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Microwave Receiver Interference

Microwave receivers are susceptible to several types of interfering signal mechanisms which can degrade system performance. This issue of the Demodulator describes how the more common types of interference affect a receiver and discusses methods for eliminating or reducing the interference. The discussion is presented from two aspects.

The first aspect considers interference as intra-system, that is self-interference originating within a system. Often, this is intra-station; a transmitter interferes with a receiver at the same location. The second aspect considers interference as inter-system, where there is a geographic separation between the path of the desired signal and the path of the interfering signal. This is the basic situation involved in prior coordination work. The same types of interference are present in both the intra and inter-system cases but the amount of system degradation each type causes may differ somewhat in each case.

Four of the most common types of interference are threshold degradation, co-channel interference, adjacent channel interference and interference effects resulting from spurious receiver responses.

Threshold Degradation

The "FM Improvement Threshold" is dependent upon the amount of front-end thermal noise passed to the discriminator by the receiver selectivity. The improvement threshold is usually 10 to 12 dB above the rms power of the thermal noise in the receiver bandwidth. When the rf receiver input signal is above this level, the detected, per-channel thermal noise decreases dB for dB with increased signal level. However, when the rf signal falls below the improvement threshold, the noise increases so rapidly that derived circuit performance is unacceptable. If interference penetrates the receiver selectivity, it has the same effect as thermal noise. If the interference power is greater than the thermal noise power, a new, higher improvement threshold will be established. This is true even when the interference power is at a frequency sufficiently removed from the desired signal that no significant baseband beats are produced.

The practical (working) threshold level, for moderate to high density systems, is generally considered to be the receiver input level that produces 55 to 58 dBrnc0 noise in the top multiplex channel. This practical threshold is usually but not always substantially higher than the improvement threshold. The system fade margin is the difference between the practical threshold level and the normal unfaded receive signal level. Figure 1 is a typical receiver "quieting" curve. It

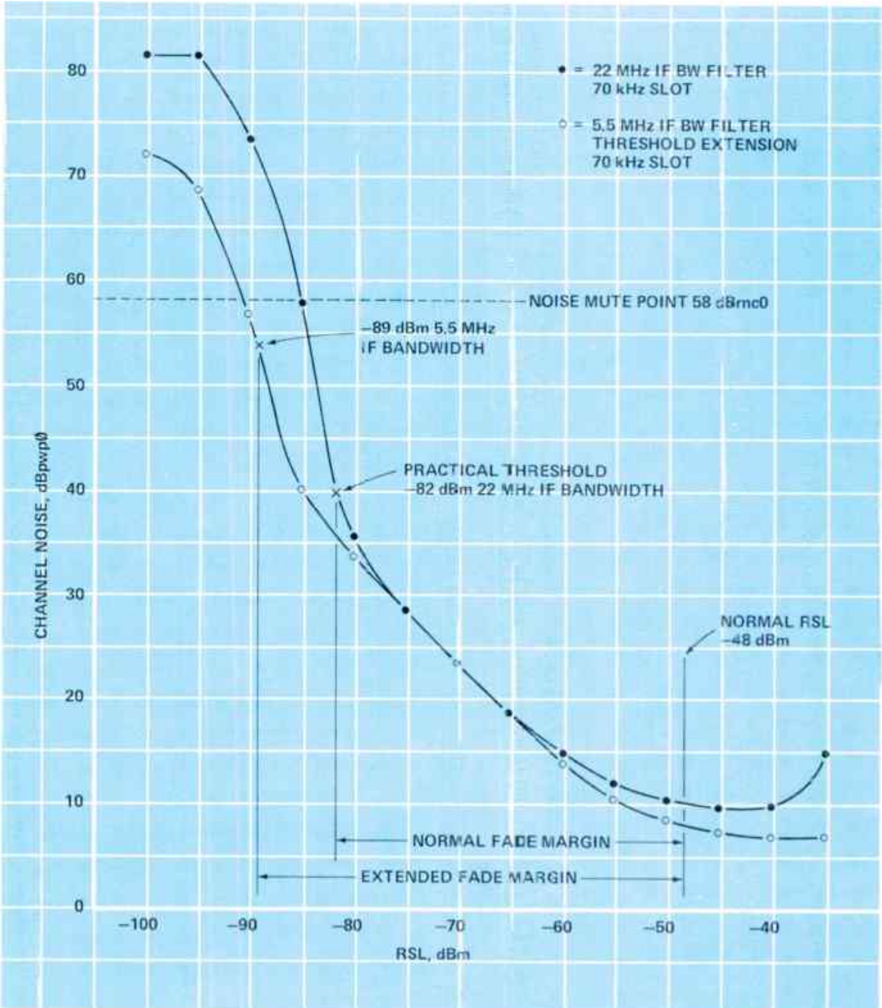

Figure 1. Receiver quieting, typical 2 GHz receiver, 300 channel, 283 kHz rms/ch deviation.

shows the relationships between normal receive signal level, practical threshold and fade margin. The extended threshold shown in the figure is discussed later in this article. Figure 2 represents the selectivity of a typical broadband microwave receiver for the 6 GHz common-carrier band.

Numerous tests have shown that interference penetrating the receiver selectivity, at a level considerably higher than the receiver noise, will establish an fm improvement threshold approximately 12 dB higher than the interfering power itself. If this "new" improvement threshold level is greater than the practical threshold level, the fade margin will be decreased. To avoid this condition, the interference power should be held to a level at least

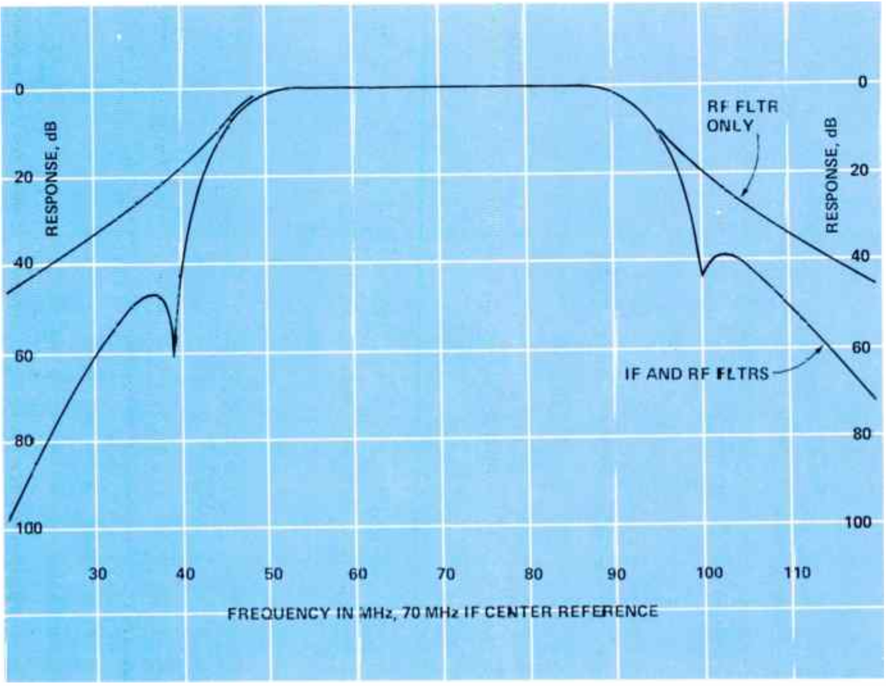

Figure 2. Receiver selectivity, typical broadband receiver 6 GHz band.

12 dB below the practical threshold. Fifteen dB is a safe value and leads to the expression:

C/I = 15 + Fade Margin − Effective Selectivity, where:

C/I is the required ratio, in dB, of the desired carrier to interference and effective selectivity is the combined selectivity of the receive filters at the minimum frequency difference between the carriers (i.e. the nominal difference minus the sum of the worst case frequency drifts).

Fifteen dB is quite conservative. Ten dB is often used for broadband, lightly deviated systems.

A frequently used fade margin requirement is 40 dB. Substituting this value in the equation: C/I = 55 − Effective Selectivity. This equation is valid for any FM system, assuming it is engineered for a 40 dB fade margin.

The effective selectivity of a receiver is generally specified by the manufacturer, usually in the form of a selectivity curve or level. It is a function of several parameters and is difficult to reliably determine in the field.

If the manufacturer's specification is not available and cannot be obtained, as may be the case with some "Grandfather" systems, the effective selectivity can be assumed to be zero, at least over the rf range [fc ± top baseband frequency]. From the equation, it is apparent that the required C/I ratio would then be 55 dB. This is a worst case condition and should be used only if threshold degradation is a real problem and reliable selectivity information cannot be obtained from the manufacturer. Another way threshold degradation affects receiver performance is described later in this article, right after the discussion of *Adjacent Channel Modulation Sidebands*.

Co-Channel Interference — Intercarrier Beat

This type of interference originates from the difference in frequency between desired and undesired carrier signals. The interference is present whenever the frequency difference between these signals causes a beat to fall in the baseband spectrum. Figures 3A and 3B illustrate this condition.

This situation occurs in two-frequency plans because use of the same frequency on alternate hops requires receiving that frequency from two directions. If there is objectionable co-channel interference it is an indication that the antenna-to-antenna isolation is inadequate for use in two-frequency plans.

Horn reflector or shrouded paraboloid antennas provide the most discrimination, standard paraboloid or paraboloid-periscope systems the least discrimination. High performance antennas with a rated front-to-back ratio of 70 dB or greater are recommended for "two-frequency plan" systems. However, final installation may not meet this criteria due to local backscatter situations. Then intercarrier beat becomes the controlling mechanism for interference. Typical limits for single exposures to tones are 30 to 500 pWp0, depending on where the beat tone is in the baseband spectrum. The level of the intercarrier beat tone

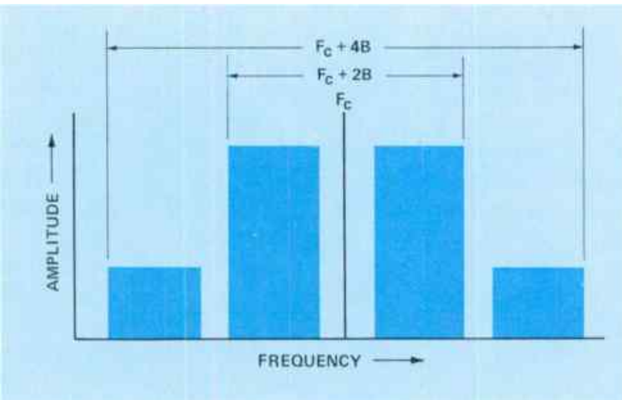

Figure 3A. Normal FM signal spectrum.

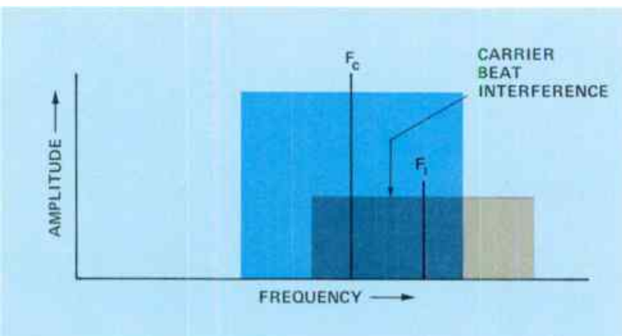

Figure 3B. Interfering signals (carrier beat).

changes dB for dB with any change in the C/I ratio.

System layouts where repeater sections are not in a straight line provide better discrimination between sections using the same frequencies, because of overshoot situations. Overshoot problems are usually intra-system and occur most frequently in systems where the points served are in a straight line; railroads or pipelines for example. Overshoot problems can be particularly troublesome in areas subject to ducting, such as the flat humid areas along the Gulf Coast. If it is impractical to zigzag the path enough to break up overshoot, it may be necessary to change the frequency plan.

During periods of heavy traffic, the carriers will be reduced slightly by load to yield about 3 to 6 dB improvement. TV modulation on either signal reduces the carrier amplitude. This provides a spreading advantage exceeding 10 dB. Spreading advantage results from the fact that usually one and sometimes both carriers are dispersed or "spread" by low frequency modulation. If spreading does not exist, it can easily be created by applying some form of low frequency modulation to one of the carriers. Even a few alarm tones in the orderwire will provide considerable spreading.

One long and one short path on either side of a repeater in a two frequency plan can cause excessive intercarrier interference. In this case, attenuation of the signal by reducing the power at the transmitter for the short path might be a feasible method for reducing the interference.

Co-Channel Interference — Modulation Sidebands

Modulation sideband, co-channel interference occurs when the interfering carrier is so close in frequency to the wanted carrier that the intercarrier beat is below all traffic in the baseband. Then the interference is not a tone but modulated sidebands. This situation is illustrated in Figure 4.

When the interference does not have sidebands, i.e. is in idle load condition, a similar noise is generated from the cross products of the sidebands of the desired signal and the interfering carrier. However, this condition is about 3 dB less severe. When the interferer is TV modulation, this type of co-channel interference will be more severe into message systems than any message interference. The severity is a function of the video signal content. Measurements with video test signals show interference 0 to 6 dB greater than message interference, although theoretically the video interference should be even larger.

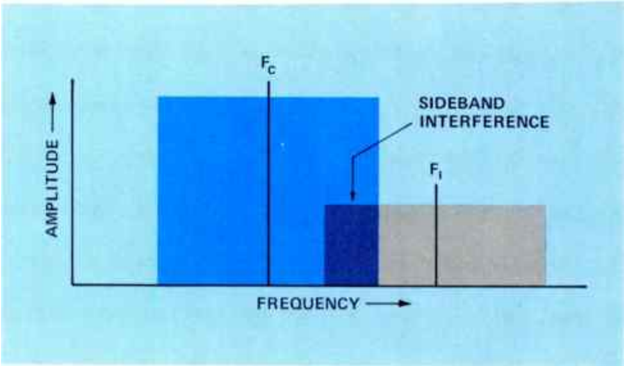

Figure 4. Interfering signals (sideband).

Adjacent-Channel Interference — Modulation Sidebands

This interference can be thought of as sideband overlap, where two fm signals, with carriers close together, have modulated sidebands occupying the same frequency spectrum. Some immunity to this overlap can be provided by polarization and/or antenna decoupling or screening, depending on the source of interference.

The amount of adjacent-channel interference noise due to sideband overlap is difficult to measure because "Direct Adjacent-Channel Interference" (DACI) combines with the overlap interference effect. In addition, there are receiver spurious responses which appear as adjacent-channel interference or co-channel interference, depending on where they are generated. DACI and spurious responses will be discussed later.

Co — and Adjacent Channel Threshold Degradation

Co and adjacent channel, sideband-overlap interference is usually the controlling mechanism when a comparatively small frequency separation exists between the desired and interfering carriers. The critical separation is within twice the top baseband multiplex channel frequency (first order sideband overlap) although measurable interference may be present out to the second order sideband overlap. When the rf separation exceeds the critical separation, threshold degradation usually becomes controlling, as shown in Figure 5.

This threshold degradation is characterized by an upset in the mute point or noise or drop level of the victim receiver. It results from an interfering signal, perhaps far removed from the modulation bandwidth, falling into the IF amplifier AGC circuits. Threshold degradation might be controlling even when the interfering carrier is so lightly deviated that sideband overlap does not occur. The following example illustrates threshold degradation.

Assume a −55 dBm interfering carrier 20 MHz removed appears at the receiver input. Assume also that the top multiplex channel is at 2.6 MHz, the IF frequency is 70 MHz, and the rf and IF filters reduce the interference signal 30 dB. We now have an indicated −85 dBm 90 MHz interfering signal in the victim IF. Assume further that the mute point for the victim receiver is also −85 dBm and the desired signal has faded to that point.

Under the above conditions, the AGC loop detects the interference as a valid signal and reacts to the −82 dBm sum of the interfering and desired signals. The IF gain is held essentially constant as the desired signal fades further. This causes depressions in the baseband drop levels but holds the noise applied to the mute unit constant. Therefore, receiver muting does not occur.

As a general rule, the interfering signal falling into the IF passband must be held to about six dB below the desired signal mute point, to limit threshold degradation to one dB (10 dB below limits threshold degradation to 0.5 dB).

Some microwave receivers have threshold extension circuits which automatically reduce the IF bandwidth about 75% during low signal level periods. In addition to lowering the fm improvement point, thereby increasing fade margin and system gain, this IF bandwidth constriction introduces 10 to 25 dB increased insertion loss to an adjacent channel interfering signal. This usually eliminates threshold degradation. This advantage is important in congested areas because it permits frequency assignments which would

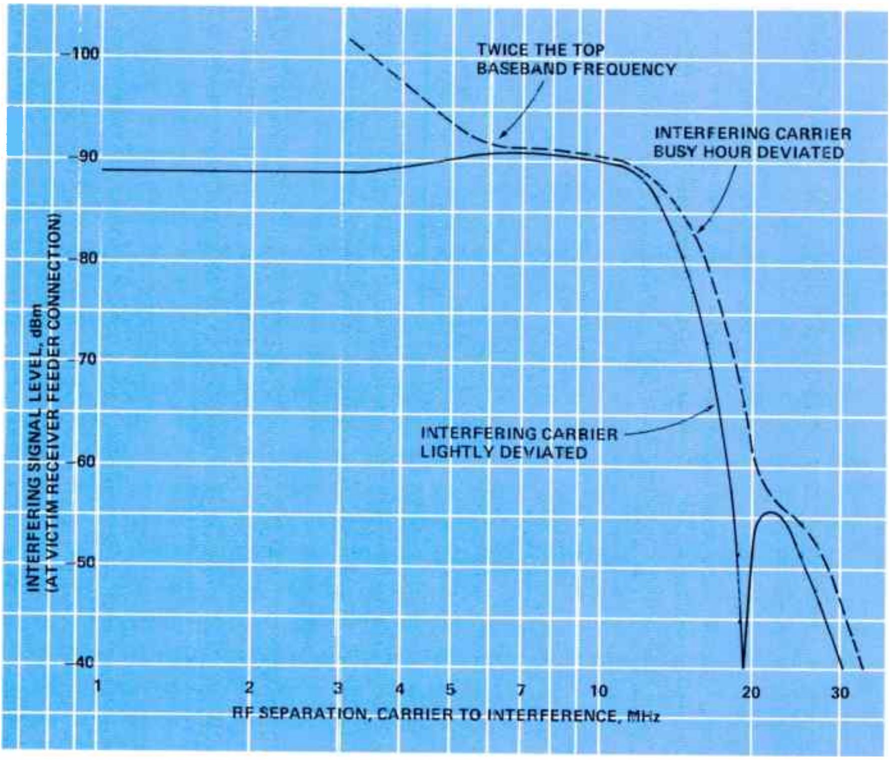

Figure 5. Interfering signal level for 1 dB threshold degradation (600 channel receiver, 22 MHz IF −83 dBm normal 58 dBrnc0 threshold mute point).

not otherwise be available. Threshold extension is shown on the quieting curve, Figure 1.

Direct Adjacent Channel Interference (DACI)

Direct adjacent-channel interference introduces intelligible crosstalk into the victim receiver's baseband so it is considerably more disturbing than the garbled noise resulting from sideband overlap. DACI may occur when a frequency deviated interfering signal appears on the steep amplitude skirt of the victim receiver's IF filter or, less frequently, the rf filter skirt.

The DACI mechanism is similar to the slope detection method for demodulating fm signals in inexpensive AM/FM broadcast receivers. The fm interference on the filter slope is converted (slope detected) into an amplitude modulated signal. This low-level AM signal is applied to limiters which create AM sidebands which are passed through the discriminator and into the baseband drop.

A reasonably high level of interference is required to generate DACI. Therefore, it is usually caused by the assignment of a transmitter frequency too close to the frequency of a receiver at the same location. In other words, DACI is most often caused by intrastation T/R interference. Strict adherence to the rules listed later under *General Frequency Assignment Considerations*, will greatly assist in avoiding DACI situations and its consequent intelligible crosstalk.

Spurious Receiver Responses

There are several potential receiver spurious responses which will convert an adjacent channel signal into the desired IF band. These signals will appear as co-channel or adjacent-channel interference as far as the receiver reaction is concerned.

Probably the best known cause for spurious response is an interfering signal at the image frequency. For systems with 70 MHz IF, the image frequency is 70 MHz removed from the local oscillator frequency and 140 MHz removed from the carrier frequency. The frequency allocation practices described under *Frequency Assignments* place the image frequency away from the transmitter frequencies at the same location. Of course this does not preclude the possibility of image frequency interference from a transmitter in a "foreign" system.

An interfering signal at or near 70 MHz from the desired signal acts like another local oscillator, resulting in a first-order mixing process. The magnitude of the undesired IF signal is dependent upon the levels of both the wanted and interfering rf signals. Fading of the desired carrier does not degrade the effective C/I ratio at IF, as is the case with direct or image frequency interference. Frequency translation is one for one; the resulting undesired IF signal frequency is equal to the frequency difference at rf. The frequency of the baseband beat tone is equal to the rf difference between the desired and undesired signals, minus 70 MHz. The magnitude of the baseband tone may be determined by taking C/I as the effective C/I ratio at IF. This ratio is expressed as:

$$(C/I)_{IF} = (C/I)_{rf} + K \text{ (dB)}$$

where $(C/I)_{rf}$ is the rf carrier-to-interference level at normal receive carrier level, i.e. under unfaded conditions. The transfer factor K is dependent upon the frequency relationships between the interference, the desired carrier, and the local oscillator. The receiver filter and the mixer conversion efficiency may also affect K so the actual value of K, for a given frequency separation between interferer and carrier, must be obtained from the receiver manufacturer.

A spurious receiver response results from the mixing of the second harmonic of the local oscillator or of the desired signal with the second harmonic of the interference, when the interference is at a frequency one half the IF frequency from the desired frequency i.e., ($f_C \pm 0.5\ f_{IF}$). There is a 2 for 1 relationship between the interfering frequency and the spurious product with regard to both frequency and level. Interference at a frequency C ± 35 ± X MHz will cause a baseband beat tone at a frequency 2 (X MHz). This tone will drop 2 dB in level if the interference drops 1 dB. This may be expressed as $(C/I)_{IF} = 2(C/I)_{rf} + K$, where $(C/I)_{rf}$ is the actual carrier-to-interference ratio and K is an empirical factor.

Frequency Assignment Considerations

The operating frequencies for each microwave terminal and repeater station must be carefully planned to prevent harmful interference between stations in the same system as well as with other systems in the same area.

Channel frequency assignments for the 6 GHz Common Carrier Band are shown in Tables 1 and 2. This band is used to illustrate basic principles for use in assigning frequencies, selecting antennas and making manifold connections. These basic principles apply to

CHANNEL NUMBER	FREQUENCY (MHz)
1	5945.20
2	5974.85
3	6004.50
4	6034.15
5	6063.80
6	6093.45
7	6123.10
8	6152.75
1'	6197.24
2'	6226.89
3'	6256.54
4'	6286.19
5'	6315.84
6'	6345.49
7'	6375.14
8'	6404.79

Table 1. Standard channel frequencies in 6 GHz band (CCIR Rec. 383-1).

CHANNEL NUMBER	FREQUENCY (MHz)
1.5	5930.375
2.5	5960.025
3.5	5989.675
4.5	6019.325
5.5	6048.975
6.5	6078.625
7.5	6108.275
8.5	6137.925
1.5'	6182.415
2.5'	6212.065
3.5'	6241.715
4.5'	6271.365
5.5'	6301.015
6.5'	6330.665
7.5'	6360.315
8.5'	6389.965

Table 2. Interleaved channel frequencies (CCIR Rec. 383-1).

other frequency bands and types of service although the actual numbers will be different because they depend upon operating frequencies, channel loading and bandwidth requirements.

The frequency assignments in Table 1 are called standard channel frequencies. They provide up to eight two-way channels in the 5.925 to 6.425 GHz band and are based on a 29.65 MHz spacing between channels. The band is divided in two so that at any one location, all transmitters operate in one half of the band and all receivers operate in the other half. This minimizes transmitter-to-receiver interference in the same station and affords full rf channel growth potential.

Some locations may be forced to deviate from the standard plan to avoid interfering with existing systems or to coordinate with other systems. Table 2 shows channel assignments which are offset 14.825 MHz from the assignments in Table 1, but with the same 29.65 MHz channel spacing. This spacing must be maintained; i.e., Table 1 and Table 2 frequencies cannot be mixed on the same manifold. The frequencies in Table 2 are called interleaved frequencies.

Refering to Tables 1 and 2, it is good engineering practice to place the receive local oscillator frequency 70 MHz below the receive frequency in the lower half of the band (channels 1 through 8) and 70 MHz above the receive frequency in the upper half of the band (channels 1' through 8'). This minimizes the possibility of image frequency interference within the system.

Two high directivity antennas with dual polarization feeds are generally required to provide eight two-way channels. All transmitters are placed on one antenna and all receivers on the other, with alternate channels cross-polarized.

The following requirements, for heavy route, broadband systems, are good practice that must be met if the allocation differs from that shown in Table 1 or 2.

a) At any one location, the transmitters should be in one half of the band and receivers in the other half.
b) Cross-polarized antennas or separate antennas on parallel paths require at least 29.65 MHz separation from transmitter to transmitter and from receiver to receiver.

c) Do not select a transmitter frequency within 20 MHz of a receiver image frequency within the same station. Standard receiver LO assignments (below signal from 5925 to 6175 MHz and above signal from 6175 to 6425) will prevent this condition from happening.

d) Reusing the same frequency on consecutive repeater sections requires receiving the same frequency from two directions. Therefore, high directivity antennas must be used. If the lower portion of the baseband is vacated to provide a guard band for the carrier beats, then 65-dB front-to-back ratio antennas are normally adequate. It should be noted that one long and one short path can introduce excessive co-channel interference. To reduce the co-channel coupling, the path must be engineered to the specific requirements.

e) Systems using common feeders may have third-order difference products of two or more transmitters generated in the waveguide joints, (such as $2f_1 - f_2$) and falling near a received frequency. This problem occurs only when transmitters and receivers share the same waveguide run. It can be avoided by carefully installing and pressurizing precision waveguide.

f) The standard frequency plan includes a transmit to receive spacing of 74.1 MHz. If this must be operated on a single or dual polarized antenna, then the affected receiver must have extremely tight rf selectivity or be equipped with a filter net.

g) On a common manifold or on a common cross-polarized feed to a single antenna, avoid, if possible, the mixing of even and odd channels from the frequency plan. Frequency expansion of this arrangement leads to a transmit to receive spacing of 44.5 MHz on a common antenna. Separate transmit and receive antennas are preferred for this arrangement.

h) The use of ±29.7 MHz spacing between cross polarized channels assumes that there is a typical polarization discrimination of 25 dB or greater. During periods of disturbed propagation, de-polarization may occur that will cause some degradation. This may occur, even though fading does not approach threshold. The problem will be most noticeable at the highest baseband frequencies where the greatest sideband overlap occurs. Systems which are loaded to 2400 channels, or flanked by a digital system spectrum, will be more susceptible to this degradation.

Until now our discussion has principally concerned intra-system interference. The following is focused on inter-system rather than intra-system interferences, although many of the concepts also apply to the latter.

In dealing with inter-system interference the microwave engineer has three basic objectives:

1. He wants to make sure that his own systems, whether existing or proposed, will be adequately free from interference by others.
2. He needs to be able to determine that his proposed new systems will not interfere with any other systems already existing or applied for, and to be able to convince the users of such other systems that there will be no interference. This latter step is done via the prior coordination process.
3. He needs to be able to determine that his proposed new system meets all the specific requirements, with respect to interference, laid down in FCC rules, and to be able to

convince the FCC that this is the case.

Up until about 1970, interference analysis and frequency coordination in the common carrier bands was a pretty simple process. Outside of the telephone companies and Western Union, there were very few users in the band and everyone was using conventional FM systems, with FDM carrier. Almost the only complication was the sharing of 4 and 6 GHz with the international satellite service, but there were only two or three earth stations, and they were buried deep in bowls well away from the regular microwave routes.

Since that time we have seen a huge proliferation of terrestrial microwave systems, the advent of the domestic satellite service, with dozens of new earth stations, many located quite near to population centers, and the implementation of numerous systems using digital microwave. Also, we have some rather definite and detailed FCC rules for coordination between terrestrial microwave systems and earth-satellite systems. Finally, the "prior coordination" process has been instituted which requires an exchange of information by the proposer of a new system with all other existing users within the area, and a study to assure that the new system will not interfere.

Since an individual microwave hop has interference potentials with all other systems sharing the same band and located within a radius of 120 miles or so (up to 200 in mountainous areas), the total problem—except in isolated areas with few systems—has become far too complex to be handled manually. Today the problem is solved, almost universally, on a computer-aided basis.

But regardless of the overall complexity, any given situation can be broken down into some number of individual interference exposures, each one of which can be treated and analyzed independently of all the others. This "unit" interference situation involves interference from a transmitter on one microwave hop into a receiver on another microwave hop. If we can come up with a satisfactory way of dealing with this unit situation, we can deal with the total problem by simply repeating the process for every possible unit situation which might arise.

The question, "Its there interference from Transmitter A into Receiver B?", can be broken into two parts:

1. How much interference can the receiver tolerate before performance become unacceptable? (Establishment of interference criteria).
2. Will the interference level from this transmitter into this receiver exceed the unacceptable value? (Establishment of calculation methods).

To resolve interference situations to the satisfaction of all parties concerned, it is highly desirable—indeed almost mandatory—to have general agreement among users and frequency planners on the parameters and the calculation methods to be used.

For coordination among terrestrial microwave systems, FCC doesn't provide any specific rules about interference (except to ban 'harmful interference' without defining it). It is up to the users themselves to work things out by a prior coordination process. In effect it is up to every user to decide (or have decided for him by whoever does his frequency planning) what criteria to use for acceptable interference, and how to calculate what the level will be. A sort of "working compromise" has developed, with everybody exchanging sets of criteria matrices and accepting the values established by others users. In other words, each user states what is a tolerable level of interference into his own receivers and the others respect this decision.

Calculation methods also differ, but here too there is considerable give and take and the process seems to be working. But it is far from ideal, and there is a great need for some sort of cooperative effort on the part of all users to see if a common set of interference criteria can be developed, and if all can agree on a unified method of calculation of the actual level of interference into a receiver.

The industrial users operating under the Safety and Special Services Bureau of the FCC have gone considerably farther along this road than the common carriers. A joint working group of the Electronics Industries Association and the Operational Fixed Microwave Council, representing microwave manufacturers and user organizations respectively, came up with a set of interference criteria which are now being used by all parties, with FCC approval. These criteria matrices, together with a considerable amount of discussion and descriptive material, have been published as "Industrial Electronics Bulletin No. 10-C" by EIA, and their existence has greatly simplified frequency coordination in the industrial bands. Perhaps some day there will be a comparable action in the common carrier bands.

For coordination between terrestrial microwave systems and earth-satellite microwave systems the situation is a little different, since the FCC rules themselves spell out many details of the process including the definition of the basic interference criteria. They also impose some restrictions on terrestrial microwave systems in the shared bands, barring paths whose beams intersect the geostationary orbit, and also restricting paths whose beams intersect a possible earth station beam within the lower atmosphere.

Establishment of Interference Criteria

This is by no means an easy matter, in fact it is of great complexity and difficulty. Here are some of the problems:

The two systems may differ widely in nature, and their spectra may be very dissimilar. For example, a terrestrial system might be FDM-FM, with channel capacities ranging from a very few up to as many as 2400 channels, it might be FM with video plus program channels, digital microwave using PSK, digital modulating an FM radio, or various kinds of hybrid systems involving combinations of two or more of these. Each of these kinds of systems has its own unique set of spectral "sensitivity to interference" characteristics, and its own unique set of spectral characteristics as an interferer.

Until quite recently, most interference analysis and even coordination was done under the assumption that the interfering system was identical in characteristics to the victim system. This was a reasonable assumption as long as the bulk of the interference problems were intra-system rather than inter-system. Also, it greatly simplified matters since it is comparatively easy to analyse interferences between identical systems. This is no longer sufficient.

The Practical Approach:

The common method, used by almost everyone, is to develop matrices with multiple columns representing the various types of victim system to be considered, and multiple rows representing the various types of systems to be considered as interferers. Appropriate numbers are pre-calculated and entered into the matrix for each particular combination of interferer and victim. These numbers, usually in the form of a minimum required C/I ratio at the input to the victim receiver, are intended to represent the just acceptable level for a single exposure of interference.

Most common carriers have developed sets of matrices for defining allowable levels of interference into their own microwave systems, and the general practice is to make these matrices available to other users in the prior coordination process. The matrice approach is far from ideal, but it is about the only workable method around, at least for the time being. One of the big problems is that to keep the matrices to even a moderately reasonable size it is necessary to "standardize" things to a very high degree, to place constraints on the parameter variations, and to make quite a number of assumptions and to some degree arbitrary decisions as to how to treat the various possibilities which can arise.

All this is in the process of preparing the matrices in the first place. Once they have been worked up and officially accepted, it then becomes possible—and to a great extent this is what is actually done—to ignore all of the foregoing and simply treat the matrix numbers as the "requirement".

For example, look at the first item in the Table 3 simplified matrix for interference into a 1800 channel system in the 6 GHz band. If the interferer is a similar system on the same assigned frequency, the requirement is a C/I ratio of 68 at the input to the victim receiver. If the assignments are separated by 7.4 MHz, the requirement is 90 dB and so on. That's all one really needs to know in order to use such a matrix. If the particular combination of interfering system type and victim system type can be located in the matrix, the answer is there. But if one of the interfering types, or something reasonably similar to it, is not in the matrix there's a problem. And if one wants to know whether or not the number is "flexible" there's a problem. In both cases a knowledge of how such matrices are derived and an understanding of their limitations can be very helpful to the engineer.

C/I Ratios Versus Absolute Interference Levels as the Criteria:

There are two schools of thought as to whether the levels of allowable interfering carrier at the receiver input should be established in absolute values, i.e., in dBw or dBm, or referenced to the level of the desired carrier and expressed as C/I in dB, where C is the normal level of the desired carrier and I is the level of interference, in the same logarithmic units.

INTERFERING SYSTEM	% STABILITY	VICTIM SYSTEM 1800 CHANNELS .002% STABILITY				
		SPACING 0.0 MHz	SPACING 7.4 MHz	SPACING 14.8 MHz	SPACING 22.2 MHz	SPACING 29.6 MHz
1800 CH	.002	68	90-C	65	47-T	27-T
1200 CH	.002	70	90-C	64	47-T	27-T
960 CH	.005	74	90-C	63	47-T	27-T
300 CH	.02	81-C	90-C	63	50-T	30-T
UNMARKED IS SIDEBAND BEAT, C IS CARRIER BEAT, T IS THRESHOLD, 2 pWp0 FOR SIDEBAND BEAT, 50 pWp0 WITH 10 dB SPREADING FOR CARRIER BEAT.						

Table 3. Simplified Matrix, C/I Ratios in dB, 5925-6425 MHz band.

In analyzing interference between terrestrial systems, the practice is to use C/I. This follows directly from the fact that the basic requirements are established as a certain amount of noise to be permitted in the derived voice channels due to the interference; this depends on the level of desired as well as undesired carriers, that is on their difference.

In analyzing interference between terrestrial systems and earth-satellite systems, the international agreements and the FCC rules have established allowable interference criteria on an absolute basis, that is, in dBw or dBw/4 kHz. But when one analyzes the derivation of these numbers, one discovers that it is actually based on an implicit C/I ratio, with the victim receiver assumed to be one of very low noise figure (750° or about 5.5 dB) and a specific receive level (the level which corresponds to 25 pWp0 of thermal noise in the top channel). Hence what they have really done is simply to assume a rather "worst case" situation as far as the victim receiver is concerned. These absolute numbers are really intended primarily for the development of coordination contours, and for a "first cut" at analyzing the actual interference problems. In analyzing such actual problems, the potentiality exists for modifying the numbers to take account of the actual receiver characteristics. In effects this is changing the criterion from absolute to C/I.

Basic Criteria:

For interference into its FDM-FM systems, GTE has established an objective of 2 pWp0 per single exposure (in any voice channel) for sideband beat 50 pWp0 for carrier beat and an objective that any single exposure shall not degrade the designed practical threshold by more than 0.5 dB.

The first two of these objectives are almost identical to Bell's objectives for interference into long-haul systems, and are the controlling objectives for co-channel interferences. The threshold degradation objective primarily affects adjacent and semi-adjacent channel interference, which Bell has not treated in the same manner.

How is a 2 pWp0 per exposure criterion arrived at? Basically by a process such as this: The noise budget for a 4,000 mile system calls for about 41 dBrnc0, or roughly 12,500 pWp0. Assign about 10% (this is good engineering practice) to intra-system and inter-system interference. In a 2-frequency system there will be 2 exposures per hop of intra-system interference, and assume there are also 2 exposures, on the average, of inter-system interference. Since there are about 150 hops in a 4,000 mile system, this means a total of 300 + 300 or 600 individual exposures, so that each exposure can have 1,250/600 = 2 pWp0 to meet the objective. Carrier beat is given a more liberal allowance because it is expected to appear in different parts of the baseband in different hops, and also because it is expected to be present in a limited number of situations.

These basic criteria are for long term interference, the kind which occurs when both the desired and undesired carriers are undergoing normal propagation. Where the interference path is line of sight, this is the controlling kind. But where the interfering path is normally obstructed so that long term objectives are met, there may be occasional unusual periods when the interference rises by a large amount. To take account of this situation a short term criterion is also necessary. This concept has not been very well developed insofar as terrestrial system interferences are concerned.

But basically it is treated by allowing the interference to rise by some amount, typically 10 dB, provided it does not do so for more than some very small percentage of the time, typically 0.01%.

Basic Criteria for Interference Between Terrestrial and Earth-Satellite Systems:

Here things are a little different since the criteria have been established by law, in the new FCC rules patterned after international recommendations by CCIR and WARC.

CCIR (and FCC) start by allocating 1,000 pWp0 as the maximum total interference from all earth stations into any microwave system. For domestic situations in the U.S.A. the FCC assumes that a long haul system might have a total of 4 exposures to earth station interference, which in effect makes the per exposure allowance 250 pWp0. This is for long term interference. For short term, the allowance is 50,000 pWp0 not to exceed .01% of the time, for a total long haul system. Here the number of assumed exposures subdivides the time percentage rather than the noise, and again FCC assumes 4 exposures in a long haul system, making the basic objective for short term 50,000 pWp0 for not more than .0025% of the time, per exposure. These are for interference into the terrestrial system by the earth station transmitters.

For interference from terrestrial transmitters into the earth station receivers, the same 1,000 pWp0 and 50,000 pWp0 numbers apply, into any earth-satellite system, but the assumed number of exposures is different, as is the time percentage.

For interference from an earth station into a terrestrial system receiver in the 6 GHz band, the allowable levels per FCC are:

Long term (not to exceed 20% of the time) −154 dBw/4 kHz.

Short term (not to exceed .0025% of the time) −131 dBw/4 kHz.

Two points are worth noting. It is assumed that the satellite service and the terrestrial service will have access to the entire band, so that all coordination is on a "worst case" basis, or at least a co-channel basis. Earth stations are required to use low frequency modulation to "spread" the carrier at all times, hence for interference purposes the earth station powers are specified and treated on the basis of power density per 4 kHz slot rather than the total output power. It thus becomes very similar to thermal noise in the way it is treated. Note also that FCC follows the international practice of expressing the power in dBw instead of dBm.

Calculation Methods

Having established what the highest acceptable level of interference can be (either as a C/I ratio or an absolute value) at the input to the victim receiver, we now turn to its companion question, "What is the level of expected interference at the input to the victim receiver?"

The following illustrates the terrestrial to terrestrial situation. We want the answer in C/I ratio, since that is how the criteria are expressed. Also we are interested in two time percentages, the 50% or median value for long term interference, and the .01% value for short term interference.

There are two basic approaches to the calculation. One is to calculate separately the value of C, the level of the desired signal in dBm or dBw and the value of I, the level of the undesired signal in the same units. C/I is then simply the difference between the two dB values: that is C − I equals C/I.

There are, however, some advantages in a more direct method, where C/I is calculated from a single equation involving several difference factors. Figure 6 depicts the "unit" interference situation, involving the direction A to D of the existing path and direction D to E of the proposed new path. The potential interference we are considering is from the transmitter at D into the receiver at B. Of course there is also an interference path from the transmitter A into receiver E, and if the systems are two way there are paths from B to D and E to A as well. In some cases there might also be interference potentials from A to D, D to A, B to E and E to B. But here we look only at the D to B situation, since all the others can be handled by repeating the process as many times as needed.

The equation for calculating C/I is:

(all quantities are in dBm or dB) C/I = $(C-I) = (P_a-P_d) + (G_a-G_d) - (L_{AB}-L_{DB}) + (M_d+M_b) - (W_a-W_d)$.

Where:

P_a is the power of the desired transmitter, at A, and P_d is the power of the interfering transmitter at D, both in dBm.

G_a is the main beam gain of the antenna at A, looking in the direction of B, and G_d is the main beam gain of the antenna at D looking toward E.

L_{AB} is the isotrophic path loss of the desired path, A to B, which for line-of-sight paths will be the free space loss in dB. L_{DB} is the isotrophic path loss of the interference path, D to B. If this path is line-of-sight it will also be the free space loss, and this initial assumption is usually made in doing interference calculations. (Where line-of-sight exists or is assumed for both paths, the bracketed term $-(L_{AB}-L_{DB})$ can be replaced by $-20 \log_{10}$ (AB/DB) where AB is the length of path AB and DB is the length of path DB, expressed in the same units.)

M_d is the discrimination of the antenna at D in the direction of the path DB, that is, the discrimination at an angle EDB away from the main beam. M_b is the discrimination of the antenna B in the direction of the path BD. The bracketed term (M_d+M_B) is not a differential since both discriminations work to reduce the level of

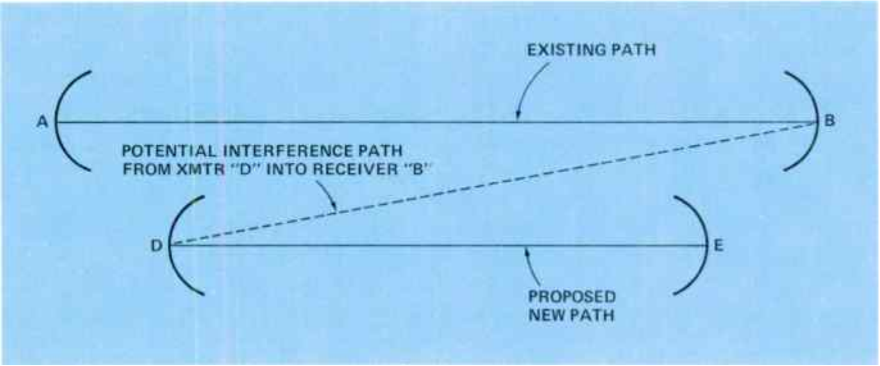

Figure 6. Unit interference situation.

the interfering signal and hence increase the value of C/I. Where the two antennas are cross-polarized one must be careful to choose the particular combination of H to V or V to H which is least favorable, that is, the one giving the lowest value for (M_d+M_b).

W_a is the waveguide and/or filter losses of the transmitter at A, and W_d is the waveguide and/or filter losses of the transmitter at D. The bracketed term is their difference, in dB.

This last bracketed term is often simply left out of the equation, either to simplify matters or because the values are not known.

One of the main advantages of this direct method of calculating C/I over the method of calculating each one separately is: In the direct method there is no need whatever to consider the waveguide and filter losses at the receiver at B, since they are identical for both the desired path and the interfering path and hence the bracketed term which would correspond to them has a value of 0 dB.

Also, our equation is affected only by the *difference* between the loss values at A and those at D, and this difference is usually considerably less than either one taken by itself.

The direct approach is particularly well suited to use in computerized interference analysis, and is also preferable even for manual computations.

A basic assumption to almost all computerized frequency analysis programs is: If the interference (C/I), calculated on the assumption that the interference path is line-of-sight, is equal to or greater than the required long-term C/I objective (for example, the value shown in the matrix), the interference is satisfactory and there is no need to investigate short term interference or do any other calculations. Indeed, this is as far as most computer analyses go, and even so they are able to eliminate the vast majority of the potential cases which must be considered.

Even on a manual basis, it is desirable to look first at the C/I on a free-space loss basis. Only if the required long-term C/I is *not* met on this basis does one have to resort to the time consuming process of checking the path profile and doing calculations of obstruction loss to see whether both long term and short term criteria are met.

The complexities involved in engineering a microwave system to minimize interference, while complying with the regulations of the licensing authority, make it impractical to discuss all the details in this publication. The references listed in the bibliography should prove useful to those who would like more information. In most cases, complete liaison with the equipment supplier will be necessary during system planning and installation. Such liaison may also be helpful when an interference problem occurs on an existing system.

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