receiving system degradation in fm repeaters

How to improve talk-in range using shielding and tuned-cavity filters

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The popularity of vhf fm repeaters is steadily increasing in the ranks of amateur radio despite several problems inherent in the design and operation of such stations. Perhaps the most serious and least understood is receiver blocking, or more properly, receiver desensitization.

This problem appears in two ways. First, it can severely limit the effective talk-in range of the repeater system. It can also show up as repeater chatter which is a cyclic keying of the station. First a signal breaks the receiver squelch and keys the transmitter. With the transmitter on, receiver sensitivity falls off, and the squelch closes. When the squelch closes, the transmitter shuts off, and the receiver sensitivity returns to normal; if the signal is still present, the squelch opens and the cycle repeats.

This article explores the causes and cures of receiver degradation, describes some measurement techniques, and offers some good methods to lick the problem.

noise

A transmitter will affect a nearby receiver's sensitivity in two ways. First, it can significantly reduce the receiver's front-end gain. This occurs when the transmitter carrier is present at the front end at a sufficient level to cause rectification in the amplifier or mixer input circuit. The resultant change in bias reduces the stage gain, which in turn reduces the noise input to the limiters and the limiter current. The effect of all this is ultimately to reduce the receiver's sensitivity.

The second effect is produced by the transmitter's noise spectrum. It is a sad but true fact that all transmitters produce not only a carrier and modulation sidebands, but noise sidebands as well. These sidebands may extend several hundred kilohertz on either side of the carrier. If the transmitter and receiver frequencies are only a few hundred kilohertz apart, which is usually the case in ham repeaters, the transmitter noise output that lands on the receiver frequency can be many times greater than front-end or antenna noise. This increased noise input to the limiters produces an increase in limiter current, which in turn reduces receiver sensitivity.

While rectification decreases limiter current, transmitter noise increases it. Thus, since both effects can occur simultaneously, it's not uncommon to find them cancelling each other in regard to changing limiter current. Therefore, there may be severe receiver degradation with no apparent change in limiter current readings.

Before proceeding to a description of techniques for curing the problem, I'll develop a method for measuring the effects so corrective steps can be properly evaluated. The problem is basically how to measure receiver sensitivity, or to be more precise, the change in sensitivity. The term sensitivity refers not only to the receiver itself, but to the entire receiving system including antenna and feedline.

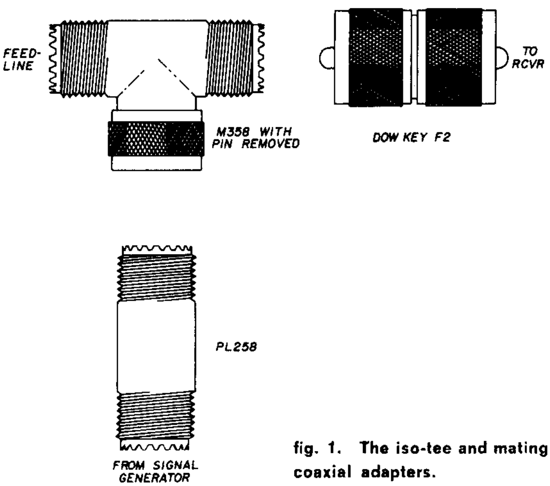


fig. 1. The iso-tee and mating coaxial adapters.

measurements

The basic piece of test gear required is a controlled signal source. A calibrated signal generator is ideal; however, most of us don't have one. Since we are primarily interested in changes of sensitity, rather than the actual measurement of it to a hundredth microvolt, simple equipment can be used with great success. You'll require a well-shielded signal source, preferably crystal controlled, and a step attenuator. Both are within the pocketbook range of most hams, supplemented by home-brewing.

Also required is an "iso-tee." This is simply a coaxial tee adapter, such as the M-358, with the center pin of the male termination removed (**fig. 1**). The female terminations are connected to the receiver and the antenna feedline. The output of the signal source is connected through the step attenuator to the male termination of the tee. The tee provides very loose coupling of the signal source to the receiving system.

receiver degradation

To measure the receiver degradation produced by the transmitter, connect an ac voltmeter across the receiver speaker terminals (see **fig. 2**). Open the receiver squelch and increase the output of the signal source until the receiver output decreases by 20 dB, just as when making a standard 20-dB quieting sensitivity check. It will probably require several hundred microvolts of rf output from the attenuator to produce this quieting, as the isolation of the tee fitting is substantial.

The next step is to key the transmitter and repeat the measurement. Ideally, it should take the same amount of signal to quiet the receiver with the transmitter on as with it off. More likely, it will require considerably more signal. If, for instance, you must inject 30 dB more signal to produce 20 dB quieting with the transmitter on, the transmitter is degrading the receiver sensitivity by 30 dB! Now the question is, what to do about it?

the cure

If the transmitter and receiver are located at the same site, the first step is to shield the two units. This includes filtering all power, control and audio leads entering or leaving the shielded enclosure. Shield kits for this purpose are available from the manufacturers, or you can brew your own. The effectiveness of the shielding can be tested by the same technique previously outlined. To test the transmitter shielding, replace the transmitter antenna with a dummy load and make the quieting measurement. To test the receiver shielding, replace the receiving antenna with a dummy load and perform the measurements.

If the shielding is effective, no degradation will be apparent during either test. Of course, this presumes no radiation from the dummy load, so forget that light bulb nonsense. Once the units are properly shielded, reconnect the antennas and check for degradation. If it is still severe or objectionable, the next step is antenna spacing.

The transmit and receive antennas should be as far apart as possible. If they are mounted on the same tower, they should be at least 100 or more feet apart. Unfortunately, few hams can realize the benefits of 200-foot towers or separate transmitter and receiver sites, so a more practical solution is the use of tuned cavities.

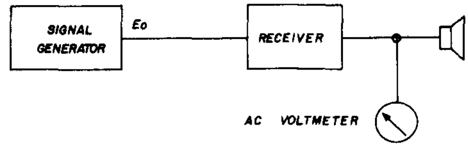
tuned cavities

A tuned cavity is essentially a very high-Q tuned circuit. A cavity placed in the receiver feedline and tuned to the receiver frequency will pass signals on the receive frequency, while rejecting all other frequencies. A cavity placed in the transmitter feedline and tuned to the transmitter frequency will pass the transmitter signal, while rejecting noise on the receiver frequency.

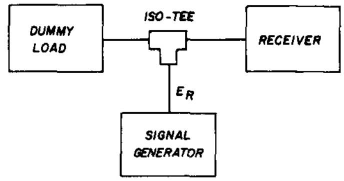
The criteria for selecting a cavity, either commercial or homebrew, are physical size and power rating. As a rule of thumb, the bigger they are, the better. Many commercial units are available with a choice of coupling loops, thus providing a selection of different amounts of selectivity. There is a tradeoff involved here as the higher the selectivity, the greater the insertion loss and the lower the power rating.

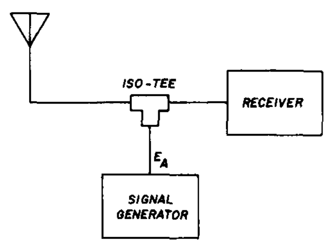
cavity location

To determine the appropriate location for the cavity, watch the limiter current as the transmitter is keyed. An increase indicates degradation due to transmitter noise, and the cavity should be placed in the transmitter feedline. A decrease indicates desensitization due to rectification,



BASIC SENSITIVITY = Eo = VOLTAGE FOR 20 dB QUIETING





EFFECTIVE SENSITIVITY $= E_o \left[\frac{E_A}{E_R}\right]$

DEGRADATION DUE TO ANTENNA NOISE (dB) $= 20 \log \frac{E_A}{E_R}$

DEGRADATION DUE TO TRANSMITTER (dB) $= 20 \log \frac{E_A \text{ XMTR "ON"}}{E_A \text{ XMTR "OFF"}}$

fig. 2. Test equipment setup for measuring receiving system degradation.

and the cavity should be placed in the receiver feedline.

If the transmitter noise is the culprit and a separate exciter and final are used, try placing the cavity between the exciter and the final. Since most of the transmitter noise is generated in multiplication stages, a cavity at the output of the exciter will reduce the noise output of the amplifier. An added benefit of this location is the fact that, since you are dealing with a low-level signal, you can use a cavity with a higher selectivity (remember the tradeoff) thus improving the noise reduction. Also, due to the reserve gain of the final amplifier, insertion at this point will result in less loss of radiated power than if the same filter were placed after the final.

After the first cavity is installed, a noticeable improvement should be observed. If some degradation still exists, it may be necessary to resort to additional cavities. Complete elimination of the problem may require several cavities in both the transmitter and receiver feedlines.

insertion loss

Many hams will object to the use of cavities because of their insertion loss. However, from a system viewpoint, they are the least of several ills. A repeater is useful only to stations who can both hear and be heard by it. If your repeater can be heard across the state, but it can only hear across town, then the repeater's effective range is just across town. Stations outside the talk-in range can't use the repeater and so are probably not very interested in hearing it. As far as they are concerned, it just ties up the frequency.

If you install a cavity or two on the transmitter, you may reduce your talk-out range to halfway across the state, but you may have reduced receiver desensitization to the point where you can hear halfway across the state. Thus, you've increased your effective range to halfway across the state, insertion loss and all.

Similarly, in the case of the receiver, what really counts is not just receiver sensitivity, but effective sensitivity when the transmitter is keyed. If adding cavities to the receiver feedline reduces the degradation produced by the transmitter, then you are improving performance and increasing operational range even at the expense of additional insertion losses.

receiver sensitivity

An interesting point regarding receivers arises at this point. If a receiver is capable of hearing external noise from the antenna, this noise is the limiting factor in weak signal detection. Low noise preamps and high gain antennas won't help matters, and they may produce additional problems. With an **a-m** receiver, the simplest test for sensitivity is to replace the antenna with a dummy load and see if the noise output of the speaker decreases. If it does, the receiver is hearing external noise. This test won't work with fm receivers; and if it does, you'd better start replacing tubes.

An equivalent test for fm receivers can be made by watching limiter current, but a much more accurate method is to perform the same test as used for measuring degradation due to transmitter noise. First, make the quieting check with a dummy load on the receiver. Then replace the normal antenna, and again check the quieting level. The difference in levels required to produce 20 dB of quieting is the amount of external degradation.

If the receiver sensitivity is being degraded by, say, 8 dB of antenna noise, then up to 8 dB of additional loss, either in the form of cavity insertion loss or attenuators, can be inserted in the feedline without affecting the effective sensitivity by more than 2 or 3 dB. The attenuator, by the way, will provide some improvement in desensing characteristics and considerable improvement in intermodulation protection.

If the receiver is not being degraded at all by antenna noise, then the limiting factor is the receiver front-end noise, and you may want to add a low-noise preamp or switch to a higher-gain antenna. If you decide on a preamp, be careful. Many preamps, especially those using bipolar transistors, are extremely susceptible to desensing problems. The same unit that works wonders in a mobile or base station may prove disastrous in a repeater.

in conclusion

The steps toward elimination of receiving system degradation in repeater applications are transmitter and receiver shielding, spacing between antennas and the proper use of tuned cavities. With enough cavities, it's even practical to use the same antenna simultaneously for transmitting and receiving.

ham radio