where the relationship between the variables I'' and I is:

$$I'' = \frac{N + I}{N} \qquad 4\text{-}5$$

and the relationship between the variables I''_{dB} and I_{dBW} is:

$$I''_{dB} = 10\log\left[\frac{10^{\left(\frac{I_{dBW}}{10}\right)} + N}{N}\right] \qquad 4\text{-}6$$

N is the value of the noise floor at the input to the FS receiver expressed in Watts. PDF data for the variable I''_{dB} defined above is needed for step 3 of the MSS/FS interference evaluation methodology. Thus, a transformation is required between the available PDF data of the variable I_{dBW} and the variable I''_{dB}.[9] Annex I provides the derivation of the required transformation. The resulting transformation is as follows:

$$\begin{aligned} f_{I''_{dB}}(i''_{dB}) &= \frac{f_{I_{dBW}}(i_{dBW} = i_{1,dBW})}{\left|g'(i_{1,dBW})\right|} \\ &= \frac{f_{I_{dBW}}\left(i_{dBW} = 10\log\left\{N10^{\frac{i''_{dB}}{10}} - N\right\}\right)}{\left[1 - 10^{\frac{-i''_{dB}}{10}}\right]} \qquad ;\ i''_{dB} \geq 0\,dB \qquad 4\text{-}7 \\ &= 0 \qquad ;\ i''_{dB} < 0\,dB \end{aligned}$$

where, in general, $f_X(x)$ represents the PDF of the variable X evaluated at X=x.

---

[9] It should be noted that PDF data for the variable I'' can be generated directly via simulation. In this case, the transformation in Step 2 of the methodology is not needed.

As shown in Equation 4-7, the transformation results in a scaling factor and a non-linear shift along the x-axis. Thus, using Equation 4-7 above, it is straightforward to generate PDF data for the variable I''_{dB} using the available PDF data of the MSS interference power.

4.2.1.3 Step 3: Quantify FS Link Performance with MSS Interference

The next step is to quantify the FS link performance in the presence of both random fades and MSS downlink interference. We take the same approach as applied in step 1 above. That is, the probability that the received SNR is less than the required SNR is determined. However, in this case, we take into consideration both random multi-path fading and MSS interference. Thus, Equation 4-2 is re-written as follows:

$$SNR_{rcv} = \frac{C/(N+I)}{A} = \frac{\left(P_t G_t G_r / (N+I) L_p\right)}{A} \qquad 4\text{-}8$$

where the variable I was defined above. Substituting the results of Equations 4-5 and 4-8 into Equation 4-1, and applying the definitions of the variables A_{dB}, I''_{dB}, and M_{dB}, provided previously, the following equation can be derived:

$$P\{SNR_{rcv,dB} < SNR_{req,dB}\} = P\{A_{dB} > M_{dB} - I''_{dB}\} \qquad 4\text{-}9$$

Although Equation 4-9 is quite similar in appearance to Equation 4-4, the analysis and methodology provided in ITU-R P.530 to calculate the probability that the receive SNR is less than the required SNR is not directly applicable to our situation since both A_{dB} and I''_{dB} are variables. An expression to calculate the above probability has been separately derived resulting in the following:

$$P\{SNR_{rcv,dB} < SNR_{req,dB}\} = p_w * f_{I''_{dB}} = \int_0^{\infty} p_w(M_{dB} - i''_{dB}) f_{I''_{dB}}(i''_{dB}) di''_{dB} \qquad 4\text{-}10$$

We note that $f_{I''db}$ is the PDF of the variable I''_{dB}. Furthermore, p_w is precisely the expression calculated in ITU_R P.530 to determine the probability of the link fade, A_{db}, exceeding some value, in this case $(M_{dB} - i''_{dB})$, where i''_{dB} represents the range of values that the variable I''_{dB} can assume.

Thus, step 3 of the MSS/FS interference analysis involves convolving the link fade probability function, p_w , with the probability density function of the variable I''_{dB}. This convolution results in the probability that the received SNR is less than the required SNR (i.e., the link fails) for a given link that is experiencing both random multi-path fading and a random MSS interference signal. The expressions given in ITU-R P.530 are used to generate the p_w data and the transformation shown in step 2 above is used to generate the PDF of I''_{dB} using the available PDF data of the MSS interference power.

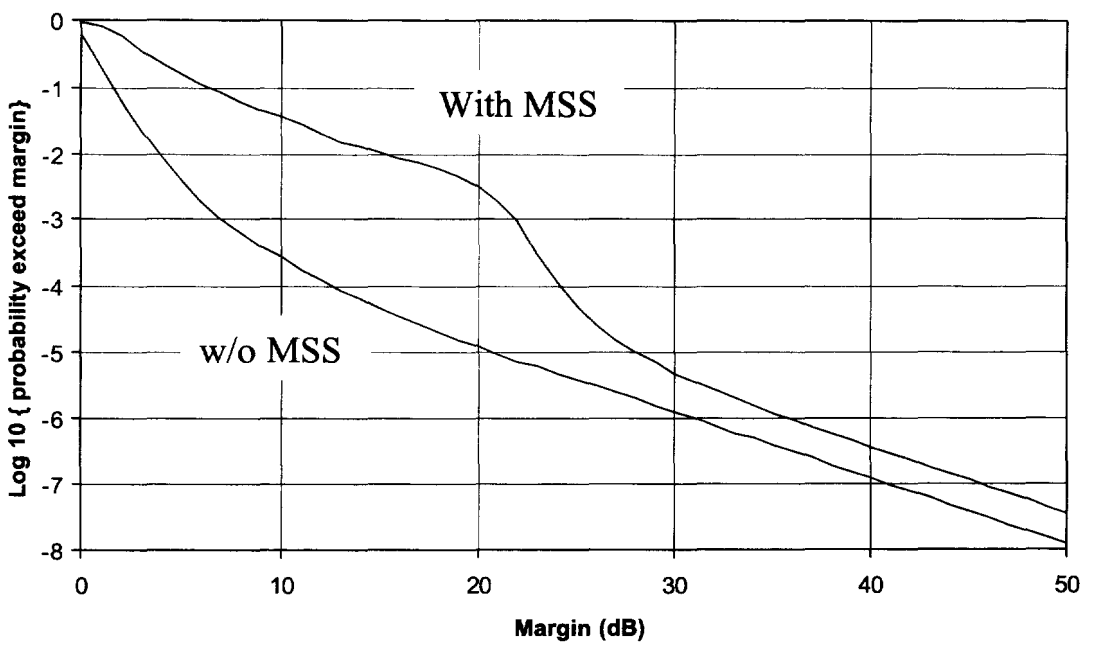

Figure 4-2: Representative Plot Depicting the Performance Results of Steps 1 through 3 of the Convolutional Approach

4.2.1.4 Step 4: Interpret the Performance Results Within the Context of the MSS Downlink Interference Criteria of Section 3

As stated above, the performance data generated using the *convolutional approach* analysis method is a plot of the probability that a link will be unavailable (i.e., link unavailability) as a function of the link margin. The MSS downlink interference criteria provided in Section 3 are given in terms of unavailability limits for digital links and baseband noise power criteria for analog links. Thus, the method for interpreting the above performance results is different depending upon the modulation of the FS link being evaluated. The following sections separately address the specific procedure to be applied in

interpreting the performance data generated by the *convolutional approach* analysis method for digital and analog FS links, respectively.

Digital Links - It is straightforward to interpret the performance data generated by the *convolutional approach* analysis method for digital links since the MSS downlink interference criteria are given in Section 3.2.2 in terms of link unavailability. The procedure is as follows:

1. Calculate the Link Margin in dB.

$$M_{dB} = RSL_{dBm} - RCVR\ Threshold_{dBm} \qquad 4\text{-}11$$

   where RSL_{dBm} is the theoretical received signal level at the input to the FS receiver in dBm and $RCVR\ Threshold_{dBm}$ is the FS receiver threshold value in dBm.

2. Determine the inherent (Pre-MSS) Link Unavailability (i.e., the FS link unavailability achieved without MSS interference) using the performance data generated by the *convolutional approach* analysis method, represented in Figure 4-2 above, at the link margin calculated using Equation 4-11 above.

3. Determine the MSS interference criteria region (i.e., *Simple Unavailability Region* or *Performance Degradation Region* from Figure 3-3 in Section 3.2.2) using the Pre-MSS Link Unavailability and Link Margin calculated above, along with the *Simple Unavailability Limit* and the *Performance Degradation Limit* provided in Section 3.2.2.

4. Determine the MSS Downlink Interference Criteria using the results from #3 above along with Figure 3-3 of Section 3.2.2.

5. Determine the Post-MSS Link Unavailability (i.e., the FS link unavailability achieved in the presence of MSS interference) using the performance data generated by the *convolutional approach* analysis method, represented in Figure 4-2 above, at the link margin calculated above.

6. Compare the Post-MSS Link Unavailability data determined in #5 above with the MSS Downlink Interference Criteria determined in #4 above.

Analog Links The downlink aggregate noise power interference criteria for analog FS links given in section 3.2.1.2 are specified in terms of a limit on the probability that the baseband aggregate noise power threshold will be exceeded. The relationship between link margin and the baseband aggregate noise power criteria is derived in Annex I. The analog FS Link Margin associated with the aggregate noise power is the lesser of the margins determined using equation 4-11 and the following equation:

$$M_{dB} = SNR_{link,dB} - X_{dBm0} + 10Log_{10}(p_{\lim,pW0p}) - 87.5 + IRF_{dB}(f_c) \qquad 4\text{-}12$$

where $SNR_{link,dB}$ was defined previously, X_{dBm0} is the per-channel load (or average talk power) in dBm0, $p_{lim,pW0p}$ is the aggregate noise interference criteria for an analog link from Section 3.2.1.2, and IRF_{dB} is the interference reduction factor in dB generated using the procedures outlined in Annex A of TSB-10F or its successor. Equation 4-12 above is used in interpreting the performance data generated by the *convolutional approach* analysis method for analog FS links. The procedure is as follows:

1. Generate the FS link performance, represented by Figure 4-2 above, for each 4-kHz channel.

2. Generate the link margin, M_{dB} using Equation 4-12 above, for each 4-kHz channel, using the Short Term I baseband power criteria of Section 3.2.1.2 for $p_{lim,pW0p}$

3. Calculate $\max\{plot_{fc}(M_{dB,fc})\}$ over all 4-kHz channels where $plot_{fc}$ refers to the FS link performance represented by Figure 4-2 above for channel frequency fc, $M_{dB,fc}$ refers to the link margin calculated using Equation 4-12 above at channel frequency fc, and $plot_{fc}(M_{dB,fc})$ refers to the resulting FS link unavailability at $M_{dB,fc}$ for channel frequency fc.

4. Compare $\max\{plot_{fc}(M_{dB,fc})\}$ to the Short-Term I baseband power <u>percentage</u> criteria provided in Section 3.2.1.2, making sure to transform the "percentage" criteria to "decimal" criteria for a direct comparison.

5. Repeat #2 through #4 above for the Short-Term II and Long-Term baseband power criteria of Section 3.2.1.2.

4.2.2 Aggregate Noise Power: Monte Carlo Approach

Sharing between MSS and FS systems involves two primary time-varying phenomena. The first phenomenon is the space-based MSS interference geometry (which affects the MSS interference power at the FS receiver), and the second is multi-path fading along the propagation path (which affects the FS received signal level at the FS receiver). In the *convolutional approach* analysis method, the first of these two phenomena is treated via simulation while the second phenomenon is treated analytically. In the *Monte Carlo approach* analysis method, both phenomena are treated via simulation. The outputs generated by using the *Monte Carlo approach* analysis method in evaluating FS link performance in the presence of MSS downlink interference on an "aggregate noise" basis generally have the form of C/N and C/(N+I) statistics presented as an exceedence function. This section describes the steps that comprise the *Monte Carlo approach* analysis method, which uses simulation to evaluate FS link performance in the presence of MSS downlink interference on an aggregate noise (per-hop) basis.

The computer simulation described below is one particular implementation of the performance degradation methodology. Collectively, all steps must be performed, but separate programs can be used to calculate the final distribution curves.

4.2.2.1 Step 1: Calculate the Total Equivalent Noise Power (N)

The thermal noise at each FS receive station can be calculated from knowledge of the FS system noise temperature taking into account the receiver noise figure, the feed losses and the antenna noise temperature. The receiver noise temperature is given by:

$$T_{eq} = NF * T_o \qquad \text{(K)}$$

where:

NF is the noise figure (not in dB)
T_o is 290 Kelvin.

The total equivalent noise power in the receiver bandwidth is given by:

$$N_{eq} = -228.6 + 10 \log T_{eq} + 10 \log B \qquad \text{(dBw)}$$

where B is the FS receiver bandwidth (Hz).

4.2.2.2 Step 2: Calculate the Received Carrier Level, C, at Each Time Step

At each time step, calculate the received carrier level C at each receive FS station in a multi-hop FS route with multipath fading taken into account on that particular hop.

$$C = \frac{P_t \cdot G_t \cdot G_r}{L_p \cdot F_{mp} \cdot FL}$$

where:

C	=	carrier power (Watts)
P_t	=	transmit power input to the antenna (Watts)
G_t	=	gain of the transmit antenna (Unitless)
L_p	=	free space path loss (Unitless)
F_{mp}	=	instantaneous multi-path fading factor (Unitless)

G_r = gain of the receive antenna (Unitless)
FL = line loss (Unitless)

a) The received carrier level C at each station is calculated from the associated transmit FS station EIRP, the free space loss corresponding to the particular path length, multipath fading propagation loss applicable to that particular hop, the receive FS antenna gain and receive FS feed losses.

b) Multipath fading is taken into account using a random fade depth predictor whose output is consistent with the multipath fading model described in Annex A. A random fade predictor generates fade depths at each relevant time step in the simulation, such that the statistical distribution of fades generated is consistent with the multipath fading model. The time step specified for the fade depth predictor can in general be different from the time step required for generating the interference PDF, since the latter involves more slowly varying parameter values.

4.2.2.3 Step 3: Calculate the Aggregate Interfering Signal Power, I_k, into each FS Hop

At each time step, calculate the aggregate interfering signal power into each hop within the reference bandwidth generated by the individual MSS network under consideration.

$$I_k = \sum_{i=1}^{N} \sum_{j=1}^{S} \frac{E_{ijk}}{L_{ik}} G_{MSS}(\alpha_{ijk}) G_{FS}(\theta_{ik}) \frac{1}{F_k} \frac{1}{P_{ijk}} \frac{1}{A}$$

where:

I_k	=	interference power (Watts) in the reference bandwidth, into the k_{th} fixed station;
i	=	1 of N satellites of the MSS constellation visible to the fixed station;
j	=	1 of S active spot beams on the ith visible satellite;
k	=	1 of M fixed stations in a fixed route;
E_{ijk}	=	the calculated EIRP (Watts) in the FS receiver bandwidth input to the antenna for the jth active spot beam in its boresight direction of the ith visible satellite;
L_{ik}	=	free space loss at the given reference frequency from the ith visible satellite to the kth fixed station;
$G_{MSS}(\alpha_{ijk})$	=	the antenna discrimination of the jth active spot beam of the ith visible satellite towards the kth fixed station;
$G_{FS}(\theta_{ik})$	=	the antenna gain of the kth fixed station in the direction of the ith visible satellite;
F_k	=	the feeder loss of the kth fixed station;

P_{ijk} = the polarization advantage factor between the ith MSS satellite and the kth fixed station;

A = interference reduction factor due to voice activation and other time variation factors;

a) The orbital positions of the MSS satellites are predicted by an orbit generator taking into account the actual or forced precession of the orbits;

b) For each MSS satellite spot beam per satellite the satellite spot beam antenna gain toward each FS station can be computed knowing the instantaneous relative position of the MSS satellite with respect to the FS station and the pointing direction of the particular satellite spot beam. The EIRP of each MSS satellite is calculated using the generic method of Annex D. The gain of each MSS satellite spot beam is characterized by the actual or predicted antenna patterns or, if unavailable, using the reference envelope radiation pattern described in Annex C;

c) For each FS station, the antenna gain towards each visible satellite is computed knowing the position of the MSS satellite with respect to the FS station and the pointing direction of the particular FS antenna. Each receive FS antenna is described by the actual or predicted antenna patterns or, if unavailable, using the reference envelope radiation pattern described in Annex B;

d) For each receive FS station, the interfering power from all MSS carriers in any spot beam of any visible MSS satellite which overlaps the FS reference bandwidth can be accumulated taking into account MSS satellite spot beam antenna discrimination, FS antenna discrimination and path loss;

e) MSS satellite systems and FS systems usually employ circular and linear polarization respectively. A polarization advantage is applied when the MSS spot beam pointing vector is within the main-lobe region of the FS antenna (see Annex B).

4.2.2.4 Step 4: Generate C/N and C/(N+I_k) at Each Time Step at the FS Receive Station

Steps 2 and 3 are repeated for each time step[10] over a statistically valid period[11] consistent with a full or equivalent orbital cycle period of the MSS satellite constellation and a representative period for

[10] The time step chosen for the interference assessment should be sufficiently small to allow for multiple samples of MSS satellite visibility within the main-beam of the particular FS stations to be considered. The selection of appropriate time step is a function of the orbital parameters of the MSS satellite constellation, the location of the FS stations and the FS antenna beamwidths.

[11] The simulation period should be sufficiently long to allow for a complete cycle period of the MSS satellite to be considered. For consideration of the effects of the uniformity of interference from a MSS satellite constellation in a month, the guidance of Annex 5 to Recommendation ITU-R F.1108 may be useful. Taking these factors into account, for MSS satellite constellations which exhibit a relatively slow orbital precession, it may be preferable to

multipath fading behavior. One method to check for statistical validity is to ensure that the results are not significantly influenced by the addition of more time steps.

4.2.2.5 Step 5: Generate the Cumulative Distribution Function (CDF) of C/(N+I)

Using the data generated in steps 1 through 5, generate the Cumulative Distribution Function (CDF) of C/(N+I). The result is a performance plot in which the x-axis represents the range of RF C/(N+I) values at the FS receiver, in dB, and the y-axis represents the probability that the received RF C/(N+I) is less than the corresponding value on the x-axis. A representative performance plot is shown in Figure 4-3.

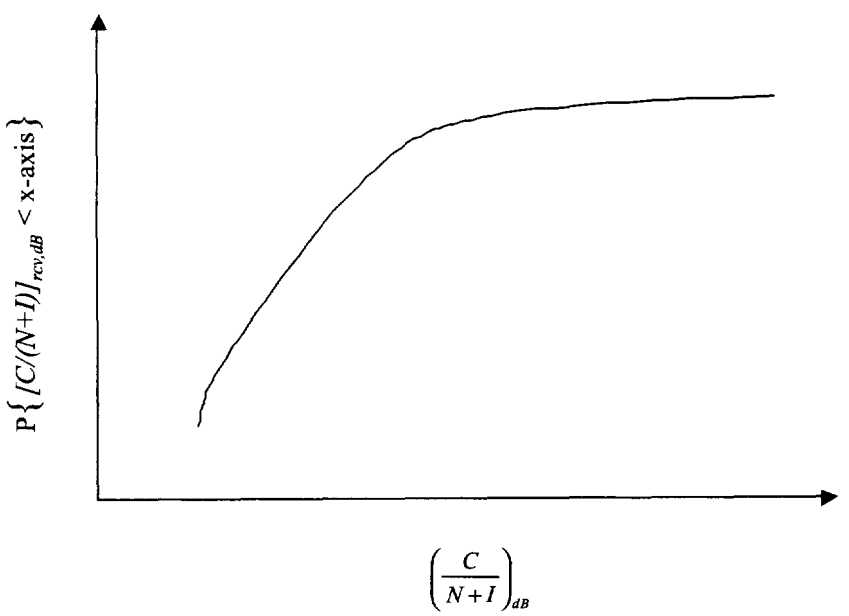

Figure 4-3: Representative Plot Depicting the Cumulative Distribution Function of the Received RF C/(N+I) in dB

4.2.2.6 Step 6: Interpret the Performance Results Within the Context of the MSS Downlink Interference Criteria of Section 3

As stated above, the performance data generated using the *Monte Carlo approach* analysis method is a plot of the cumulative distribution function for the RF C/(N+I) at the FS receiver. The MSS downlink interference criteria provided in Section 3 are given in terms of unavailability limits for digital links and

establish a forced precession rate to allow for simulation of the complete cycle period within a reasonable elapsed simulation time.

baseband noise power criteria for analog links. Thus, the method for interpreting the above performance results is different depending upon the type of FS link being evaluated. The following sections separately address the specific procedure to be applied in interpreting the performance data generated by the *Monte Carlo approach* for digital and analog FS links, respectively.

Digital Links - The procedure for interpreting the performance data generated by the *Monte Carlo Approach* analysis method for digital links is as follows:

1. Determine the theoretical C/N, in dB, required to achieve a bit error rate (BER) of 10^{-6} using the data from Annex B of TSB-10F and based on the type of modulation used by the affected FS path.

2. Calculate the Link Margin in dB:

$$M_{dB} = RSL_{dBm} - RCVR\ Threshold_{dBm}$$

   where RSL_{dBm} is the theoretical received signal level at the input to the FS receiver in dBm and $RCVR\ Threshold_{dBm}$ is the FS receiver threshold value in dBm

3. Determine the Pre-MSS Link Unavailability (i.e., the FS link unavailability achieved without MSS interference) using the appropriate FS system parameter data and the methodology presented in ITU-R P.530, or by applying the techniques described in Annex A of this document, to address multi-path fading along the FS propagation path.

4. Determine the MSS interference criteria region (i.e., *Simple Unavailability Region* or *Performance Degradation Region* from Figure 3-3 in Section 3.2.2) using the Pre-MSS Link Unavailability and Link Margin calculated above, along with the *Simple Unavailability Limit* and the *Performance Degradation Limit* provided in Section 3.2.2.

5. Determine the MSS Downlink Interference Criteria using the results from #3 above along with Figure 3-3 of Section 3.2.2.

6. Determine the Post-MSS Link Unavailability (i.e., the FS link unavailability achieved in the presence of MSS interference) using the CDF plot of the received RF C/(N+I) generated by applying the *Monte Carlo approach* analysis method, represented in Figure 4-3 above, at the theoretical C/N determined in #1 above.

7. Compare the Post-MSS Link Unavailability data determined in #6 above with the MSS Downlink Interference Criteria determined in #5 above.

Analog Links - The MSS downlink aggregate noise power interference criteria for analog links given in section 3.2.1.2 are given in terms of a limit on the probability that the baseband aggregate noise power

limit is exceeded. As stated above, the data generated using the *Monte Carlo approach* analysis method is in the form of the received RF C/(N+I) in dB. Thus, an expression that provides a limit for the received RF C/(N+I) at the FS receiver in terms of the baseband aggregate noise interference limits provided in Section 3.2.1.2 is needed to interpret the *Monte Carlo* performance results for analog FM-FDM links. This expression is derived in Annex J and is repeated below:

$$\left(\frac{C}{N+I}\right)_{\lim, dB} = X_{dBm0} - IRF_{dB}(f_c) + 87.5 - 10Log(p_{\lim, pW0p})$$

where X_{dBm0} is the per-channel load (or average talk power) in dBm0, $p_{lim,pW0p}$ is the aggregate noise power interference criteria for an analog link from Section 3.2.1.2, and IRF_{dB} is the interference reduction factor, in dB, generated using the procedures outlined in Annex A of TSB-10F. The equation above is used in interpreting the performance data generated by the *Monte Carlo approach* analysis method for analog FS links. The procedure is as follows:

1. Generate the FS link performance, represented by Figure 4-3 above, for the worst case 4-kHz channel.

2. Generate the C/(N+I) criteria , using the equation above, for the worst case 4-kHz channel, and using the Short Term I baseband noise power criteria of Section 3.2.1.2 for $p_{lim,pW0p}$

3. Using the CDF plot generated as a result of applying the *Monte Carlo approach* analysis method, determine the probability that the C/(N+I) criteria calculated in #2 above is not met.

4. Compare this probability to the Short Term I baseband power <u>percentage</u> criteria provided in Section 3.2.1.2, making sure to transform the "percentage" criteria to "decimal" criteria for a direct comparison.

5. Repeat #2 through #4 above for the Short Term II and Long Term baseband noise power criteria of Section 3.2.1.2.

4.2.3 MSS-Only Interference Noise Power

The MSS-Only interference calculation (Stage 1 or 2) is intended to be performed for *analog* FS systems as a preliminary, simplified calculation step in order to eliminate, if possible, non-problematic cases from further consideration using more detailed analyses (the *Convolution* or *Monte Carlo* approaches). While this approach is nearly identical to the international system-specific methodology (refer to Recommendation ITU-R IS.1143, Annex 1), the JWG has tested the approach using US-based software and added another set of steps to evaluate the MSS interference in terms of the

equivalent baseband noise power (per hop). A simple calculation method is given below; it is based on converting the MSS RF interference power into baseband noise power--through the standard FM equation. This makes the simplifying assumption that the MSS interference spectrum is "noise-like." It has been shown that this method is conservative compared to the aggregate noise power calculation method.

The input to the calculation is the PDF of MSS radio-frequency interference power at the FS receiver input. For non-GSO MSS systems this has to be generated through simulation. The RF interference power is then converted to baseband noise power using equation 4-13.

$$\frac{s}{n_i} = \left(\frac{\Delta f_r}{f_{\max}}\right)^2 \frac{p \cdot w \cdot B}{b} \cdot \frac{c}{i} \qquad 4\text{-}13$$

where:

s is the baseband signal power, equal to 1 mW;
n_i is the baseband interference noise power;
Δf_r is the per channel RMS frequency deviation of the FS signal, given by Table 4-1;
f_{max} is the highest baseband channel frequency of the FS system, given by Table 4-1;
p is an improvement factor due to pre- and de-emphasis (if no emphasis is used this is equal to 1);
w is a psophometric weighting factor, equal to 1.8 (2.5 dB);
B is the FS RF bandwidth, given in Table 4-1;
b is the bandwidth of one telephone channel, equal to 3100 Hz;
c is the nominal received FS carrier power in W;
i is the RF interference power of the MSS system in the FS RF bandwidth, in W.

Table 4-1: Characteristics of typical FDM/FM FS receivers (from TSB-10F)

Number of channels	Per channel RMS frequency deviation (kHz)	Highest channel frequency (kHz)	RF bandwidth (Hz)
96	47	408	1,600,000
48	26	204	800,000
24	13	108	400,000

The MSS baseband interference noise power is thus calculated as

$$n_i = \frac{s \cdot b \cdot i}{p \cdot w \cdot B \cdot c}\left(\frac{f_{\max}}{\Delta f_r}\right)^2 = 1.74 \cdot 10^{12} \cdot \left(\frac{f_{\max}}{\Delta f_r}\right)^2 \frac{i}{p \cdot B \cdot c} \qquad 4\text{-}14$$

where n is given in pW0p.

The results should be compared to the criteria given in section 3.2.1.1.

4.3 Comparison of Results with Criteria

Finally, in the comparison area (Figures 4-1a and 4-1b), the FS link performance data calculated above is compared to the MSS/FS interference criteria provided in Section 3.2 of this bulletin in order to determine whether or not a specific FS link passes the criterion.

If the FS link passes the applicable criteria, no further evaluation is required. If the FS link fails to meet the criteria and if the level of fidelity and/or accuracy of the system operational model can be improved to better represent actual operations, the system operational model should be modified and the analysis redone. At this stage, more detailed interference analysis must be undertaken which necessitates a departure from the generic model approach. In general, the additional assumptions used in the interference analysis will be agreed upon between the concerned parties.

a) In some cases, FS hops may not have first Fresnel Zone clearance. In such cases, it is appropriate to add an additional loss factor to the free space loss and multipath fading loss. This factor should be based on measured data, where available.

b) In cases where statistically valid measured propagation data is available for individual FS hops, this data could be used in place of the assumed propagation model on agreement between the concerned parties. It may be possible in some cases, e.g. based on measured data, to take into account diurnal and/or seasonal variations in multipath fading propagation behavior.

c) Based on predicted realistic diurnal and geographic subscriber traffic distributions and system-dependent satellite spot beam traffic allocation, the total traffic carried in each spot beam of each MSS satellite can be identified by the MSS party using proprietary or representative algorithms (see Annex D). Based on the system-dependent internal frequency reuse constraints for the MSS satellite system, the nominal frequency plan applicable to each spot beam of each MSS satellite can similarly be identified if necessary.

If the link still fails the interference criteria after all reasonable modifications have been made to characterize actual MSS and FS operations, then further discussions between the FS and MSS system operators will be required.

5. Candidate Approach for Assessing Interference from Fixed Service Transmitters to Mobile Satellite Service User Terminals

5.1 Introduction

MSS operators may seek coordination of frequency assignments for receiving mobile earth stations (MES) operating in or near US territories with respect to US FS transmitters. Internationally, under RR No. S9.11A, this coordination may be requested when the coordination area around the MES service area (calculated in accordance with RR Appendix S7) extends into US territory. This section summarizes an approach that, if mutually agreed upon, may be used for evaluating the potential interference from FS stations to MES. The approach can also be considered for assessing the effectiveness of interference mitigation techniques that may be deemed necessary in the course of coordination.

5.2 Characterization of Potential Interference Modes

5.2.1 Overview

Several considerations provide the basis for a methodology for evaluating potential interference from FS stations to MES. Two types of interference from FS stations can occur. The first (mode 1) consist of an increase in the bit and frame error ratios resulting from the interfering signals present at the MES demodulator; the second (mode 2) type of interference results in receiver desensitization, signal distortion and intermodulation due to the presence of nearby, relatively powerful FS signals (including non-co-channel signals) in receiver stages prior to the demodulator (referred to as receiver spurious response). Interference occurs in either mode when the C/(N+I) level falls below certain threshold levels for sufficiently long periods of time to impact MES performance. These thresholds correspond with increases in BER and frame losses that result in subjectively unacceptable performance, which depend on the data and voice coding techniques employed by the MSS system (typically symbol interleaving using block coding, convolutional coding and voice processing tolerant of random frame losses). These thresholds should be agreed upon between the parties concerned.

5.2.2 Interference Thresholds

Typically, the MSS voice coding subsystems (vocoders) are designed to yield peak subjective voice transmission performance at BER of about 10^{-3} or somewhat lower, and no improvement in voice transmission quality is achieved at lower BER. As the BER is increased from about 10^{-3} the voice transmission quality typically decreases and reaches a minimum acceptable level of performance at a sustained BER of the order of 1.5×10^{-1}. At this point, the voice frame error rate is too high to permit suitable interpolation over unrecoverable frames. Each voice or data frame generally has a header that enables instant receiver recovery after reception of a corrupted data frame. This robust performance capability generally is deemed necessary because of inherent MSS signal propagation vagaries, which

include rapidly varying multipath, shadowing, blockage, depolarization, and Doppler effects. Hence, MESs are very tolerant of interfering signals from FS stations, which also vary substantially. There inherently is a small probability of receiving a near-peak interfering signal level at the same instant in time that the MSS signal is severely faded, and so, satisfactory MSS performance can be achieved during transmission sessions when the average C/(N+I) is very low (e.g., typically substantially less than 10 dB). The specific thresholds to be applied in consideration of interference mode 1 (interfering signals at the demodulator) must be specified by the MSS operator seeking coordination based on the MSS system design and the agreed upon MSS performance objectives.

For co-channel interfering signals, mode 1 interference occurs at much higher C/(N+I) levels than does mode 2 interference (receiver spurious response); hence, mode 2 can be ignored for co-channel sharing situations. However, in order to enable flexible coordination and assignment of frequencies throughout the MSS allocation, MES generally will have a tuning range of at least 2170-2200 MHz. Consequently, the RF and IF filtering at the MES receiver front-end will not attenuate FS signals falling in band segments that are not actually used by the MSS system, and strong FS signals from transmitters in close proximity to the MES can overload MES receiver front-end components. This can result in receiver desensitization (e.g., automatic gain control erroneously reduces IF gain), intermodulation or saturation (normally linear amplification becomes non-linear). The occurrence of these effects is mainly dependent on the dynamic range of the MES receiver, improvement of which is generally costly. For example, assuming a dynamic range of 80 dB with respect to a 6-dB nominal signal-to-noise power ratio, the MES receiver will not suffer mode 2 interference unless the C/(N+I) (or C/I) is lower than -74 dB, in which case the FS interfering signal power would have to be of the order of 84 dB greater than the co-channel interfering signal level causing unacceptable increases in BER and frame errors.

5.2.3 Interfering and Desired Signal Propagation Considerations

Various models are used to characterize the propagation effects on desired MSS signals, including Rayleigh fading (e.g., when there is no unobstructed line-of-sight path) and log-normal fading (e.g., during shadowing from trees), which convey temporal variability for a specific MES operating environment (e.g., see Recommendations ITU-R P.680-2, P.681-3, and P.682-1 for applicable models). These models convey general effects encountered in an MES operating area, but there generally are additional local degradation effects, such a head-blockage of the desired signal. The latter local effects sometimes are controllable by the MES user (e.g., by avoiding a certain head orientation that yields high attenuation from head blockage). Because the temporal variability of the desired signal is highly dependent on the general and local MES operating environment, it is necessary to consider spatial variability of propagation phenomena in addition to temporal variability. Likewise, the interfering signals from FS stations are subject to similar propagation phenomena, such that their temporal as well as general and local spatial variabilities must be considered (i.e., tri- variate statistics).

5.3 Potential Basis for a Methodology

Further review and development of the following analysis approach is needed to establish a complete methodology for evaluating potential interference from FS transmitters to land-based mobile earth

stations (MESs). The following information is suggested for consideration when developing an approach to be used for coordination in the subject frequency-sharing situation.

5.3.1 Application of Area-Indexed Interference Probabilities

In order to make this potential interference situation analytically tractable, the general and local spatial variables can be bounded by considering specific operating areas for MES. This practice has the benefit of also enabling consideration of specific FS transmitters that may interfere with MES. Specifically, the entire MES operating area can be considered as a collection of different operating environments that are distinguished by the applicable propagation models for desired and interfering signals, such that within each type of area the temporal effects and spatial effects can be evaluated. The deployment of FS stations in the overall band of concern (i.e., the tuning range of the MES plus guard-bands) and their characteristics can then be considered in an assessment of the probability of interference in each area. This task can be simplified by addressing typical areas having substantially different FS station deployments and desired and interfering signal propagation characteristics, then applying the results to other similarly defined areas.

As in the case of potential interference to FS stations from MSS satellite downlinks, it is helpful to perform relatively simple analyses first in order to dismiss cases that will not be problematic and do not warrant further, detailed analysis. This can be accomplished by first applying simple propagation models to identify two areas around an FS station in which interference might exceed acceptable levels (potentially affected operating areas): one area for mode 1 interference and another, much smaller, area for mode 2 interference. These areas could be determined assuming that the desired signal power is at the level exceeded most of the time (e.g., 80th percentile) and the interfering signals propagate over smooth, spherical Earth (i.e., disregarding terrain and other attenuating features). The areas should be determined taking into account the heights of the FS station and mobile earth station antennas. Each area would be within contours corresponding to a nominal interfering signal power level that may unacceptably degrade performance (i.e., reduce the C/(N+I) level to the applicable threshold value). More detailed analyses would be performed for MES locations within these areas using more realistic propagation models (with terrain effects) for both the desired and interfering signals in order to determine the probabilities of mode 1 and mode 2 interference, which would be compared with the performance objectives of the MSS system.

5.3.2 Potentially Affected MES Operating Areas

Using a relatively simple propagation analysis methodology, it is straightforward to determine the magnitude of the mode 1 and mode 2 potentially affected areas in which an MES might be impaired by local fixed service operations. The radial distances from the FS station that define this contour can be calculated as follows:

$$I(\text{mode}) = G_t + P_t + G_r - L_b(d) - B \qquad (5\text{-}1)$$

where:

I(mode) = interfering signal power threshold (dBW) for the mode of potential interference being considered;

G_t = transmitting antenna gain (dBi) of the FS station in the azimuth being considered;

P_t = antenna input power (dBW) of the FS station (for the carrier falling within the MES receiver necessary (channel) bandwidth;

G_r = receiving antenna gain (dBi) of the MES in the direction of the FS station, excluding local effects such as head blockage;

$L_b(d)$ = basic transmission loss (dB) predicted by a smooth Earth model (e.g., Recommendation ITU-R P.526) at a distance d;

B = ratio of FS signal bandwidth to the applicable MES receiver bandwidth (dB), using the MES receiver necessary (channel) bandwidth for interference mode 1 and the RF bandwidth for interference mode 2.

To determine the distances "d" corresponding to the contour for the interference mode under consideration, Equation 5-1 generally must be applied iteratively for various distances until the distance yielding the I(mode) threshold is found. This is because Equation 5-1 cannot generally be arranged to yield a direct solution for distance (due to the smooth Earth propagation model).

5.3.3 Assessment of Probability of Interference

The probabilities of mode 1 and mode 2 interference within a given potentially affected area of MES operation should be determined using suitable, detailed models for the propagation of desired and interfering signals. These models must take account of FS and MES antenna heights, as well as natural and man-made terrain features and foliage; however, local propagation phenomena should be initially disregarded. This can be accomplished for each potential mode of interference as follows:

A) Establish a grid of MES locations within the potentially affected area of operation, the resolution of which should be commensurate with the general spatial variabilities of desired and interfering signals;

B) Calculate the cumulative time distribution of C/(N+I) for each grid point, and identify the C/(N+I) level exceeded for the percentage of time associated with the temporal element of the MES performance objective;

C) Construct contours around contiguous grid points at which the temporal C/(N+I) threshold is not exceeded;

D) The areas within the above contours are the maximum size areas in which, depending on head blockage and other local propagation impairments, interference might exceed acceptable levels. Assessment of local propagation effects will be highly dependent upon the specific design of the MES (e.g., antenna clearance), and appropriate evaluation methodologies must be determined during coordination on a case-by-case basis.

The areas of potential interference identified above will not be defined by simple contours because the interfering signal is not attenuated monotonically with increasing distance. For example, terrain and foliage may sufficiently attenuate interfering signals at sites near an FS transmitter station, but not at more distant MES locations having higher terrain elevations.

6. Examples of Estimating Interference Between Fixed-Service Systems and Mobile-Satellite Service Systems

This section presents two examples that apply the methodologies of Section 4 to representative system scenarios. It should be noted that the examples in this section are not meant to predict the performance results of any particular system and should not be interpreted as such. The *convolutional approach* analysis method described in Section 4.2.1 was used to generate the performance results provided in this section. In example A, the maximum MSS EIRP and the theoretical received signal level (RSL) at the input to the FS receiver were chosen so as to yield a potentially small impact to FS performance due to the presence of MSS interference. In example B, these two values were changed so as to yield a more substantial impact on FS performance due to the presence of MSS interference.

6.1 Example A

The FS system parameters used in this example are shown in Table 6-1. The FS path used was a digital path having an azimuth angle of 90.2°. The path length was 9.27 km and 6-ft antennas were used. The noise floor at the input of the receiver was -135.1 dBW and the theoretical received signal level (RSL) at the input to the receiver was -33.7 dBm. The equipment used had a receiver threshold of -78.1 dBm. Note that these FS system characteristics indicate a "pre-MSS interference" fade margin of –33.7 dBm minus (–78.1 dBm) = +44.4 dB, which is representative of a fairly high margin FS path. In this example ATPC and receive antenna diversity were <u>not</u> used by the FS system.

The MSS system parameters used in Example A are shown in Table 6-2. A ten-satellite non-GSO system was modeled, with two orbit planes, each plane containing five satellites having circular orbits with an altitude of 10,355 km. The inclination angle is 45°. For simplicity, an omni-directional (isotropic) satellite antenna pattern was used and a constant transmit power model was used at a maximum EIRP of 34.2 dBW. A simulation of the 10 non-GSO MSS satellites was performed over a 24-hour period with a time step of one minute.

The PDF of the MSS interference power at the FS receiver, I, was generated and the results are shown in Figure 6-1. The PDF transformation described in Annex G was used to generate the PDF of the variable I", which is shown in Figure 6-2.

The PDF of I" was used in applying the *convolutional approach* analysis method to generate the performance results provided in Figure 6-3. Figure 6-3 includes the performance data both with and without MSS interference power. This corresponds to steps 1 and 3 of the *convolutional approach* analysis method. As shown in Figure 6-2, the calculated unavailability for the FS path without MSS interference was 2.57×10^{-9}. When MSS interference is present, the FS path unavailability degrades to 3.29×10^{-9}. These two performance results would then be compared with the appropriate criteria in Section 3, using the procedure outlined in step 4 of Section 4.2.1.4, in order to determine whether or not the MSS system in question meets the MSS downlink interference criteria limits (for digital links).

6.2 Example B

The only differences regarding the FS and MSS system parameters used in Example B relative to Example A were: a large reduction in the theoretical received signal level (due to increased path length), from -33.7 dBm to -60.1 dBm, yielding a "pre-MSS interference" fade margin of –60.1 dBm minus (-78.1 dBm) = +18 dB, representative of a very low margin FS path; and a substantial increase in the maximum MSS EIRP from 34.3 dBW to 45 dBW. As stated previously, these two parameters were chosen for Example A so as to result in a potentially small impact to FS performance due to the presence of MSS interference. In contrast, the impact due to MSS interference in example B is quite strong due to much lower FS link margin and higher MSS downlink EIRP.

Using the FS and MSS system parameters of Tables 6-1 and 6-2, along with the two modifications identified above for the theoretical FS received signal level and the maximum MSS EIRP, the PDF of the MSS interference power, I, at the FS receiver was generated with the results shown in Figure 6-4. The PDF transformation described in Annex G was used to generate the PDF of the variable I", which is shown in Figure 6-5.

The PDF of I" was used in applying the *convolutional approach* analysis method to generate the performance results provided in Figure 6-6. Figure 6-6 includes the performance data both with and without MSS interference power. As shown in Figure 6-6, the calculated unavailability for the FS path without MSS interference was 1.3×10^{-6}. When MSS interference is present for the Example B scenario, the FS path unavailability is impacted considerably more strongly than Example A -- it is degraded to a link unavailability of 1.9×10^{-4}. These two performance results would then be compared with the appropriate criteria in Section 3, using the procedure outlined in step 4 of Section 4.2.1.4 (for digital links) in order to determine whether or not the MSS system in question met the MSS downlink interference criteria limits.

Table 6-1: Fixed Service System Parameters Used for Example A

Parameter[12]	Units
Waveform Description	Assume MSS interference power is fully contained within the occupied BW of the FS receiver
Latitude/Longitude for XMT/RCV antennas	XMT (lat: 30.35944 deg; long: -103.5511 deg) RCV: (lat: 30.35972 deg; long: -103.6475 deg)
Height above sea-level for XMT/RCV antennas	XMT: 12.86 m RCV: 8.57 m
Path Length	9.27 km
Frequency	2.1684 GHz
FS Receiver Reference Bandwidth	1 MHz
Azimuth of RCV antenna	90.2 deg
Receive antenna gain pattern	6-ft dish; use ITU-R F.1245 for antenna gain roll-off pattern
Noise floor at input of FS receiver	-135.1 dBW
Total RCV losses (other than propagation)	2 dB
Theoretical Received Signal Level (RSL) at Input to Receiver[13]	-33.7 dBm
Receiver Threshold (R_t)	-78.1 dBm
Terrain Designator	Mountains
Geoclimatic factor, K	$2x10^{-6}$ (assumes C_0=10.5, C_{lat}=0, C_{long}=-3, and p_L=20; see ITU-R P.530-7)
System Length (i.e., route length)	9.27 km (i.e., single path system)
Number of Hops	1
Pre-Emphasis?	Not Applicable (N/A)
ATPC?	No
RCV Antenna Diversity?	No

[12] Based upon using ITU-R P.530 for the fading model.
[13] Takes into consideration free space loss.

Table 6-2: MSS System Parameters Used in Example A

Parameter	Units
Waveform Description	Constant envelope; Assume MSS interference power is fully contained within the occupied BW of the FS receiver
Constellation design	
GSO, non-GSO, Elliptical, hybrid, etc.	non-GSO
Number of satellites	10
Number of orbital planes	2
Number of satellites per orbital plane	5
Ascending Node separation between planes	180° +/- 0.5°
Phase between in-plane satellite	72° +/- 0.5°
Apogee of each orbital plane	16,733 km
Perigee of each orbital plane	16,733 km
Inclination	45°
Frequency	2.1684 GHz
XMT antenna gain pattern	Isotropic (for simplification)
Maximum XMT power	Maximum EIRP = Transmit power (dB) + Maximum Gain (dB) = 34.3 dBW.
XMT power model	Constant EIRP at 34.3 dBW
Total XMT losses (other than propagation)	0 dB

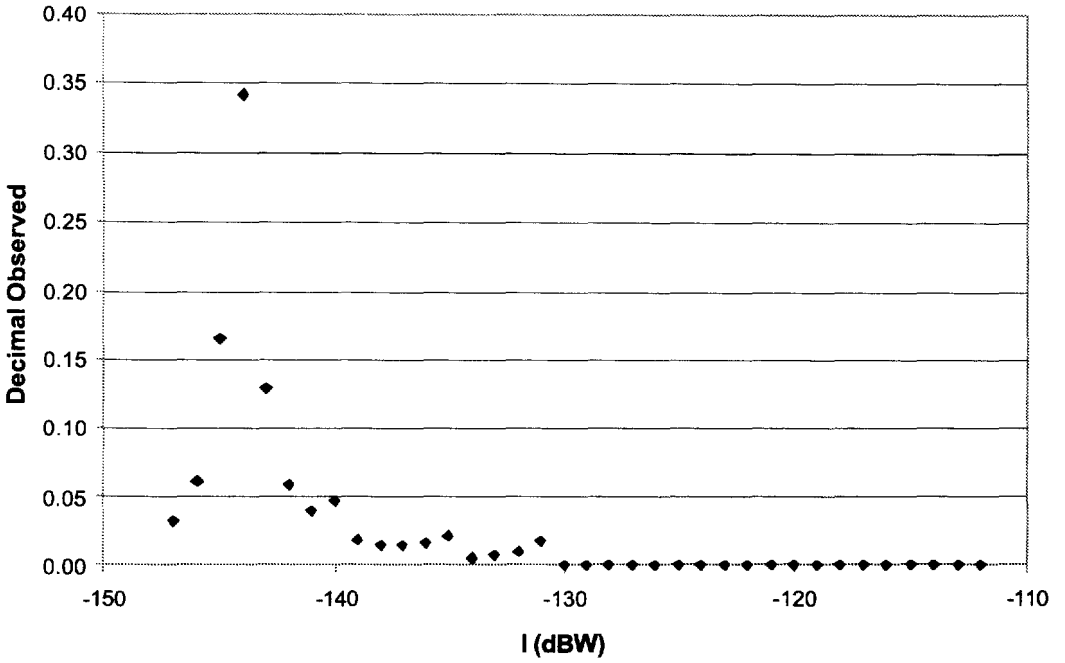

Figure 6-1: PDF of the MSS Interference Power, I, for Example A

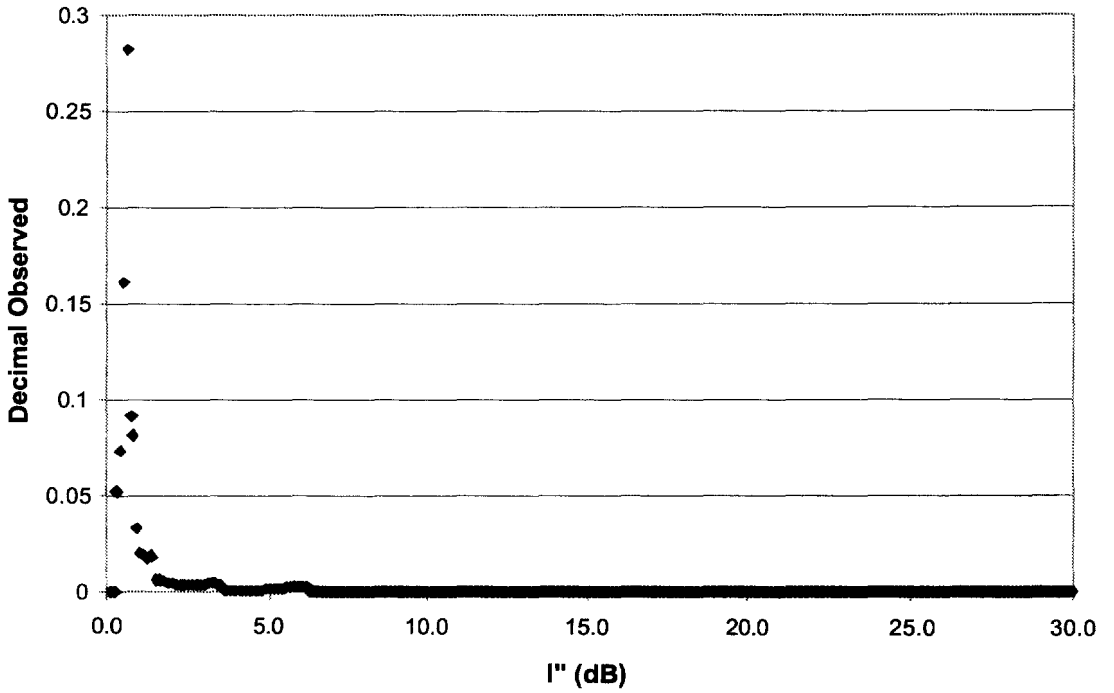

Figure 6-2: PDF of the Variable I" For Example A

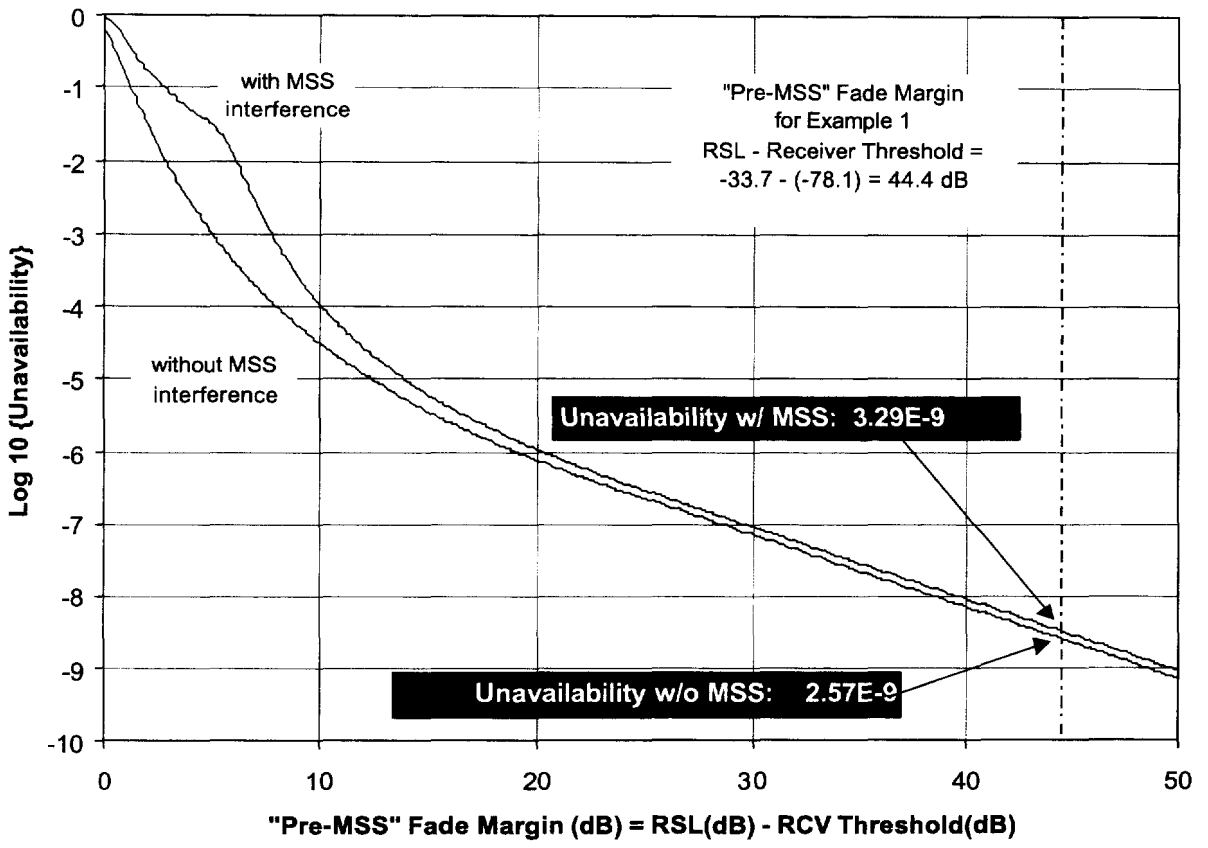

Figure 6-3: FS Performance Results for Example A