2. Typical System Characteristics

2.1 Introduction

This section summarizes the characteristics of fixed service point-to-point systems (both analog and digital) and mobile satellite systems in the 2.110-2.200 GHz bands.

2.2 Fixed Service System Characterization in the 2.11 - 2.20 GHz Frequency Band.

The 2110-2150/2160-2200 MHz frequency range is currently used by two separate services. These services are Common Carrier (CC) (formerly Part 21) users, and Private Operational Fixed Service (POFS) (formerly Part 94) users (CFR Part 101). The frequency band allocations and channel bandwidths are as follows:

Frequency Range (GHz)	Bandwidth	Users
2.11-2.13 & 2.16-2.18	3.5/3.6 MHz	CC
2.13-2.15 & 2.18-2.20	0.8/1.6 MHz	POFS

The CC users are primarily cellular radio providers who are using the microwave radios for cell site interconnection. There are a few Common Carrier telephone companies that also use 2 GHz microwave radios for low capacity needs in their networks. The microwave radios in the Common Carrier bands are primarily digital radios with capacities of 2-, 4-, 8-, and 12-DS1s.

The 2.1 GHz POFS band encompasses a large variety of different users and applications. State and local governments (including public safety), railroads, pipelines, and electric utilities are the majority of the users. There are also some corporate networks utilizing microwave radios in this band. The microwave radios used in the Private bands are primarily analog radios, though many of these analog radios employ digital modems with modulation complexities of up to 256 QAM to provide data traffic over the analog network. These analog radios have capacities ranging from 24 to 96 voice channels.

2.2.1 Characteristics of Analog Radios in the 2.1 GHz band.

Table 2-1 summarizes the most commonly used analog radios in the 2.1 GHz POFS band.

Table 2-1 Commonly used radios in the 2.13-2.15 and 2.18 - 2.20 GHz (private) band

Radio Model	Voice Channel Capacity & Bandwidth (MHz)	Transmit Power (dBm)	Receive Threshold (dBm)	Critical C/I (dB)	Modulation	Usage %
Granger						
HR2.1	96 (1.6)	33	-88	18	FM/FDM	0.7
Harris						
LR1-2	48 (0.8)	29/36	-87.5	16	FM/FDM	14.4
LR1-2	96 (1.6)	29/36	-87	17	FM/FDM	12.4
TR2000-R	24 (0.8)	33	-88	14	FM/FDM	1.5
Lenkurt						
70F1	48 (0.8)	30	-89	11	FM/FDM	1.7
70F2	96 (1.6)	30	-87	12	FM/FDM	2.0
70F3	96 (1.6)	30	-88	13	FM/FDM	1.4
Motorola						
CC6001	48 (0.8)	21/31	-88.5	13	FM/FDM	17.5
CC6001	96 (1.6)	21/31	-87.5	18	FM/FDM	30.2
MA373	48 (0.8)	37	-83	20	FM/FDM	2.5
Western Multiplex						
HZB-12000	96 (1.6)	30/37	-88	14	FM/FDM	1.0

2.2.2 Characteristics of Digital Radios in the 2.1 GHz band.

Table 2-2 illustrates the wide variety of commonly used digital radios in the 2.1 GHz Common Carrier bands. This is not an all-inclusive list.

Table 2-2 Commonly used radios in the 2.11-2.13 and 2.16 - 2.18 GHz (common carrier) band

Radio Model	Channel Capacity	Transmit Power (dBm)	Receive Threshold (dBm)	Critical C/I (dB)	Modulation	Usage %
Alcatel						
MDR-5102	12 T1	28/30/32*	-72.5	33	256 QAM	5.5
MDR-5202	8 T1	30/32/35*	-80	26.6	64 QAM	4.7
MDR-5302	4 T1	30/32/35*	-83	26.6	64 QAM	6.6
Tadiran						
DR2C	4 T1	20/27/32	-86	16	QPR-3	5.4
DR2L	4 T1	20/27/31	-88	18	QPR-3	3.8
DR2D	8 T1	20/23/29.5 /32	-78	22	QPR-7	18.1
2G-4DS1	4 T1	24/30**	-87.5	18.3	8 QAM	4.5
2G-8DS1	8 T1	24/30**	-82.5	24.5	32 QAM	2.8
2G-12DS1	12 T1	21/27**	-75.5	30.3	128 QAM	2.8
Harris						
DM2-3A-6	4 T1	21/29	-84	14	9 QPRS	5.7
DM2-4A-12	8 T1	33	-80	21	16 QAM	2.4
DVM2-8T	8 T1	21/29	-77.5	24.6	49 QPRS	16.4

Notes:

1. The multiple power levels shown in the 3rd column are the different output full-power options.
2. Non-starred (*) power levels do not have ATPC capability in this frequency band.

* All Alcatel radios have ATPC capability,

** These Tadiran radios only operate under ATPC.

As shown in Table 2-2, many digital radios shown above can operate under ATPC (Automatic Transmit Power Control), although the degree to which this option is implemented has not been studied. In systems implementing ATPC, the radios are backed-off from their maximum transmit power by 6-10 dB minimum (ATPC-equipped Tadiran radios are backed off 6 dB, Alcatel radios are backed off 10 dB). Radios using ATPC are operating at a C/N level that is less than that associated with operation of the transmitter at a constant, peak power level. Under ATPC conditions, transmitter power is increased when the desired signal fades to some predetermined fade depth. For Alcatel radios, the transmitter

power begins to increase linearly with fade depth when the far-end receivers fade below -65 dBm. The ATPC-equipped Tadiran radios increase their power in a single step when their far-end receivers fade to wthin 15 dB of receive threshold and the BER is 10^{-11}. In all cases, whether the path was coordinated under ATPC rules or not, the users may be using ATPC since its implementation reduces radio power consumption, thereby both enhancing equipment reliability and reducing air conditioning and battery plant requirements.

The 2.1 GHz band has been extremely popular for cellular users because it was the only low-capacity band available before the release of FCC Part 101. Additionally, since there are no FCC antenna performance requirements below 2.5 GHz, these FS sites tend to employ low wind resistance monopole towers instead of more expensive guyed towers. Grid antennas as small as four feet in diameter are in use. The table below shows the characteristics of some of the grid antennas used in this band.

Diameter	Gain	Beamwidth	Cross-Polarization Discrimination	Front-to-Back Ratio
4 ft	26.1 dB	8.1 deg	32 dB	34 dB
6 ft	29.9 dB	4.9 deg	34 dB	39 dB
8 ft	32.2 dB	4.0 deg	37 dB	40 dB

High-performance antennas have the same gain and beamwidth values, but they have 23-25 dB better front-to-back ratios.

2.3 Mobile-Satellite Service System Characteristics

A number of MSS systems have been proposed to provide data and telephony services in the 2 GHz bands, as shown in Table 2-3. Table 2-3 provides representative MSS system characteristics which have been extracted from the license applications. In some cases, specific values are still being finalized and could be subject to change pending ongoing FCC processes. The specific MSS system operator should be contacted to determine the actual (updated) required operational parameters.

All of the systems, except for the Boeing MSS system, are being developed to provide services to terrestrial-based mobile and portable terminals. The Boeing MSS system is being developed to provide aeronautical communications, navigation, and surveillance services for global avionics. Thus, for the Boeing MSS system, the user terminal would be located on an aircraft.

As shown in Table 2-3, the proposed MSS systems comprise a wide spectrum of constellation designs, including both GSO and non-GSO configurations. In the case of the Ellipso 2G system, elliptical orbits have been proposed. All of the MSS systems employ multiple beam-type antennas having up to several hundred beams. The antenna polarizations used in any given MSS system are exclusively circular (depolarization due to signal propagation phenomena prevents the use of linear polarization or both circular polarizations). A variety of multiple access schemes have been proposed

including time division multiple access (TDMA), code division multiple access (CDMA), frequency division multiple access (FDMA) and multiple combinations.

Mobile satellite systems operating in the 1-3 GHz range must share the available spectrum with a number of other MSS systems. In order to efficiently use the limited resource, MSS systems are designed to re-use the frequency spectrum by employing mulitple beam satellite antennas. Frequency re-use is achieved by assigning the same frequencies (or frequency blocks) to several spot beams in a cellular frequency assignment scheme. Any two co-frequency spot beams must have sufficient isolation to ensure an adequate carrier-to-interference ratio. An example of a multiple-beam satellite antenna, employing a four-cell frequency re-use scheme is shown in Annex K.

Table 2-3: Representative Mobile Satellite Service (MSS) System Characteristics

Category	Parameters	Iridium (Macrocell)	Globalstar (GS-2)	ICO	Boeing (Note 2)
Constellation	Orbit	Circular	Circular	Circular	Circular
	Inclination	98.8°	54° for non-GSO	45°	53°
	# Satellites	96	64 non-GSO; 4 GSO – preferably 80° W, 10°E, 100° E and 170°W	10 to 12	16
	# Planes	8	8 for non-GSO	2	16
	Satellite Separation	30°		60° for 12 satellite configuration; 72° for 10 sat configuration	N/A
	Altitude (km)	850 (nom)	1420 for non-GSO, 35750 (nom) for GSO	10,355	20,181
Space Station Design	Antenna Type	Multiple Beam Antenna	Multiple Beam Antenna	Multiple Beam Antenna	Multiple Beam Antenna
	# Beams	228	non-GSO: 96 GSO: 64	163	37
	Polarization	RHCP	LHCP	RHCP	RHCP and LHCP
User Terminal Design (Note 3)	Antenna Type	Non-Directional	Non-Directional	Non-Directional	Non-Directional
	Receive G/T (dB/K)	-24.8	-24.5 (derived)	-23.8	ATN: -17.55 (derived) TIS: -19.3
S-E Service Link Parameters	Access Scheme	Data: CDMA/FDMA Voice: TDMA/FDMA	CDMA/FDMA & TDMA/FDMA	TDMA/FDMA	ATN: CDMA TIS: TDMA/FDMA
	Frequency (GHz)	Uplink: 1.990 – 2.025 Dnlink: 2.165 – 2.200	Uplink: 1.990 – 2.025 Dnlink: 2.165 – 2.200	Uplink: 1.985 – 2.015 Dnlink: 2.170 – 2.200	Uplink: 1.990 – 1.99825 Dnlink: 2.170 – 2.17825
	Modulation	QPSK	QPSK	QPSK	ATN: Same as IS-95A TIS: QPSK

Table 2-3 (Continued): Representative Mobile Satellite Service (MSS) System Characteristics

Category	Parameters	MCHI (Ellipso 2G)	Constellation II	CELSAT	TMI (CANSAT-M3)
Constellation	Orbit	Circular and Elliptical	Circular	Circular	Circular
	Inclination	(Note 1)	62° for 7 planes of 5 satellites each, Equatorial for 1 plane of 11 satellites	GSO	GSO
	# Satellites	26	46	1 (Initial) 3 (Total - Future); #1: 90° - 100° W, #2: 65° - 75° W, #3: 110° - 120° W	1; 106° - 112° W with 106.5° W preferred
	# Planes	5 (4 elliptical and 1 circular)	8	1	1
	Satellite Separation	(Note 1)		Longitudinal spread > 21°	N/A
	Altitude (km)	(Note 1)	2035 for 62° planes, 1965 for equatorial plane	35,750 (nom)	35,750 (nom)
Space Station Design	Antenna Type	Multiple Beam Antenna	Multiple Beam Antenna	Multiple Beam Antenna	Multiple Beam Antenna
	# Beams	127	32	480	72
	Polarization	Circular	RHCP	RHCP	RHCP
User Terminal Design	Antenna Type	Non-Directional	Non-Directional	Non-Directional	Non-Directional
	Receive G/T (dB/K)	Handheld: -25.4 Transportable: -14.0	-22.1	-26	-10 to -24
S-E Service Link Parameters	Access Scheme	FDMA/CDMA	CDMA	CDMA & TDMA	CDMA & SCPC/FDMA
	Frequency (GHz)	Uplink: 1.990 – 2.025 Dnlink: 2.165 – 2.200	Uplink: 1.980 – 2.025 Dnlink: 2.165 – 2.200	Uplink: 1.990 – 2.025 Dnlink: 2.165 – 2.200	Uplink: 1.990 – 2.025 Dnlink: 2.160 – 2.200
	Modulation	Data: BPSK Spread: QPSK & Offset QPSK	Offset QPSK		QPSK

Table 2-3 (Concluded): Representative Mobile Satellite Service (MSS) System Characteristics

Category	Parameters	Inmarsat (Horizons)
Constellation	Orbit	Circular
	Inclination	GSO
	# Satellites	4; #1: 20° E, #2: 110° E, #3: 170° W, #4: 90° W
	# Planes	1
	Satellite Separation	Function of which satellites considered
	Altitude (Km)	35,750 (nom)
Space Station Design	Antenna Type	Multiple Beam Antenna
	# Beams	120 to 300
	Polarization	LHCP
User Terminal Design	Antenna Type	Directional and Non-Directional
	Receive G/T (dB/K)	-16 to -6
S-E Service Link Parameters	Access Scheme	TDMA
	Frequency (GHz)	Uplink: 1.980 – 2.025 Downlink: 2.160 – 2.200
	Modulation	

(1) Borealis – 2G
3 planes (all Elliptical)

5 satellites/plane

Elliptical (Apog: 7513.4 km, Perig: 674.3 km; Inc: 116.6°)

Spacing: 72°

Concordia – 2G
2 planes (1 Elliptical and 1 Circular)

5 satellites in elliptical plane; 6 satellites in circular plane

Elliptical (Apog: 7975.7 km, Perig: 4285.6 km; Inc: Equatorial)

Circular (Alt: 7747.3 km)

Spacing: 72° (Elliptical), 60° (Circular)

(2) The Boeing MSS system is proposed to be used for the provision of communications, navigation, and surveillance services for global avionics commonly referred to as Aeronautical Mobile-Satellite (Route) Services. In this context, ATN refers to the Aeronautical Telecommunications Network and TIS refers to Traffic Information Services. ATN supports two-way communications while TIS is only a one-way, ground-to-satellite-aircraft broadcast link.

(3) The user terminal for the Boeing MSS system is an aircraft terminal.

3. Interference Criteria for MSS Downlink Interference into FS Receive Stations

TIA Bulletin TSB-10F (Interference Criteria for Microwave Systems) provides the interference criteria that are in use for frequency coordination within the fixed service in the US The implicit assumptions and level of detailed information that is built into the criteria of TSB-10F may not all be appropriate for sharing between MSS and FS systems. The objective of this section is to provide MSS/FS interference criteria at an equivalent level of performance protection to the fixed service while affording the maximum operational freedom to the mobile satellite service.

3.1 Background

A key characteristic of the interference from MSS satellites that must be accommodated is its time variability. The interference criteria in Bulletin TSB-10F were developed to address interfering signals with non-varying power. (Even in the case of an interferer using ATPC, coordination is conducted with these criteria by placing suitable requirements on the implementation of the power control.) This does not mean that the interfering signals from fixed service transmitters do not occur with time-varying levels at an interfered-with receiver, but rather, that the variations are independent of and less severe (milder) than the variations of the desired signal.

In the case of interference from non-GSO MSS satellites, there is a large component of variability in the received interference due to the regular motion of all the satellites in a uniform constellation. While these variations can be examined through computer simulation and modeling, heretofore there have been no appropriate US FS interference criteria to use as a measure of acceptability. In situations where the interference power is variable, the usual engineering practice has been to require conformance with both long-term and short-term interference criteria. Such an approach is taken in earth station coordination and in the ITU-R in sharing studies between the FS and the MSS. In this context, the interference criteria of Bulletin TSB-10F may be considered to be long-term criteria.

The long-term criteria are criteria that must be met by an interferer for all but 20 percent of the time. (While other percentages could be used, the 20 percent level has been used internationally by the fixed service for many years.) During the time that the interfering signal power exceeds the long-term criteria, it is expected to be statistically well behaved, and to exceed a threshold level significantly greater than the long-term level only very rarely. This higher interference threshold level is referred to as a short-term interference criterion and corresponds to a performance degradation not to be exceeded at the system level for more than some small percentage of time (typically much less than 1% of the time).

The following section provides the criteria that represent the maximum permissible levels of interference when coordinating MSS downlinks with respect to FS receiving stations.

3.2 Criteria for MSS Interference Into FS Receivers

The criteria for interference from MSS systems provided in the following sections are to be applied on a *per-link* basis, including multi-hop FS systems. Section 3.2.1 addresses MSS/FS interference criteria for analog FS links while section 3.2.2 addresses the interference criteria for digital FS links.

3.2.1 Analog Link Interference Criteria

For analog links, a further distinction is made between MSS-only interference noise power criteria and aggregate noise power criteria. As the name suggests, MSS-only interference noise power criteria applies to the additional interference noise power contribution that results from the MSS interfering signals. Aggregate noise power criteria, on the other hand, applies to the aggregate of thermal noise power and MSS interference noise power and takes into account multi-path fading and other sources of noise within the FS system.

Long- and short-term "MSS-only interference noise power" criteria are provided in Section 3.2.1.1 while long- and short-term "aggregate noise power" criteria are presented in Section 3.2.1.2.

3.2.1.1 Criteria for MSS-Only Interference Noise Power

The MSS-only interference noise power criteria for MSS/FS interference evaluations are shown pictorially in Figure 3-1. There are both long-term and short-term criteria that must be met. Recommended values for the long-term and short-term MSS-only interference noise power criteria are:

- Long Term[2]:

  X pW0p not to be exceeded for more than 20% of the time where X is defined as follows:

  a. For a FS route length greater than 400 km,

     X = 20 pW0p per 4 kHz at baseband

  b. For a FS route length less than or equal to 400 km (or for routes of unknown length)

     X = max {25, 250/n} pW0p per 4 kHz at baseband

[2] The long-term criterion of 20 pW0p for FS route lengths greater than 400 km was determined by linearly apportioning the 12-hop, 240 pW0p criteria identified in RR Appendix S5 (Resolution 46 (rev WRC-97), Annex 2) on a single-hop basis. The long-term criterion for FS routes less than or equal to 400 km was taken from Annex A of TSB-10F.

where n = number of hops

- Short Term: 50,000 pW0p per 4 kHz at baseband not to be exceeded for more than 0.0002% of the time

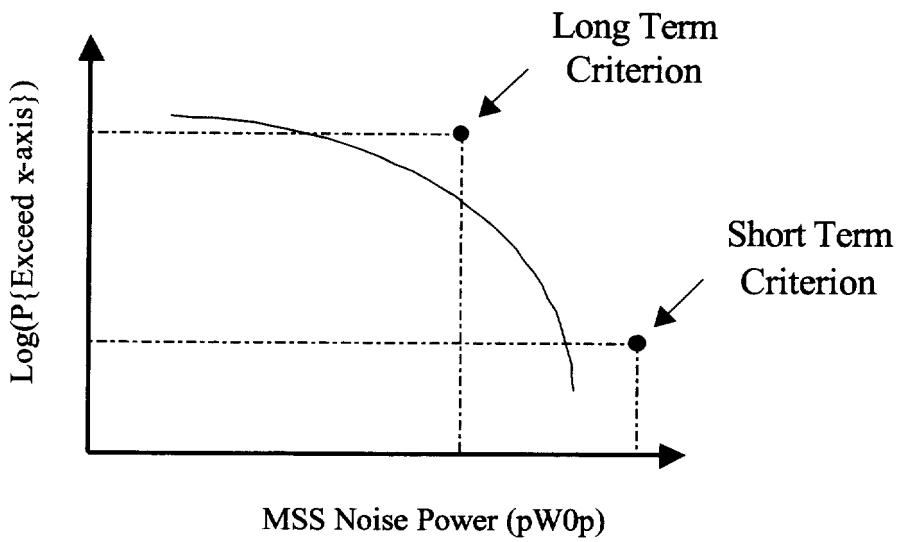

Figure 3-1 MSS-Only Interference Noise Power Criteria for Analog Links

3.2.1.2 Limits for Aggregate Noise Power

The aggregate noise power criteria for evaluations of MSS interference to an analog FS link are shown pictorially in Figure 3-2. As discussed further below, the three aggregate noise power thresholds (one long-term and two short-term thresholds) are assumed to exclude noise power generated by intermodulation within the FS system. The recommended values for the long-term and short-term aggregate noise power criteria are:

- Long Term: 150 pW0p per 4 kHz at baseband not to be exceeded for more than 20% of the time

- Short Term I: 50,000 pW0p per 4 kHz at baseband not to be exceeded for more than 0.002% of the time

- Short Term II: 1,000,000 pW0p per 4 kHz at baseband not to be exceeded for more than 0.0002% of the time

The long-term and short-term criteria were determined by linearly apportioning the 50-hop limits identified in Recommendation ITU-R F.393-4 on a single-hop basis. Specifically, for the long-term criterion, the power threshold of 7500 pW0p (ITU-R F.393-4) was divided by 50, yielding 150 pW0p, on a per-hop basis. For the short-term I and II criteria, the percentages of times (in ITU-R F.393-4) of 0.1% and 0.01% were divided by 50 to obtain 0.002% and 0.0002%, respectively.

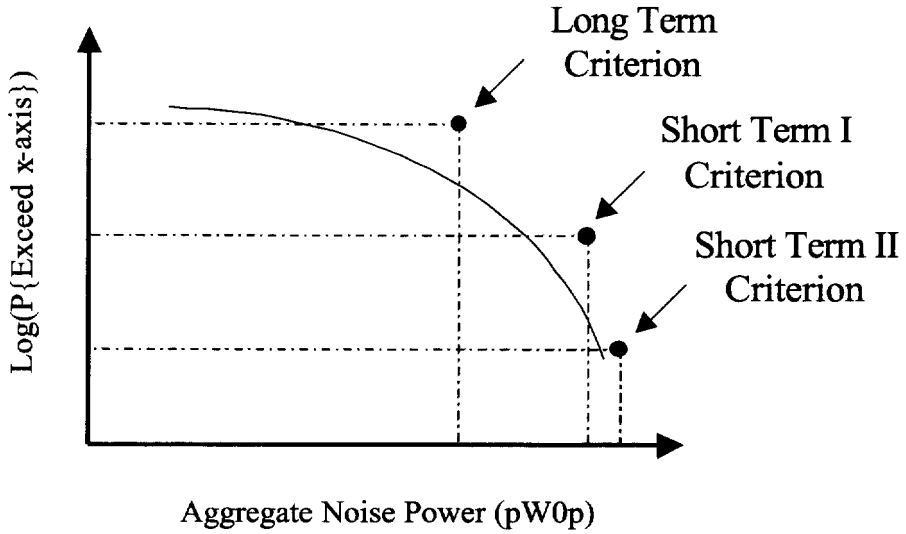

Figure 3-2 Aggregate Noise Power Criteria for Analog Links

Typically, a significant portion of the long-term aggregate noise power in the circuits at the terminating receiver of an analog FS system arises from intermodulation of desired signals within the FDM payload carried by the FS system.[3] However, inclusion of the intermodulation noise power component in calculations of the long-term aggregate noise power for an individual FS link would greatly complicate the analysis. Two approaches were considered for eliminating the need to calculate intermodulation noise power levels: (1) reduce the aggregate noise power threshold by a typical level of intermodulation noise power, or (2) assume the impact of intermodulation noise power contribution is offset by the shorter lengths of current systems. The latter approach was taken in setting these specified criteria. In particular, the aggregate noise power criterion of Recommendation ITU-R F.393-4 is specified for a reference hypothetical 2500 km FS system comprised of 50 hops. However, most analog 2 GHz FS systems have fewer than 50 hops, and it is assumed that the specified interference power can be applied equally to each of these. For comparison, a 12-hop reference system is assumed for assessing

[3] Intermodulation noise is assumed to comprise a negligible portion of the short-term aggregate noise power and need not be considered when applying the short-term criteria.

MSS interference into analog FS systems in Recommendation ITU-R IS.1143 and in Appendix S5 of the Radio Regulations.

3.2.2 Digital Link Interference Criteria

No specific numerical interference criteria have been developed in either the TIA or the ITU-R to specifically address short-term interference into digital receivers. The typical or default path design criteria for digital radios operating in this band is for a two-way path availability of 99.999%, although higher or lower levels are sought and achieved in practice. A potential difficulty with short-term interference levels lies in the possibility that if they are much higher than long-term levels, they could be strong enough to cause performance problems to a digital system even in the absence of any fading. Furthermore, only criteria pertaining to aggregate noise power are provided for digital links. Aggregate noise power in a digital FS system comprises thermal noise power and MSS interference noise power and takes into account multi-path fading.

The terms "link availability" and "link reliability" in an FS link are treated synonymously in this document; they are defined as the probability that the FS link fade depth will not exceed the link fade margin. Conversely, link "unavailability" is defined as the probability that the FS link fade depth will exceed the link fade margin, and it is simply 1 minus the link availability.

Using the definitions above, the digital link interference criteria are shown pictorially in Figure 3-3, in terms of a limit on link "unavailability" and mathematically as follows:

$$\text{"}post\text{-}MSS\text{" } Link\ Unavailability\ Limit = \max\left\{simple\ unavailability\ limit, \left(1+\frac{PDL}{100}\right)(\text{"}pre\text{-}MSS\text{" } Link\ Unavailability)\right\} \qquad 3\text{-}1$$

As shown in Figure 3-3, the criteria comprise two regions referred to as the *simple unavailability region* and the *performance degradation region*, respectively. The threshold in the *simple unavailability region* takes the form of a *simple unavailability limit* that must be achieved for an FS link in the presence of MSS interference. It is applicable to FS links having an inherent or "pre-MSS" unavailability level (i.e., no MSS interference) better (i.e., smaller) than the cut over point identified in Figure 3-3 (i.e., to the left of the cut over point)[4]. For example, if an FS link were operating at an inherent unavailability level of 10^{-6} and the *simple unavailability limit* was set at 10^{-5} (corresponding to

[4] The use of a cut over value in Figure 3-3 is needed to account for sharing in situations in which the pre-MSS FS link unavailability level is very close to the *simple unavailability limit*.

a "reliability" of 0.99999), then the FS link unavailability in the presence of MSS interference is limited to a maximum level equal to the *simple unavailability limit* of 10^{-5}.

The threshold in the *performance degradation region* takes the form of a maximum percentage of FS availability degradation, referred to as the *performance degradation limit* (PDL), that the MSS interference is allowed to cause to the FS link . Specifically, the PDL is specified as the percentage increase in unavailability due to MSS interference. The *performance degradation region* is applicable to FS links having an inherent link unavailability equal to or worse than the cut over point identified in Figure 3-3 (i.e., equal to or to the right of the cut over point). For example, if an FS link were operating at an inherent unavailability level of 10^{-4} (corresponding to a "reliability" level of 0.9999) and the *simple unavailability* and *performance degradation limits* were set at 10^{-5} and 25%, respectively, then the FS link unavailability in the presence of MSS interference is limited to a maximum level of 1.25×10^{-4}. For this example, the maximum unavailability level was calculated as follows:

$$\text{Maximum unavailability level} = (1 + \text{PDL}/100)(10^{-4}) = 1.25 \times 10^{-4} \qquad 3\text{-}2$$

where the PDL is given as a percentage. This example corresponds to a minimum link reliability level of 0.999875.

Recommended values for the *simple unavailability* and *performance degradation limits* are[5]:

- $(5x10^{-5})/n$ *simple unavailability limit* where "n" is the number of hops in the end-to-end system (corresponds to an end-to-end reliability of 0.99995). For system lengths less than or equal to 400 km, the *simple unavailability limit* is relaxed to 10^{-5}.

  Example 1: For a 400-km system having 10 hops, the per-hop *simple unavailability limit* would be the relaxed value of 10^{-5} (corresponds to a per-hop reliability of 0.99999).

  Example 2: For a 1,200-km system length having 30 hops, the per-hop *simple unavailability limit* would be $(5x10^{-5})/30$ or $1.667x10^{-6}$ (corresponds to a per-hop reliability of 0.9999983).

- 25% for the *performance degradation limit, assuming an I/N ratio of less than or equal to 20 dB.*

[5] The approach for calculating the *simple unavailability limit* is consistent with section 4.2.2 of Bulletin TSB-10F.

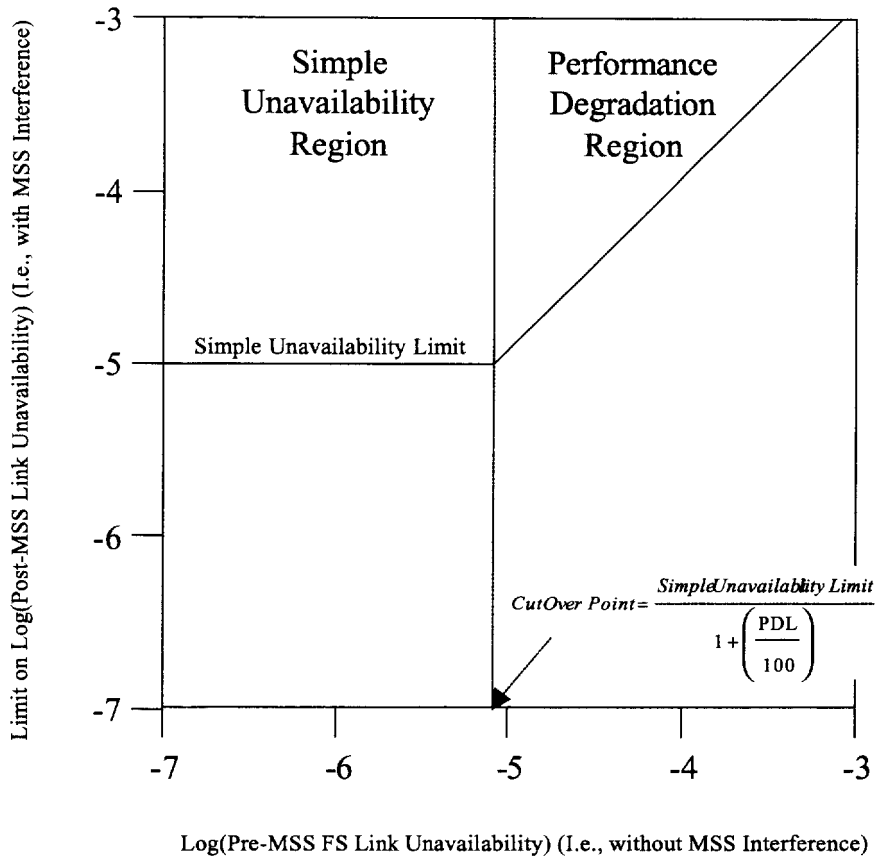

Figure 3-3 Aggregate Noise Power Interference Criteria for Digital Links

3.3 Multiple Exposure Allowance for Multiple MSS Systems

The interference criteria presented in this chapter for the "aggregate noise power" cases were derived assuming that only one MSS system is producing interference at the FS receiver. In some cases, however, an FS system may receive interference from more than one MSS system. This section explains how to deal with such situations. It should be noted that the method given here assumes that all MSS assignments are known. Thus, if an MSS system has been coordinated based on an assumed MSS band plan, and that band plan subsequently changes (for example, by the introduction of a new MSS system), the previously coordinated systems may have to be re-coordinated.

3.3.1 Multiple Interference Scenarios

There are basically three scenarios where a particular FS receiver channel may experience interference from two or more MSS systems.

Scenario 1: several MSS systems operate on a co-frequency, co-coverage basis. This might occur only for CDMA systems, which may in any case be designed to operate at PFD levels lower than the PFD thresholds for coordination.[6]

Scenario 2: the bandwidth of an FS receiver straddles the non-overlapping, assigned bands of two MSS systems, as shown in Figure 3-4.

Scenario 3: a combination of the two above scenarios.

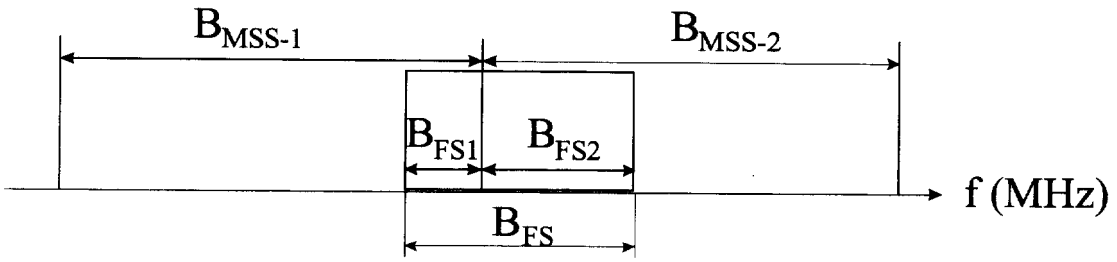

Figure 3-4 Multiple interference to an FS receiver from two MSS systems in adjacent bands.

3.3.2 MEA Alternative Methods of Computation

Three theoretical methods have been considered for taking multiple interference exposures into account.

Method 1: include all relevant MSS systems in the interference calculation methodology.

Method 2: apportion the criteria between all relevant MSS systems (and do the calculation for each MSS system separately).

Method 3: "inflate" the MSS interference power to account for the existence of multiple interfering MSS systems.

As the coordination procedure assumes a bilateral negotiation process between one MSS operator and FS operators, the interference calculation methodology in this TSB has been developed for a single MSS system. Thus, Methods 2 and 3 are the only possible ones.

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[6] Studies have shown that up to four MSS systems using CDMA can share the same frequencies under ideal circumstances (e.g., all such systems operating at about the same PFD level). In other bands, however, CDMA systems operate at PFD levels below the coordination threshold (e.g., 2483.5 – 2500.0 MHz). Studies have also shown that non-CDMA MSS systems (e.g., TDMA systems) *cannot* operate with overlapping coverage areas on the same frequencies as other MSS systems---either other TDMA or even CDMA systems.

Method 3 is similar to Method 2, but instead of apportioning the criteria, the actual interference is appropriately inflated to account for multiple systems. If the end results of the MSS interference analysis (i.e., the quantity that is directly compared to the criteria), then the effect of scaling that quantity up (Method 3) would be the same as scaling the criteria down (Method 2). However, by scaling the interference power upward, the adjustment is performed at a different point in the analysis (except in the case of the MSS-only analysis for analog FS receivers, where the final result of the analysis *is* the interference power). FS system noise should *not* be scaled, of course. In contrast, in Method 2, the FS noise would actually be counted multiple times (once for each MSS system being coordinated). Thus, Method 3 most accurately takes multiple interference into account and *is the recommended approach in this TSB.*

Scaling of the MSS interference power is done most simply by shifting the power scale of the PDF of interference. A more refined method is to convolve the interference PDF with itself (N-1) times, where N is the number of systems. This approach is analytically correct, assuming independence of the systems, and it causes the low-probability part of the curve to be shifted in probability--which is what would be expected with multiple interferers. Both these approaches may be used for different parts of the recommended MEA procedure given in the next section.

3.3.3 Recommended MEA Procedure (Based on Method 3)

MSS systems sharing *the same* band (Scenario 1) are given equal interference allowances. It is necessary to allocate the interference between MSS systems using *adjacent band* segments (Scenario 2) in proportion to the overlap of the segment with the FS radio-frequency channel. The generic scenario (Scenario 3) can be dealt with by combining these two principles, which gives rise to the following step-by-step procedure:

Step No.

1. For an MSS system operating in the band $B_{MSS\text{-}X}$, reduce the power scale of the original MSS interference PDF by the factor: (B_{FS}/B_{FSx}), where B_{FS} is the FS receiver bandwidth (MHz) and B_{FSx} is the amount by which the MSS system frequency assignment overlaps the same FS RF receiver bandwidth (MHz). See Figure 3-4.

2. Convolve the new interference PDF derived in the previous step with itself (N-1) times, where N is the number of co-frequency MSS systems in the band, B_{FSx}.

3. Run the methodology in Section 4 for the "aggregate noise power" calculations with the new interference PDF.

4. Compare the results with the criteria in Section 3.2.

4. Interference Evaluation Methodologies to be Applied in Evaluating MSS Downlink Interference into FS Receive Stations

Diagrams describing the interference evaluation methodologies to be used in evaluating the impact of MSS downlink interference into analog and non-ATPC digital[7] FS receive stations are shown in Figures 4-1a and 4-1b. The roadmap identifies the three "areas" that comprise the overall evaluation methodology and the applicable sections in this TSB: (1) inputs; (2) analysis and (3) comparison.

There are two "simple" analysis methods to apply in order to determine whether or not there is a need to perform more detailed interference calculations. For analog FS links the simple method is referred to as a Power Flux Density (PFD) calculation, and for digital FS links the simple method is referred to as a Fractional Degradation of Performance (FDP) calculation; both are identified in boxes at the top of Figures 4-1a and 4-1b. These simpler, initial analysis methods are the same as those used internationally to determine the need to coordinate MSS networks with FS assignments in the 2 GHz frequency bands, and they are described in the ITU Radio Regulations Appendix S5 and Recommendation ITU-R IS.1143.

As noted in Figure 4-1b for digital systems, the FDP calculation is performed in two, distinct stages. In the first stage, *representative* FS system parameters from ITU-R IS.1143 are used to evaluate whether or not the FDP criteria of RR Appendix S5 are met. For those cases in which the FDP criteria are not met, the FDP calculation is repeated in a second stage, this time using the *actual* FS system parameters.

If the PFD criteria are not met for FS analog links using *representative* FS system parameters, then a more detailed interference analysis is necessary. The initial detailed calculations involve MSS-only calculations as shown on Figure 4-1a. As noted in that figure, the MSS-only calculation is performed in two distinct stages similar to the FDP calculation described above. In the first stage, *representative* FS system parameters from RR Appendix S5 are used to evaluate whether or not the MSS-only criteria of Section 3.2.1.1 are met. For those cases in which the MSS-only criteria of Section 3.2.1.1 are not met, the MSS-only calculation is repeated in a second stage, this time using the actual FS system parameters.
As shown in Figures 4-1a and 4-1b for both FS analog and digital links, respectively, the next analysis stage, if required, is to perform one of two detailed analyses which are applicable for "aggregate noise

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[7] It is important to note that the number of digital radios operating under ATPC conditions can be significant. As shown in Table 2-2 (Section 2.2.2), approximately 10% of the radios in service are Tadiran radios which only operate under ATPC regardless of whether or not they are coordinated this way. Approximately 17% of the radios in service are Alcatel radios which have ATPC capability built-in; and, *may* be operating under ATPC regardless of whether or not they are coordinated this way.

power" calculations. These two analytical methods are referred to as the *convolution approach* and the *Monte Carlo approach*.

The *convolution approach* is a combination simulation and analysis approach. It involves simulation of the MSS space segment in order to determine probability density function (PDF) data for the received MSS interfering signal power as a function of azimuth angle and antenna size. The link performance is then calculated analytically using a convolution to account for the variation in MSS receive interference power and multi-path fading. The *Monte Carlo approach* involves a full simulation to characterize both the MSS space segment and multi-path fading. Both approaches should result in equivalent performance data; however, the *convolution approach* precludes the need for developing a Monte Carlo-type simulation to address multi-path fading and the resulting computer processing time required to run the Monte Carlo simulation.

The FS link performance data generated via the above detailed methods are then compared to the appropriate "aggregate noise power" criteria described in Section 3.1.2.1 (analog links) or 3.2.2 (digital links). If the interference criteria are met, the evaluation is complete. If the evaluation criteria are not met, further analysis and/or negotiation is required.

The input, analysis and comparison areas identified in Figures 4-1a and 4-1b are more fully discussed below.

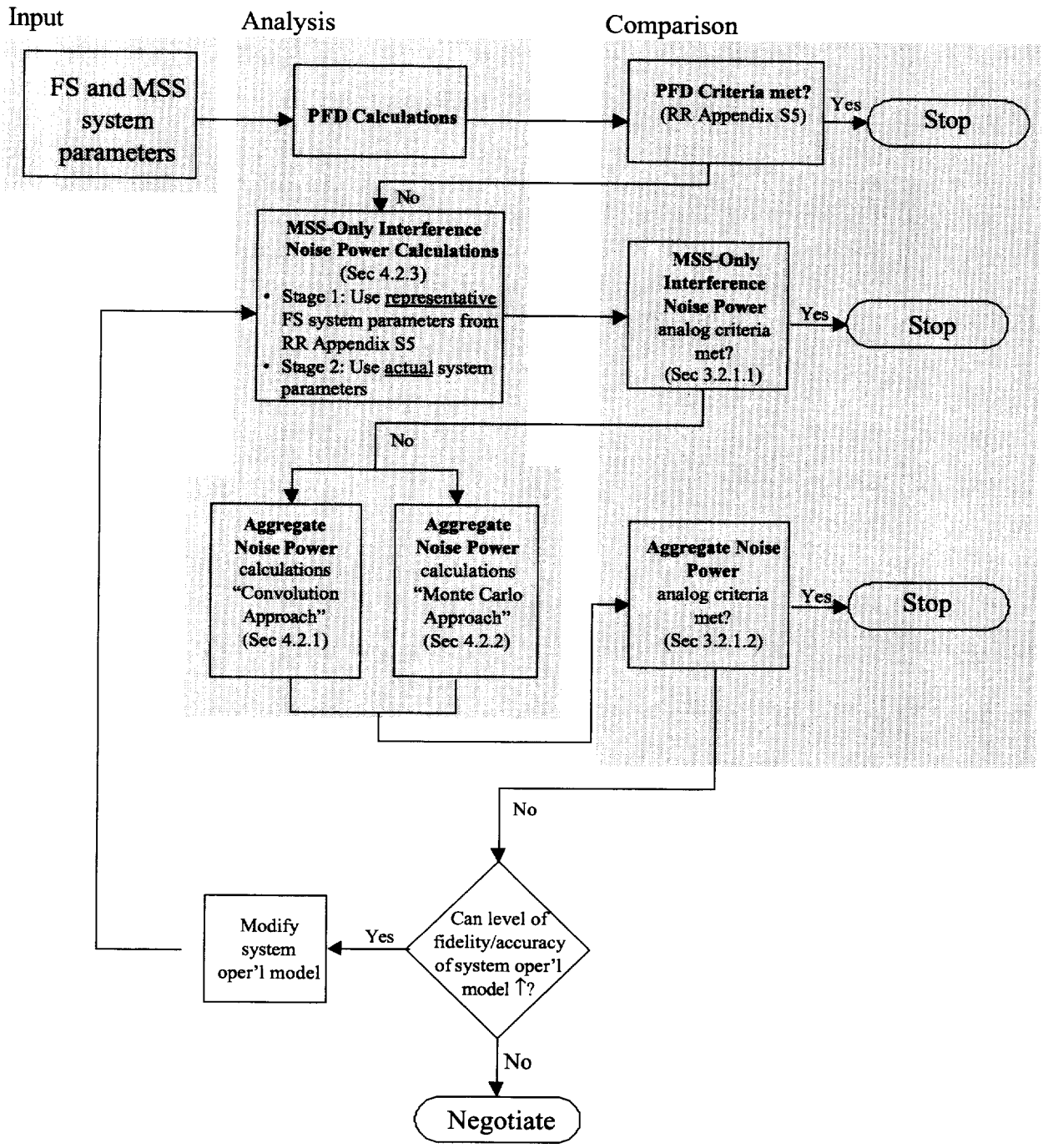

Figure 4-1a: Road Map of the MSS/FS Interference Evaluation Methodologies for Analog Links

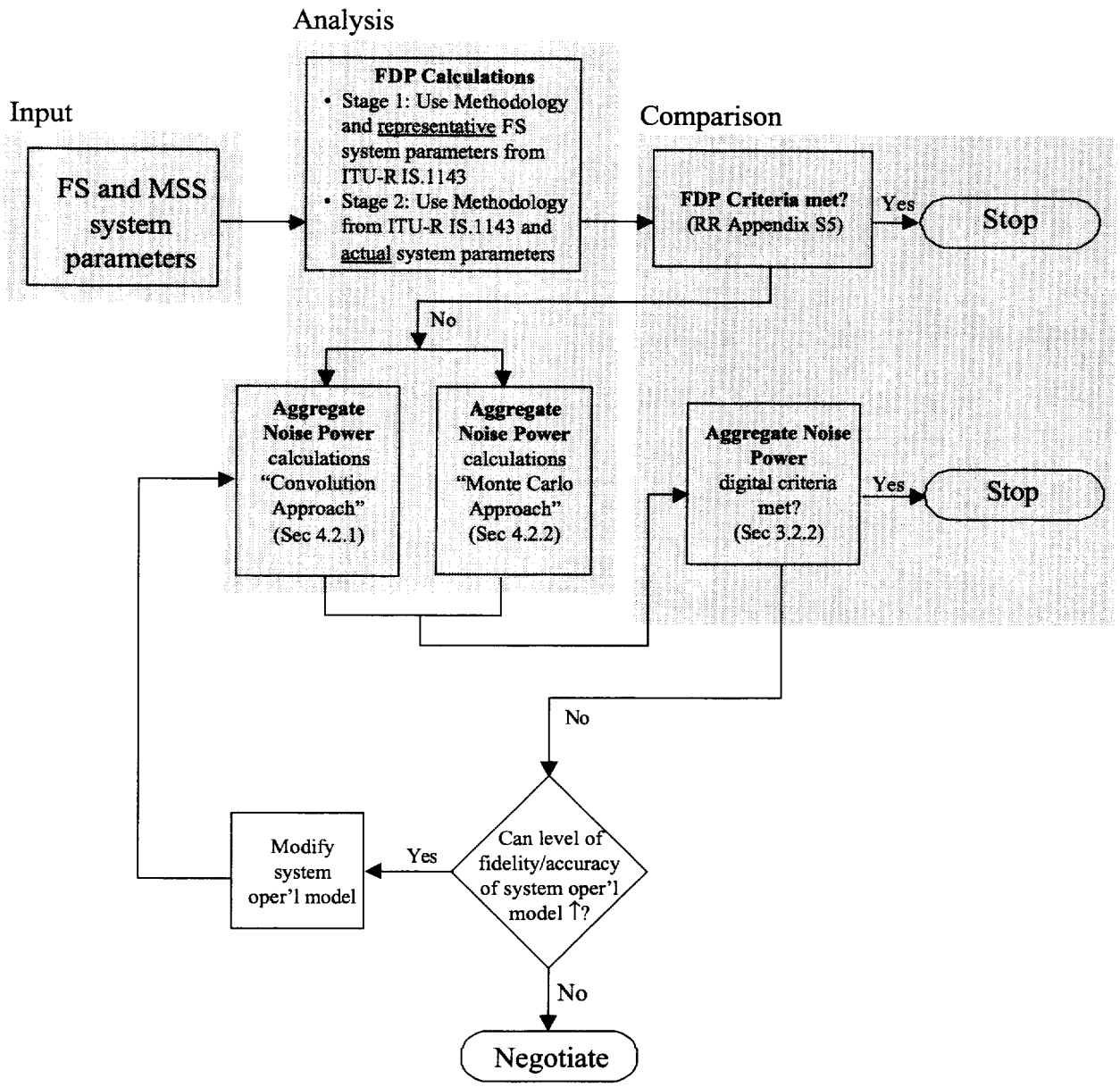

Figure 4-1b: Road Map of the MSS/FS Interference Evaluation Methodologies for Digital Links

4.1 Analysis Inputs

The interference evaluation methodology to be used in assessing the potential impact of MSS downlink interference into FS receive stations requires input data characterizing various aspects of both the MSS systems and the FS system being coordinated.

FS System The required FS system input data includes the path design parameters. Examples of these items include receiving antenna heights, gains, and gain pattern characteristics, receiver equipment characteristics, terminal location, path length and azimuth angle, operating frequency, etc. These parameters may be obtained from the FS system providers, equipment vendors and/or existing FS microwave databases. Annex H includes a list of the required FS system parameters.

Note that the actual or predicted FS antenna patterns and equipment characteristics must be used whenever possible. In the absence of actual or predicted antenna patterns, the reference antenna pattern in Recommendation ITU-R F.1245, Recommendation ITU-R F.699, or Annex B should be used. (Note: Annex B also includes an adjustment for different antenna polarization schemes for MSS satellite systems and FS receive systems.)

MSS System

The required MSS system input data includes information characterizing the MSS space segment and certain system operational parameters.

Data characterizing the levels of MSS interference power is needed that accounts for the receive antenna pattern, azimuth angle and latitude/longitude, of the FS receiver being considered. For digital FS links, the MSS interference power is calculated over the RF bandwidth of the FS receiver, whereas for analog FS links the MSS interference power is calculated over the 4-kHz bandwidth of the channel being investigated. This data is commonly expressed in the form of a probability density function (PDF).

For the *convolution approach* analysis method described in Section 4.2.1, the PDF of the MSS interference power will either be provided directly by the MSS system operators or it will be generated using the MSS system orbital characteristics, the MSS traffic model, FS receiver antenna and equipment characteristics, etc. For the *Monte Carlo approach* analysis method described in Section 4.2.2, the PDF of the MSS interference power are generated and applied internally as a part of the overall simulation.
Annex H includes a list of the required MSS system parameters. Modifications to the MSS input parameters may result in the need for re-coordination (i.e., if the potential levels of interference are increased). Note that the actual or predicted FS antenna patterns should be used whenever possible. In the absence of actual or predicted antenna patterns, the reference antenna pattern in Recommendation ITU-R F.1245, Recommendation ITU-R F.699, or Annex B should be used. The methods described in Recommendation ITU-R F.1108, or similar methods, should be used to determine the visibility statistics of MSS space stations as seen by a terrestrial FS receiver station. The method of Recommendation ITU-RF.1108 has been included in Annex E.

4.2 Analysis Area

As previously stated, there are three primary analysis methods presented in this TSB: (1) Aggregate noise: Convolution Approach, (2) Aggregate noise: Monte Carlo Approach, and (3) MSS-only

Interference Noise Power. The details for each of these analysis methods are presented in sections 4.2.1, 4.2.2, and 4.2.3, respectively.

4.2.1 Aggregate Noise Power: Convolution Approach

The *convolution approach* analysis method to be used in evaluating FS link performance in the presence of MSS downlink interference on an "aggregate noise" basis comprises the three steps described below.

4.2.1.1 Step 1: Quantify Baseline FS Link Performance without MSS Interference

In this step, the baseline FS link performance is quantified in a multipath fading environment without the presence of MSS interference. An equation is derived that generates the probability that a given fade value, in dB, exceeds the link margin.

In general, we want to calculate the probability that the received signal-to-noise ratio (SNR) for a given link[8] is less than the required SNR:

$$P\{SNR_{rcv} < SNR_{req}\} \qquad 4\text{-}1$$

SNR_{req} represents the signal-to-noise ratio required at the receiver on a given link to ensure a desired level of performance. SNR_{rcv} is a random variable that represents the actual received signal-to-noise ratio at the receiver, taking into consideration random multi-path fading. Its value is derived as follows:

$$SNR_{rcv} = \frac{SNR_{link}}{A} = \frac{C/N}{A} = \frac{P_t G_t G_r / NL_p}{A} \qquad 4\text{-}2$$

where:

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[8] For the purposes of this analysis, the terms "path" and "link" are used interchangeably. There is no difference in the meaning of the terms. However, it is noted that in the engineering literature, the power margin above a specific SNR threshold on a specific microwave link or path is usually referred to as "link margin" rather than "path margin." Nevertheless, is convenient to use both terms throughout the discussion within TSB-86.

C/N	=	Carrier-to-Noise power ratio (unitless)
N	=	Noise Power (Watts)
P_t	=	Transmit Power (Watts)
G_t	=	Transmit Gain (unitless)
G_r	=	Receive Gain (unitless)
L_p	=	Path Loss (unitless)
A	=	A variable that represents the link fade depth (expressed as a unitless factor)

and SNR_{link} represents the ideal signal-to-noise ratio at the receiver in benign conditions (i.e., without fading taken into account). Substituting the results of Equation 4-2 into Equation 4-1 we obtain:

$$P\{SNR_{rcv} < SNR_{req}\} = P\left\{A > \frac{SNR_{link}}{SNR_{req}}\right\} \qquad 4\text{-}3$$

If we define the following:

A_{dB}	=	A variable that represents the link fade depth (expressed in dB)
$SNR_{rcv,dB}$	=	SNR_{rcv} in dB
$SNR_{req,dB}$	=	SNR_{req} in dB
$SNR_{link,dB}$	=	SNR_{link} in dB

we can write:

$$\begin{aligned} P\{SNR_{rcv,dB} < SNR_{req,dB}\} &= P\{A_{dB} > M_{dB}\} \\ &= p_w(M_{dB}) \end{aligned} \qquad 4\text{-}4$$

where M_{dB} is the link margin, in dB, and it is simply the difference between the link SNR and the required SNR, both in dB (i.e., M_{dB} is equal to $SNR_{link,dB} - SNR_{req,dB}$).

Equation 4-4 above states that the probability that the received SNR is less than the required SNR, both measured in dB, is equal to the probability that the fade experienced on the link, A_{dB}, is greater than the link margin, M_{dB}, with both measured in dB. We define this latter probability as the function,

p_w, and note that it is dependent upon M_{dB}. The importance of this observation will become apparent in the following section, where MSS interference is considered. The expressions derived in ITU-R P.530 should be used to quantify Equation 4-4 above.

4.2.1.2 Step 2: Transform the PDF of the MSS Interference Power at the FS Receiver into PDF data for a Newly Defined Variable

In this step, the PDF of the MSS interference power at the FS receiver is transformed into the PDF of a different variable required by the analysis in step 3 below. It will be assumed that the PDF of the MSS interference power into the FS receiver as a function of azimuth and antenna size is available as an input, either directly from the MSS system operator or by generating it via simulation using the appropriate MSS system characteristics. It is noted that the MSS interference power seen at the FS receiver is a variable that can be expressed either in Watts or in dBW, and the following two variables are defined to represent the MSS interference power for each case:

I = A variable that represents the level of interfering signal power, in Watts, arriving from the mobile satellite system (MSS) at the input to the fixed service (FS) receiver

I_{dBW} = A variable that represents the level of interfering signal power, in dBW, arriving from the mobile satellite system (MSS) at the input to the fixed service (FS) receiver

The PDF of I can be easily derived from the PDF of I_{dBW} and vice versa.

In order to facilitate the calculations in step 3 below, two new variables, I'' and I''_{dB}, are defined as follows:

I'' = A variable that represents the amount that the MSS interference power plus the FS noise power exceeds the noise floor, N, at the input to the FS receiver (expressed as a linear power ratio)

I''_{dB} = A variable that represents the amount that the MSS interference power plus the FS noise power exceeds the noise floor, N, at the input to the FS receiver (expressed in dB). I'' can be considered to be the threshold degradation (or "fade margin loss" in ITU-R Study Group 9 Recommendations),