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CARRIER-TO-INTERFERENCE OBJECTIVES

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C/l TUTORIAL

1. INTRODUCTION

Microwave radio has been a dependable and durable communications medium for years. Since its introduction in 1947, microwave radio has evolved into nationwide networks. While its growth has produced a dense array of efficient radio networks, this growth has been accompanied by an inevitable increase in radio interference within these systems. To assure that future networks can grow and be upgraded, we continuously must guarantee controlled and coordinated interference environments, even in the face of ever-increasing interference.

The process of frequency planning in microwave systems involves knowledge of

o The various characteristics of microwave systems
o The limitations on allowable interference for the types of traffic being transmitted
o Many other factors that determine the acceptability of using any frequency for a given purpose.

This tutorial is intended to help those who are engaged in the field of frequency planning and coordination as practiced in the United States, primarily in the common carrier service, officially designated as Domestic Public Fixed Service.

To maintain acceptable interference levels, engineering and administrative techniques have been developed for estimating the magnitude of radio interference. The most accurate and efficient way to analyze interference is to devdop and apply Carrier-to-Interference (C/I) objectives. C/I objectives are the minimum ratios of the desired signal levels (C) to the interfering signal levels (1) that are necessary to protect radio systems against interference from other radio systems. The C/I values are referenced to the radio receiver input and represent the total isolation required between two or more radio systems to meet a given interference exposure allotment. The required signal protection is a minimum C/I separation that must be present to prevent interference from other radio systems.

C/I objectives are developed based on the modulation type, baseband capacity, required baseband performance, and carrier frequency separation. Essentially, each combination of radio equipment, modulation type, frequency separation, and channel capacity forms a unique C/I relationship. The objective is to predict the ratio of carrier to interference at the victim receiver and, given the spectral characteristics, filter selectivity, and baseband performance requirements, determine the signal level separation needed to prevent objectionable interference.

Let's begin by listing some of the factors that affect interference and continue by discussing the types of interference, the objectives for determining what is an acceptable level of interference, and the process of coordinating the proposed usage of the radio spectrum for communications.

1.1 Factors Affecting Interference

Route design and equipment design are the main factors affecting interference levels On the most basic level interference is caused by the proximity of other systems sharing the same frequency band. The controlling factor at this level is route design. Because antennas used in point-to-point radio engineering use a highly focused beam, radiation emitted "off" the main beam is measured by determining the angular relationships between two interfering paths.

Exactly how focused the main beam is, or the reduction in transmitted (or received) power at any angle off the main beam, is determined by equipment design or, more specifically, by a particular antenna discrimination pattern. Other equipment design factors affecting interference levels are frequency selection, modulation schemes, and signal polarization’s. Some of the factors that affect interference and determine the acceptability of using particular frequencies are discussed in the following sections.

1.1.1 Antennas

The antennas used for microwave communications systems are very directional, i.e., they radiate most of the energy in the desired direction toward the receiving station with which the transmitter station is to operate. The directive radiation patterns of microwave radio antennas are one of the most significant factors in preventing one system from interfering with another. As the microwave spectrum has become more congested, it has been necessary to improve the antenna patterns to allow continued growth of systems.

Over the last few years, antenna manufacturers have developed classes of antennas called high-performance, ultra-high performance, ultra-directive, suppressed radiation, etc. By judiciously selecting from this group of antennas, we can densely pack microwave paths.

1.1.2 Polarization

An antenna's response to (or isolation from) signals radiated in a differently polarized electrical field is another characteristic of antennas that is significant in frequency planning. All antennas radiate or respond to the field opposite to the one **in which** they are designed; i.e., a horizontally polarized antenna radiates and responds to energy in the vertical plane. The amount of energy received by an antenna on the opposite polarity depends on the cross-polarized response of the antenna. The optimum isolation is received when both the transmitting (causing interference) and the receiving (victim) antennas have a similar cross-polarized response.

1.1.3 Frequency Separation

Another factor that we consider in frequency planning is frequency separation between the desired and undesired signals. This factor has limited applicability when users must operate all channels (frequencies) in a particular frequency band, which is sometimes called "block" frequency planning. If block planning is not required, we usually must know the interference criteria that is acceptable for situations other than cochannel. This often requires information on specific characteristics of the equipment involved.

1.1.4 Distance Differential

The signal energy received by an antenna is a function of the antenna's distance from the transmitter. When considering the ratio of one signal level to another, we can calculate the difference in loss from the desired transmitter to the undesired one as one term without calculating the actual level of either signal. This ratio is expressed in dB and is simply 20 log of the distance ratio between the normal and interfering paths. If the desired path is shorter than the interfering path, the distance differential is positive; conversely, if the desired path is longer than the interfering path, the differential is negative. This relationship can be justified as shown in Equation 1.

The free-space path loss for the plane wave propagation can be obtained by assuming that if a power P is radiated through an isotropic antenna in free space, the flux density Pu at a distance D is given by

$$\mathbf{P_u = P/4\pi D2} \qquad (1)$$

which is the radiated power per surface area of a sphere with radius D. When this flux is received by an isotropic antenna, the isotropic input power in free-space Pio,

taking into account that the effective aperture area of the isotropic antenna is Ai = $\lambda/4\pi$, is given by

$$\mathbf{P_{io} = P(\lambda/4\pi D)^2} \qquad (2)$$

Therefore, the free-space propagation loss L (in dB) is given by

$$\mathbf{L = 10\log(P/P_{io}) = 20\log D(km) - 20\log \lambda\ (cm) + 121.98} \qquad (3)$$

Equation (3) can also be written in terms of the frequency (in GHz) and the distance in miles:

$$L = 96.6 + 20\ \text{1og}\ F + 20\ \text{1og}\ D \qquad (4)$$

If we consider that the transmitters of the desired and undesired signals are at distances D1 and D2, respectively, from the receiver, then the total path loss difference for this condition will be given by

$$L = 20\ \text{1og}(D_l/D_2)\ \text{in dB} \qquad (5)$$

where L is the distance differential between the desired and undesired signals.

Note that in this calculation we have not considered atmospheric absorption. At the 11-GHz frequency, we can neglect this type of loss. However, at higher frequency bands (above 18 GHz), we should consider this type of loss. At higher frequency bands, the loss caused by the distance differential will not be the simple ratio between the distances because we must consider the atmospheric absorption also.

1.1.5 Over-the-Horizon Propagation

When a radio path is obstructed by mountains, trees, buildings, etc. (Figure 1.1), the field intensity obtained at the receiving point is considered to be produced by electromagnetic waves diffracted by such obstacles. The standard approach in estimating radio transmission loss is to calculate the expected line-of-sight transmission attenuation, and then include additional losses caused by over-the-horizon propagation.

In this case, three main mechanisms propagate energy beyond the radio horizons (of the transmitter or the receiver): reflection from obstacles, refraction caused by atmospheric layers, and diffraction caused by the earth's bulge and irregular terrain. We can use the additional path loss over the free-space loss caused by these propagation mechanisms to determine specific interference cases.

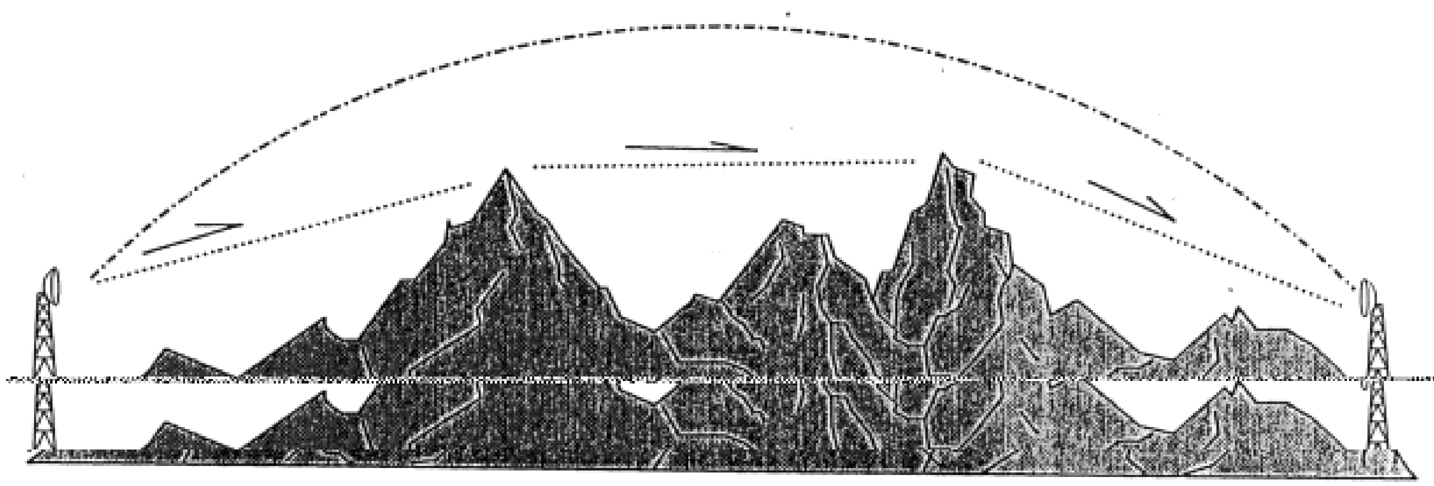

Figure 1.1 Diffraction over the horizon

1.1.6 Terrain Scatter

The most obvious way to evaluate an unwanted signal is over the direct path from the interfering transmitter to the victim receiver. Unfortunately, it is also possible to experience interference from the indirect coupling caused by terrain scatter. Such scatter may arise when beams intersect over a portion of terrain that is visible to both the interfering transmitter and the victim receiver. Thus, even a high directional antenna cannot discriminate against interference that comes in via a scatter source on or near the boresight direction.

Other NSMA documents describe terrain scatter in more detail. This tutorial briefly mentions it for the sake of providing a complete list of factors affecting interference.

1.2. Carrier-to-Interference Ratio

The carrier-to-Interference (C/I) ratio is the ratio, expressed in dB, between a desired carrier (C) and an interfering carrier (1) received by the same receiver, which is called the "victim" receiver. The desired carrier level and the interfering carrier level are calculated and measured in dBm.

For convenience, we normally use the C/I ratio to determine whether an interference case is acceptable or not. The carrier signal level (C) and the interfering signal level (I) can be expressed as follows.

1.2.1 Equation for Determining Desired Carrier Power

$$\mathbf{C = PTD + GTD + GRD - FSLD - LWGTD - LWGRD} \quad (6)$$

Where,

C	is the received desired carrier power.
PTD	is the transmit power from the desired station in dBm.
GTD	is the antenna gain of the desired transmit station in dB.
GRD	is the antenna gain of the desired receive station in dB.
FSLD	is the free-space loss of the desired path in dB.
LWGTD	is the loss of the waveguide of the desired transmit station.
LWGRD	is the loss of the waveguide of the desired receive station.

1.2.2 Equation for Determining Interference Carrier Power

$$\mathbf{I = PTI + GTI + GRD - GCD - FSLI - LWGTI - LWGRD} \quad (7)$$

Where,

I	is the received interfering carrier power.
PTI	is the transmit power from the interfering station in dBm.
GTI	is the antenna gain of the interfering transmit station in dB.
GRD	is the antenna gain of the desired receive station in dB measured at the angle of arrival of the interfering signal.
GCD	is the combined angular discrimination of the two antennas at their respective discrimination angles.
FSLI	is the free space loss of the interfering path in dB.
LWGTI	is the loss of the waveguide of the interfering transmit station.
LWGRD	is the loss of the waveguide of the desired receive station.

The C/I ratio in dB is calculated as the difference between Equations (6) and (7).

1.2.3. Calculation Methods for Analog Systems

Analog C/I objectives are set to allocate a specific portion of the baseband noise that has been exclusively caused by radio frequency (RF) interference. This noise allocation is based on a system noise model that divides routes into two categories: long-haul and short-haul**.** The short-haul routes are designed for lengths up to 250 miles and they are usually used in intrastate or feeder services. The long-haul routes generally extend up to about 4000 miles.

The per-exposure noise allocation for RF interference on long-haul routes is 17 dBrnc0 (50 pWp0). for carrier-beat interference and 4 dBrnc0 (2.5 pWp0) for sideband interference. (Carrier-beat and side-beat interference are described in Section 3.2.) The junction interference allotment for long-haul systems is 8 dBrnc0 (6.3 pWp0) The short-haul noise allocation is 14 dBrnc0 (25 pWp0) per exposure for any type of interference.

To calculate interference objectives between two analog systems, we must describe both systems by the following baseband characteristics:

- Channel capacity
- Top baseband frequency
- Bottom baseband frequency
- Total RMS" frequency deviation (for frequency modulated [fm] systems)
- Carrier frequency tolerance
- Pre-emphasis type
- Difference in operating frequency between the two systems
- Noise objective.

The two RF spectra are processed (convoluted) with each other to arrive at a baseband spectrum of interference. We then compare the processed spectra with the baseband multiplex signal. Based on the level of tolerable noise, we can find the necessary RF discrimination.

To analyze the output, we must determine a carrier-beat objective and a sideband objective. We determine the C/I objective for the carrier beat by taking the calculated noise for the carrier beat and subtracting the appropriate noise objective. In addition, if the system's short-term stability is low, we must subtract a factor of 10 dB to determine the C/I objective. This is known as a burble factor. We determine the sideband objective by selecting the largest C/I ratio in the baseband spectrum for a given RF receiver discrimination. The C/I objective normally used will be the largest of the carrier-beat and sideband objectives.

1.2.4. Calculation Methods for Digital Systems

Allocations for interference into digital radio systems have a very different character than those for analog radio systems. They take the form of a minimum C/I required when the desired digital signal is faded. In normal, nonfaded conditions, the digital signal can tolerate fairly high levels of interference; however, to protect short-term performance and hop reliability, it is critical to control interference in deep fades. Digital C/I objectives are allocated on a per-hop basis rather than on a 4000-mile route basis. Moreover, digital C/I objectives are set to insure error-free operation.

* dBrnc0 and pWp0 are noise measures that are defined in detail in reference [4].
** RMS = root mean square

Interference into a digital radio system causes an outage based on the bit error rate (BER) rather than noise in a 4-kHz channel (as in analog systems). An outage does not occur until the interfering signal is large enough to cause the digital radio to make a false decision. Typically, the signal-to-interference ratio power is within 15 to 40 dB. Field tests have concluded that 10-3 is the criterion for outage. The 10-3 bit error rate is roughly analogous to the 55-dBrnc0 noise limit for analog radio.

A digital C/I objective is simply the ratio of the faded carrier and the total interference power, plus the fade margin of the desired hop. If the total C/I allocation for the digital radio hop is exceeded, it will degrade the designed fade margin almost dB-for-dB in a severe case. The C/I ratio described above applies for any type of co-channel RF interference, whether it be FM, AM, video or digital into digital systems.

Adjacent-channel C/I objectives may be lower than the co-channel ratios bemuse of the effect of RF and IF filtering in the digital receiver. If the interfering signal is off frequency, its power will be decreased by channel-separating and IF filters. Determining the filtered, unwanted signal spectrum and total integrated input power (over the spectrum) provides the amount of signal discrimination at a given frequency separation.

1.3. Using C/l Objectives for Frequency Planning

Specially designed computer programs calculate the initial interference between terrestrial microwave systems and also between terrestrial microwave systems and satellite earth stations that share the same frequency bands; These programs consider the transmitter power, antenna discrimination (or off-axis gain), and freespace loss between the source of the undesired signals and the victim receiver.

The output of these programs is a listing of selected cases that do not meet the prescribed interference criteria. We evaluate these cases to determine if there are other conditions that we can consider to eliminate the potential interference. Factors that we might apply are obstruction loss caused by blockage between the source and the victim, changes in antenna type or size, changes in transmitter power, and changes in loading that may change the interference criteria.

Digitized terrain databases are available that can help in the initial culling process. We must be careful in how much we rely on these terrain databases and must make sure that an indicated obstruction actually exists and that enough loss will result to reduce the probability of interference to an acceptable level. Possible problems with these terrain databases are the precision of the data and the accuracy of interpolations of the data.

Two common versions of this terrain data are grid-oriented; one at 3-second intervals and the other at 30-second intervals. The 30-second version is a subset of the 3-second data and both are based on 1:240,000-scale topographic maps. When this data is used to indicate the clearance of interference cases based on obstruction, the actual terrain should be verified from larger-scale maps, preferably 1:24,000 scale.

In cases where the interference cases cannot be cleared by over-the-horizon propagation loss (as calculated by programs such as OH LOSS), we can try using antennas with better off-angle radiation patterns to resolve the indicated cases. If the cases are near the main beam, higher-gain antennas will sometimes resolve the cases as long as the additional gain does not exceed the additional discrimination for the off-angle radiation. In other cases, larger antennas, combined with reduced transmitter power, may resolve the cases.

If the situation is one in which another party's antenna can be changed to resolve an interference case, such changes may be accomplished through negotiations with that party. These changes will normally have to be funded by the party planning the new system unless the other party is using antennas that do not meet the minimum Federal Communications Commission (FCC) requirements for radiation patterns.

1.4. Using C/l Objectives for Frequency Protection

The analysis for frequency protection is the same as for frequency planning except that the protection analysis does not require us to resolve an interference case by making changes to a system. The party who is proposing the new system is responsible for engineering the necessary changes to resolve interference. The person making the analysis for protection must be aware of the methods for resolving interference and be able to evaluate any factors that may be encountered.

1.5. Frequency Coordination

The *FCC Rules** use the term "frequency coordination" to refer to the process of exchanging information on the technical characteristics of any proposed new system that shares the frequency spectrum with other parties already authorized to operate facilities in the same frequency band. In practice, the process also includes those who have previously coordinated facilities although the *FCC Rules* do not require them to do so. The *FCC Rules* require that parties whose facilities may be affected be given a minimum of 30 days to analyze and respond to a proposal to add new facilities or change an existing system.

Frequency coordination is required in all frequency bands authorized for common carrier operation and those bands that are shared equally with users in other services, e.g., 18-GHz, which is shared by Private Operational Fixed Service, Broadcast Auxiliary Service, and Cable Television Service. The content of Prior Coordination Notices (PCN's) must include enough information to enable the party receiving the PCN to analyze the interference impact of the proposed system on their system.

2. ALLOWABLE DEGRADATION

The criterion used for limiting interference to allowable levels is the C/I objective. For analog FM radio systems, these objectives are based on a per-exposure allowance of 4 dBrnc0 of noise from foreign systems. Interference criteria in a digital radio system that causes outage are based on a bit error rate. (Normally, 10-5 is used as an outage criterion.)

2.1. FM Analog Message Systems

In a situation where the victim receiver is FDM-FM,** the specified C/I objective is the ratio of the unfaded desired carrier level (C) to the unfaded interfering carrier level (I), which after demodulation will contribute no more than an additional 4 dBruc0 or 2;1 pWp0 of noise power to the total noise present in the top baseband channel. The emphasis/de-emphasis and baseband-combining features of the radio equipment are taken into account in the design of objectives. We can calculate the 4-dBrnc0 or 2.1-pWp0 contribution from the radio equipment's known parameters. In computing overall system noise, it is easier to work in pWp. Because of C Message and psophometric filter-weighting characteristics, the correct relationship between dBrnc and pWp is accepted as

$$\text{dBrnc0} = 10 \log \text{pWp0} + 0.8$$

As an example, consider a 2400-FDM-FM radio application that has a typical RF design carrier input level of 25 dBm (C) and a receiver threshold of approximately 67 dBm to the 55-dBrnc0 point. For this example, the system requires a 65-dB C/I objective to meet a 4-dBrnc0 (or 2.1 pWp0) noise contribution. This case would require the interfering carrier (I) level not to exceed the -90-dB objective level into the victim receiver.

Consider what the effects would be on noise contribution when the required -90-dB level (I) is 10 dB out of the objective. To estimate the effects of noise contribution in the baseband, let's consider two cases:

(1) When the required -90-dB (1) interfering level is 10 dB out of the objective (2) When the carrier signal (C) fades 10 dB.

The first case constitutes a 10-dB "case" under an unfaded condition of the desired carrier. This results in a 55-dB C/I, which is 10 dB out of the C/I objective. The 10-dB case would contribute about 21 pWp0 of additional noise into the top baseband channel, compared to the 2.1-pWp0 design objective.

* FCC Rules is the informal name for the Code of the Federal Regulations, which is listed as Reference [3].
** FDM-FM = frequency-division multiplexed - frequency-modulated

In the second case, the -90-dBm interfering signal level (I) is met, but the desired carrier (C) fades 10 dB from -25 dBm to -35 dBm. For the l0dB fade, the variable idle noise contribution added into the top baseband channel would be much less than in the first case. The amount of noise contribution would depend on the operating characteristics of the flat or curved portion of the receiver noise sensitivity quieting curve. Typically, a l0-dB fade would contribute about 7 pWp into the top 3-kHz baseband slot.

Thus, on FDM-FM systems, system performance becomes impaired in two ways when the desired C/I objective is not met on a path.

- The fixed noise contribution increases in the derived 3-kHz top baseband channels. When the interfering signal level becomes the dominant noise contributor above the inherent noise floor of the receiver, the increase in noise will be on a dB-for-dB basis with decreases associated with the objective. The noise is added logarithmically on a power basis above the 2.1-pWp0 design objective.

- Because a path fade margin is generally referenced to the 52- or 55-dBrnc0 noise threshold point of the receiver, the fade margin is effectively reduced on a dB-for-dB basis because of the increased noise contribution above 4 dBrnc0. Over a single hop of FDM-FM radio, the additional fixed-noise contribution resulting from a 10-dB case interfering in a victim receiver due to C/I objectives not being met can be significant. A 10-dB case could also be significant and affect propagation reliability if the case is on a path that is subject to heavy fading.

Transmission impairments to the overall system propagation reliability, path fade margin, and noise contribution could become even more noticeable by accumulative "cases" building up throughout the route or network.

2.2. FM Video Systems

The end-to-end overall noise objective for television is 53-dB peak-to-peak signal to-weighted-interference noise. We assume that half the noise will be contributed by the local network and toll-connecting system. Thus, the long-haul objective becomes 56 dB.

We further assume that the total interference will be 6 dB below the noise. The objective becomes 62-dB peak-to-peak signal-to-weighted-interference noise. This is a total interference objective and we derive a per-exposure limitation by examining the expected number of exposures over 4000 miles. The expected interference exposures are 207 same-route, 308 junction, and 156 foreign-system. Together, these add up to 1134 equally-weighted interference’s. Therefore, the objective becomes 92.5-dB peak-to-peak signal-to-weighted-interference noise, which is rounded to 92 dB.

We derive short-haul objectives in the same way over a 250-mile route. Starting from 53 dB and allocating half the noise objective to long-haul, we further divide the resulting 56 dB into the local and short-haul connections. Allocating half the remaining noise objective to the local connection, the short-haul objective becomes 59 dB. Again, assuming the interference will be 6 dB below the noise, the total peak-to-peak signal-to-weighted-interference noise becomes 65 dB.

To arrive at a per-exposure objective, we assume 30 same-route, 8 junction and 13 foreign-system interference’s for a total of 53 equally-weighted exposures. The per exposure objective for short-haul radio results in an 82-dB peak-to-peak signal-to-weighted-interference noise objective.

Using normalized signals, we calculate the interference contribution from a distributing system with reference to an average power spectral density spectrum of a video signal. The results of this calculation are then applied to the interference objective to arrive at a C/I objective.

2.3. AM Analog Message Systems (SSB)

The noise objective for a 4-kHz voice channel on Single-Sideband (SSB) radio is 4 dBrnc0. We determine SSB interference objectives by computing the maximum noise the interference would cause in any SSB voice channel. The worst case for interference from an FM signal into SSB is caused when the carrier of the FM signal uses the baseband of the SSB signal.

Both a carrier and a sideband objective are given if the stability of the interfering system would allow the carrier to use the SSB baseband. For SSB, we use a 4dBrncO objective for both carrier and sideband interference. If the interference is caused by the carrier of the interfering system, we apply a 10dB reduction to account for the “burble" factor.

2.4. AM Video Systems (to be added)

2.5. Digital Systems

Consider a 64-QAM 4-GHz digital radio application that typically has an RF-design carrier level of about -39 dBm (C), a receiver threshold of about -75 dBm to the

10-3 BER threshold point (C), and, as an example, requires a 65-dB C/I objective. Such an application will require that an interfering carrier signal level does not exceed -104 dBm.

In digital radio applications, the interfering carrier level (1) of the C/I objective is that value which will not degrade the 10-3 BER threshold point less than 1 dB under conditions when (C) fades to the threshold. The path fade margin is referenced also to the 10-3 BER point. Under normal, unfaded path conditions, the digital transmission runs essentially error free, about 10-14. when the prescribed C/I objective is met.

In digital radio applications, when the level of an interfering signal does not meet the C/I objective, it degrades to the 10-3 BER threshold. This degradation will be on a dB-for-dB basis in situations where the interfering carrier level is more dominant than the inherent kTB noise level. The degradation to the 10-3 threshold is based on the power summation of kTB (dBm) plus the interfering signal (dBm).

For example, let's examine a case in which the objective is missed by 15 dB. In that situations threshold degradation will be on a dB-for-dB basis. The 10-3 threshold point is now effectively at -60 dBm, compared to the design value of -75 dBm. The effect is a 21-dB fade margin on the path instead of the design value of 36 dB.

Operationally, even with the presence of the 15-dB interfering carrier (I), the data transmission performance is still relatively error free (10^{-9} of 10^{-10}) under unfaded path conditions. However, the BER will begin to accumulate quite rapidly for fading depths beyond an initial 10-dB fade. On digital radio systems, when the C/I objective is not met, it could

- Degrade the 10^{-3} BER threshold point
- Affect the propagation reliability of the path due to the lower fade margin
- Significantly impair transmission on paths that experience heavy fading.

At the 10^{-6} BER, the total interference power will nominally be within 25 dB of the desired signal. This interference power is the power sum of all interference’s from all sources on any one hop. To protect the digital radio from foreign system interference, we must allocate some of the total interference power to a per exposure C/I

2.6. Satellite Earth Stations

The successful operation of fixed satellite systems in the shared frequency band depends on the avoidance of objectionable interference between them. We evaluate interference between satellite systems and terrestrial systems according to permissible objectives expressed in absolute levels (i.e., -131 dBw/4 kHz and -154 dBw/4 kHz).

The -131-dBw/4-kHz level is the acceptable level for short-term transmissions (.01% of the time). This translates to about 8 hours over a one-year period. The 154-dBw/4.kHz level reflects the long-term objective (20% of the time). This translates to about 73 days per year. The -154-dBw/4-kHz level is the one usually used by coordinators for both transportable, temporary uplinks and permanent earth stations.

Part 25.252, Table 1 of the *FCC Rules* relates noise in terrestrial microwave systems to a minimum (lower bound) receiver noise temperature of 750 degrees R. The *FCC Rules* also assume that in a single terrestrial hop, thermal noise in a baseband will amount to 25 pW0p. These two factors, combined with the CCIR* short- and long-term permissible interference levels of 50,000 pW0p and 250 pW0p (1000 pW0p divided four ways), respectively, and appropriate constants, produce the following objective RF levels of interference for coordination:

Boltzman's constant (k) = -228.6 dBw/degree/Hz
Temperature 750 ° K = 28.8 dB

dBw 4 kHz = 36.0 dB
-163.8 dBw/4kHz (8)
(about-164 dBw/4kHz)

Thus, we assume that RF noise power in a terrestrial receiver converter of -164 dBw produces 25 pW0p of thermal noise at the baseband. If we assume that interference is similar to noise, we would require interference levels at the receiver conversion point 10 dB (250 pW0p/25 pW0p greater than -164 dBw/4 kHz equal to -154 dBw/4 kHz just to produce the long-term interference objective of 250 pW0p A short-term interference level corresponding to 50,000 pW0p would be 33 dB greater or -131 dBw/4 kHz.

The earth-station operator usually sets earth-station objectives. These objectives may or may not represent boundary or ultimate sensitivity values. Interference from terrestrial microwave radio stations to satellite earth stations is nominally controlled by limiting the interfering power density, expressed in dBw per MHz. Each earth station operator sets specific objectives for interference protection.

Whether an interference exposure for a terrestrial system is acceptable depends on whether the terrestrial operator can demonstrate that the expected interfering power density is no higher than the specified objective in any 1-MHz bandwidth within the frequency range coordinated for the earth station.

2.6.1. Frequency Offset _

Truly co-channel operation in which the frequency separation is zero may cause a high interference condition in some channels, though not necessarily. the worst condition. Generally, the worst interference occurs where the separation between centers of the wanted and interfering signals is between zero and the top baseband frequency of the wanted signal multiplex.

As the interfering signal center is separated from the wanted signal center by more than the top baseband frequency of the multiplex, the interference diminishes. Its rate of decrease beyond the first-order sidebands depends on the nature of the

interacting signals. Spiky or narrow interference would decrease very rapidly, whereas a widely-distributed signal would cause interference to taper off much more slowly with separation.

The FCC recognizes block frequency coordination in the *FCC Rules*, Part 25.251 section d (5). However, in Part 25 the FCC also recognizes partial frequency band usage. Partial frequency band usage may result from a satellite system discretely occupying several channels of a standard terrestrial channeling plan and a terrestrial microwave system occupying the remaining channels. Under these circumstances, there will probably be a substantial frequency offset advantage by which the negative margins can be substantially reduced or eliminated.

* CCIR stands for Comite Consultatif International das Radio (International Radio Consultative Committee)

2.6.2. Spectral Distribution of the Interfering Signal Over the Carrier Band

It is well known that in a case of interference between FM carriers, the desired carrier may suffer the largest interference when both carriers are unmodulated. The beat frequency of the two carriers appears in the baseband of the desired signal. If either the interfering or the victim carrier is frequency modulated, the interference noise power is dispersed over the baseband so that the effect of the interference noise power on each channel is reduced. Therefore, it is expected that the increase of interference noise is prevented by adding a modulating signal to the FM carrier when traffic is light. The added signal that prevents an increase of interference noise is called the "energy-dispersal signal."

Satellite down-link radiation may result in interference between satellite systems and terrestrial microwave systems sharing the same band. This type of interference is of most concern when it is in the 4- or 6-GHz bands. To limit such interference, the FCC has restricted the satellite Effective Isotropically Radiated Power (EIRP) to 12 dBw in any 4-kHz band. The down-link EIRP is calculated as the transmitted power less the feeder loss (typically 1 dB), plus the antenna gain (about 30 dB for a CONUS coverage antenna). For example, a satellite-transmitted power of 7 dBw (5 watts) results in an EIRP of 36 dBw along the main beam.

To meet the FCC limit on EIRP in any 4-kHz band, we must continuously modulate the carrier with a special energy-dispersal signal in addition to the baseband signal. This ensures that the carrier power will be uniformly distributed over a required band. This spectrum results in interference in the terrestrial microwave system.

3. INTERFERENCE MODES

Microwave systems depend on the transmission of energy by way of electromagnetic waves between two highly-directional antennas. The media traversed by the electromagnetic waves and the spectrum used is shared. Therefore, any transmitter within the line of sight is a potential interferer. This shared environment allows several modes of radio frequency interference:

- Between the same systems (intrasystem)

- Between different systems (intersystem).

These further break down into types of systems (analog or digital), modulation types, and channel loading.

3.1. Types of Interference

Interference in microwave systems is caused by the presence of an undesired signal in a receiver. When this undesired signal exceeds certain limiting values, the quality of the desired received signal is affected. To maintain reliable service, the ratio of the desired received signal to the (undesired) interfering signal should always be larger than the threshold value.

Interference can have many causes. It can be caused by the presence of other sources or sources in the same route. Both these possibilities can be eliminated or minimized by selecting a good site when selecting the route, and by considering proper antennas and operating frequencies. Interference can be categorized into three different types:

- Intrasystem
- Intersystem
- External.

3. 1.1. Intrasystem

This type of interference is caused by an undesired signal generated within the system. The received signal in a particular hop can be affected by undesired radiation from a transmitter in the same route but of a different hop. This type of interference can also be classified into two different categories:

- Overreach interference
- Spur or junction interference.

Overreach Interference

Figure 3.1 shows overreach interference in which the frequencies in one direction of transmission are indicated. Here, the problem is to reduce the receiving signal level at station D, which is transmitted from station A at frequency F1 when there is a fade condition for the F1 signal received from station C. We can minimize this type of interference by adjusting the following parameters:

- A longer overreach path than the direct path from station C to station D. This will provide additional free-space loss to the undesired signal.

- Antenna discrimination against the overreach path. With proper antenna discrimination, the power level of the undesired signal from station A to station D can be minimized.

- By using a suitable route, the overreach path can be blocked by the terrain. This blockage will reduce the transmitted signal level from station A to station D.

Spur or Junction Interference

This type of interference occurs in the same system at the junction and in a system using the so-called two-frequency plan. Figure 3.2 shows this. In all these cases, far-end crosstalk is the concern because it qualitatively depends on the discrimination patterns of the transmitting and receiving antennas.

The criterion in both near-end and far-end crosstalk is the signal-to-interference ratio, which is a function of antenna discrimination. In this type of junction, we should be careful about the type of antenna we use. For example, we would not use a periscope-type antenna at a junction or on the main route using the two frequency plan because this type of antenna has a low front-to-back ratio and may have some odd side lobes.

3.1 .2. Intersystem

This type of interference is caused by an undesired signal received from a transmitter of a different system. Figure 3.3 shows this. In the case of paralleling or intersecting microwave systems, the transmitted output power of the two systems may be comparable. This type of interference can be coordinated by adjusting the antenna discrimination and receiver selectivity, and choosing proper frequency plans.

The control of external interference partly depends on coordination, control, and sometimes compromising on the radio channel through direct negotiation. This interference can be caused by undesired co-channel signals or adjacent-channel signals. The FCC allocates the spectrum to the industrial users. The criteria for external interference depend on several factors:

- An absolute value of the interfering signal power should not be exceeded at any time, or should not be exceeded for more than some specified percentage of time at the input to the interfered-with receiver.

- A minimum value of the C/I ratio should be maintained at the receiver input. The criterion for this ratio (defined as the "objective") also depends on the types of interference (i.e. co-channel or adjacent-channel). This is also substantially affected by the selectivity of the particular receiver involved.

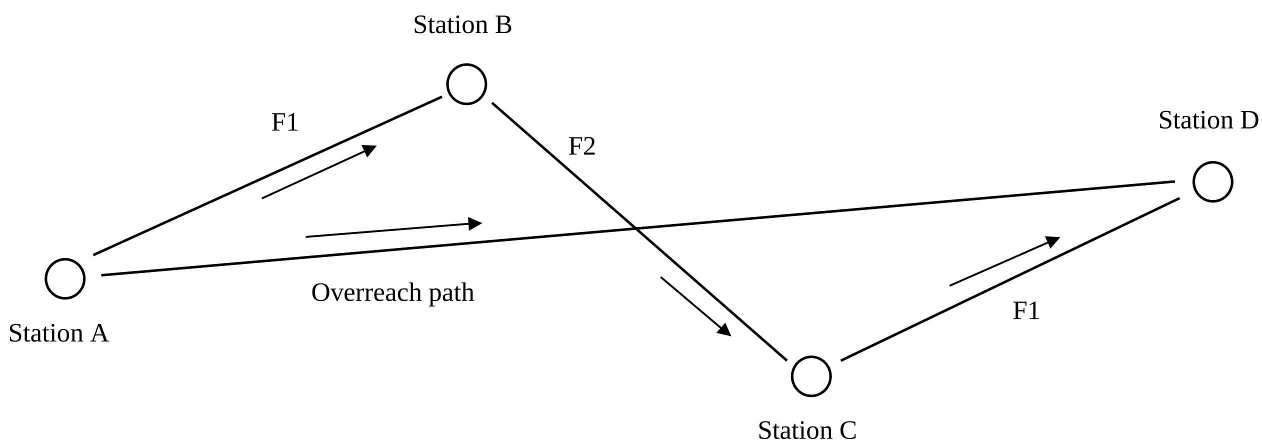

Figure 3.1 The Overreach Interference Phenomemon

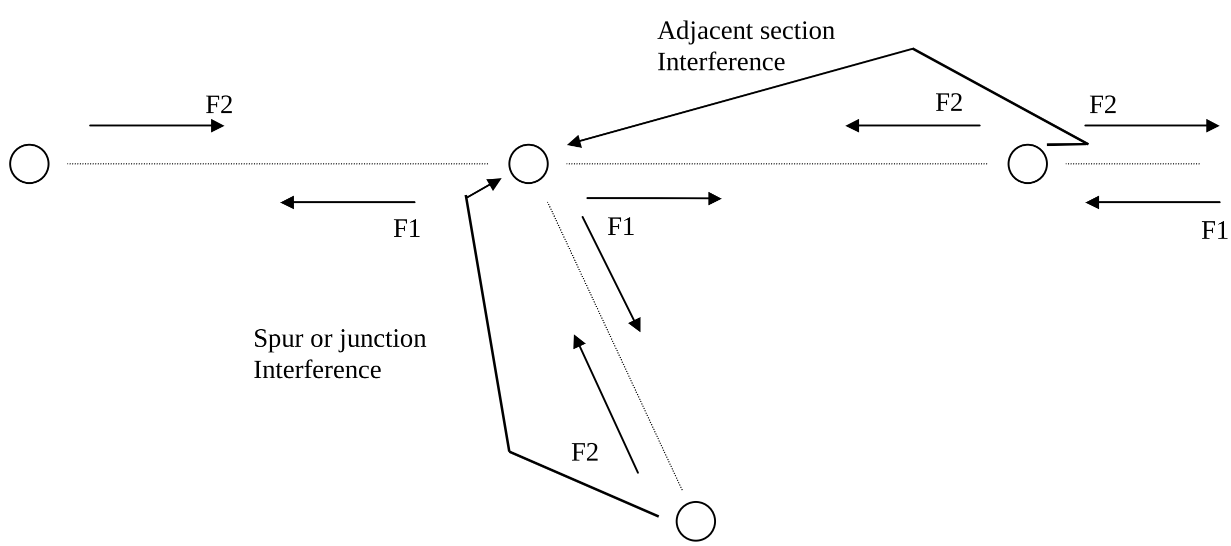

Figure 3.2 Adjacent Section and Spur Interferences

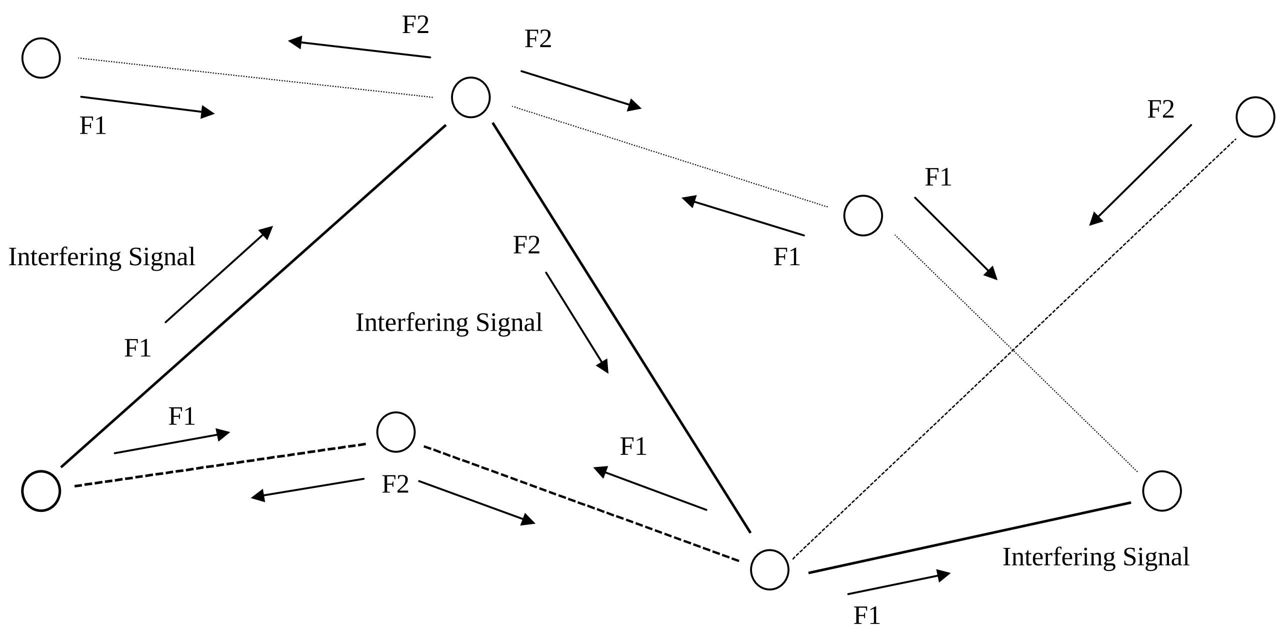

Figure 3.3 Inter-System Interference between 2 Different Systems

3.2. Radio Frequency Interference (RFI) Mechanisms

Determining the type of radio frequency interference mechanism is crucial in the analysis of potential interference. Various mechanisms are possible in analog systems and will be explained in detail. Digital systems outage is based on BER and fade margin degradation.

3.2.1. Analog FM Systems

The categories of RFI noise mechanisms in analog FM systems are

- Carrier beat
- Sideband-to-sideband beat
- Carrier-to-sideband beat
- Threshold Degradation.

Carrier Beat

Carrier beat is noise generated by an unwanted carrier interfering with the desired carrier. If the interfering carrier is 10 dB or more below the level of the desired carrier, which is usually the case, it will cause significant interference only at the difference frequency of the two carriers. Carrier beat is the result of the interfering carrier causing phase modulation in the desired carrier.

To determine if carrier beat is causing interference, we must know

- The lower frequency of the baseband signal

- The assigned carrier frequencies

- The frequency stability of each transmitter.

From the assigned frequency and frequency stability of each transmitter, we must first determine the maximum one-sided drift of each carrier. We assume that the carriers will drift to the maximum value in opposite directions and when this occurs, we determine the difference frequency. We must always shift the carriers to get the worst case.

If the difference frequency is greater than the lower baseband frequency, carrier beat is the source of the interference.

Sideband-to-Sideband Beat

This is noise originated by beating the sideband of the interfering signal and the sideband of the desired signal. This interference can be generated with carriers at the same assigned frequency or at adjacent frequencies. The carrier beat tone may appear as a sinusoidal interference in some channels, normally as unintelligible crosstalk.

Carrier-to-Sideband Beat

This is noise caused by beating the interfering carrier and the sideband of the desired signal, or vice versa. The carrier frequencies, e.g., of two transmitters on adjacent carrier frequencies, could drift toward each other so that the interfering carrier could get into the sideband of the desired carrier. This mechanism also results in sinusoidal interference appearing in some particular channels, normally as unintelligible crosstalk.

Threshold Degradation

Threshold degradation is caused when the interfering power level is high enough to raise the noise floor and Degrades the switching threshold, causing significant baseband interference, even when the two signals have little frequency overlap. Normally, FM receivers for terrestrial application operate in the linear range of the FM receiver characteristic (S/Nin versus S/Nout) and are set to switch to the protection equipment before the "knee" or breaking region.

In this normal operating range, noise rises dB-for-dB with the decreasing signal level. S/N and C/I ratios also decrease dB-for-dB with the signal level. If the interference level is close to the signal level in a deep fade, the "knee" may begin to
occur sooner than expected as the signal level decreases. Because the "knee" or threshold now occurs at a higher S/Nin, a threshold degradation is incurred.

Near the threshold point, noise begins to rise non-linearly with the decreasing signal, faster than dB-for-dB. Top baseband channel noise would reach 55 dBrnc0 before the full, designed fade range (assuming a lower threshold point) was traversed. Thus, the fade margin would also be degraded.

To limit fade margin reduction to about 1 dB, a minimum C/I of 6 dB is required in a deep fade. To protect against this phenomenon, a minimum C/I equal to the fade margin plus 6 dB is required. If the receiver filter reduces the interfering power, the amount of this reduction can be used to lower the overall C/I objective. This effect has been compensated for in all objectives so that the equation for threshold degradation C/I objectives becomes

C/I (threshold degradation) = Fade margin + 6 dB - Selectivity (9)

3.2.2. Digital Systems

For digital systems, we focus our attention on the effect of interference on outage. Digital microwave radio is engineered on a hop-by-hop basis. Therefore, we develop the C/I objectives by first obtaining the maximum amount of interference power that can be tolerated in each radio receiver. We then relate the interference power that we calculated to outage time.

Outage has been determined to be a bit error rate of 10^{-3}. (We need to specify the criteria from transmitting earth stations because it was not adequately covered when Part 25 of the *FCC Rules* was written since digital microwave was just beginning to be used.) The fade margin for digital systems is comprised of three parts:

- Thermal fade margin
- Dispersive fade margin
- Interference fade margin.

These fade margins are power-added to constitute the composite fade margin. The
calculation for this type of fade margin is as follows:[1]

$$\mathbf{CFM = -10\ log[\ 10\text{-}(TFM/03) + 10\text{-}(DFM/10) + 10\text{-}(IFM/10)} \qquad (10)$$

where,

CFM = Composite fade margin.
TFM = Thermal fade margin (dB). This is the algebraic difference between the nominal received carrier level and the 10^{-3} BER threshold.
DFM = Dispersive fade margin, provided by the radio manufacturer.
IFM = Interference fade margin. This is allotted for total expected interference.

IFM is defined as follows:[2]

$$\mathbf{IFM = C/I - C/N} \tag{11}$$

where,

C/I = The necessary C/I objective in dB.
C/N = The carrier-to-noise power ratio in dB at the detector.
CFM = One of the parameters necessary to compute the expected outage on a given hop. Thus, when the C/I is not met, IFM changes. This changes CFM and, consequently, the expected outage.

BER Degradation

Protection of digital microwave systems may vary depending on the proportion of digital data the system is to transmit. If most or all the data is pulse-code modulated (PCM) voice and the PCM channel-bank synchronization is the level of protection desired, a BER of 10^{-3} may be appropriate. If the system is to transmit a large proportion of digital input data, the system should be protected to a BER rate of 10^{-6} or better. In either case, the final acceptable interference level must be based on information from the manufacturer of the equipment unless a C/I that includes an acceptable fade margin for the system can be met.

A bit error rate of 10^{-3} is considered to be the outage threshold (analogous to 55 dBrnc0), and 10^{-6} is considered the quality threshold (switching will usually be attempted at a BER of 10^{-6}).

Fade Margin Degradation

Because digital microwave systems are fairly immune to interference when the received signal is well above threshold, we can consider the impact of interference to be a degradation of the threshold and thus the fade margin of the path. The question, then, is how much fade margin degradation the owner of the path is willing to accept. Factors that must be considered include the type of service being provided and the length of the total system.

4. OUTAGE TIME ALLOCATION

The interference levels derived from the C/I tables are intended to be steady-state and are considered long-term objectives. The first calculations we make to determine whether these objectives are met consider the free-space loss between the interfering transmitter and the victim receiver. If the interfering path is line-of sight, this loss will apply for almost 100 percent of the time and the objective must be met without any additional loss caused by obstructions.

If the interfering path is obstructed, we can consider the additional loss caused by the obstruction. If we consider obstruction loss, the percentage of time the loss will exceed free space becomes an important factor. We then must evaluate the probability of interference for short periods of time when the loss may approach free space.

4.1. Terrestrial Systems

There are no FCC prescribed maximum interference levels acceptable for common carrier systems for either the long term or short term. The industry has used some arbitrary practices for several years that seem to have been adequate for reducing interference to acceptable levels. These are discussed below. In all cases, we must meet both the long-term and short-term objectives to consider interference cases to be clear.

4.1.1. Long Term

It has been established that the additional loss caused by obstructions normally will not vary much from the median up to approximately 80 percent of the time. Therefore, we consider long term to include the percentage of time and the additional loss calculated to be exceeded for 80 percent of the time applied toward meeting the long-term interference objective. To provide greater assurance that the calculated loss will be exceeded, we apply the probability factor of .95 to the calculated loss.

4.1.2. Short Term

It has been accepted that for short periods of time, a higher level of interference can be tolerated without serious degradation to the service being provided. The commonly used percentage of time for the short-term objective is .01. We then must determine the loss that is expected to be exceeded for 99.99 percent of time, again with a probability of .95. To do so, we reduce the objective by 10 dB from the long-term criteria. We then apply the additional loss for 99.99 percent of the time toward meeting the reduced objective.

4.2. Satellite Earth Stations

For satellite earth stations that share frequency bands with terrestrial systems, the FCC has specified the long-term and short-term percentages of time for applying the criteria for interference between the two facilities. The FCC defines a general equation for the interference protection criterion from satellite earth stations. This criterion varies for different bands, different services, and different modulations (see Table 1, Section 25.252 of [3]). The equation characterizing the long-term (20 percent) interference power is as follows.

$$PMAX(20\%) = 10\log(n20)\ (kTB) + J - W - 10\ (dBw) \qquad (12)$$

where,

PMAX(20%) = Maximum permissible interference, in dBw, within the dBw bandwidth B of the potentially interfered-with station, not to be exceeded for all but 20 percent of the time from each source of interference.

n20 = The number of assumed simultaneous interference entries of equal power level for 20 percent of the time.

k = Boltzmann's constant (1.38 * 1023 Joules per degree K).

T = Thermal noise temperature of the receiving system (degrees Kelvin).

B = Reference bandwidth (in Hz).

J = Ratio (in dB) of the maximum permissible 20 percent interfering power to the 20 percent thermal noise power in the receiving system. J = 16 dB for FDM-FM systems and J = 0 dB for digital systems.

W = Equivalence factor (in dB) relating the effect of interference to that of thermal noise of equal power in the reference bandwidth (See Table 1, Section 25.252 of [3]).

4.2.1 . Long Term

Long term is defined as all but 20 percent of the time both for interference into earth stations and from earth stations into terrestrial systems. This is the same as stated above for terrestrial systems.

4.2.2. Short Term

The definition of short term is different for interference into earth stations and from earth stations. For cases of interference into earth stations, the percentage of time is .01, and we apply the loss expected to be exceeded for 99.99 percent of the time to meet the objective. For cases from earth stations, the short-term percentage of time stated by the FCC is .0025. In this case, we use the loss predicted for 99.9975 percent of the time to meet the objective. The maximum permissible interference power from a satellite earth station for the short term is given by a generalized version of that given in Section 4.2. The generalized equation is as follows.

$$Pmax(P) = 10Log(kTB) + J + M(p) - W\ (dBw) \qquad (13)$$

where,

M(p) = M(p0/n) = MO(p) (14)

n = Number of expected entries of interference assumed to be uncorrelated.

p = Percentage of time during which the interference from one source may exceed the allowable maximum value.

p0 =Percentage of time during which the interference from all sources may exceed the allowable maximum value, since the entries of interference are not likely to occur simultaneously.

$$p0 = np \qquad (15)$$

M(p) =Ratio (in dB) between the maximum permissible interference power during **p** percent of the time for one entry of interference, and during 20 percent of the time for all entries of interference, respectively.

M0(p0) = Ratio (in dB) between the maximum permissible interference power during **p0** percent and 20 percent of the time respectively, for all entries of interference.

W = Equivalence factor (in dB) relating the effect to that of thermal noise of equal power in the interference bandwidth.

The remaining parameter definitions are as given with Equation (12) in Section 4.2. In addition, the particular values of the parameters in Equation (13) are given by Table 1 in Section 25.252 of [3].

5. CONCLUSIONS

This tutorial provides the user with an overview of the development and use of carrier-to-interference ratios and objectives. The tutorial was written to provide a reference for standardizing the development and use of C/I objectives.

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7. REFERENCES

[1] AT&T Network Systems, AT&T National Digital Radio Customer Seminar,. (Boston, October 1987), pp. 15-18.

[2] Harris Farinon, Microwave Transmission With Digital Applications - A Tutorial Seminar,(Melbourne, March 22-24, 1988), pp. X-46.

[3] Office of the Federal Register, Code of the Federal-Regulations,. Title 47, Section 25

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