Report SFCG 34-1R1

WORST CASE INTERFERENCE LEVELS FROM MAINLOBE-TO-MAINLOBE ANTENNA COUPLING OF SYSTEMS OPERATING IN THE RADIOLOCATION SERVICE (RLS) 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 two typical RLS systems. The potential worse case interference from mainlobe to mainlobe coupling into the EESS (active) receiver from the RLS systems 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 two typical RLS systems and the potential worse case interference from mainlobe coupling into the EESS (active) receiver from the RLS systems 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.

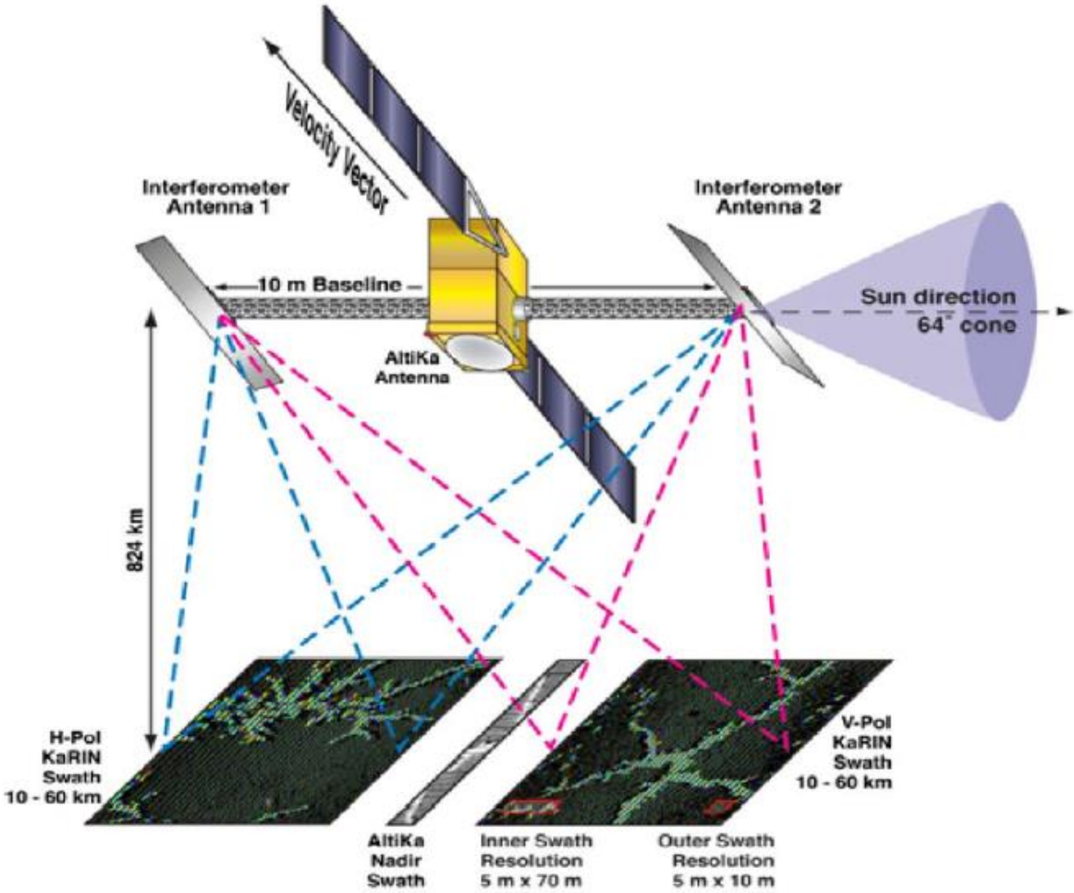
The InSAR is an interferometric synthetic aperture radar with which operates in the 35.5-36 GHz.

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)



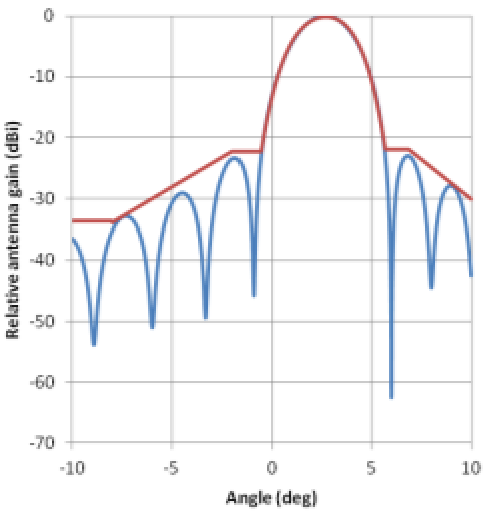
The 35.5-36.0 GHz InSAR transmits linear FM pulses with 1300 MHz bandwidth centered at 35.35 GHz with a pulse repetition rate approximately at 4400 Hz per antenna. The signal is horizontally and vertically polarized at both transmission and reception. The significant parameters for the InSAR are given 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 2a and 2b, 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

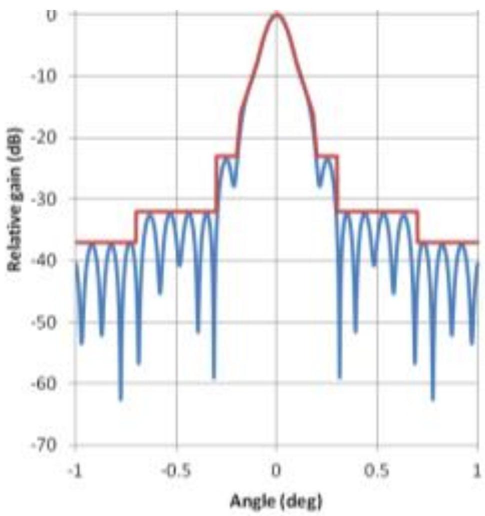


TABLE 1

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

3.1 Radars listed in Recommendation ITU-R M.1640

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

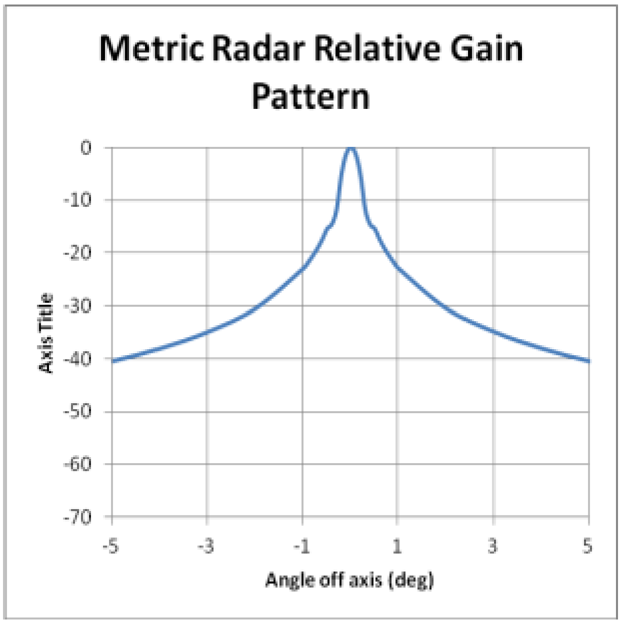
Typical terrestrial tracking radars cover elevation angles from 0 deg to 90 deg during the track, and can have mainlobe-to-mainlobe coupling in elevation. The 35.5-36.0 GHz InSAR sensor beams which point near nadir move past the terrestrial systems as the spacecraft proceeds in its orbit. For a sensor 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.

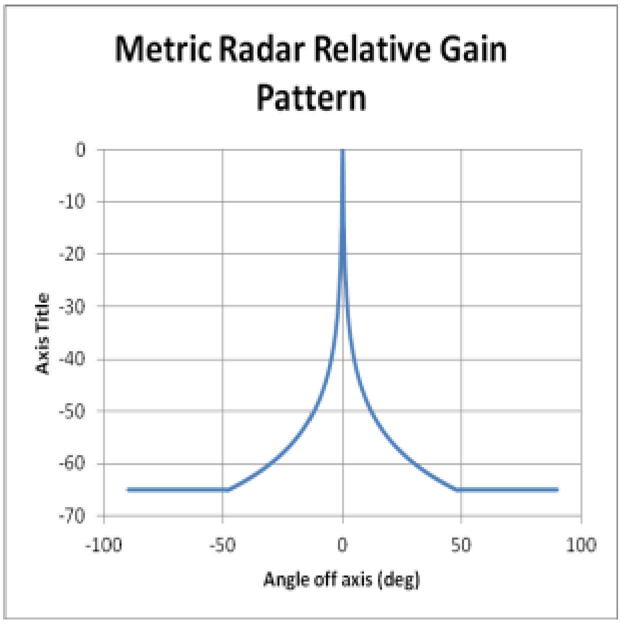
FIGURE 3

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



3.2 MMW Radar

There is a more powerful radar operating in the 35.5-36.0 GHz frequency band known as the Millimeter-wave radar (MMW) with characteristics as shown in Table 3. The MMW has 60 kW transmit peak power and 71.2 dBi antenna gain, giving an EIRP of 119.0 dBW, compared to the metric radar's EIRP of 103.3 dBW.

TABLE 3

Characteristics of the MMW at 35 GHz

Parameter	**Metric**
Sensor type	Active
Modulation	Pulse
Compression ratio	–
Pulse width (μs)	50
Tx peak power (kW)	60
PRF (kHz)	2
RF bandwidth (MHz)	1000
Antenna gain (dBi)	71.2
Beamwidth (degrees)	0.0435 × 0.0435
Rx IF bandwidth (GHz)	2

NOTE – PRF = pulse repetition frequency.

One objective of the MMW is space object tracking whereby it can cover elevation angles from 0 degree to 90 degrees during the track, and can have mainlobe-to-mainlobe coupling in elevation.

4. Potential Interference between EESS (active) and Radiolocation Service

4.1 Static Analysis of Mainlobe-to-Mainlobe Coupling of RFI in InSAR

4.1.1 Static Analysis of Mainlobe-to-Mainlobe Coupling of RFI in InSAR using the Metric Radar

In Figures 4 and 5 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 4

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

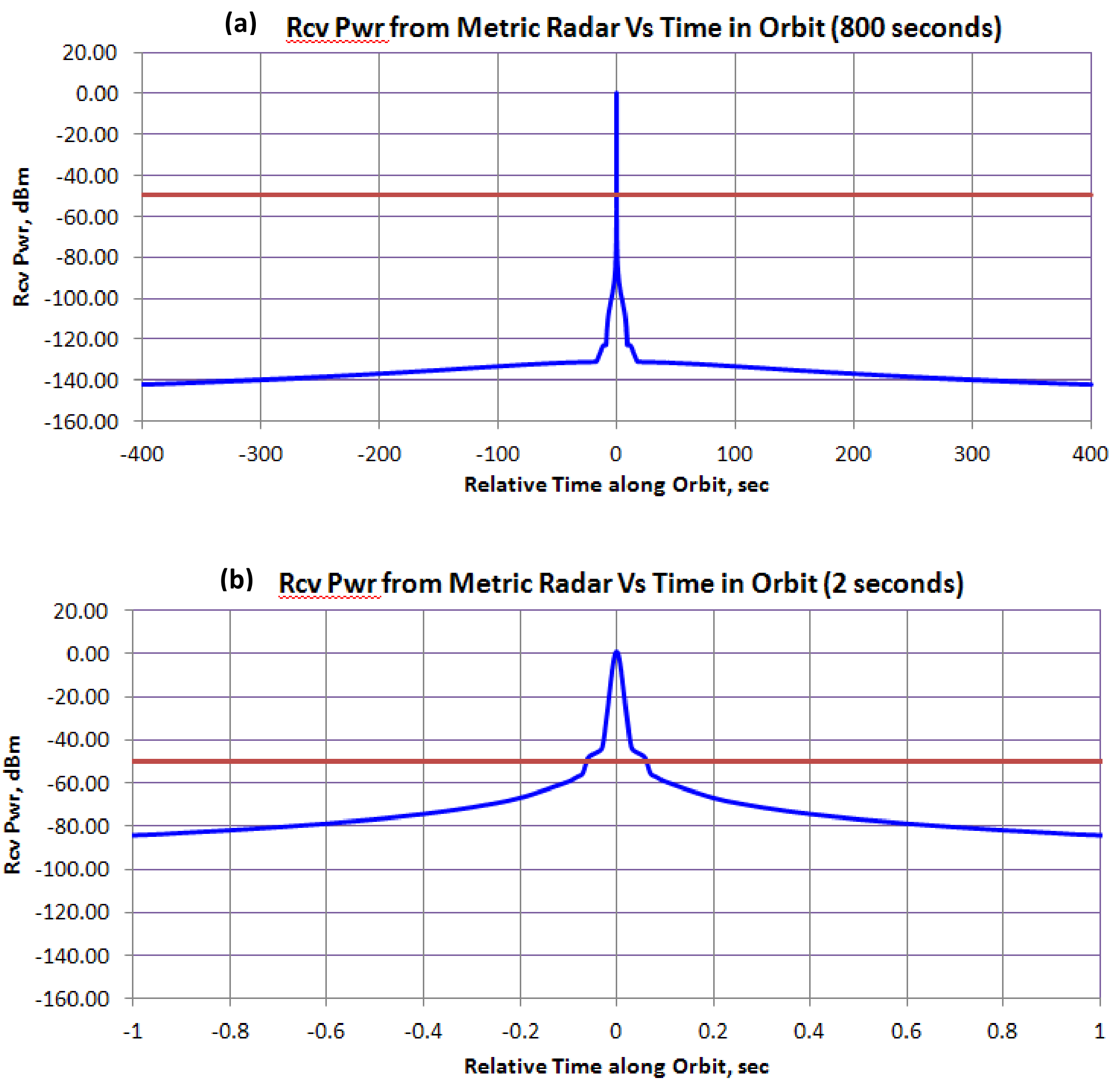
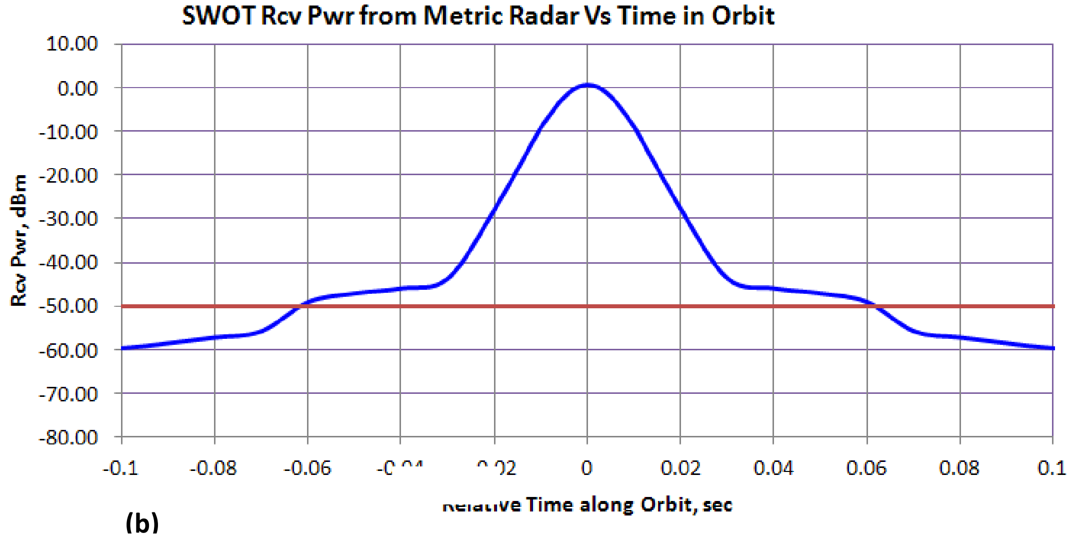


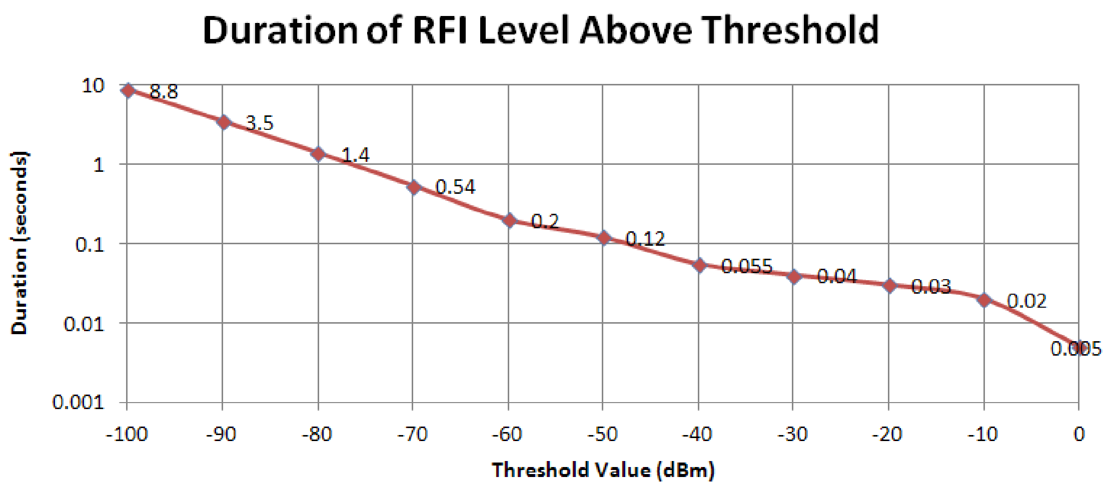
FIGURE 5

(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)



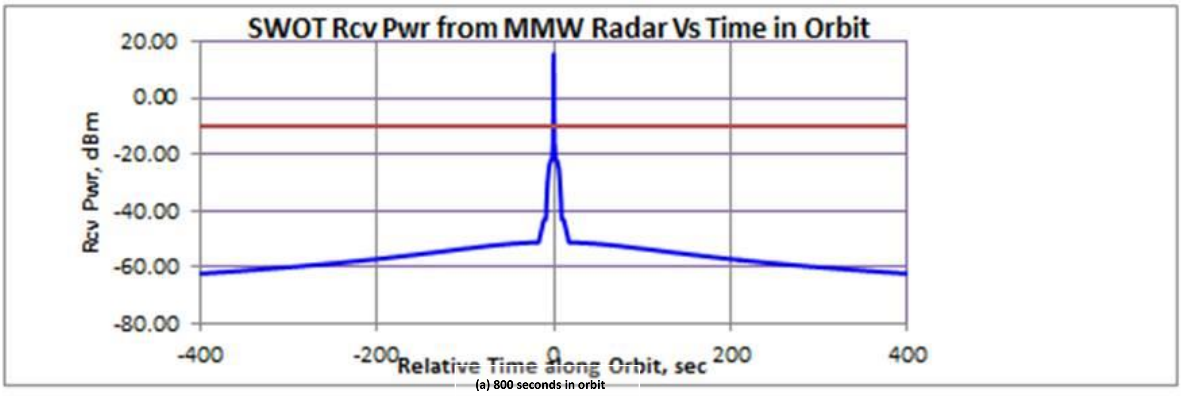
4.1.2 Static Analysis of Mainlobe-to-Mainlobe Coupling of RFI in InSAR using the MMW Radar

The MMW antenna is a 13.7m diameter parabolic dish with 70.1 dBi gain at 35.0 GHz and 0.0435 degree beamwidth. For this simulation, the InSAR antenna gain is assumed to be slightly reduced, at 48.5 dBi. The MMW is assumed to be tracking the InSAR over the single pass.

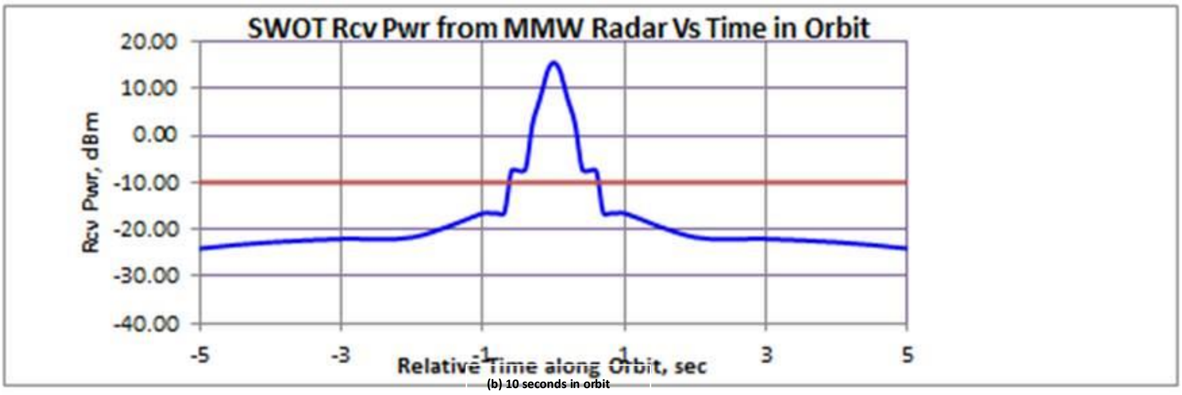
In Fig 6 below the single pass simulation of the RFI from the MMW into the InSAR over 800 seconds, 10 seconds and 2 seconds shows the received power into the Ka-band InSAR peaks to about +15.5 dBm in the middle of the pass. The InSAR receiver must be protected up to +15.5 dBm, or +21.5 dBm if a 6 dB margin is imposed. The duration of the radio-frequency interference (RFI) above –10 dBm is about 1.2 seconds.

FIGURE 6

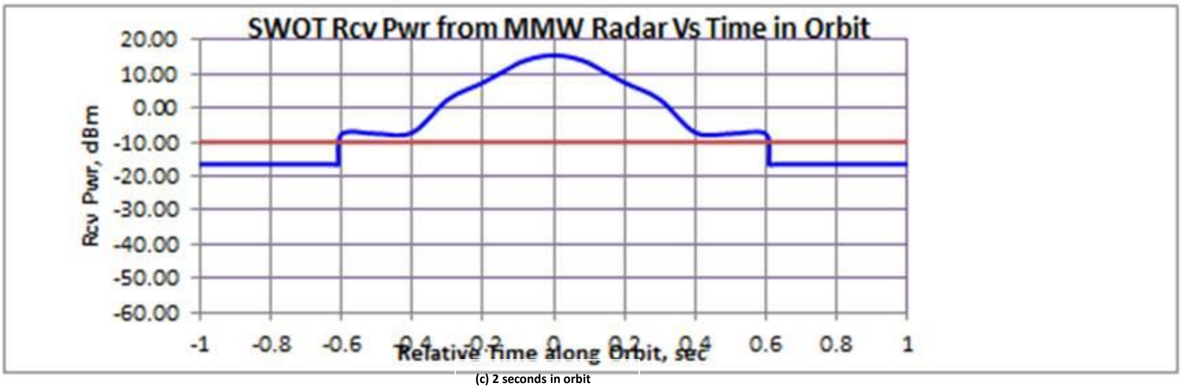
Single pass simulation of received power in 35.5-36.0 GHz InSAR from the MMW (a) 800 seconds in orbit (b) 10 seconds in middle of orbit (c) 2 seconds in middle of orbit



(a) 800 seconds in orbit



(b) 10 seconds in orbit



(c) 2 seconds in orbit

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.

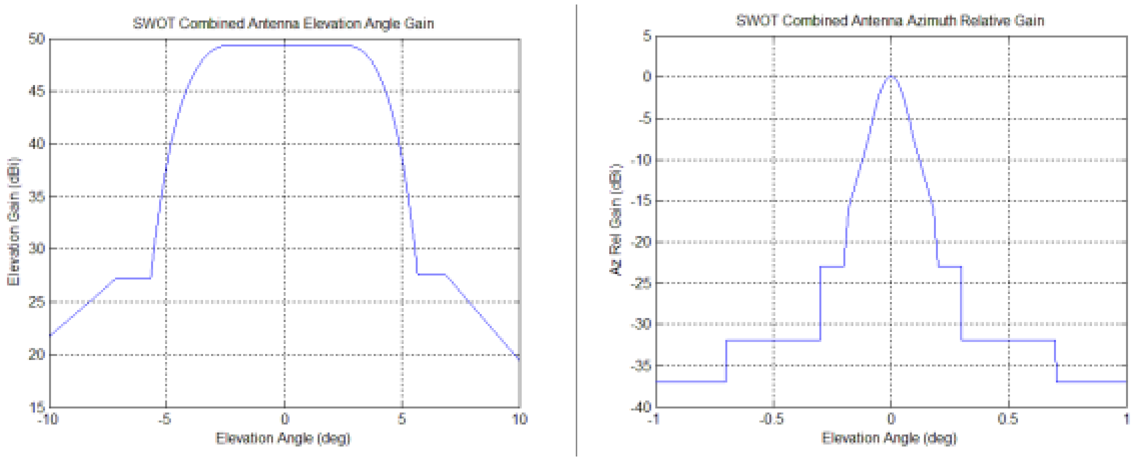
4.2.1 Dynamic analysis 1: Use of Combined InSAR Receive Antenna Pattern

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 the left side of Figure 7 . The combined antenna pattern in azimuth is shown in the right side of Figure 7.

FIGURE 7

Combined Antenna Patterns of EESS (active) system in Elevation and Azimuth



4.2.1.2 Terrestrial radar characteristics

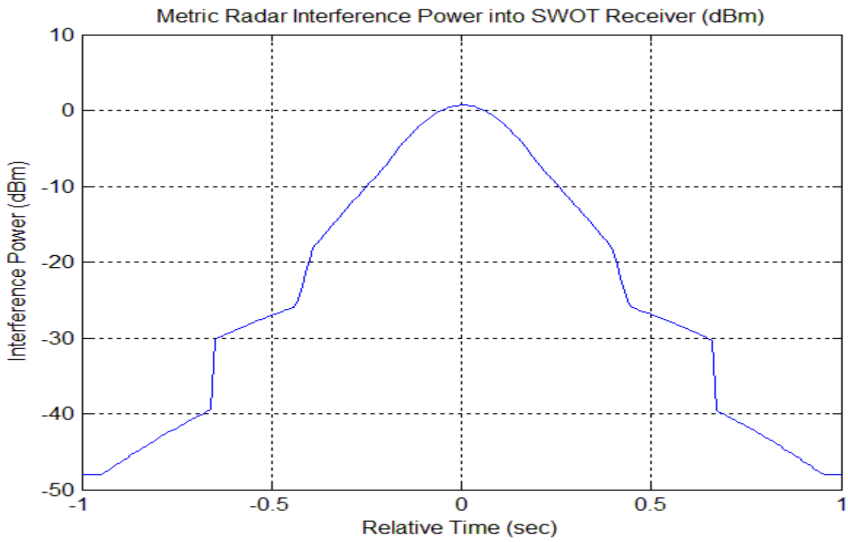
The terrestrial radar was modeled to be pointed in a fixed zenith-looking position. Its characteristics were assumed to be those of the “metric radar” in Table 2. The peak transmit power is 135 kW, the peak antenna gain is 52 dBi, and the frequency is 35.7 GHz. The antenna patterns were modeled as in 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 8 shows the peak received worst case interference power into the EESS (active) receiver.

FIGURE 8

Metric radar RFI Level into EESS (active) Receiver (worst case)



In Figure 8, 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.

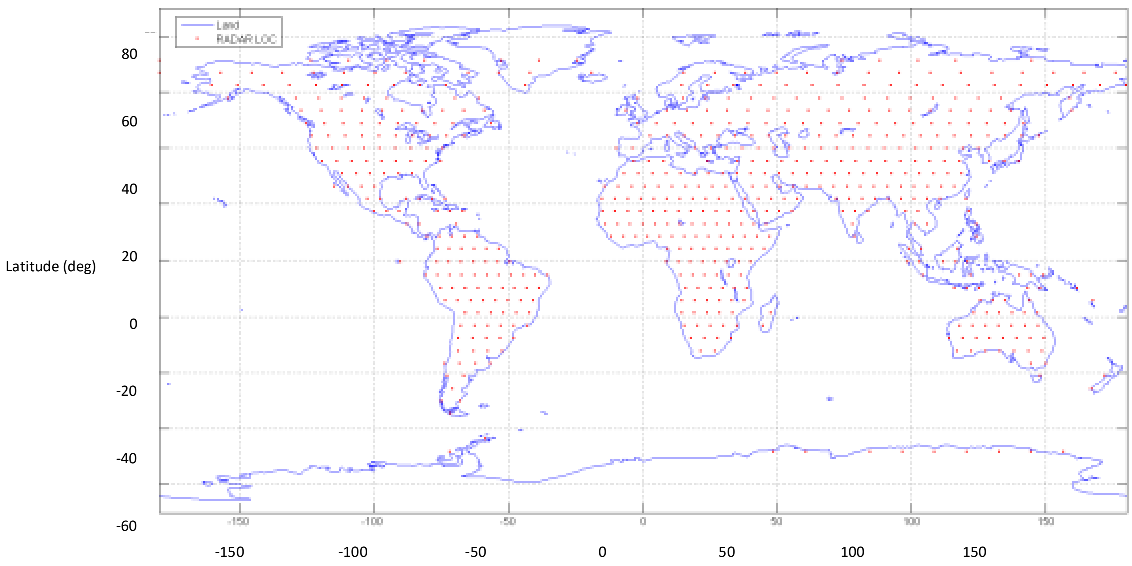
4.2.2.2 Terrestrial radar characteristics

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 9.

FIGURE 9

Worldwide distribution of terrestrial tracking radars

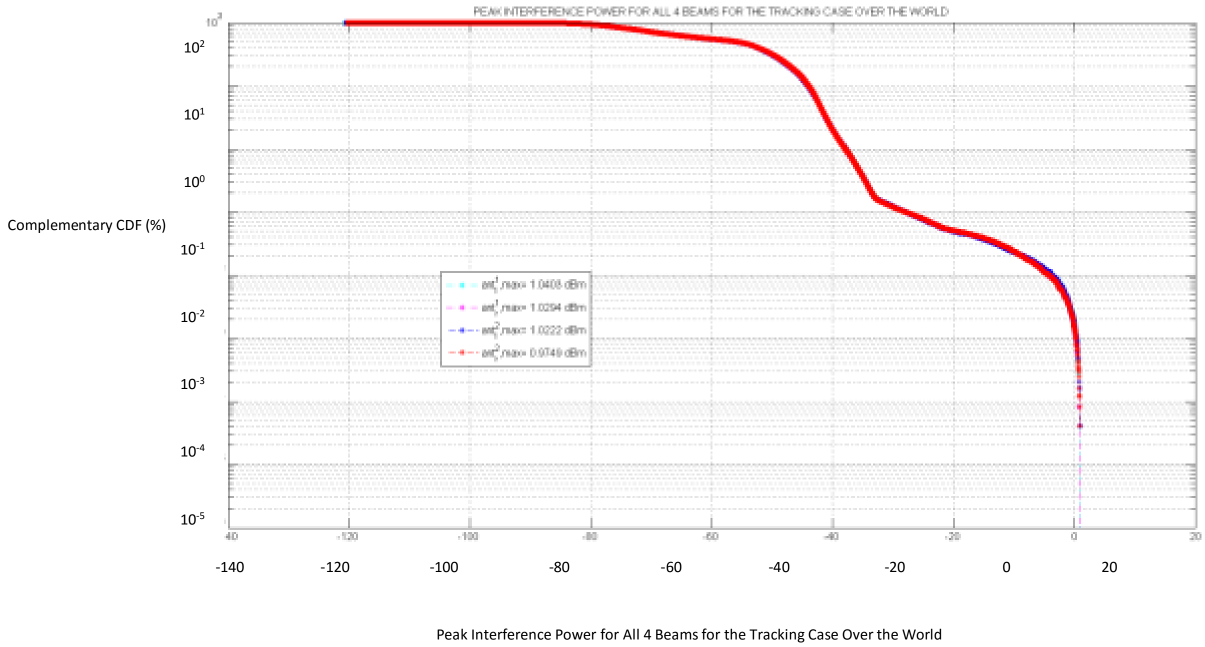


4.2.2.3 Orbit simulations

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 10 is about +1 dBm.

FIGURE 10

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 from the metric radar 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. Preliminary static analysis shows that the received power from the MMW into the InSAR peaks at about +15.5 dBm in the middle of the pass. Therefore, the InSAR receiver should be protected from the MMW up to +15.5 dBm with no margin or up to +21.5 dBm if a 6 dB margin is imposed.

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.