STRONG SIGNAL HANDLING

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In the October 1975 issue of Ham Radio[1] James Fisk makes a statement which I think contains the most important principle needing consideration by the MW DXer seeking a receiver suited for his somewhat unique needs. His statement is: "Why design a high frequency receiver for extraordinary sensitivity when its performance is limited by external noise over which you have no control? A very sensitive receiver is more prone to intermodulation and cross-modulation effects, and these may be more important".

Indeed for the broadcast band DXer, strong signal handling is likely to be the most important quality of his receiver. To those accustomed to judging a receiver in terms of sensitivity and selectivity, this may come as somewhat of a surprise. In order to explain the wisdom behind Mr. Fisk's words and justify the above statement, let us now take a look at just what dictates the reception of a station at MW frequencies.

I. Selectivity

If you were to install a mechanical filter in your receiver or purchase one with an excellent crystal lattice filter or mechanical filter, you would expect top-notch selectivity and the accompanying ability to DX up close to the locals. This is not guaranteed, however. When considering selectivity, two major factors tend to be ignored: ultimate rejection of the filter, and where in the receiver (electrically) the filter is located. Ultimate rejection of a filter is defined as the greatest amount of signal that will be rejected; this value is a function of the charactistics of the filter and the amount of signal that leaks around the filter and appears at the input to the next stage. Figure One is a diagram of the selectivity of (a) a good quality ceramic filter, (b) an average crystal lattice (8 pole) or mechanical filter, and (c) the best quality mechanical filter available. One can easily see that the ultimate rejection of (a) is around 40 dB, of (b) around 70 dB, and (c) around 90 dB. Now what does this mean in terms of practical performance? As the average S-meter is calibrated to a standard of 6 dB/S-unit, filter (a) will totally reject only an S7 signal, (b) only a S9+16 dB signal, and (c) a S9+36 dB signal. As we are interested in strong signal handling, we can see that (a) will handle no locals, (b) might handle the weaker ones, and (c) will handle most of them. We will discuss the importance of this situation a bit later on when we devote our attention to strong signal handling by itself. Let us now return to where in the receiver (electrically) our filter is located. The chief consideration here is the old adage "place maximum selectivity in front of maximum gain", or, "put the selectivity as close to the antenna as possible". Why? Because the more stages that are exposed to a large number of strong signals, the more the receiver will suffer the effects caused by strong-signal overloading. Ideally, the selectivity should come at the first mixer output that is at the center frequency of the filter. Therefore, one stage may precede the filter in a receiver with no RF stage and single conversion, or as many as six stages in the case of a dual RF stage, triple conversion receiver with the filtering located after a stage of amplification at the final IF. Receivers have been built with both extremes! With the latter scheme, the strong signal damage is done before the sharp filter gets a chance to do its job and remove the unwanted numerous signals. This particular situation is even more undesirable than it sounds because certain types of distortion caused by strong signals increase 3 dB as the strong signal level increases by 1 dB; therefore if we have 30 dB more gain in in front of the filter with the 6-stage scheme, we may possibly have 90 dB more intermodulation distortion (a term to be explained later).

II. Sensitivity

Briefly in the discussion on selectivity, we touched on what happens when there is an excess of gain in front of the filter. This situation may also occur if the receiver has too much sensitivity for MW DX. Impossible, you say? The more sensitivity, the weaker the signal that can be heard? You are thinking in terms of a signal that does not have to compete with either man-made or natural noise, both of which are at very significant levels at MW frequencies; these levels in fact are higher at MW frequencies than at SW frequencies. The required sensitivity of a MW receiver will be, on the average, almost 100 times less than that required for DX on the 10 meter ham band at 29 MHz. A good range of sensitivity for MW DX is the 10-20 uV area. A full discussion of why this is the case would take up too much space and bog the article down with figures and graphs; the interested reader can find all the information needed on man-made and atmospheric noise levels in the material referenced in the appendix. Particularly useful are the Fisk article, the CCIR report, and the Skomal book.

If you are using a receiver with "good" sensitivity by modern standards (less than 1 uV), you should be thinking hard about what Mr. Fisk had to say at the beginning of this article. Your situation is the dangerous one he refers to, with even more emphasis, as what he had in mind of course refers to situations likely to be encountered on the ham bands. The MW situation is much more difficult; while a ham might complain if he lives within a mile of a few friends running the 1 kw legal limit, we must contend (assuming an urban location) with 50 kw NSP locals and a total of perhaps 20-30 stations all running the same power or more than the ham is allowed. In addition, the MW DXer is often interested in hearing a station only 5 or 10 kHz away from a very strong local. The ham can exercise the option of moving his frequency away from the interference. Hardly a viable option on the BCB...We are thereby in an unfortunate position: the MW DXer needs better strong-signal handling than possibly anyone else, but also suffers from a great deal of unneeded sensitivity that is detrimental to strong signal handling.

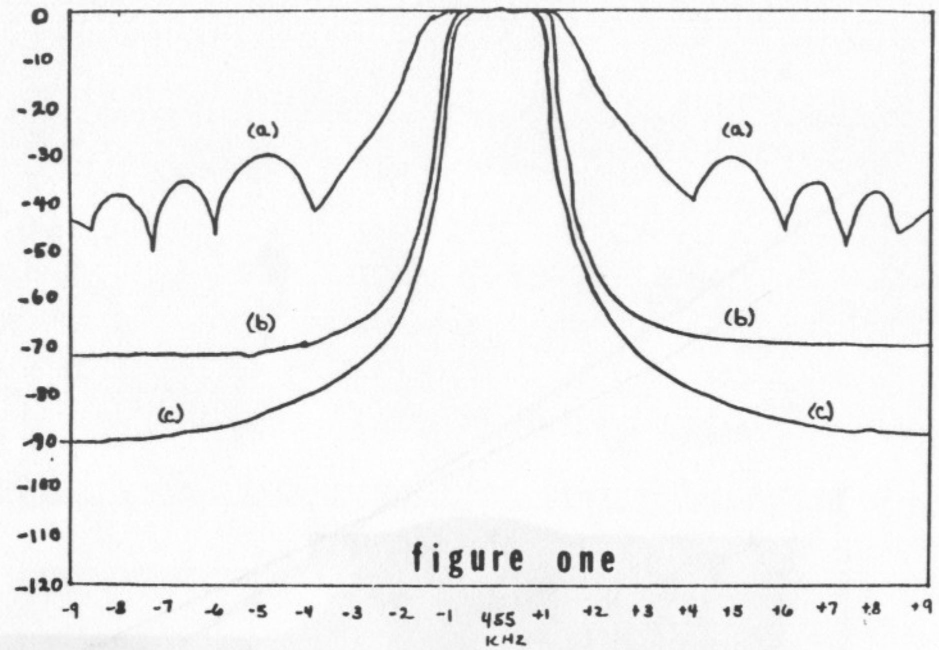

figure one

III. Strong Signal Handling

So far we have made reference to two parameters that may make a receiver handle strong signals in a poorer fashion than the receiver is basically capable of. Or rather, than the mixer(s) is/are capable of. It is in the mixer that most unwanted effects are produced. The RF stage (if used) may contribute to the problems to be outlined below but this is usually secondary as the signal levels are higher in the mixer(s) and this leads to a greater concentration of problems, in addition to the fact that by nature, the mixing process is prone to produce certain unwanted products. To describe the basic strong-signal handling of a receiver, let us launch into a basic description of some terms that are applied to mixer performance.

When a non-linear device (a mixer as opposed to an ideal amplifier) is presented with two frequencies, the unfortunate by-product is a complicated assortment of new frequencies. For example, take f_1 of 750 kHz and f_2 of 790 kHz. Intermodulation distortion (the process referred to above) will produce a plethora of unwanted signals at frequencies related to the originals with definite mathematical relationships. The third-order intermodulation products will fall at 830 and 710 kHz, the frequencies where I note an unfortunate jumble of audio from super-local WSB-750 and local WQXI-790. The importance of third-order IM products is that: as the desired frequency levels are increased, the third-order IM products increase, but for every 1 dB increase in the input level, the IM level at the output increases by 3 dB. Taking that fact into account, it becomes apparent that as the input level to the mixer increases, a point will be reached where the level of the undesired IM products will be equal to the level of the desired input frequencies. This point is referred to as the third-order intermodulation level intercept point. A mouthful of a phrase indeed, but a very important term to become acquainted with because it is the internationally recognized standard of performance for mixers and an excellent way for the DXer to evaluate the strong-signal handling of his receiver. A top quality receiver will specify this data, as the manufacturer will be aiming for a market that both wants and understands strong signal handling. An average receiver is not likely to include this data with its advertising specs because the intended market is not likely to be familiar with such terms.

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Figure Two illustrates the process by which the third-order IM intercept point is established. As seen by examining the portion of the graph near the intercept point, a real-life amplifier goes into a condition known as "gain compression" before it is actually possible to establish the intercept point. Interpolation is used to establish the intercept point once the data at other levels has been obtained. Gain compression is mentioned because it has a practical effect on DX'ing; when your receiver is tuned to a wanted, weak station near in frequency to an unwanted, strong station, the result is an apparent weakening in the level of the weak station. An example would be DX'ing for R. Melodia, Quito on 735 kHz while WSB-750 is on the air. Melodia appears quite weak while WSB's carrier is on the air, not because WSB is interfering in a direct sense, but because WSB is so strong here that their RF is exceeding the bias on either the RF or mixer stages. This drives the grid into conduction which reduces gain and increases distortion. When discussing gain compression, the standard is the 3 dB compression point; this usually occurs 10-15 dB below the intercept point.

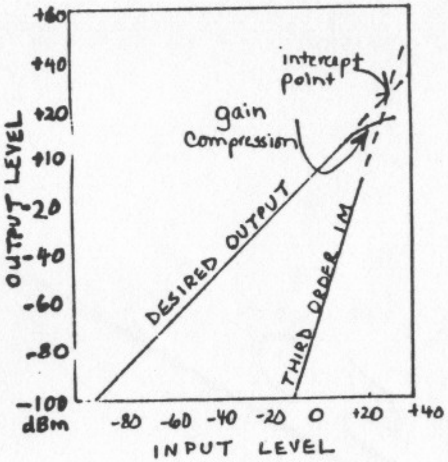

figure two

Cross-modulation is yet another type of amplitude distortion caused by strong signals. It is defined as the transfer of modulation from an undesired signal to a desired signal that the radio is tuned to. Cross modulation is unrelated to the desired-signal level, instead being proportional to the square of the undesired signal level. A pleasant effect of this relationship is that if you can afford to place 5 dB of attenuation in front of the receiver (an RF attenuator such as supplied on the FRG7) cross modulation will be reduced by 10 dB. With a sensitive receiver (and therefore too much gain for the MW band) it is often quite feasible to do just this. Cross modulation can be related to third-order IM intercept point by the equation

$m/m' = (P_{ip}/4P_c) - \frac{1}{2}$

where:

m/m' = ratio of cross-mod transferred from the larger signal to the smaller one.

P_{ip} = intercept point power

P_c = interfering signal power

and cross-mod in dB is $m/m'(dB) = 20 \log (m/m')$

This formula is included in order to allow interested DXers to compare third-order IM intercept point (the usual standard) to cross-modulation levels (sometimes specified instead)

The last strong signal concept to be discussed is dynamic range. This is an attempt to specify the range of signals that the receiver is capable of handling. In other words, the range from the weakest signal that can be used to the strongest signal that can be handled. It is an important value to specify because it demonstrates the ability of the receiver to handle both situations; a receiver may be able to handle extremely strong signals simply because it has very little gain (and therefore less sensitivity) ahead of the mixer. A receiver that handles a 100 mV signal by applying it straight to the mixer is obviously inferior to a receiver that can also handle a 100 mV input signal but also sends it through a stage of amplification before it proceeds to the mixer.

IV. How to Achieve Strong Signal Handling

So far we have touched on the above in relation to RF stages (don't have more sensitivity than you actually need) and IF stages (use filtering that will be effective against strong locals). Our discussion of the heart of the matter, the mixer(s), has been limited to terms used to quantitate mixer performance. Back-tracking a bit, we should also take note that at MW frequencies, the RF selectivity can be very important to the mixer. A large number of high-Q tuned circuits ahead of the mixer is going to prove beneficial to the receiver. A practical example is the R390A, which features an elaborate network of mechanically tracked tuned circuits of high Q and moderate loss. This situation is excellent for MW DX, as the mixer(s) are thereby protected to some degree from many unwanted strong signals.

The heart of the matter is the performance of the mixer itself. Different mixers have third order IM intercept points ranging from -40 dBm to +30 dBm. A -40 dBm level mixer will manifest itself in a MW band full of cross-modulation, third order intermodulation, and slop from locals. A +30 dBm level mixer will provide performance almost totally free from said effects as it will prove close to impossible to overload such a mixer. With no RF stage ahead of the mixer (not only possible but desirable for MW and most SW frequencies) we are talking about close to a volt of RF before performance is impaired. A mixer like this is obviously no ordinary mixer; it is a double balanced Schottky diode mixer developed specifically for this purpose. A poor mixer is typified by a bipolar transistor and a fair mixer by a tube or good FET design. A balanced FET design (such as used in the FRG7) will yield improved performance over that of a single semi-conductor, but performance will still fall far short of a double balanced diode mixer. This type of design has been incorporated in many new high-performance receivers such as the Drake R7, the Dymek DR series, the new RACAL receivers, and the Rohde and Schwartz receiver. A good way for you to get a feel of what this type of mixer can do would be to proceed to the nearest ham outlet that carries Drake equipment and give the R7 the once-over.

You may have noticed that these receivers carry hefty price tags. This is not because of the mixers! Basic double balanced mixers start at less than $5 to the experimenter, with the high performance types ranging up to $25. Considering the price reduction manufacturers of receivers will obtain, it is likely that in the very near future, we will see moderately priced receivers featuring these mixers.

The best way for you to obtain further, more detailed information on strong signal handling is to obtain good references and read them at the pace correct for your interest and knowledge. The material listed is not overly technical and should allow the reader to go farther than is possible here.

(ed note: The term dBm used above is a unit indicating power: the number of decibels in relation to a milliwatt. 0 dBm is one milliwatt, +3 dBm is two milliwatts, -3 dBm is ½ milliwatt etc.)

References

1. "Receiver noise figure, sensitivity, and dynamic range--what the numbers mean", Ham Radio, October 1975. A thorough and knowledgeable digest of receiver parameters. By all means obtain a copy of this article through your local library or the back issues available from HR.

2. "Man made Radio Noise", Edward N. Skomal, Van Nostrand Press, 1978. For those wishing to pursue further the subject of atmospheric and man-made noise in order to draw conclusions about receiver sensitivity needed on the MW band. Contains many excellent graphs.

3. "Atmospheric Noise and Receiver Sensitivity", QST, November 1969. Introduces the reader to the CCIR charts and receiver noise figure.

4. "Receiver Sensitivity", QST, September 1969. A companion article to the above.

5. "World Distribution and Characteristics of Atmospheric Radio Noise", CCIR Report 322, International Radio Consultative Committee (CCIR), 1963. The bible for those interested in atmospheric and man-made noise. Comprised of charts of noise levels for radio frequencies by location, time, and season.

6. "Get the Most From Mixers", Mini-Circuits Laboratory, Brooklyn, NY. An incredibly informative publication giving detailed data on the double-balanced diode mixers.

In addition, there have been a good number of articles published in the amateur press over the past five years that deal with receiver front ends. The best single source of these is Ham Radio; the yearly receiver issue is worth the cost of a subscription alone.