Simulation of Interference Between Earth Stations and Earth-Orbiting Satellites

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Abstract

It is often desirable to determine the potential for radio frequency interference between Earth stations and orbiting spacecraft. This information can be used to select frequencies for radio systems to avoid interference or it can be used to determine if coordination between radio systems is necessary. A model is developed that will determine the statistics of interference between Earth stations and elliptical orbiting spacecraft. The model uses orbital dynamics, detailed antenna patterns, and spectral characteristics to obtain accurate levels of interference at the victim receiver. The model is programmed into a computer simulation to obtain long term statistics of interference. Two specific examples are shown to demonstrate the model. The first example is a simulation of interference from a fixed-satellite Earth station to an orbiting scatterometer receiver. The second example is a simulation of interference from Earth exploration-satellites to a deep space Earth station.

I. Theory and Models

A. Introduction

Fig. 1 contains an illustration of the interference geometry for Earth orbiters and an Earth station. Spacecraft 1 may be transmitting or receiving. Its antenna is pointed toward an arbitrary location on Earth. The Earth station may be transmitting or receiving. Its antenna is pointed toward spacecraft 2 or toward an arbitrary point described by the Earth station antenna azimuth and elevation.

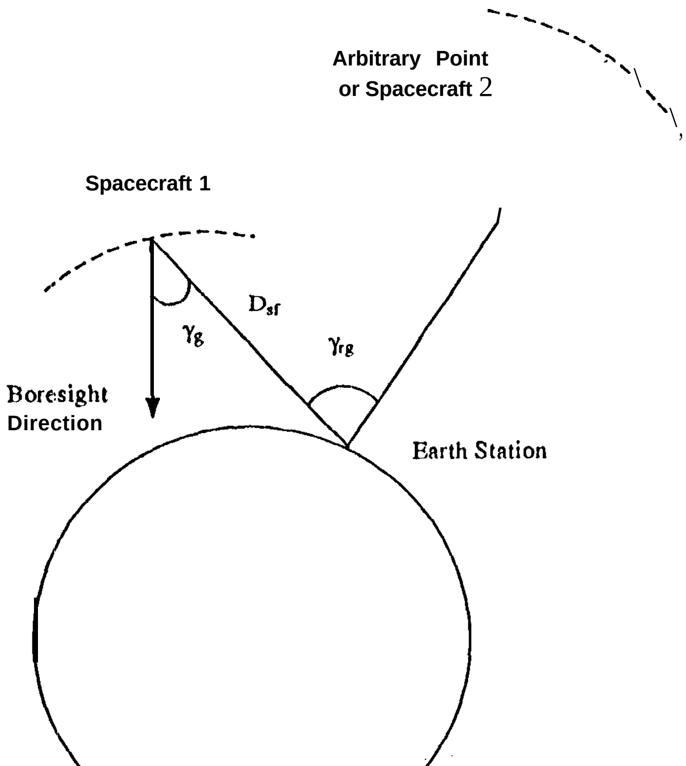


Figure 1. Interference Geometry for Earth Orbiters and an Earth Station

Two interference scenarios are considered. In the first scenario, the Earth station is transmitting a signal toward spacecraft 2. This signal is unintentionally received by spacecraft 1. In the second scenario, spacecraft 1 is transmitting a signal that is unintentionally received by the Earth station.

The interference geometry shown in Fig. 1 is common to many interference scenarios that occur between two different radio systems. The level of interference that occurs at a victim receiver depends on angles, γ_g and γ_{rg}, and the distance, D_{sf}, that are shown on Fig. 1. The primary emphasis of Part I of this paper is to show how to compute these parameters as a function of time. The antenna gain of spacecraft 1 in the direction of the Earth station is a function of angle γ_g. The path loss between spacecraft 1 and the Earth station is a function of the distance D_{sf}. Lastly, the antenna gain of the Earth station in the direction of spacecraft 1 is a function of angle γ_{rg}. The antenna gains and path loss are used to determine interference levels at the victim receiver as a function of time. The interference angles and path distance in Fig. 1 may be computed with standard orbit determination methods [1].

The International Telecommunication Union (ITU) antenna pattern is used to calculate the Earth station antenna gain [2].

$$
\begin{aligned}
G(\gamma_{rg}) &= G_p - 2.5\times10^{-3}(D\gamma_{rg}/\lambda)^2 \text{ (dBi)}, & 0^\circ \le \gamma_{rg} < \phi_m \\
&= G_1 & \phi_m \le \gamma_{rg} < \phi_r \\
&= 32 - 25\log(\gamma_{rg}) & \phi_r \le \gamma_{rg} < 48^\circ \\
&= -10 & 48^\circ \le \gamma_{rg} < 180^\circ
\end{aligned} \tag{1}
$$

where

G_p = peak antenna gain (dBi)
D = antenna diameter (m)
λ = wavelength (m) = c/f
$G_1 = 2 + 15\log(D/\lambda)$ (dBi)
$\phi_m = 20\lambda(G_p - G_1)^{1/2}/D$ (deg.)
$\phi_r = 15.85(D/\lambda)^{-0.6}$ (deg.)
c = speed of light = 3×10^8 m/s
f = frequency (Hz)

This equation is valid for $D/\lambda \ge 100$. For $D/\lambda < 100$ a different pattern is used.

$$
\begin{aligned}
G(\gamma_{rg}) &= G_p - 2.5\times10^{-3}(D\gamma_{rg}/\lambda)^2 \text{ (dBi)}, & 0^\circ \le \gamma_{rg} < \phi_m \\
&= G_1 & \phi_m \le \gamma_{rg} < 100\lambda/D \\
&= 52 - 10\log(D/\lambda) - 25\log(\gamma_{rg}), & 100\lambda/D \le \gamma_{rg} < 48^\circ \\
&= 10 - 10\log(D/\lambda) & 48^\circ < \gamma_{rg} < 180^\circ
\end{aligned} \tag{2}
$$

The path loss from spacecraft 1 to the Earth station is computed.

$$P_l = 20\log(c/[4\pi D_{sf} f]) \text{ (dB)} \tag{3}$$

The angle, γ_g, on Fig. 1 is used to compute the antenna gain of spacecraft 1 in the direction of the Earth station. The spacecraft gain pattern is mission dependent.

II. Application 1: Simulation of Interference From a Fixed-Satellite Earth Station to a Scatterometer Receiver and Calculation of Scatterometer Power Flux Density

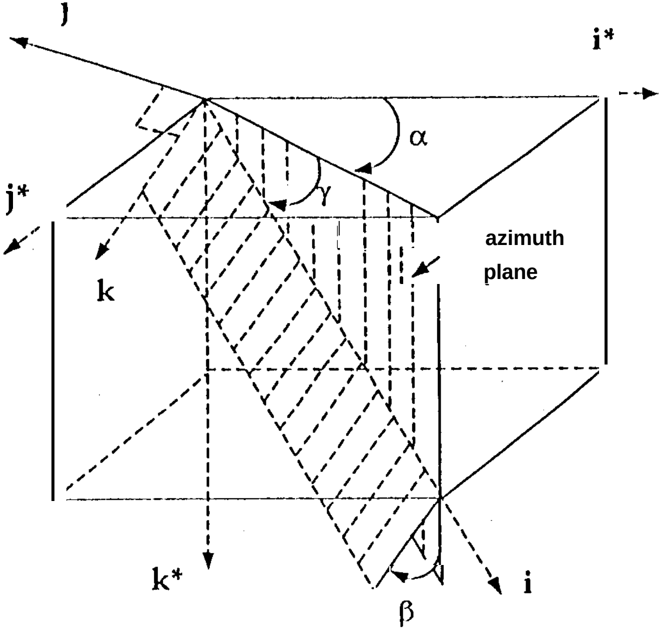
A. Introduction

The World Administrative Radio Conference of 1992 (WARC-92) allocated the 13.75-14 GHz frequency band to the fixed-satellite (Earth-

1[)-space) service on a primary basis. NASA scatterometers are permitted to use this band under the category of space research (spacecraft radiolocation) service on a secondary basis. The International Radio Consultative Committee (CCIR) formulated Task Group 7/3 (TG 7/3) to study the use of the 13.4-14 GHz frequency band by science services. One of the goals of TG 7/3 was to determine the effect that the new allocation (to the fixed-satellite service in the I 3.75-14 GHz hand) would have on NASA scatterometers near 14 GHz. The models developed in section I were used to generate a simulation of interference from a fixed-satellite Earth station to a scatterometer in Earth orbit. The scatterometer is represented by spacecraft 1 and the fixed-satellite spacecraft is represented by spacecraft 2 on Fig. 1. The fixed-satellite Earth station is represented by the Earth station on Fig. 1.

B. Analysis

The computation of the scatterometer antenna gain in the direction of the fixed-satellite Earth station depends on components of the angle, γ_g, in Fig. 1. The scatterometer antenna coordinate and spacecraft coordinate systems are illustrated on Fig. 2. There are six antenna beams, whose positions are defined by angles a, β, and γ. A vector in the antenna coordinate system can be transformed into a vector in the spacecraft coordinate system,



a = azimuth angle
β = - dip angle
γ = - roll single

Figure 2. Antenna and Spacecraft Coordinate Systems

$$x_s = Ax, \tag{4}$$

where

$$A = \begin{bmatrix} A & D & G \\ B & E & H \\ C & F & I \end{bmatrix}$$

A = cos(γ)cos(α)
B = cos(γ)cos(90-α)
C = cos(90-γ)
D = -cos(90-α)cos(β) + cos(90-β)cos (90-γ)cos(α)
E = cocos + cos(90-β)cos (90-γ)cos(90-α)
F = -cos(90-β)cos(γ)
G = -[cos(90-α)cos(90-β) + cos(90-γ)cos(β)cos(α)]
H = cos(α)cos(90-β) - cos(90-γ)cos(β)cos(90-α)
I = Cocos

A vector in the spacecraft coordinate system can be transformed into a vector in the orbit-plane coordinate system.

$$x_{wa} = Bx_s \qquad \text{(s)}$$

where

$$B = \begin{bmatrix} -\dfrac{y_w}{a} & 0 & -\dfrac{x_w}{a} \\ -\dfrac{x_w}{a} & 0 & -\dfrac{y_w}{a} \\ 0 & -1. & 0 \end{bmatrix}$$

a = semi-major axis (Earth radii)
(x_w, y_w) = location of spacecraft in orbit plane

A vector in the orbit-plane coordinate system can be transformed into the right ascension-declination coordinate system.

$$x_{an} = Px_{wa} \tag{6}$$

where

1' is defined in [1]

The vector (from the scatterometer spacecraft to the fixed-satellite Earth station) is transformed from the right ascension-declination coordinate system into the antenna coordinate system. This is done by converting from the right ascension-declination system to the orbit-plane system, to the spacecraft system, and to the antenna system.

$$x_{sfa} = -A^T B^T P^T x_{fs} = (x_{sfa}, y_{sfa}, z_{sfa})^T \tag{7}$$

These components are used to determine the off-axis angles in the narrow-beam plane (±i directions) and wide-beam plane (±j directions) of the fan beam antenna (Fig. 2). The antenna boresight points in the k direction.

$$\cos(\beta_g) = z_{sfa}/(x_{sfa}^2 + z_{sfa}^2)^{1/2}$$
$$\cos(\alpha_g) = z_{sfa}/(y_{sfa}^2 + z_{sfa}^2)^{1/2} \tag{8}$$

These angles are used to compute the narrow-beam and wide-beam components of the fan beam antenna gain.

$$\begin{aligned} G_1(\beta_g) &= -3(\beta_g/0.173)^2, && 0° < \beta_g < 0{,}5° \\ &= -23.9 - 2.16\beta_g, && 0{,}5° < \beta_g < 5.6° \\ &= -48, && 5.6° < \beta_g < 180° \end{aligned} \tag{9}$$

(narrow-beam component, dBi)

$$\begin{aligned} G_2(\alpha_g) &= 34 - 3(\alpha_g/13.9)^7, && 0° \le \alpha_g c\ 20° \\ &= 35.83 - 0.402\alpha_g, && 20° \le \alpha_g < 114° \\ &= -14.5, && 114° \le \alpha_g < 1800 \end{aligned}$$

(wide-beam component, dBi)

The fan beam antenna gain in the direction of the fixed-satellite Earth station is the summation of the narrow-beam and wide-beam components.

$$G_{fb} = G_1(\beta_g) + G_2(\alpha_g) \qquad \text{(lo)}$$

the minimum value of G_{fb} is -14 dBi

At this point there is enough information to compute the level of interference from the fixed-satellite Earth station to the scatterometer.

$$1 = P_1 + G(\gamma_{rg}) + SL + PL + G_{fb} \qquad \text{(1l)}$$

where .

I = interference power spectral density (dBW/Hz)
P_T = fixed-satellite Earth station transmitter power
= 85 - 53.4 (dBW)
$G(\gamma_{fg})$ = fixed-satellite Earth station antenna gain in direction of scatterometer (1)
G_p = 53.4 dBi
D = 4.5 meters
f = 13.995 GHz
SL = 10log(1/BW) (dBW/Hz)
BW = bandwidth = 2 MHz
PL = path loss from fixed-satellite Earth station to scatterometer (3) (dB)
G_{fb} = fan beam antenna gain in direction of fixed-satellite Earth station (10) (dBi)

The threshold level where interference is considered harmful to the scatterometer is -207 dBW/Hz [3]. The ground track of the scatterometer may be computed to provide a visual indication of where the scatterometer is interfered with or not interfered with. The latitude of the ground track is computed first,

$$L_{agt} = 90 - \cos^{-1}(z/a) \tag{12}$$

Then, the longitude is computed.

$$\begin{aligned} L_{ogt} &= L_{o1} - 360t/1436.1,\ y \geq 0 \\ &= -L_{o1} - 360t/1436.1,\ y < 0 \end{aligned} \tag{13}$$

where

$L_{o1} = \cos^{-1}(x/[a(\sin[90-L_{agt}])])$
(x,y,z) = location of spacecraft in the right ascension-declination coordinate system

The longitude is transformed to obtain values between -180° and 180°.

C *Statistics and Probability of Interference*

When the scatterometer is visible to the fixed-satellite Earth station it is possible for interference to occur. The duration of these interference episodes varies with each orbit of the scatterometer. The scatterometer simulation program computes the maximum time of an interference episode and the average time of an interference episode for the complete simulation period. Then histograms of these interference episodes are generated. From the histograms the distribution of interference episodes may be estimated.

The scatterometer measures wind speed over the ocean. Taking this measurement requires that 3 antenna beam (beams 1-3 or beams 4-6) have no interference. The effect of interference from a fixed-satellite Earth station to the scatterometer is to create certain areas on the ocean where measurements of the wind speed cannot be taken by the scatterometer. It is possible that the scatterometer will have interference on the ascending portion of the orbit over a particular area of the Earth. When the scatterometer passes over this area on a descending portion of the orbit it is possible that there will be no interference. Therefore, it is desirable to compute the statistics of interference for areas of the Earth.

For a simple example, the Earth is divided into areas that are 100 km x 100 km near the equator. To facilitate the programming, this is done by dividing the Earth into areas that are 0.898° longitude in width and 0.898° latitude in height. The width of these areas is 100 km at the equator, tapering off to a width of 0 km at the North and South poles. The antenna beams are very narrow in one direction and wide in the orthogonal direction. Therefore, the beams are approximated with 31 vectors in the wide-beam plane of the antenna. These vectors are spaced 1° apart, yielding a total coverage of 30° in the wide beam plane. The point of intersection of an antenna vector with the Earth is determined. This vector location is converted to latitude and longitude (12, 13). Then, the area that this point belongs to is determined.

Wind speed measurements on the right side of the scatterometer are taken by combining signals from beams 1-3 and, on the left side, by combining signals from beams 4-6. An area on the right side is considered to be covered if a vector from each of beams 1-3 intersect the area on the same orbit and the interference is below the receiver interference threshold for each of beams 1-3. Likewise, an area on the left side is considered to be covered if a vector from each of beams 4-6 intersect the area on the same orbit and the interference is below the receiver interference threshold for each of beams 4-6. An area is considered to be interfered with if any of the beams produce an interference level above the receiver interference threshold. The probability of interference is estimated.

$$p = n/d \tag{14}$$

where

p = estimate of probability of area interference
n = the number of times that an area is covered and interfered with
d = the number of times that an area is covered

Where the definitions of "covered" and "interfered with" are provided in the paragraph above.

D. *Power Flux density of the Scatterometer*

Compatibility between terrestrial radio systems and spacecraft radio systems is often determined from the power flux density of the spacecraft on the surface of the Earth. Therefore, the power flux density of the scatterometer is computed.

$$P_{fd} = P_t + G_2(\alpha_g) + FSS \tag{15}$$

where

P_{fd} = power flux density of scatterometer at surface of the Earth (dBW/m^2)
P_t = scatterometer transmit power (dBW)
$G_2(\alpha_g)$ = scatterometer transmit antenna gain as a function of angle (α_g) in the wide-beam plane (dBi)
FSS = free space spreading loss (dB/m^2)
= $10\log(1/[4\pi D_{se}^2])$
D_{se} = distance to Earth (m)

The elevation angle on Earth is a function of α_g. Therefore, the power flux density can be computed as a function of elevation toward the scatterometer.

E. *Simulation*

Table 1 shows the results of an example simulation. Interference is considered harmful if it exceeds the threshold shown on the table. The fixed-satellite Earth station and geostationary satellite arc arbitrarily located, Interference is computed at 1 second intervals. The estimated probability of interference is the number of interference minutes divided by the simulation minutes. The scatterometer orbital period is approximately 100 minutes. The position of the orbit changes relative to the fixed-satellite Earth station. Therefore, on some orbits there is no interference and on other orbits there are episodes of interference for varying amounts of time. The maximum and mean of these interference episodes are provided. Fig. 3 shows the probability of area interference for 1,1 orbits. The fixed-satellite Earth station is located at 0° E, 0° N and points toward a geostationary satellite at 0° E. The areas near the fixed-satellite Earth station have interference probabilities of 1 and the other areas have probabilities of 0.

III. Application 2: Simulation of Interference from an Earth Exploration-Satellite to a Deep Space Earth Station

Table 1, Example of Interference Simulation - Fixed-Satellite Interference to a Scatterometer

Scatterometer Interference Threshold	-207 dBW/Hz
Scatterometer Altitude	797 km
Fixed-Satellite Earth Station	85 dBW EIRP 2 MHz Bandwidth 4.5 m antenna 34° N, 128° W
Geostationary Satellite	196° W
Simulation Time	10,000” minutes
Interference Computations per Minute	60
Scatterometer Antenna Beam Element	1
Interference Duration (minutes)	2.067
Estimated Probability of Interference	2.067×10^{-4}
Maximum Period of an Interference Episode (minutes)	0.567
Mean Period of an Interference Episode (minutes)	0.129

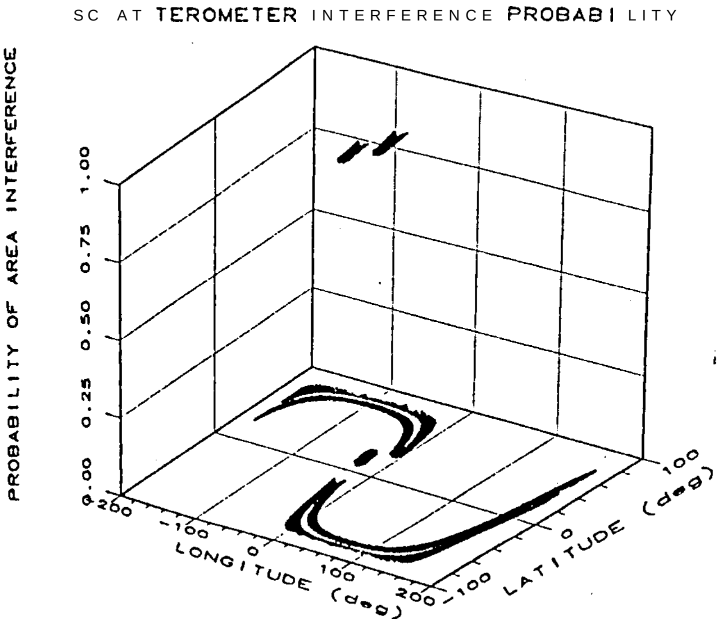


Figure 3. Estimate of Probability That Areas Have Interference

A. Introduction

The Deep Space Network (DSN) uses the 8400-8450 MHz band for space-to-Earth transmissions. The Earth station receivers are protected by interference criteria [4] that have been negotiated in international forums. Other radio services that use the 8400-8450 MHz band are aware of the interference criteria and limit their transmissions accordingly. However, radio services that transmit in bands that are adjacent to the DSN bands may not be fully aware of their emissions in the DSN band. If these out-of-band emissions are strong enough they can disrupt DSN communications. This section investigates some of the low Earth orbiting spacecraft that transmit in bands that are adjacent to the DSN bands near 8400 MHz.

B. Power Spectral Density of Adjacent Band Interferers

The power spectral density from an Earth orbiting spacecraft is computed with the following equation:

$$P_{SD} = P_T + SD(f) + G_T + PL_T + G_R \tag{16}$$

where

P_{SD} = power spectral density of interfering spacecraft at deep space Earth station receiver (dBW/Hz)
P_T = spacecraft transmitter power (dBW)
$SD(f)$ = spectral density of spacecraft transmitter (dB/Hz) (Table 2)
G_T = peak transmit antenna gain (dBi)
PL_T = path loss (dB) $= 20\log[c/(4\pi A_m f)]$
c = speed of light = 3×10^5 km/s
A_m = minimum orbit altitude (km)
f = frequency (Hz)
G_R = DSN receive antenna gain = 74 dBi

The spectral density is computed from the equations shown in Table 2 [5,6].

Table 2. Spectral Density Equations

Modulation	Spectral Density (Baseband)*
QPSK	$(2/SR)[\sin(2\pi f/SR)]^2/(2\pi f/SR)^2$
UQPSK	$(r_I/SR_I)[\sin(\pi f/SR_I)]^2/(\pi f/SR_I)^2 +$ $(r_Q/SR_Q)[\sin(\pi f/SR_Q)]^2/(\pi f/SR_Q)^2$
PSK	$(1/SR)[\sin(\pi f/SR)]^2/(\pi f/SR)^2$
MSK	$[16/(\pi^2 SR)][\cos(2\pi f/SR)]^2/(1-16f^2/SR^2)^2$

QPSK - Quadriphase-Shift Keying
UQPSK - Unbalanced Quadriphase-Shift Keying
PSK - Phase-Shift Keying
MSK - Minimum-Shift Keying

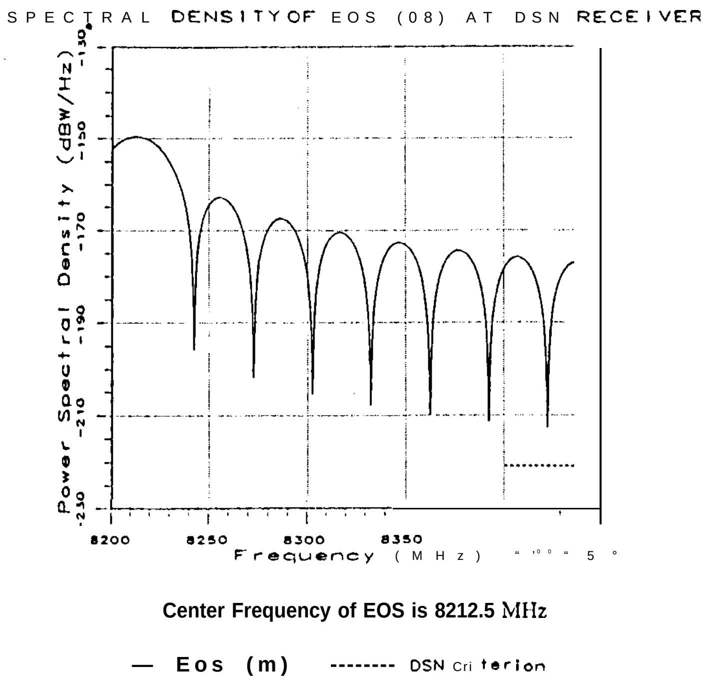
SR = total output symbol rate
f = frequency
r_I = ratio of power in I channel to total power
SR_I = symbol rate of I channel
r_Q = ratio of power in Q channel to total power
SR_Q = symbol rate of Q channel

* Replace "f" with "$f-f_c$" (where f_c is the center frequency) to obtain the spectral density at the center frequency

In particular, the Earth Observing System (EOS) program is planning the launch of several spacecraft [7] that will have spectral emissions in the 8400-8450 MHz band. Fig. 4 is a plot of (16) for the Earth Observing System (EOS) spacecraft transmitting in the direct broadcast (DB) mode. It shows that the emission of an EOS spacecraft exceeds the DSN interference criterion (-220.9 dBW/Hz) by about 45 dB in the 8400-8450 MHz band. This is a worst-case power spectral density at the deep space Earth station because peak antenna gains are used and the minimum orbit altitude is used to compute the path loss. Determination of the statistics of interference is shown next.

C. Simulation of Interference to a Deep Space Earth Station from Low Earth Orbiting Spacecraft in an Adjacent Band

It is useful to know the amount of time that the power spectral density from an adjacent band spacecraft exceeds the interference criterion of the



Center Frequency of EOS is 8212.5 MHz

Figure 4. Power Spectral Density of EOS (DB mode) at DSN Receiver

deep space Earth station. Interference times depend on spacecraft transmitter power, orbits, antenna gains, etc.

Fig. 1 can be used to illustrate the interference geometry. The EOS spacecraft is represented with spacecraft 1. The deep space Earth Station points at a specified azimuth and elevation. The EOS spacecraft is in a circular orbit around the Earth. Its antenna points toward the center of the Earth.

The deep space Earth station (70 meter) antenna gain in the direction of the EOS spacecraft is computed with (1).

$$\begin{aligned} G(\gamma_{rg}) &= 74 - 0.0025(19fioyr8)2 \text{ (dBi)}, && 0^\circ \le \gamma_{rg} < 0.0485^\circ && (17)\\ &= 51.4 && 0.0485^\circ \le \gamma_{rg} < 0.168^\circ \\ &= 32 - 25\log(\gamma_{rg}) && 0.168^\circ \le \gamma_{rg} < 48^\circ \\ &= -10 && 48^\circ \le \gamma_{rg} \le 180^\circ \end{aligned}$$

The EOS spacecraft antenna gain in the direction of the deep space Earth station is computed next. The model is a set of straight line segments that approximate the actual pattern [8].

$$\begin{aligned} G_e(\gamma_g) &= -3.5 + 2.5\gamma_g/3 \text{ (dBi)}, && 0^\circ \le \gamma_g < 3^\circ && (18)\\ &= 0.091 - 4\gamma_g/11 && 3^\circ \le \gamma_g < 14^\circ \\ &= -8.5 + 14\gamma_g/56 && 14^\circ \le \gamma_g < 700 \\ &= 84.25 - 21.5\gamma_g/20 && 70^\circ \le \gamma_g < 90^\circ \\ &= -14.5 && 90^\circ \le \gamma_g \le 180^\circ \end{aligned}$$

The interference power spectral density level at the Deep Space Earth station receiver is computed.

$$I_o = SD(f) + P_e + G_e(\gamma_g) + PL + G(\gamma_{rg}) \quad (19)$$

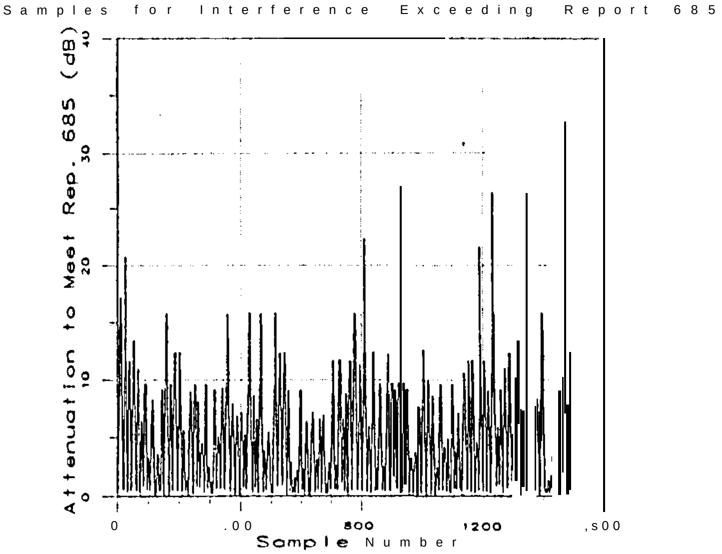
where

P_e = EOS transmitter power = 11.8 dBW

The first simulation on Table 3 is for 1 EOS spacecraft (S/C) transmitting in the direct playback (DP) mode' (QPSK, 150 MSPS per channel). Statistics of the interference are provided. The second simulation on Table 3 is for 5 different spacecraft, The antenna pattern for the last 4 spacecraft is the same as the EOS antenna (18) except for additive constants to provide the correct peak antenna gain for each spacecraft. Each interference event is composed of a number of interference samples that occur at 0.5 second intervals. Samples are plotted on Fig. 5 for the second simulation on Table 3. At each sample interval the amount that the interference exceeds the -220.9 dBW/Hz criterion is plotted. Some events have only 1 sample (0.5 seconds of interference) and some events have up to 20 samples (10 seconds of interference). The simulation was run on a Sun workstation.

Table 3. Comparison of Simulation Results for 1 EOS Spacecraft versus 5 Spacecraft - EOS(DP), SPOT-4, IRS-1B, POEM 1, and RADARSAT-1

Parameter	1 S/C	5 S/C
Duration of Simulation (years)	1	1
Interference Events	37	128
Interference Percentage	8.89×10^{-4}	2.39×10^{-3}
Interference Duration (seconds)		
Shortest	3.5	0.5
Longest	10	10
Average	7,58	5.90
Time Between Interference Events (days)		
Shortest	1.99	0.08
Longest	13.44	12.83
Average	10.11	2,87



1 Year Simulation (0.5 Second Intervals)

EOS(DP), SPOT-4, IRS-1B, POEM 1, RADARSAT-1

Figure 5. Interference Samples for 5 Different Spacecraft

The antenna pattern of the deep space Earth station that is provided in (17) was developed a number of years ago for generalized Earth stations. More accurate gain data has been made available for the 70 meter antennas of the DSN [9]. This data has been fit with a number of equations.

$$\begin{aligned} G_m(\gamma_{rg}) &= 74.15 - 0.0025(2400\gamma_{rg})^2 \text{ (dBi)}, && 0^\circ \le \gamma_{rg} < 0.0376^\circ && (20)\\ &= 53.7 && 0.0376'' \le \gamma_{rg} < 0.04^\circ \\ &= 57.4 - 0.0025(1350[\gamma_{rg} - 0.049])^2 && 0.04^\circ \le \gamma_{rg} < 0.0626^\circ \\ &= 49 && 0.0626^\circ \le \gamma_{rg} < 0.09050 \\ &= 25 - 23\log(\gamma_{rg}) && 0.0905^\circ \le \gamma_{rg} < 33.2^\circ \\ &= -10 && 33.2^\circ \le \gamma_{rg} < 1800 \end{aligned}$$

The computer simulation was conducted with $G_m(\gamma_{rg})$ replacing $G(\gamma_{rg})$ in (19). In the first simulation 1 EOS spacecraft transmitted in the I W mode. In the second simulation 5 different spacecraft were transmitting. The interference percentage is one fourth (of that on Table 3) with the new antenna model for 1 EOS spacecraft. For 5 spacecraft the interference percentage is approximately one fourth (of that on Table 3) with the new antenna model.

All of the simulations use an elevation of 5° and an azimuth of 100" for the deep space Earth station antenna. When larger elevation angles are used the interference percentages are decreased. This is because the spacecraft spends less time within the same Earth station antenna beamwidth at higher elevations. The interference levels are computed at 0.5 second intervals in all simulations.

IV. Summary and Conclusions

Detailed models of the interference geometry of Earth orbiters and an Earth station are developed. These models allow the accurate determination of antenna gains and path distances. These parameters and the radio system characteristics determine the interference levels at the victim receiver.

The first example is a simulation of interference from a fixed-satellite Earth station to an orbiting scatterometer receiver. Table 1 contains a summary of a simulation that was performed. The scatterometer measures wind speed over the ocean. Models were developed to estimate the probability that certain areas of the Earth would not have accurate measurements due to interference. Also, the power flux density on Earth of the scatterometer signal as a function of elevation angle is determined. Results from the simulations showed that the scatterometer should use a different frequency to avoid interference from several fixed-satellite Earth stations.

The second example is a simulation of interference from an Earth exploration-satellite to a deep space Earth station. Worst-case levels of power spectral density from low Earth orbiters at a deep space Earth station are computed. These levels exceed the interference criterion of the deep space Earth station in the 8400-8450" MHz band. A simulation of interference from low Earth orbiters to a deep space Earth station is conducted. This simulation computes the path loss and off-axis antenna gains as a function of orbital position of the low Earth orbiter. It can be used to predict the statistics of interference to the deep space Earth station. Table 3 contains a summary of two different simulations that were performed. Figure 5 shows the interference samples for the second simulation. Results from the simulation show that excessive coordination could be avoided if the Earth exploration-satellite spacecraft reduced their emissions by 20 dB in the 8400-8450 MHz band.

More recent analysis has indicated that modulators with data asymmetry produce line spectrums. Preliminary work has shown that a 5% data asymmetry can produce spectral components (assuming a 1 Hz bandwidth) that are 60 dB or more above the Meat QPSK spectral density. If one or more of these components falls in the deep space Earth station receive bandwidth interference can occur. Additional filtering of these components (above the 20 dB mentioned above) is required.

The simulations are programmed in Fortran and run on a Sun workstation. The author may be contacted for instructions on the operation of the simulation programs.

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