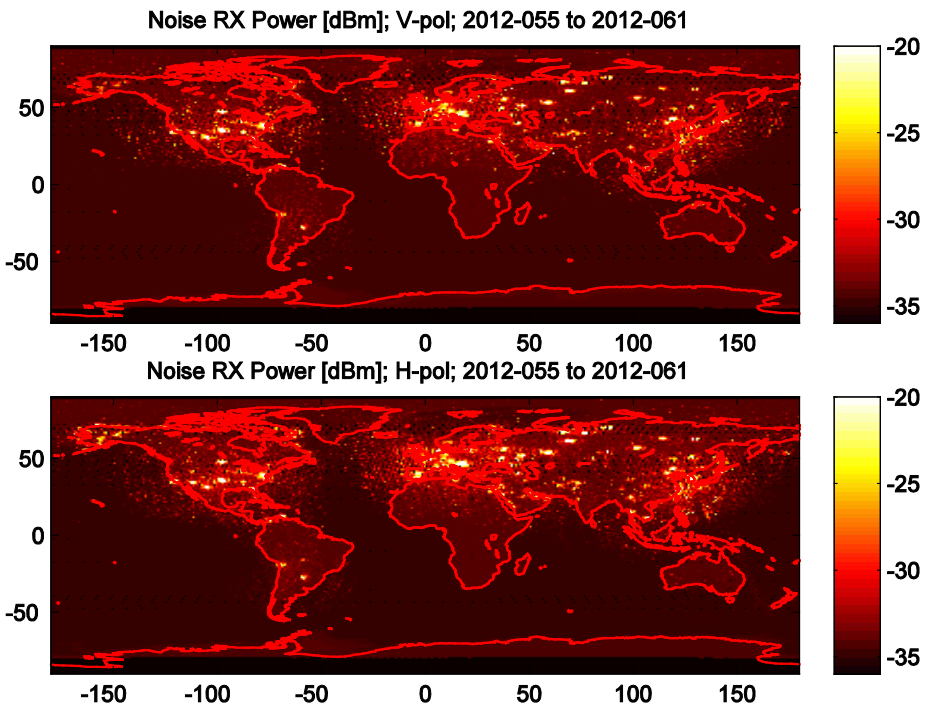


c) Aquarius Scatterometer Receiver Noise Power 2011-329 to 335

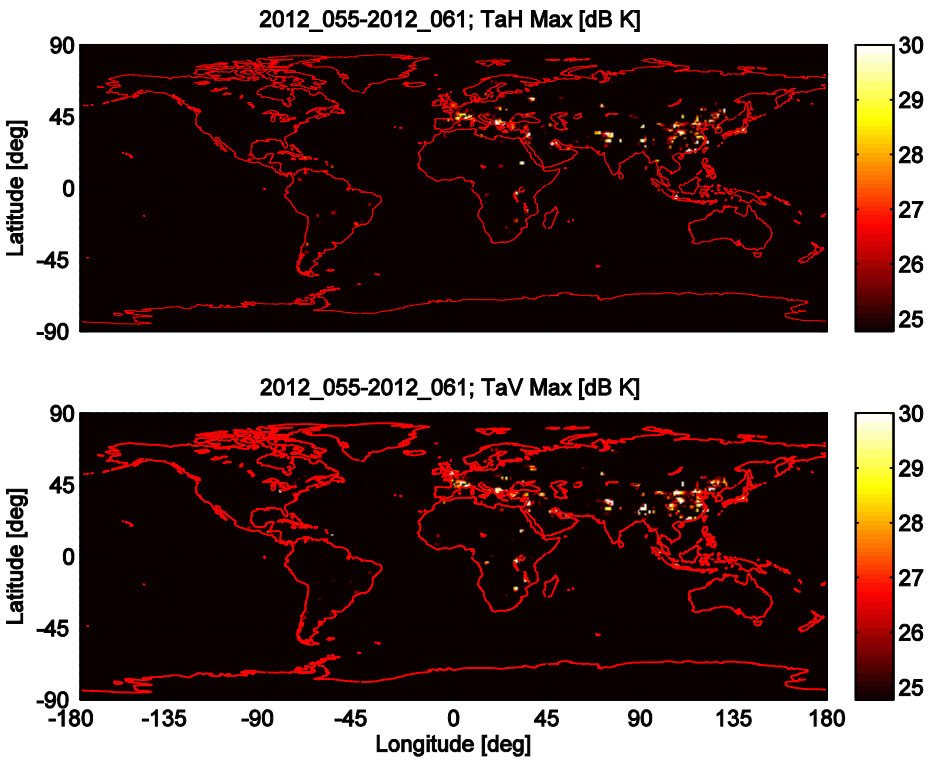


d) Aquarius Radiometer Brightness Temperature 2011-329 to 335

Figure 3.2-3 (contd). Global Maps of Aquarius Scatterometer and Radiometer RFI

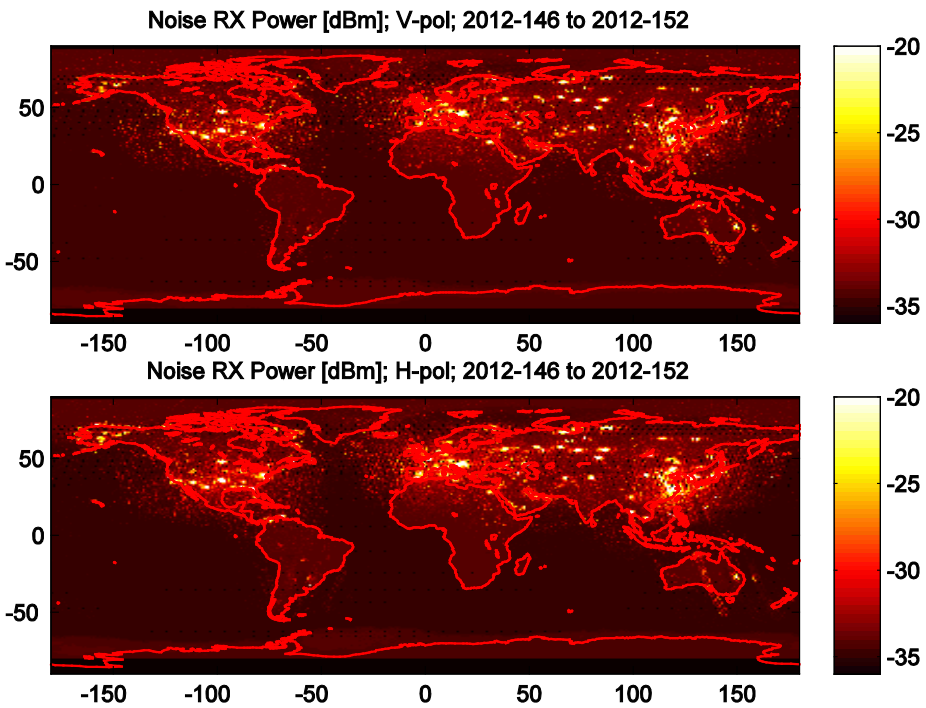


e) Aquarius Scatterometer Receiver Noise Power 2012-055 to 061

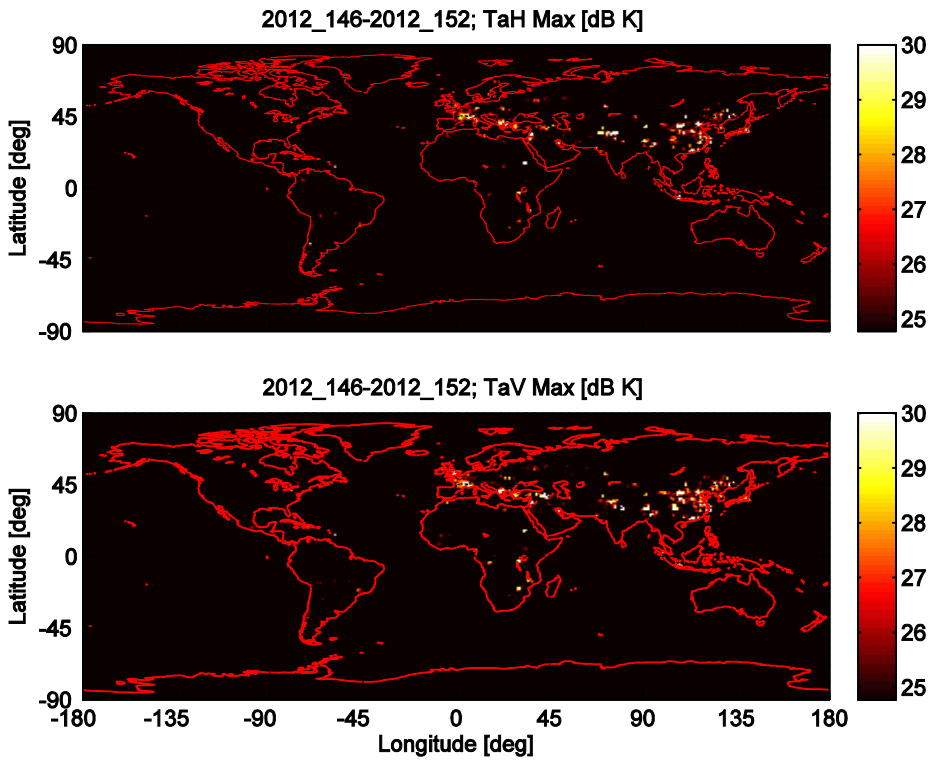


f) Aquarius Radiometer Brightness Temperature 2012-055 to 061

Figure 3.2-3 (contd). Global Maps of Aquarius Scatterometer and Radiometer RFI

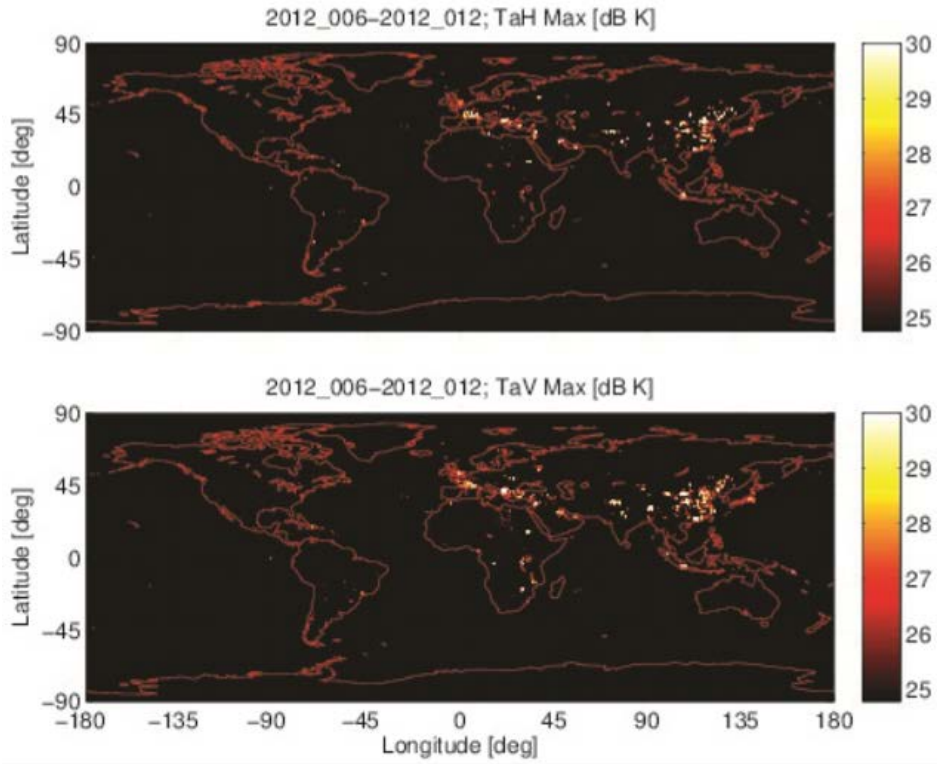


g) Aquarius Scatterometer Receiver Noise Power 2012-146 to 152

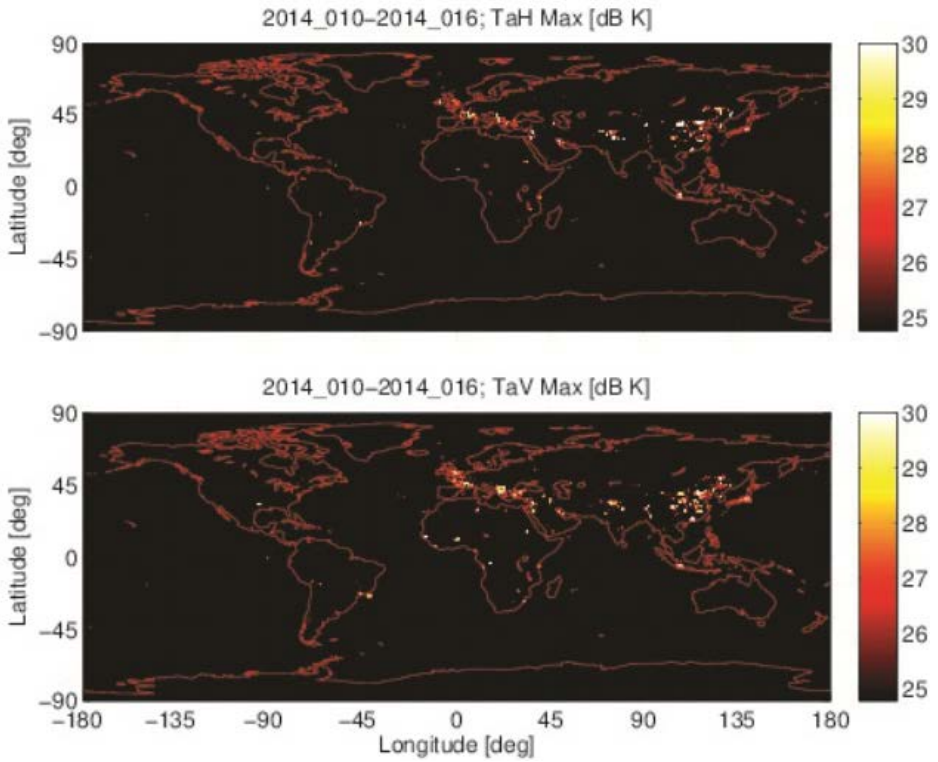


h) Aquarius Radiometer Brightness Temperature 2012-146 to 152

Figure 3.2-3. (contd). Global Maps of Aquarius Scatterometer and Radiometer RFI



a) **Aquarius Radiometer Brightness Temperature 2012-006 to 012**



b) Aquarius Radiometer Brightness Temperature 2014-010 to 016

Figure 3.2-4 . Global Maps of Aquarius Radiometer RFI Two Years Apart (2012-2014)

GLOSSARY

BITTT	Beijing Institute of Tracking and Telecommunications Technology
BR	Radiocommunication Bureau of the ITU
CAST	Chinese Academy of Space Technology
CEPT	European Conference of Postal and Telecommunications Administrations
CCSDS	Consultative Committee on Space Data Systems
CGMS	Coordination on Geostationary Meteorological Satellites
CITEL	Conference on Inter-American Telecommunications
CMA	Chinese Meteorological Agency
CNES	Centre National d'Études Spatiales (France)
CNSA	Chinese National Space Agency
CONAE	Comisión Nacional de Actividades Espaciales (Argentina)
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DLR	Deutsche Forschungs - und Versuchanstalt fur Luft - und Raumfahrt e.V.
DSN	Deep Space Network
EDRS	European Data Relay System (ESA)
EESS	Earth Exploration Satellite service
EIAST	Emirate Institution for Advanced Science and Technology

EIRP	Effective isotropically radiated power
ESA	European Space Agency
EUMETNET	European MetOffices Network
EUMETSAT	European Meteorological Satellite Organization
G/T	Ratio of gain to noise temperature
GCOS	Global Climate Observing System
GRSS	Geoscience and Remote Sensing Society
GSO	Geostationary satellite orbit
IOAG	Interagency Operations Advisory Group
IFRB	International Frequency Registration Board (As of 1 March 1993 replaced by Radiocommunication Bureau of the ITU)
INPE	Instituto de Pesquisas Espaciais (Brazil)
INTA	Instituto Nacional de Técnica Aerospacial
ISRO	Indian Space Research Organization
ITU	International Telecommunication Union
IUCAF	Inter-Union Commission of Frequency Allocations for Radio Astronomy and Space Science
IWG	Intersessional Working Group (of the SFCG)
JAXA	Japan Aerospace Exploration Agency
LEO	Low earth orbit
MetSat	Meteorological Satellite service
NASA	National Aeronautics and Space Administration (USA)
NOAA	National Oceanographic and Atmospheric Administration (USA)

NSO	Netherland Space Office
PFD	Power flux density
RAS	Russian Academy of Science
RB	Radiocommunication Bureau of the ITU
RFSA	Russian Federal Space Agency
RR	Radio Regulations of the ITU
SG 7	Radiocommunication Study Group 7: Science Services
SNIP	Space Network Interoperability Panel
SSC	Swedish Space Corporation
TDRSS	Tracking and Data Relay Satellite System (NASA)
TTC	Tracking, telemetry, and command
UKSA	United Kingdom Space Agency
UWB	Ultra Wide Band
WCRP	World Climate Research Program
WMO	World Meteorological Organization

SFCG Method of Operation

SFCG meets at approximately one year intervals. Resolution A2-1 (most recent version) describes the scheduling and location of these meetings. Each meeting is hosted by a member agency. At the conclusion of a meeting, an invitation for the next meeting is extended by a member agency.

Each SFCG meeting is chaired by a representative of the host agency. The Chairman serves from the time that the invitation from his agency is accepted until the conclusion of the meeting over which he presides.

English is the language used for the conduct of SFCG meetings and for documentation, in accordance with Resolution A2-2 (most recent version).

The secretariat function for SFCG is performed by the European Space Agency (ESA). The Head of the ESA Frequency Management Office (Code ESA/TIA-W) acts as the Executive Secretary of SFCG. The Secretariat provides continuity in the affairs of SFCG and prepares the SFCG meetings, including development of an appropriate agenda. The Executive Secretary provides support to the Chairman for the conduct of each meeting.

The Secretariat provides written minutes of each meeting. These minutes include, in particular, the following items:

a list of input documents;
reports of working groups;
texts of new or revised Resolutions, Reports and Recommendations;
texts of new or revised Action Items;
texts of new Decisions, and a list of earlier Decisions still in effect;
other actions taken by the meeting;
matters of historical interest.

The several types of SFCG documentation are defined in Resolution A2-3 (most recent version).

Information documents and discussion documents are serially numbered by the Secretariat in the order of receipt prior to a meeting. The number includes identification of the SFCG meeting number, e.g., SF/20-4 refers to the fourth document received for consideration at SFCG 20.

Resolutions and Recommendations adopted by a meeting are numbered and classified according to the

method described in *Classification and Numbering of SFCG Recommendations and Resolutions*, found in Section I of this handbook.

Action Items, and Decisions (other than decisions concerning documents) that are adopted during a meeting are numbered according to the meeting and serial number, e.g., AI 20/6.

HOSTS OF SFCG MEETINGS

SFCG 1	CNES, France	12 - 14	November,	1980
SFCG 2	DFVLR, Germany	29 2	September – October,	1981
SFCG 3	ISRO, India	15 - 19	November,	1982
SFCG 4	DTI/RAL, United Kingdom	14 - 18	November,	1983
SFCG 5	NASA, USA	22 - 26	October,	1984
SFCG 6	NASDA, Japan	21 - 25	April,	1986
SFCG 7	ESA, France	16 - 20	November,	1987
SFCG 8	CNIE, Argentina	9 - 16	November,	1988
SFCG 9	SBSA/SSC, Sweden	28 1	August – September,	1989
SFCG 10	NASA/NOAA, USA	1 - 5	October,	1990
SFCG 11	INTA, Spain	17 - 23	April,	1991
SFCG 12	ASO/CSIRO, Australia	28 5	October – November,	1992
SFCG 13	CSA, Canada	13 - 21	October,	1993
SFCG 14	EUMETSAT, Germany	14 - 22	September,	1994
SFCG 15	ISRO, India	7 - 15	December,	1995
SFCG 16	RSA/ISDE, Russia	25 3	September – October,	1996

SFCG 17	NASA, USA	17 - 25	September	1997
SFCG 18	NASDA, Japan	9 - 17	September	1998
SFCG 19	ESA, The Netherlands	8 – 15	September	1999
SFCG 20	CSIRO, Australia	7 – 16	November	2000
SFCG 21	CNES, France	26 4	September – October	2001
SFCG 22	ASI, Italy	9-16	October	2002
SFCG 23	NASA/NOAA, USA	17-25	September	2003
SFCG 24	ITWG, France	15-23	September	2004
SFCG 25	NSMC/CMA, China	12-20	October	2005
SFCG 26	DLR, Germany	19-27	September	2006
SFCG 27	INSA/INTA, Spain	19-27	September	2007
SFCG 28	CSA, Canada	16-24	September	2008
SFCG 29	RFSA, Russian Federation	3-12	June	2009
SFCG 30	CSIRO, Australia	6-14	July	2010
SFCG 31	NASA, USA	7-15	June	2011
SFCG 32	ESA, Germany	12-20	June	2012
SFCG 33	CNES, France	25 3	June – July	2013
SFCG-34	NOAA, USA	3-11	June	2014

THE SFCG SILVER PIN FOR MERITORIOUS SERVICE

The following individuals have received the SFCG Silver Pin Award for Meritorious Service: [1)]

Awarded at SFCG 12, 5 November, 1992:

Michel Alonso	CNES
Gerhard Block	ESA
Robert Bowen	DoC, Canada
Daniel Breton	CNES
Boris Doubinski	RAS
Norman de Groot	NASA/JPL
Yasushi Horikawa	NASDA
Fred Horner	IUCAF
Karyl Irion	NASA/ARC
D.W.H. Johnston	NASA
Nobuhiro Kawajiri	NASDA
John Kelleher	NASA
John Kiebler	NASA
Harold Kimball	CCIR, (ex-NASA)
Wilhelm Kraemer	DLR
K.S. Mohanavelu	ISRO
Manfred Otter	ESA
James Scott	NASA
Véronique Simpson	ESA
Robert Taylor	NASA
Luis Vadillo	INTA

Awarded at SFCG 13, 21 October, 1993:

Warren L. Martin	NASA/JPL
Robert Wolf	EUMETSAT
David Struba	NASA

Awarded at SFCG 15, 15 December, 1995:

Shayla Davidson	NASA
S. Sayeenathan	ISRO

1) See Glossary for meaning of acronyms and abbreviations.

Awarded at SFCG 16, 3 October, 1996:

Jean-Luc Gerner	ESA
Mikhail Vasiliev	RISDE

Awarded at SFCG 17, 25 September, 1997

Arvind Bastikar	CSA
Franz Borncamp	NASA/JPL
Richard Jacobsen	CSIRO

Awarded at SFCG 18, 17 September, 1998

Korehiro Maeda	NASDA
David McGinnis	NOAA

Awarded at SFCG 19, 15 September, 1999

Albert Nalbandian	ITU-BR

Awarded at SFCG 20, 16 November, 2000

Edoardo Marelli	ESA

Awarded at SFCG 21, 4 October, 2001

John Zuzek	NASA

Awarded at SFCG 22, 16 October 2002

Wayne Whyte	NASA

Awarded at SFCG 23, 21 September 2003

Enrico Vassallo	ESA

Awarded at SFCG 24, 21 September 2004

Guy Rochard	ITWG

Awarded at SFCG 25, 18 October 2005

Brad Kaufman	NASA

Awarded at SFCG 26, 25 September 2006

Vincent Meens	CNES

Awarded at SFCG 27, 25 September 2007

Michel Gaudreau	CSA

Awarded at SFCG 28, 23 September 2008

Farzin Manshadi	NASA

Awarded at SFCG 29, 10 June 2009

Cathy Sham	NASA

Awarded at SFCG 30, 13 July 2010

Tsutomu Shigeta	JAXA

Awarded at SFCG 31, 13 June 2011

Markus Dreis	EUMETSAT

Awarded at SFCG 32, 19 June 2012

Glenn Feldhake	NASA

Awarded at SFCG 33, 27 June 2013

Ted Berman	NASA

Awarded at SFCG-34, 6 June 2014

Phillipe Tristant	ESA

SFCG MEMBER EMERITUS

The following former SFCG Members have been nominated **SFCG Member Emeritus** on the basis of Resolution A23-1R1.

With this title the SFCG intends to honor these members for the great contribution they gave to the growth of the SFCG.

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Norman DE GROOT	Tel: e-mail: ndegroot@mcn.org	Sadly Norman passed away in March 2004
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(S F C G)

Members & Observers

For delegations with several members listed the Delegation Coordinator is identified by an asterisk. Delegates authorised to input frequency data under the provisions of RES A21-2R4 are identified by a double asterisk.

June 2014

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