communications

DATAFILE BULLETIN

FILE UNDER: Servicing

INTERFERENCE

BULLETIN NO: 10002-2

DATE: December 1961

RADIO-FREQUENCY INTERFERENCE (RFI)
in
TWO-WAY FM RADIO SYSTEMS

ABSTRACT

The major types of radio-frequency interference (RFI) which are apt to be encountered in two-way FM radio systems are described in this bulletin. Special emphasis is placed on the role of receiver selectivity in preventing interference. Since technicians normally notice and identify RFI by its degrading effects on receiver performance, the effect of each type of interference on the receiver is discussed in detail. A practical procedure for (1) analyzing and solving RFI problems in existing radio systems or (2) predicting problems in proposed systems is presented, based upon the use of the *Interference Analysis Work Sheet* (Bulletin No. 10002-3).

COMMUNICATION PRODUCTS DEPARTMENT, GENERAL ELECTRIC COMPANY, MOUNTAIN VIEW ROAD, LYNCHBURG, VIRGINIA

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RADIO-FREQUENCY INTERFERENCE (RFI)

in

TWO-WAY FM RADIO SYSTEMS

As the two-way radio frequencies become more and more crowded, radio-frequency interference (RFI) occurs more and more frequently. This is due not only to the large number of new users, but also to the creation of many new channels by channel-splitting. Much of the unused space between the original wide-band channels, where RFI may have existed unnoticed, is now being brought into use. Also, many of those "ideal" antenna sites on mountain tops or tall buildings now bristle with new antennas --- and complex RFI problems.

As a result, two-way radio technicians are being called upon more frequently to solve interference problems. This bulletin is intended to acquaint technicians servicing General Electric Two-Way FM Radio Systems with the basic facts about RFI problems they are apt to encounter, so that they will be better prepared to solve them to their customers' satisfaction. In addition, a procedure is presented for predicting RFI problems in proposed radio systems.

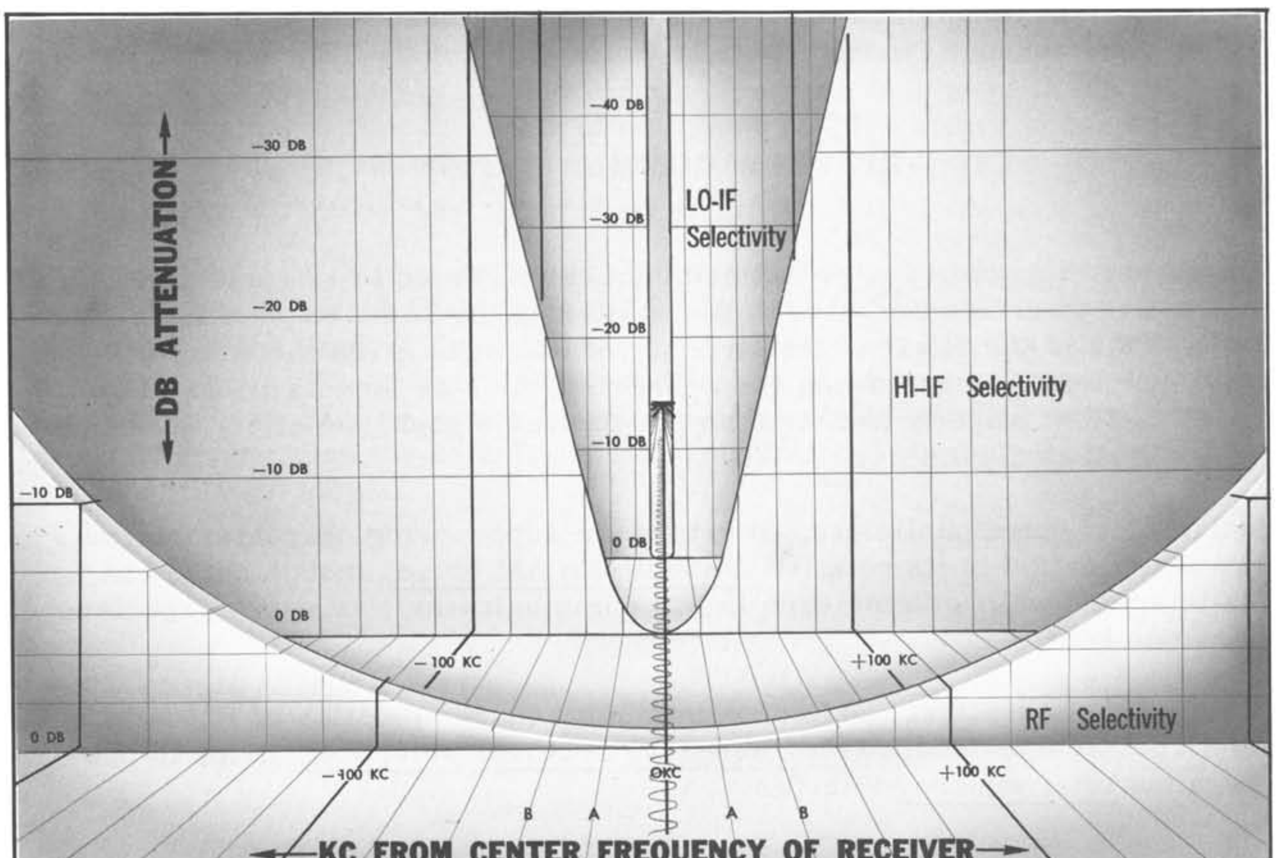

Figure 1 - "View" of Typical Low-Band FM Receiver's Selectivity (narrow band)

DEFINING RFI

Radio-frequency interference (RFI) can be defined as either (1) RF power which tends to interfere with the reception of desired signals or (2) the disturbance of signals which results. This RF power may be either natural or man-made, but the result is the same: reduced intelligibility.

Not all undesired signals can be classified as interference. Calls heard from users sharing the same channel, for instance, are not interference if they are not disrupting the reception of desired signals. They are a nuisance, however, and for this reason have sometimes been referred to as "botherance." This can be particularly annoying to radio users in metropolitan areas, where the channels are crowded, and in the lower frequencies, where frequency assignments have been particularly dense. CHANNEL GUARD, tone signaling and dial signaling, although they are very effective in reducing "botherance", will not be considered in this bulletin, because they are not effective in reducing interference.

Further complicating the channel-crowding problem is skip interference, bringing interfering signals from transmitters hundreds --- even thousands --- of miles away. Most technicians are well aware of the relationship of skip propagation to the 11-year sunspot cycle.

RFI IN FM COMMUNICATION

One inherent characteristic of FM communication which is extremely valuable in preventing interference between users sharing the same channel is "capture effect". This is the effect of the stronger of two signals (on the same frequency) completely suppressing the weaker signal. As long as an undesired signal is at least slightly weaker than the desired signal, the effect of the undesired signal is negligible.

A second, and more publicized, interference-suppressing characteristic of FM communication is its relative immunity to AM noise, though noise can cause interference problems even in FM communication, as every experienced serviceman knows.

While the "capture effect" and noise-immunity characteristics of FM help to protect against interference on frequency, receiver selectivity helps to protect against off-frequency interference.

RECEIVER SELECTIVITY

Selectivity is the receiver's first defense against off-frequency interference. A clear picture of how the receiver's selectivity operates is essential, therefore, to an understanding of interference. Figure 1 is a perspective "view" of a typical low-band receiver's selectivity, looking in the "front door" of the receiver. The three "walls", with progressively narrower openings, running across the receiver represent the three stages of the receiver's selectivity (RF, Hi-IF and Lo-IF), each having a progressively narrower bandwidth. Notice that signals within a few hundred KC of the center frequency are not appreciably attenuated by the RF selectivity. Those channels immediately adjacent to the center frequency, such as the adjacent channels ("A") and the alternate channels ("B"), are also passed by the Hi-IF selectivity. Even if these signals are later rejected by the Lo-IF selectivity, they are still capable of causing interference --- particularly if they are strong. Receiver desensitization, receiver intermodulation and receiver spurious response are three types of interference which may result.

The question naturally arises, "Why not move all of the selectivity 'up front' and keep those off-channel signals out of the receiver?" To obtain this selectivity in the RF stages, however, would require filters of fantastically high Q --- in the order of 15,000 in high band, for instance. Even the best high-band cavity filters have Q's of only 1000 to 3000 before becoming very lossy. Not only would low-band or high-band cavity filters be expensive, they could hardly be considered "mobile".

Nevertheless, RF filters with much narrower bandwidth are already on the market. The General Electric RASER (RAnge and SEnsitivity Resonator), currently being used in Transistorized Progress Line, is a triple-section miniature cavity filter which shows more than 25 db improvement over the older single-tuned, iron-core filters (see Figure 2). RASER selectivity actually approaches the selectivity of a conventional quarter-wave cavity resonator with 1-db loops.

In our discussion of RFI, we need consider only three sources of interference (see Fig. 3): co-channel transmitters (transmitters on the same channel as the receiver), off-channel transmitters (transmitters operating on other channels), and noise sources (which produce interference across all channels). RFI from off-channel transmitters can usually be relieved by adding RF selectivity to the receiver. Interference falling on the receiver frequency, however, cannot be eliminated at the receiver, since circuits which would eliminate the interference would also eliminate desired signals. Co-channel interference can only be eliminated at its source.

It would be a mistake to place a majority of the blame for RFI on either FM transmitters or FM receivers. Some engineers have estimated that as many as half the interference problems can only be corrected externally to the equipment affected.

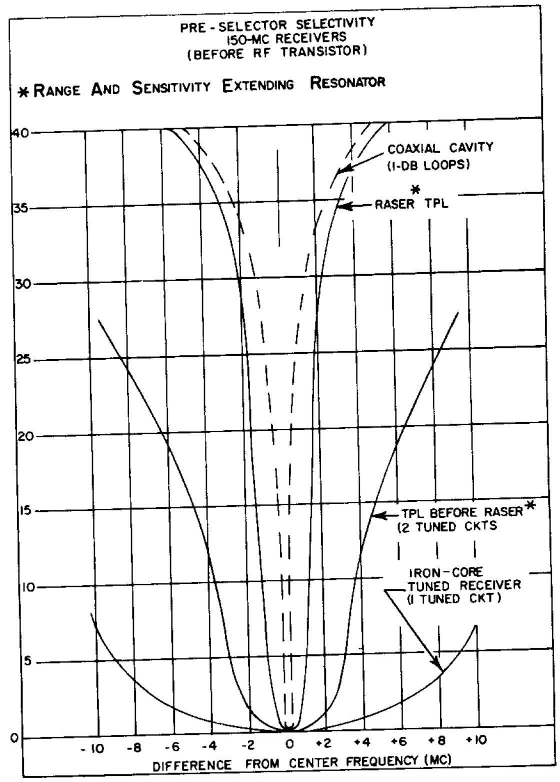

Figure 2 - RF Filter Selectivity, Showing Improved Selectivity of RASER Over Older Circuits

EFFECTS PRODUCED IN FM RECEIVERS BY RFI

RFI produces a degrading effect on receiver performance. Since technicians normally notice and identify interference by this degrading effect, this discussion will approach the subject of interference from this same viewpoint: its effects upon the receiver. Taking each of the effects shown in Figure 3, we will describe how each is produced, its characteristics, and how it is normally relieved.

CO-CHANNEL INTERFERENCE

Co-channel interference is interference falling within the receiver's passband. Ironically, of the five different types, only capture effect is caused by co-channel transmitters; the other four are caused by off-channel transmitters (see Fig. 3):

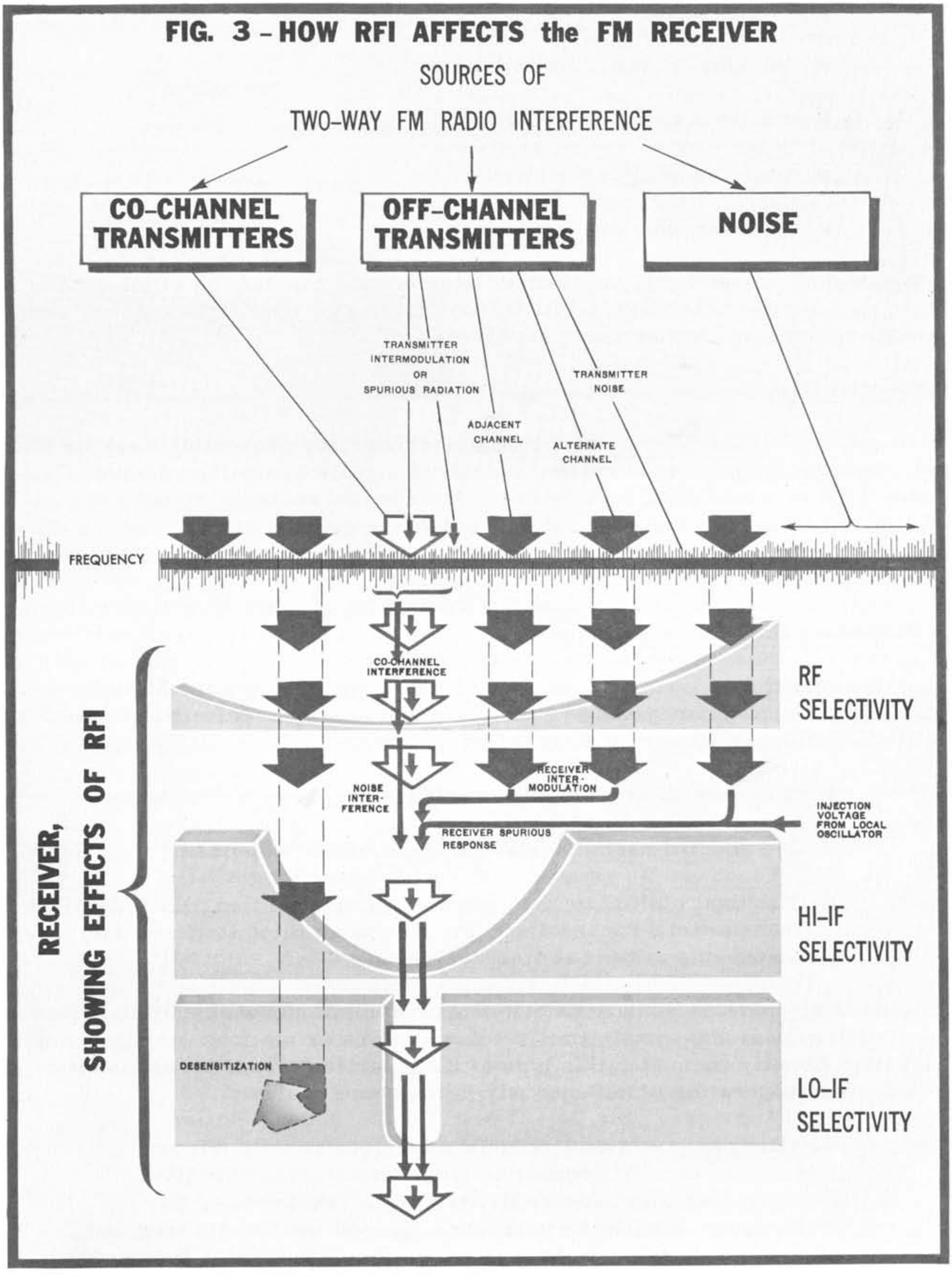
FIG. 3 - HOW RFI AFFECTS the FM RECEIVER
SOURCES OF
TWO-WAY FM RADIO INTERFERENCE
CO-CHANNEL TRANSMITTERS
OFF-CHANNEL TRANSMITTERS
NOISE
TRANSMITTER INTERMODULATION OR SPURIOUS RADIATION
TRANSMITTER NOISE
ADJACENT CHANNEL
ALTERNATE CHANNEL
FREQUENCY
CO-CHANNEL INTERFERENCE
RF SELECTIVITY
RECEIVER INTER-MODULATION
NOISE INTER-FERENCE
INJECTION VOLTAGE FROM LOCAL OSCILLATOR
RECEIVER SPURIOUS RESPONSE
HI-IF SELECTIVITY
DESENSITIZATION
LO-IF SELECTIVITY
RECEIVER, SHOWING EFFECTS OF RFI

- capture effect
- transmitter spurious radiation
- transmitter intermodulation
- interchannel interference
- receiver spurious radiation

As previously mentioned, co-channel interference can only be eliminated at its source, although CHANNEL GUARD, tone dialing or tone signaling may reduce some "botherance" to operating personnel.

Capture Effect

Capture effect usually helps prevent interference, by preventing weak co-channel interference from being heard while desired signals are being received. Near the outer edge of a system's service area, however, a stronger signal from another system sharing the channel could overpower the desired signal (capture effect). Monitoring the channel before transmitting as required by the FCC, however, normally prevents this.

Transmitter Spurious Radiation

Even transmitters which well exceed the FCC requirements for 60 to 80 db spurious attenuation may cause interference in nearby receivers. Those transmitter spurious most apt to cause interference are:

- Spurious (2) at transmitter frequency ± crystal frequency
- 2nd and 3rd harmonics of the transmitter's operating frequency
- The final multiplier frequency of the transmitter. In 450-470 MC transmitters for instance, the final multiplier (tripler) may radiate a spurious in the 144 to 174-MC band.

Transmitter spurious radiation normally causes interference only in receivers located very near the transmitter. Relay stations or stations operating duplex may occasionally encounter this type of RFI, particularly if the transmitter and receiver are operating simultaneously in the same cabinet.

Example 1 - In this example, spurious radiation from transmitter "A" (operating frequency + crystal frequency) is causing interference in System "B" in the same city. Although it might be possible to change the crystal frequency and multiplication of each System "A" transmitter (requiring re-filing with the FCC), it would probably be easier to add a filter to each transmitter to attenuate the spurious frequency.

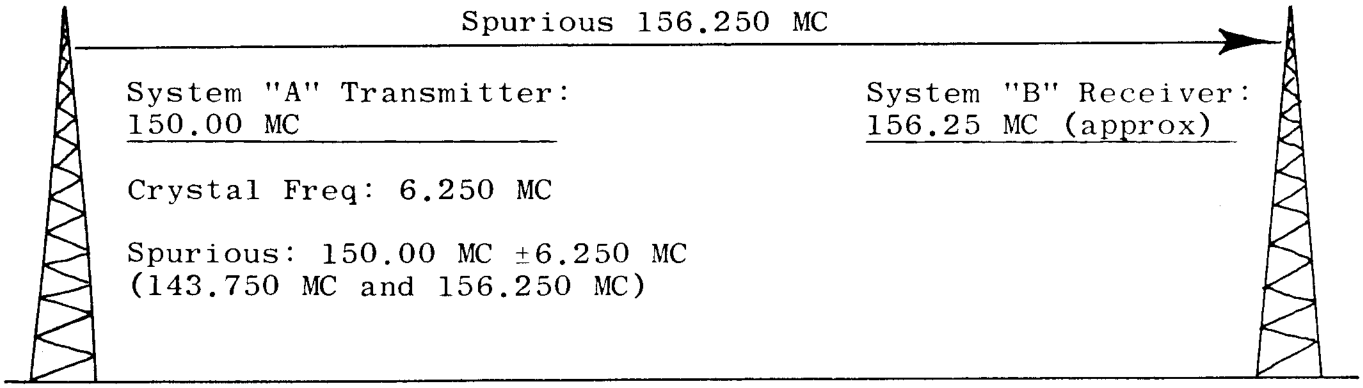

Figure 4 - Example of RFI Caused by Transmitter Spurious Radiation

Transmitter Intermodulation

Intermodulation (IM) products are generated when two or more frequencies mix in a non-linear element. The non-linear operation usually occurs in the transmitter power amplifier (transmitter IM) or in the receiver first converter (receiver IM). Transmitter intermodulation products cause RFI if they happen to fall in the receiver's passband. Since receiver intermodulation is caused by off-channel signals entering the receiver (Remember that wide "front door" of the receiver in Figure 1?), this characteristic is useful in distinguishing between them:

REMEMBER

> ... transmitter intermodulation causes co-channel RFI;
> receiver intermodulation is caused by off-channel RFI.

Example 2 - This is an example of transmitter IM in which the signal from one transmitter is mixing in the power amplifier of another transmitter to produce interference. Of course, this interference will only be present while both transmitters are on the air. Suppose that base stations "A" and "B", located adjacently, were on the air simultaneously on 151.00 MC and 151.50 MC, respectively. It would be possible, if their antennas were sufficiently close together, for the signal from Transmitter "A" to be received by the base station "B" antenna and coupled into the PA of Transmitter "B". By mixing in the PA with the Transmitter "B" signal, several new frequencies at intervals of 0.50 MC could be generated and transmitted, causing interference to any nearby receiver on one of those frequencies.

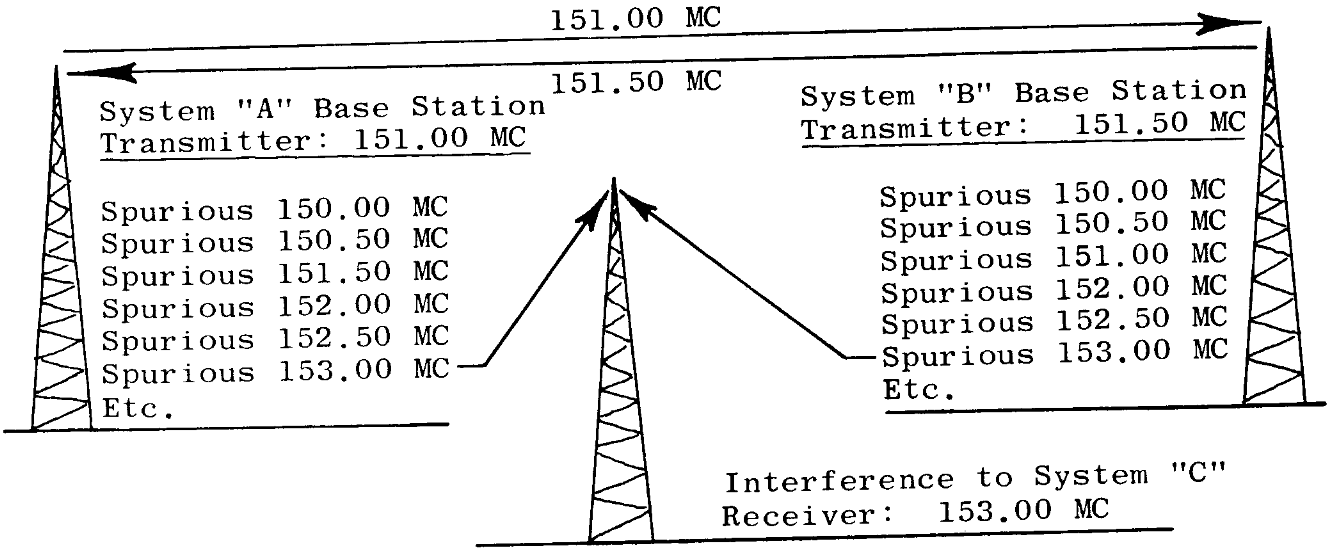

Figure 5 - Example of RFI Caused by Transmitter Intermodulation

> Installing a filter in the antenna circuit of Base Stations "A" and/or "B" to attenuate the frequency of the other transmitter should reduce the interference to a negligible level.

Intermodulation products can be produced outside of either the transmitter or the receiver. In some rare cases, this has been due to the presence of a non-linear conducting element, such as corroded connections between antenna guy wires and anchor rods, acting as a rectifier, in the vicinity of one or both of the transmitters.

> "On one occasion, it was found that a 14-year old . . . truck parked 90 feet from the antenna towers was a prolific source of intermodulation interference. The interference was eliminated by driving the truck 200 feet from the antenna towers."[1]

Although one of the transmitters could be located at some distance from the receiver (particularly a high-power transmitter), one of the transmitters and

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[1] N. H. Shepherd, "A Report on Interference Caused by Intermodulation Products Generated In or Near Land Mobile Transmitters," <u>IRE Transactions on Vehicular Communications</u>, 1959, PVGC-13, p. 16.

also the non-linear device are usually located close to the receiver experiencing the RFI.

No matter where the IM is produced, the resulting IM products are the same. These new frequencies can be easily calculated from the following table, using "A" for the frequency of the first transmitter and "B" for the frequency of the second.

Table I - Calculating Intermodulation Products

ORDER	FORMULAS FOR CALCULATING POSSIBLE INTERMODULATION PRODUCTS
Second	A ± B
Third	A ± 2B, 2A ± B
Fourth	A ± 3B, 2A ± 2B, 3A ± B
Fifth	A ± 4B, 2A ± 3B, 3A ± 2B, 4A ± B
Seventh	A ± 6B, 2A ± 5B, 3A ± 4B, 4A ± 3B, 5A ± 2B, 6A ± B

Only a small number of these products are significant in creating interference. The odd orders of intermodulation products (3rd, 5th and 7th) are most apt to cause RFI, particularly the lower orders (3rd and 5th). Higher orders may produce intermodulation closer to the receiver frequency, but they are apt to be weak, unless the transmitters are very close together or very close to the receiver.

Even if an intermodulation product does not fall within the receiver passband, the deviation (especially of the higher orders) may swing across the passband, causing RFI. Remember that the deviation of the intermodulation equals the sum of each component signal's deviation, each multiplied by the coefficient for that signal indicated in the formula (see Table I). If signal "A" has a ±5-KC swing and signal "B" has a ±10-KC swing, the 5th order intermodulation product represented by "2A ± 3B" will have a peak deviation of (2 x 5) + (3 x 10) = ±40 KC.

Example 3 - Calculate the 3rd and 5th order intermodulation products for transmitter "A" at 152.03 MC and transmitter "B" at 152.27 MC and predict any possible interference with a receiver on 151.565 MC, if the deviation of both "A" and "B" is ± 5 KC.

ORDER	FORMULA	INTERMODULATION PRODUCTS OF A AND B	MODULATION
3rd	A ± 2B	(456.57 MC) and 152.51 MC	±15 KC
	2A ± B	(456.33 MC) and 151.79 MC	±15 KC
5th	A ± 4B	(761.11 MC) and (457.05 MC)	±25 KC
	2A ± 3B	(760.87 MC) and 151.75 MC	±25 KC
	3A ± 2B	(760.63 MC) and 151.55 MC	±25 KC
	4A ± B	(760.39 MC) and (455.85 MC)	±25 KC

Those intermodulation products which lie near "A" and "B" are underlined. Notice, in Figure 6, how these products lie at intervals of Δ f on either side of "A" and "B". (Δf is equal to frequency "A" minus frequency "B".) This is another means of rapidly calculating the products immediately adjacent to "A" and "B".

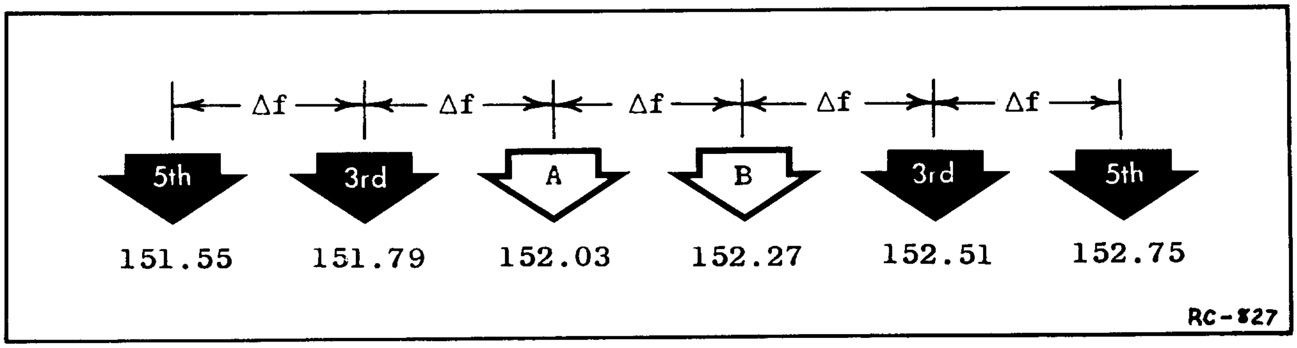


Figure 6 - Intermodulation Products Adjacent to "A" and "B"

> The only interference near the receiver frequency of 151.565 MC is at 151.550 MC. This 15-KC spacing might appear adequate to prevent interference, but the ±25-KC modulation could produce co-channel interference.

Interchannel Interference

Interchannel interference can occur when an adjacent-channel transmitter operates off-frequency or over-modulates. This type of interference is apt to occur during the present conversion to narrow-band standards in low-band and high-band receivers which have not been converted for narrow-band operation.

> "After the date by which a user must reduce his system deviation to ±5 kc, the FCC will not consider any interference which he might experience as harmful interference if he is still using wide band receivers. This means that the user has no recourse except to convert to narrow band receiving equipment if interference is experienced."[2]

Receiver Spurious Radiation

At certain operating frequencies, harmonics of the receiver's second or third oscillator may fall on or near the operating frequency. If one of these harmonics feeds back into the RF stages of the receiver, a continuous "tweet" may result. It is standard practice, if one of these channels is selected, to shift one or both of the local oscillator frequencies and the intermediate frequencies slightly to eliminate the tweet. It is also possible to shift the frequency of the local oscillator to the other side of the desired signal, retaining the same IF's.

RECEIVER SPURIOUS RESPONSE

Response of the receiver to any signal other than a signal on the desired frequency is called spurious response. It can occur in a receiver when one or more off-frequency signals having some peculiar relationship to each other or to an IF and oscillator frequency is received. Spurious responses can be classified as:

- IF feedthrough response
- single-signal spurious response (including image response)
- multiple-signal spurious response (receiver intermodulation)

[2] T. A. McKee, "Practical Narrow Band System Operation," AIEE Conference Paper, 1960, Paper No. CP 60-794, p. 2.

IF Feedthrough Response

IF feedthrough response results when RFI at an intermediate frequency enters the receiver, usually via external leads, and is capacitively coupled into an IF amplifier stage, causing interference. Since intermediate frequencies are selected to avoid frequencies widely used for other purposes, this type of interference is rare in good receivers. When encountered, it can usually be eliminated by by-passing power supply and control leads to the receiver or by additional shielding.

Single-Signal Spurious Response

Single-signal spurious response results when a single off-channel signal, even though attenuated by the RF selectivity, enters the receiver and mixes with a harmonic of a local oscillator to produce a signal on an intermediate frequency. These responses can be predicted from the equation:

$$f_{RFI} = \frac{Pf_{INJ} \pm f_{IF}}{Q} \qquad (1)$$

P and Q are positive whole numbers

f_{RFI} = interfering frequency

f_{INJ} = injection frequency

f_{IF} = intermediate frequency

Image response is a special case of single-signal spurious response, in which P and Q are equal to 1 and the sign ($\pm$) is minus if the local oscillator is tuned below the operating frequency or plus if the oscillator is tuned above the operating frequency. Figure 7 shows the mechanics of image response. As indicated in the figure, the image frequency always lies two IF's (17.4 MC in this case) away from the desired frequency.

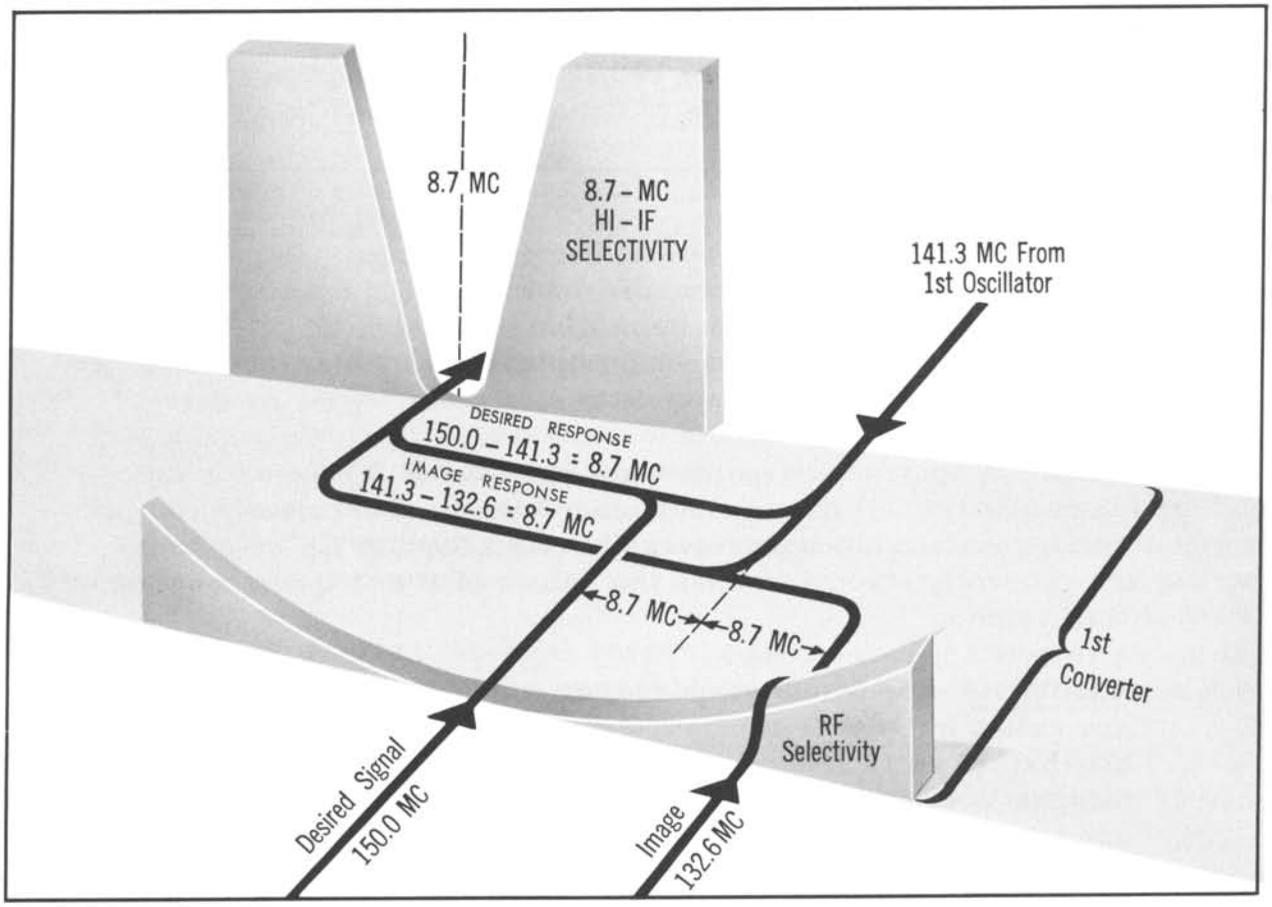


Figure 7 - Image Response

Double-conversion superheterodyne receivers have two image frequencies, triple-conversion receivers have three: one for each converter. Equation (1) describes the receiver's first image, the Hi-IF image. For the other image(s), "F_{RFI}" represents the spurious frequency after conversion. Appropriate calculations would have to be made to determine the spurious frequency entering the receiver. If the injection voltage from the 2nd oscillator were tuned 290 KC (Lo-IF) above the Hi-IF signal, for instance, there would be an image 580 KC (two IF's) above the Hi-IF signal. Before conversion, this image would be 580 KC above the operating frequency.

REMEMBER

... the image for an IF lies two IF's above the operating frequency if injection is above the signal or two IF's below if injection is below.

Spurious response is normally the result of receiver design. Remember the relatively wide "front door" of the receiver pictured in Figure 1? By using high RF selectivity, the 1st image can be minimized. High IF selectivity minimizes the 2nd image (and 3rd image in triple-conversion receivers). An image rejection ratio of 60 db or greater is desirable in a good receiver.[3]

An infinite number of spurious responses are possible at frequencies for which P and Q in equation (1) have values other than 1. Fortunately, few of these are actually measurable in receivers having adequate RF selectivity. Responses are generally strongest when the values of P and Q are most nearly equal and low in value.

Example 4 - Spurious responses in which P and Q both equal 2 are called half-IF responses, because they produce a response one-half of an IF frequency away from the operating frequency. Suppose a 47.20-MC receiver has a Hi-IF frequency of 3.2 MC and the 1st injection frequency is tuned below the signal frequency. The half Hi-IF spurious response of the receiver would be:

$$f_{RFI} = \frac{(2 \times 44.00) \pm 3.2}{2} = 45.60 \text{ MC (or } 42.40 \text{ MC)}$$

Because the 42.40 MC spurious lies so far from the operating frequency, it can usually be safely ignored. Notice that the 45.60-MC spurious lies half a Hi-IF (1.6 MC) away from the operating frequency.

As P and Q become larger, the spurious responses become weaker, but the spurious may lie closer to the desired frequency.

[3] H. M. Sachs and J. J. Krstansky (Armour Research Foundation), "Controlling RFI Susceptibility in Receivers," Electronic Industries, September 1960, XIX, p. 94.

Example 5 - If P and Q were 9 and 8, respectively, and the Hi-IF were 4.7 MC, a 37.92-MC receiver might have a spurious response at 37.96 MC:

$$f_{RFI} = \frac{(9 \times 33.22) \pm 4.7}{8} = \frac{298.98 \pm 4.7}{8} = \frac{303.68 \text{ or } 294.28}{8} =$$

37.96 MC (36.78 MC too far off frequency)

Although it would take a high level of interference to produce such a spurious response, the RF selectivity would be too small to prevent it, since the response is located only 40 KC from the desired channel.

For each IF frequency, the following spurious responses are those most apt to be encountered:

- Image response: twice the IF frequency above or below the operating frequency (below, if injection is below the signal; above, if injection is above the signal)
- Half-IF response (P and Q = 2): spurious one-half IF from the operating frequency (see Example 4)

Many receivers employ multiplication after the 1st oscillator to obtain the first injection voltage. Though unlikely, it would be possible for a harmonic of the 1st oscillator to produce a spurious response, especially if the selectivity in the multiplier string were abnormally low.

RECEIVER INTERMODULATION (Multiple-Signal Spurious Response)

Although receiver intermodulation, by definition, is a special type of receiver spurious response, it will be considered separately here. You will recall from the discussion of transmitter intermodulation that intermodulation (IM) is the mixing of signals in a non-linear circuit, producing new frequencies. Receiver IM results when two or more off-channel signals enter a receiver and interact, due to receiver non-linear characteristics (usually in the 1st converter). It may be difficult to determine where intermodulation is occurring because the new frequencies which can be generated (Table I) are exactly the same, whether they are generated in the transmitter, in the receiver or at some point between. Since transmitter IM enters the receiver on-frequency, whereas receiver IM enters at the original off-channel frequencies, a filter (tuned to pass the receiver frequency) can be inserted in the receiver's input to distinguish between them. If the interference drops to a low level, it must have been due to receiver IM. If the output drops only a few db (due to the insertion loss of the filter), transmitter IM must have been the cause.

To determine which order of IM is occurring, it is sometimes helpful to vary the frequency of a suspected transmitter 1 KC, while noting the change in apparent frequency on the receiver's discriminator (a 1-volt change usually indicates a change of approximately 1 KC). A 2-volt change, for instance, would indicate a doubling of the transmitter's signal during intermodulation. Under the proper conditions, skip can also contribute to IM.

In order for intermodulation to occur, all of the interfering signals must be on the air simultaneously. It can best be minimized in a receiver by using cavity filters or highly selective RF stages, but even the best available techniques fall short of perfection and IM does occur. Receiver IM results primarily from (1) the fact that receivers have a relatively broad RF passband (Remember the "front door" in Figure 1?) and (2) the fact that the relationship of grid voltage to plate current in the first converter is not linear.

2-Signal Intermodulation

As in transmitter intermodulation, the odd orders of receiver IM, particularly the lower orders (3rd and 5th), are most apt to cause interference. These can also be calculated from the formulas in Table I. Remember, from Figure 6, that if signals "A" and "B" are Δf apart, they create intermodulation products on both sides of "A" and "B" at intervals of Δf. It can be seen that IM will produce interference on the receiver frequency when "A" and "B" are located Δf away from the receiver frequency.

The closer the interfering signals are to the receiver frequency, the easier they will get through the receiver's RF selectivity. The most common type of two-signal intermodulation results from interaction of the adjacent and alternate channels on the same side of the desired frequency (see Figure 2).

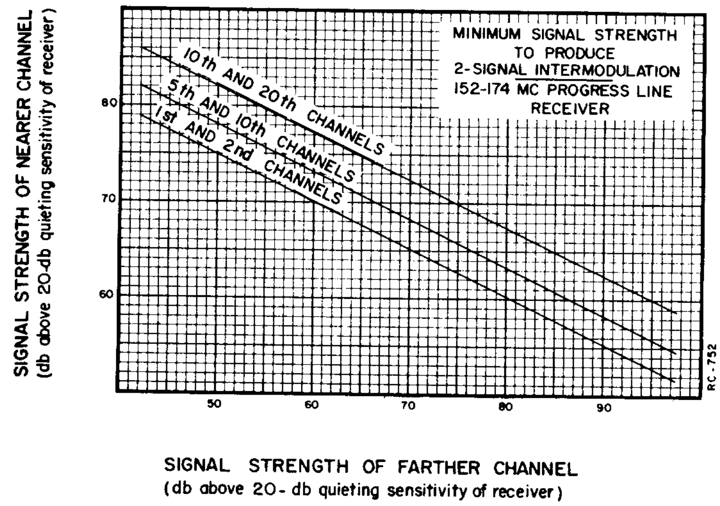
Example 6 - Suppose that a station is operating at 152.30 MC with two other stations in the vicinity: the 152.33-MC adjacent channel and the 152.36-MC alternate channel. With both interfering transmitters on the air, the antenna picks up both signals and carries them to the grid of the first RF amplifier. Due to non-linearity, usually in the first converter, 3rd order IM products result, giving 152.30 MC --- right on the receiver frequency:

$$2A \pm B = (2 \times 152.33) \pm 152.36 = 304.66 \pm 152.36 =$$

$$152.30 \text{ MC (or } 457.02 \text{ MC)}$$

The adjacent and alternate channels are not the only combination of frequencies which can produce receiver intermodulation. In general, if one interfering signal is spaced twice as far from the receiver frequency as the other (f), on the same side, interference can result. At greater RF spacings, however, the RF selectivity of good FM receivers will effectively reduce intermodulation. Figure 8 indicates the minimum signal strengths of 1st and 2nd channels, 5th and 10th channels, or 10th and 20th channels (on the same side of the receiver frequency) which could cause intermodulation in a typical high-band Progress Line Receiver.

Figure 8



Example 7 - Intermodulation Involving One AM Broadcast Station: With one interfering station at f ± 1 MC and a broadcast station at 1 MC, addition or subtraction may produce intermodulation interference on frequency f.

Multiple-Signal Intermodulation

Receiver intermodulation involving more than two interfering signals is occasionally encountered, particularly in metropolitan areas where several transmitters may be located in the same building or within a few hundred feet of each other. It is difficult to predict the combinations or 3 or more signals which are apt to produce intermodulation, but Examples 8 and 9 will present some clues to look for:

Example 8 - Here is a case history in which the combination of three frequencies (f_1, f_2 and f_3) produced interference on frequency "f". Notice the general form of the interfering signals.

General Form for Interfering Signals	Case History in Which $f = 152.15$ MC
$f_1 = f + m\Delta f$, where m is any whole number	$f_1 = 152.27$ MC
$f_2 = f + n\Delta f$, where n is any whole number	$f_2 = 152.51$ MC
$f_3 = f + (m + n)\Delta f$	$f_3 = 152.63$ MC
	$\Delta f = 0.12$ MC
	$m = 1$
	$n = 3$

Notice how subtracting f_3 from the sum of f_1 and f_2 gives f --- right on the desired frequency. When all three signals were received and appeared on the RF amplifier grid simultaneously, intermodulation interference resulted.

	f_1	= 152.15 MC	+ 0.12 MC	= 152.27 MC
	+ f_2	= 152.15 MC	+ 0.36 MC	= 152.51 MC
SUM		= 304.30 MC	+ 0.48 MC	= 304.78 MC
	- f_3	= 152.15 MC	+ 0.48 MC	= 152.63 MC
INTERFERENCE		= 152.15 MC		= 152.15 MC

Example 9 - Intermodulation Involving Two AM Broadcast Stations: In this example, two broadcast stations (1.600 MC and 1.320 MC) interact with a transmitter on 35.70 MC to produce interference on 35.98 MC.

$$35.70 + 1.600 \text{ MC} - 1.320 \text{ MC} = 35.98 \text{ MC}$$

Methods of Alleviating Receiver Intermodulation

Receiver intermodulation involving AM broadcast stations can usually be alleviated by by-passing power supply leads entering the receiver. In those rare instances where a broadcast signal is entering via the antenna, an RF trap in the transmission line can be used. Situations involving frequencies near the operating frequency are usually solved through the use of cavity filters in the receiver input or a crystal filter in the antenna transformer.

The crystal filter simply consists of a piezoelectric quartz crystal, connected across the primary or secondary of the antenna transformer, to effectively short out one undesired frequency, with negligible loss at the desired frequency. Crystal filters are particularly valuable because they are not expensive and because they are useful up to within a few KC of the desired frequency.

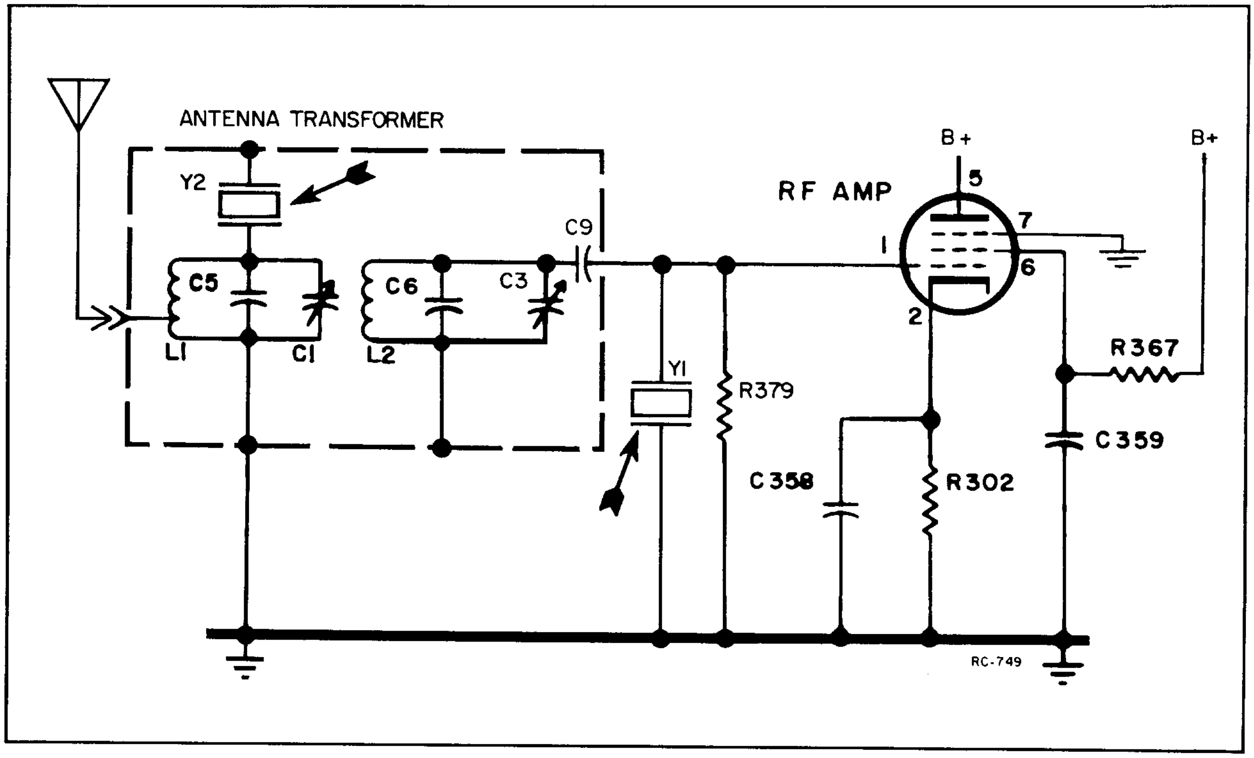


Figure 9 - Low-Band Progress Line Antenna Circuit with Wave-Trap Crystal Filters Added (Y1 for first spurious, Y2 for second spurious)

Crystal filters are presently available for low-band Progress Line Receivers and are applied as shown in Figure 9. When a single crystal is used, the crystal is normally applied across the secondary winding of the antenna transformer (crystal Y1). If it is necessary to trap a second interfering signal, the crystal for this frequency should be connected directly across the primary of the antenna transformer (crystal Y2).

For series resonance of the crystals, each winding of the antenna transformer is loaded with the equivalent resistance of the crystal (approximately 30 ohms at the undesired frequency). This produces a very effective short across each winding of the antenna transformer at the undesired carrier frequency. The impedance of the windings in the antenna transformer is in the order of 10K to 30K ohms, within its band pass. Within a 20-KC channel, the crystals will also pass parallel resonances which occur at a slightly higher frequency than that of the series-resonant point. At parallel resonance, the crystals have an absorption effect which broadens the effective frequency spectrum over which the crystals disable the antenna transformer. The total effect is sharp enough so that the crystals can be used for protection against adjacent 20-KC channels in the 25-50 MC band, with negligible loss to the desired signal. At present, use in high band or 450-470 MC band is not so effective.

DESENSITIZATION

The sensitivity of a receiver tells us how weak a signal to that receiver can be and still provide useable communication --- or at least that is what we would like it to tell us. If we were concerned only with controlled laboratory situations, a simple 20-db quieting measurement might give us an adequate indication of sensitivity. In actual practice, however, we find that the presence of undesired signals getting through the receiver's "front door" can cause a loss in the receiver's sensitivity. This loss of sensitivity to desired signals is called desensitization. It is because of desensitization that the EIA recommends the 2-signal method of measuring selectivity. The 20-db quieting method cannot indicate which receivers lack adequate selectivity to prevent severe desensitization.

The mechanics of desensitization are illustrated in Figure 10. If an undesired signal is sufficiently close to the operating frequency, it may get through the RF selectivity and even the Hi-IF selectivity before being rejected. Even if a signal is eventually rejected by the Lo-IF, a strong signal may already have done its damage. Through each of the amplifier stages, it may have been amplified sufficiently to overload the 2nd mixer. This limiting action causes a loss in the level of the desired signal --- effectively, a loss of sensitivity. Naturally, this is most noticeable while weak signals are being received.

Interfering signals which are not so close to the operating frequency may not get through as many stages of selectivity before being rejected. If sufficiently strong, however, they may cause desensitization (overloading) in earlier stages of the receiver, such as the 1st mixer or the RF amplifier. It is not uncommon for a mobile receiver, operating close to a base station many channels away to experience severe desensitization for a short time until moving away from the immediate vicinity of the base station transmitter.

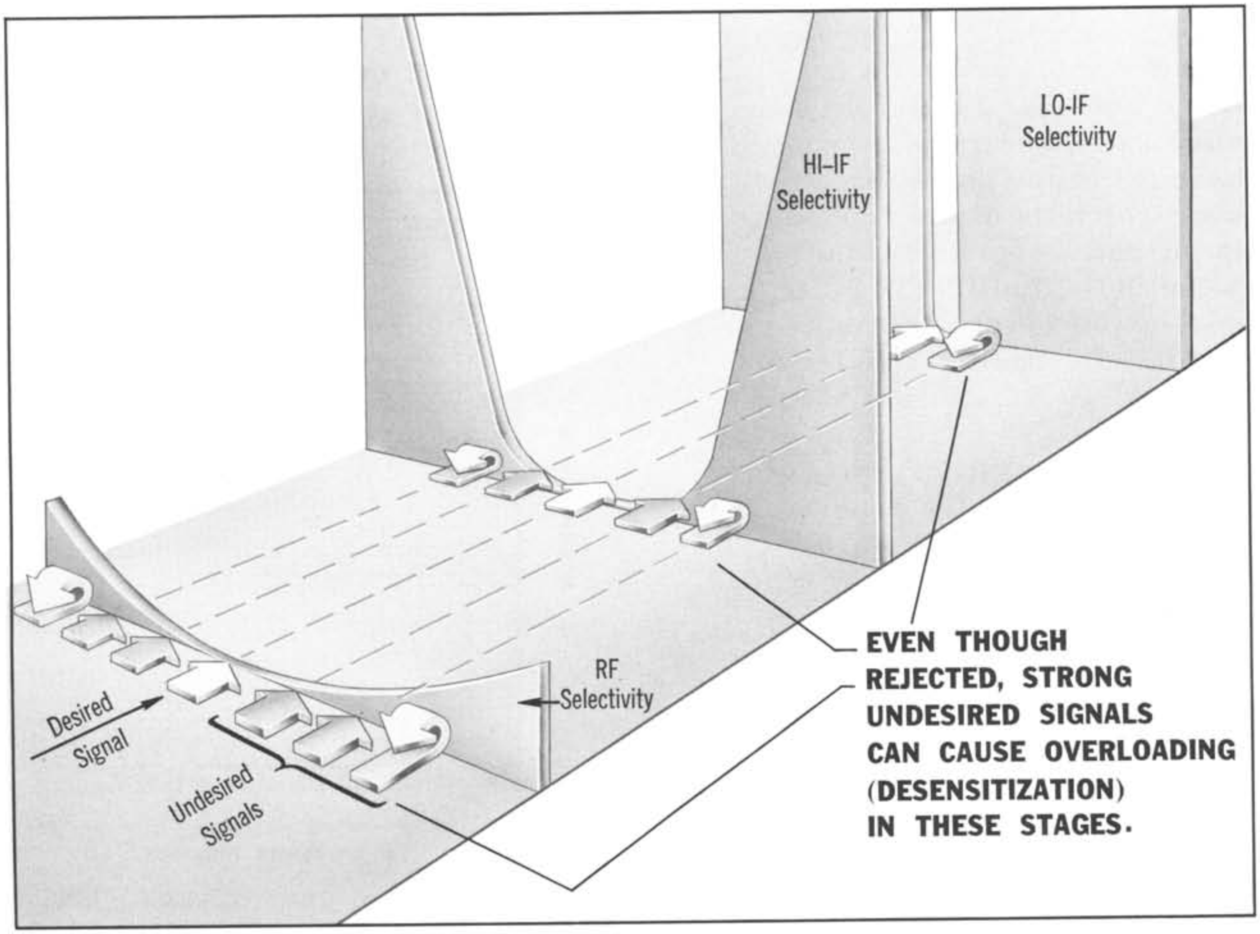


Figure 10 - Desensitization

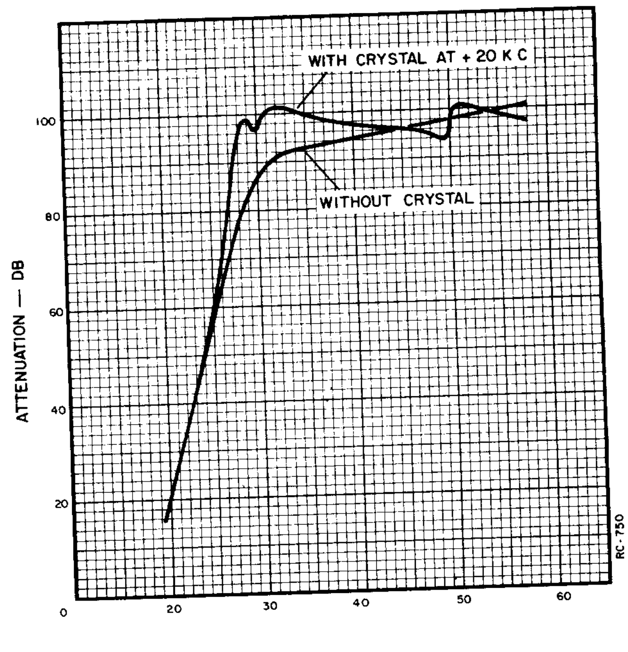
Triple-conversion receivers, often used in 450-470 MC radio systems, may not experience overloading until the 3rd mixer.

Three techniques are commonly employed for reducing desensitization:

- Increasing the attenuation between the receiver and the interfering transmitter by increasing the vertical or horizontal spacing between their antennas.
- Increasing the RF selectivity of the receiver by the addition of cavity filters or slot filters (notch filters) in the antenna line.
- Low-Band Progress Line: Adding a crystal filter in the receiver's RF circuit, as described in the preceding RECEIVER INTERMODULATION section. This may provide only slight improvement in sensitivity if the frequency separation is less than 200 KC and if transmitter noise has not been attenuated.

The low resistance of a crystal filter in series resonance can often be used very effectively to improve the desensitization characteristic of the receiver up to the point where transmitter noise is the limiting condition, in cases of severe desensitization. Desensitization from an adjacent 20-KC channel should be improved 10 to 15 db by using a series-resonant crystal across the secondary of the antenna transformer (Y1 in Figure 9). If further improvement is needed, an additional 10 db can be obtained by adding a crystal across the primary of the transformer (Y2 in Figure 9). A typical desensitization curve is shown in Figure 11, using only one crystal filter.

Figure 11 - Typical Desensitization Curve



NOISE INTERFERENCE

The sensitivity of FM receivers is primarily limited by the receiver's noise level (due to thermal noise and tube noise inherent in the receiver). Any additional noise received from external sources decreases the receiver's apparent sensitivity by either of two mechanisms, depending upon whether it is impulse noise or random noise. This bulletin will not present a detailed analysis of noise interference, since this will be the topic of a future DATAFILE Bulletin, but the following brief analysis will serve to introduce the subject.

Random Noise

Random noise, as the name implies, consists of a "picket fence" of noise impulses scattered randomly and more-or-less uniformly across the receiver's passband (Figure 12A). The amplitude of these impulses varies from very small to very large, but the average level of the noise is constant. Random noise produces the "hash" or "hiss" heard while a very weak signal is being received. The hiss is the resultant of the noise combining with the desired signal and producing audio noise (when demodulated).

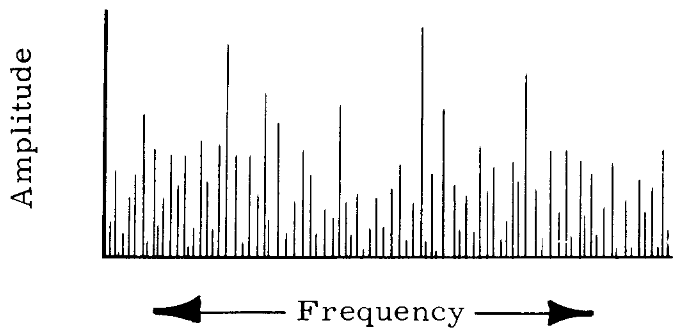


Figure 12A - Random Noise, as Viewed for Short Interval of Time

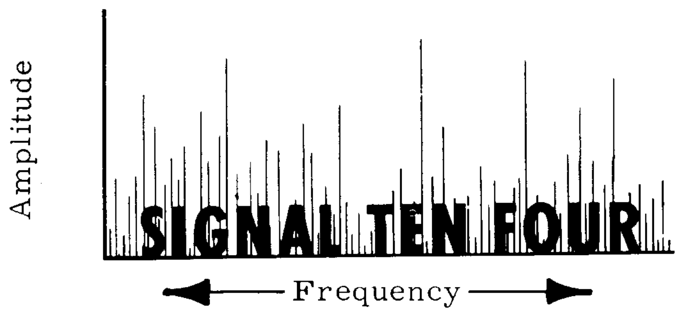


Figure 12B - Good Signal-to-Noise Ratio

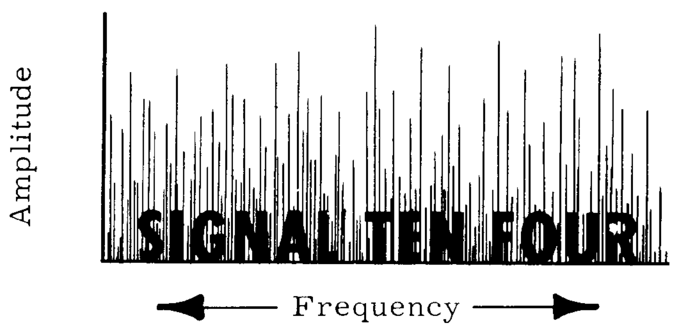


Figure 12C - Poor Signal-to-Noise Ratio

While a strong signal is being received (high signal-to-noise ratio), the modulation is readily intelligible above the random noise (inherent in the receiver and from external sources), just like the printing in Figure 12B can be easily read. If random noise interference is increased, however, it is easy to visualize how this increased noise level decreases readibility --- particularly the readibility of weak signals. Either decreasing the signal level or increasing the noise level contributes to a poorer (lower) signal-to-noise ratio and poorer readibility (see Figure 12C).

Impulse Noise

Impulse noise consists of individual noise spikes which are appreciably stronger than the signal being received. Spikes as strong as a 1000-microvolt signal are not uncommon in mobile installations. 35 db above one microvolt per MC is the approximate level at which impulse noise interference begins. These giant spikes momentarily excite the tuned circuits in the receiver, but each successive circuit continues to "ring" for a slightly longer period of time --- stretching out the pulse. The ringing time is proportional to the strength of the noise pulse, and may be several hundred milliseconds for very strong pulses. During this time, the pulse actually "takes over" the receiver (capture effect); no modulation gets through. If the time between pulses is longer than the ringing time, the tuned circuits recover before being struck by the next pulse.

Fig. 13 - Audio Output During Reception of a Strong Noise Pulse

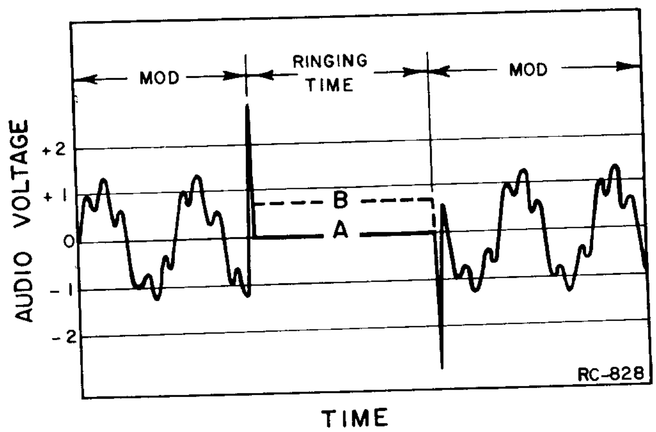


Figure 13 represents the receiver's output voltage while a single strong noise pulse is being received. Remember: this voltage changes as the frequency of signals entering the discriminator varies in relation to the discriminator center frequency. If the discriminator sees a sudden phase shift when the noise pulse excites the filters, an audio spike is produced. If the ringing frequency of the filters is centered on the discriminator, the output returns to zero (see "A" in Fig. 13). A second spike, having opposite polarity, will result when the filters stop ringing, if the discriminator sees a sudden phase shift back to the signal frequency. Due to the roll-off characteristic of the receiver's audio above 3000 cps, these two spikes produce only a "clicking" sound from the receiver.

If the ringing frequency of the filters is not centered on the discriminator, however, the audio voltage will not return to zero after the first spike ("B"). It is this voltage which produces the annoying "pop" from the receiver. Phase tuning lines up the filters' ringing frequency with the discriminator to minimize this "popping".

Sources of Noise

The common sources of noise reaching the receiver can be classified as follows:

	Impulse	Random
● Man-made noise		
Transmitter noise from nearby transmitters		X
Vehicular noise		
Ignition noise	X	
Generator or alternator noise	X	X
Voltage regulator noise	X	X
Noise from electric motors	X	X
Noise from neon & fluorescent lights		X

	Impulse	Random
• Natural noise		
Atmospheric noise (lightning discharges)	X	X
Static discharges		X
Galactic noise (noise from outer space		X

Reducing Noise Interference

Transmitter noise must always be considered (along with desensitization) whenever a receiver is operated simultaneously near a transmitter. Calculations for predicting degradation due to transmitter noise and desensitization are described in detail in DUPLEX OPERATION CURVES, such as Bulletin 10007-1.

The analysis and suppression of vehicular noise will be discussed in detail in a future DATAFILE Bulletin. Ignition and generator noise suppression and phase tuning are valuable techniques for reducing this type of interference.

Interference from other types of man-made noise can usually be reduced by careful placement of the antenna and transmission line, by shielding and by by-passing or filtering power and control leads. Interference from natural sources is usually negligible, except for noise produced by corona discharge from the antenna. Most modern antennas, particularly station antennas, have been designed to reduce this static which can build up during precipitation, dust storms, etc.

THE "OUNCE OF PREVENTION" (PLANNING FOR RFI)

During the planning stage for a new radio communication system or the expansion of an existing system, careful attention should be given to RFI problems. Although it is impossible to predict all possible interference, the time required to avoid (or at least plan for) the more common types of interference is time well invested.

The Interference Analysis Work Sheet (10002-3) can be helpful in predicting possible interference problems. For each base station planned, fill out a Work Sheet. Describe the proposed station by filling out sections ❶, ❷ and ❿ on the work sheet and perform each of the steps marked with an asterisk (*) in the procedure which follows. Although it is not usually possible to select a channel which will be interference-free, it will be possible to plan for adequate antenna spacing, necessary cavity filters, etc. to prevent the more obvious or more common types of RFI.

ANALYZING RFI PROBLEMS

Unless RFI is due to some obvious cause, it may be necessary to make a thorough analysis of all electronic equipment in the vicinity radiating signals strong enough to cause interference.

The most obvious symptoms of RFI are those heard from the receiver output. They are often sufficient to identify the type of interference and its source. If the call sign of the interfering station is heard, for instance, the frequency and licensee can be readily détermined. More difficult problems will usually require measurements and tests to ascertain the type of interference.

In general, the DISCRIMINATOR reading is most valuable in determining whether interference is entering on the receiver's operating frequency or some other channel. The LIMITER reading will usually increase while an interfering signal is being received, unless it is having a desensitizing effect on the receiver. Densensitization is indicated by a decreased LIMITER reading.

Use the attached Interference Analysis Work Sheet (10002-3)[4] and the following procedure to identify the type of RFI and to pinpoint its source. Use a

[4] Additional copies available in limited quantities from the Communication Products Department, General Electric Company, Lynchburg, Virginia

separate Work Sheet for each case of interference and attach additional sheets if more space is required. Label any information which has been estimated with "est."

Procedure

1. Describe the receiver and its RFI symptoms by filling in pages 1 and 2 of the Interference Analysis Work Sheet as completely as possible.

*2. Describe nearby transmitters, which may cause RFI, by filling in pages 3 and 4.

*3. Do any of the transmitter frequencies ⓭ fall near the receiver's spurious frequencies ❿ ? Examples:

- First image of ER-24-A or B = operating freq - 6.4 MC
- First image of ER-25-A,B,C or D = operating freq - 17.4 MC
- First image of ER-26-B = operating freq - 96 MC

*4. On pages 5 and 6, calculate the more common intermodulation products and transmitter spurious frequencies which could cause RFI. Examples:

- 3rd harmonic of high-band transmitter in 450-470 MC band
- Final multiplier (tripler) spurious freq of 450-470 MC transmitter in high band
- 2nd harmonic of TV channel 5 in high band

*5. Are any of these IM products or spurious frequencies close enough to the receiver frequency to cause RFI? Remember that the total modulation of IM products (particularly the higher orders of IM) and the modulation level of spurious frequencies may be great enough to swing into the receiver's passband, even though the interference itself is centered several channels away.

*6. Complete step ⓰ on page 6 to see if there is sufficient attenuation between the receiver and nearby transmitters to prevent desensitization. This is particularly important when the receiver is used for duplex operation.

7. If the cause of the RFI is still not apparent, use the SYMPTOMS, TESTS and MEASUREMENTS in Table II to identify the type of interference.

Continued on p. 30

TABLE II– RECOGNIZING AND REDUCING RF INTERFERENCE

TYPE OF INTERFERENCE	SYMPTOMS	TESTS	METHODS OF REDUCING INTERFERENCE
RECEIVER SPURIOUS RESPONSE and TRANSMITTER SPURIOUS RADIATION	It is generally difficult to distinguish between these two types of interference. Try TEST 1 to determine which type is involved. ● LIMITER current always increases ● FM interference having modulation within receiver's bandwidth may be intelligible, in the case of image response and some types of transmitter spurious radiation, if DISCR indicates a signal close to the receiver's center frequency. Video or AM signals will not usually be intelligible. ● If audio is garbled and LIMITER current and/or DISCRIMINATOR current fluctuate with modulation, interference may be a transmitter harmonic. Receiver spurious response, receiver intermodulation and transmitter intermodulation can also give this same indication. ● CW signals causing interference may not produce audio in the receiver. DISCRIMINATOR reading should always be observed to determine the stability and apparent frequency of such signals. ● AM signals cause very low level audio, usually with an increase in LIMITER current during modulation. ● These types of RFI are caused by radiation from a <u>single</u> transmitter. Therefore, interference will usually last as long as the <u>interfering</u> transmitter is on the air. Intermodulation (described below) requires the presence of <u>more than one</u> interfering signal --- so RFI lasts only as long as <u>all</u> signals are on <u>the air</u>.	<u>TEST 1</u>: Insert a tunable cavity filter (with <u>high-loss</u> loops) in the transmission line to the receiver and tune it to the receiver frequency. If the RFI remains unchanged or drops only a few db due to the insertion loss of the cavity, co-channel interference (transmitter spurious or transmitter intermodulation products) is causing interference. Reduction of the RFI more than the cavity's insertion loss indicates that an off-channel signal is causing spurious response in the receiver. <u>TEST 2</u>: If interference from AM signals is <u>suspected</u>, use RF signal tracer (such as Heathkit T-4) to detect strong signals in RF amplifier or Hi-IF stages. Use audio amplifier plugged into LIM-1 to locate AM signals in IF-2 pass-band. <u>TEST 3</u>: Check for receiver spurious <u>response</u> with signal generator accurately set to suspected transmitter frequency.	<u>CO-CHANNEL INTERFERENCE</u> (including transmitter inter-<u>modulation</u> and <u>transmitter</u> spurious radiation) ● Increase attenuation between antennas by increasing antenna spacing or changing antenna radiation pattern. ● Add cavity filter(s) in output of transmitter to attenuate intermodulation products or spurious. ● Low-pass filter may be useful added to output of older transmitters if a harmonic is causing interference. ● See Bulletin 10002-1 for construction of quarter-wave stub filter which can be connected to transmission line of an interfering transmitter. ● Change crystal frequency and/or multiplication of transmitter to eliminate an interfering spurious. <u>RECEIVER SPURIOUS RESPONSE</u> ● Use cavity filter(s) in receiver input. ● Use crystal filter(s) in low-band Progress Line Receiver's antenna circuit. ● Change Hi-IF frequency (to move spurious frequency). ● Increase attenuation between antennas by increasing antenna spacing or changing antenna radiation pattern. ● Change local oscillator and injection to opposite side of signal.
RECEIVER INTERMODULATION and TRANSMITTER INTERMODULATION	IM can result when <u>two or more</u> interfering transmitters are on the air simultaneously. Although one of the <u>transmitters</u> could be located at some distance from receiver (especially a high-power transmitter), at least one of transmitters is usually located close to the receiver. ● LIMITER currents rise during interference. Stability of reading decreases with higher orders of IM. ● Intelligibility of audio depends upon how signals mix (see formulas in Table I). FM signals with coefficient of "1" may be intelligible, those with "2" will usually be garbled and those with higher coefficients will be unintelligible. ● The modulation of more than one interfering signal may be intelligible simultaneously. ● If the audio is intelligible, it may start or end in the middle of a conversation, when one of the interfering transmitters comes on or goes off the air. This may not be recognizable if one of the interfering signals (such as a broadcast or common carrier station) remains on the air for long periods of time. ● Transmitters operating close to each other can produce an intermodulation product <u>directly</u> which may cause RFI. TEST 1 will determine whether or not the receiver is <u>responsible</u>. ● Skip interference can contribute to IM under proper conditions.	TEST 1, described above, can be used to determine whether transmitter IM (co-channel interference) or receiver IM (off-channel interference) is involved. <u>TEST 4</u>: To determine which order of IM <u>is occuring</u>, vary frequency of suspected transmitter 1 KC, noting change in apparent frequency on DISCR. (1-volt change usually indicates a change of 1 KC.) A 2-volt change, for instance, would indicate doubling of that transmitter's signal during IM. <u>TEST 5</u>: To determine if interference is <u>entering</u> via power supply or control leads, connect an "antenna" (20-foot length of wire) to the leads. Increased interference indicates that RFI (usually low-frequency RFI) is entering via leads.	<u>TRANSMITTER INTERMODULATION</u>: See methods for reducing Co-<u>Channel Interference listed</u> above. <u>RECEIVER INTERMODULATION</u> ● Use cavity filter(s) in receiver input. ● Use crystal filter(s) in low-band Progress Line Receiver's antenna circuit. ● Increase attenuation between antennas by increasing antenna spacing or changing antenna radiation pattern. ● Interference entering via power supply or control leads can usually be eliminated by additional by-passing or shielding.
RECEIVER DESENSITIZATION	Normally caused by <u>one</u> transmitter, located in close physical proximity to the receiver. ● LIMITER current <u>decreases</u> with interference. ● Usable sensitivity decreases during interference. Weak signals may become unintelligible. ● DISCRIMINATOR may be unstable and have larger fluctuations in the presence of modulation if the interfering signal is from an adjacent channel. ● Increased receiver noise level may be noticed during interference.	<u>TEST 6</u>: Use a well shielded coupling to <u>couple</u> a communications receiver into the Hi-IF to detect and identify desensitizing AM signals.	● Increase attenuation between antennas by increasing antenna spacing or changing antenna radiation pattern. ● Use cavity filter(s) in receiver input. ● Use crystal filter(s) in low-band Progress Line Receiver's antenna circuit.
NOISE INTERFERENCE	● Usable sensitivity decreases during random noise interference. ● LIMITER current increases with random noise interference. Reading will fluctuate with noise level and may be observed for a pattern. ● SQUELCH setting may be affected. ● The sound of the noise from the speaker, while receiving a weak signal, may be a valuable clue in determining the source of impulse noise. Open the squelch control, if necessary, to hear noise. Refer to more detailed discussion of noise problems (future DATAFILE Bulletin).		● For impulse noise interference, phase-tune receiver. ● For transmitter noise, use cavity filter(s) in transmitter output. ● For transmitter noise, increase attenuation between antennas by increasing antenna spacing or changing antenna radiation pattern. ● Relocate antenna and transmission line to location having lower noise level. ● See future DATAFILE Bulletin on <u>Noise Interference</u> for noise-suppression techniques, particularly on vehicles.

8. If assistance is needed, send the completed Work Sheet to the Communication Engineer at your nearest General Electric Radio Communication District Sales Office. Be as complete as possible. Remember: the more information that can be included on the interference problem, the better the chances for locating its source and suggesting specific ways of reducing it.

9. Once the source of the interference and the path it is following into the receiver have been determined, steps can be taken to reduce the interference, using one of the techniques listed in Table II.

REDUCING INTERFERENCE

The technique selected for reducing RFI will depend upon the severity of the interference, the desired range of the radio system, cost and public relations. In situations where the receiver is not at fault, the cooperation of the licensee of the interfering transmitter(s) will be required.

CAVITY FILTERS

Cavity filters are one of the most useful tools for reducing RFI. Applied to an interfering transmitter, a cavity is effective against co-channel interference. Applied to the receiver, it is effective against off-channel interference.

Cavity filters are available for use in high band, low band and 450-470 MC band, and are usually supplied with several pairs of loops, each having a different insertion loss. Remember that using 3-db loops means a 50% loss of power, 1-db loops means a 22% loss of power and 0.5-db loops means an 11% loss of power. Consequently, it is advisable to use a loop with the lowest insertion loss that will provide the required attenuation. Where maximum power output is needed and cost is not prohibitive, it is better to use two or more cavities with low-loss loops than to use a single cavity with high-loss loops, since greater attenuation can be obtained for the same loss of power. The lengths of the cables used to connect cavities are critical; so the installation instructions must be followed carefully.

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COMMUNICATION PRODUCTS DEPARTMENT LYNCHBURG, VIRGINIA
(In Canada, Canadian General Electric Company, Ltd., 100 Wingold Ave., Toronto 19, Ontario)

Printed in U.S.A.