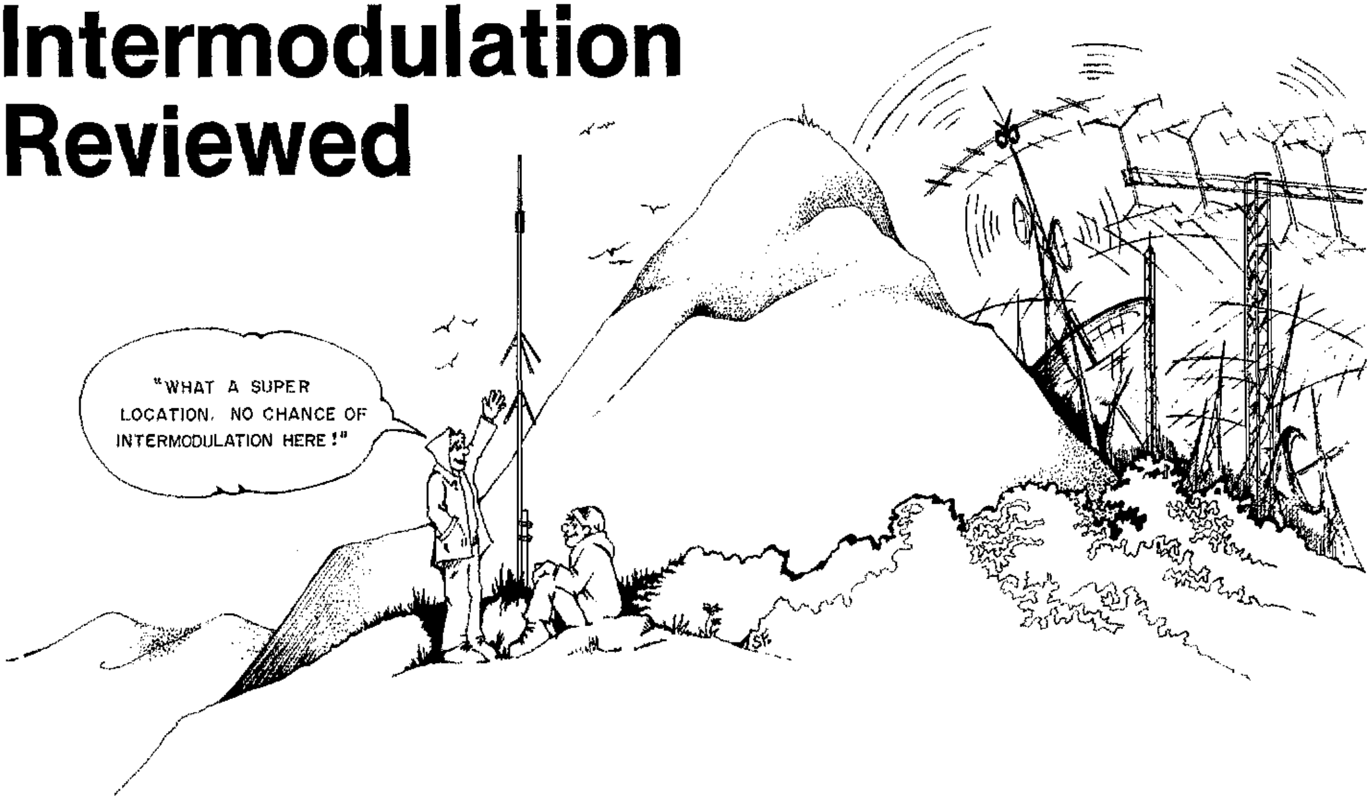
Intermodulation Reviewed



Hearing unwanted signals on your favorite repeater? Intermodulation may be the culprit!

By David W. Potter,* W2GZD

Intermodulation (IM) is defined as the undesired mixing of two or more frequencies in a nonlinear device, which produces additional sum-and-difference frequencies. Problems with IM seem prevalent in the vhf and uhf bands, because amateur repeaters tend to cluster around hills and mountain-tops — in close proximity to commercial and government vhf and uhf radio services. The intermodulation problem has been understood for years, but a review of the subject can be helpful.

Types of Intermodulation

The simplest kind of intermodulation is the mixing of two frequencies. The equation for *second-order* IM is

$$f_{IM} = f_1 \pm f_2 \qquad \text{(Eq. 1)}$$

where f_{IM} is the frequency of the IM product, and f_x are the mixing frequencies.

Intermodulation products are the sum and difference of the two mixing frequencies. These are similar to the familiar products deliberately generated by the mixing process used in superheterodyne receivers. Note that if f_1 and f_2 are frequencies within an amateur band f_{IM} must be an out-of-band signal.

Third-order IM products can produce both in-band and out-of-band signals when f_1, f_2 and f_3 are all in-band frequencies as given by the equation

$$f_{IM} = f_1 \pm f_2 \pm f_3 \qquad \text{(Eq. 2)}$$

In-band signals are generated by the sum of any two frequencies minus the frequency of the third signal. The out-of-band signal is the sum of all three frequencies. A special case of Eq. 2 is

$$f_{IM} = f_1 + f_1 - f_2 = 2f_1 - f_2 \qquad \text{(Eq. 2A)}$$

Here, the second harmonic of an in-band signal can beat with a fundamental frequency to produce another in-band signal.

Fifth-order IM products are given by

$$f_{IM} = f_1 \pm f_2 \pm f_3 \pm f_4 \pm f_5 \qquad \text{(Eq. 3)}$$

with special cases:

$$f_{IM} = 3f_1 \pm 2f_2 \qquad \text{(Eq. 3A)}$$

$$f_{IM} = 3f_1 \pm f_2 \pm f_3 \qquad \text{(Eq. 3B)}$$

$$f_{IM} = 2f_1 \pm f_2 \pm f_3 \pm f_4 \qquad \text{(Eq. 3C)}$$

$$f_{IM} = 2f_1 \pm 2f_2 \pm f_3 \qquad \text{(Eq. 3D)}$$

Some fifth-order products are in-band and others are out-of-band. Notice that second- and third-harmonic signals may be involved. Odd orders of in-band mixing frequencies produce some in-band products, but when out-of-band mixing frequencies are involved, even-order products may fall in band!

The above equations are valid for steady carriers, and it is easier to understand the concept of intermodulation by using them. Most of the signals we deal with are not steady carriers, however, but modulated ones.

The bandwidth of an IM product may be wider than the bandwidths of the individual signals. This is because the instantaneous frequency of the product is the algebraic sum of the instantaneous frequencies of the mixing signals. For fm, it would be equivalent to adding three voice signals together in a wide-band fm transmitter. Assume that the audio amplitude is limited on *each* signal to produce a deviation no greater than 5 kHz. When the three signals are added together, they could produce an IM product having much greater deviation than any of the individual signals.

Intermodulation may involve any number of frequencies, but let's concen-

*51 Bayport Ave., Bayport, NY 11705

trate on the more common third-order types. I will show some examples to make these abstract concepts more meaningful.

Field Examples of Intermodulation

Consider two repeaters that are physically located close to each other. One repeater transmits on 146.70 MHz, with a 146.10-MHz input, and the second has a 145.31-MHz output and a 144.71-MHz input. Assume that the .31 repeater output causes the .70 repeater first receiver stage to be driven into nonlinear operation (overload). This means that mixing of all frequencies seen by the first stage will occur.

Case 1: The .70 repeater is off, but the .31 machine is operating and a local 145.50-MHz simplex signal is present. The .31 repeater input and output signals and the simplex signal mix to produce an IM product on 146.10 MHz: 145.31 − 144.71 + 145.50 = 146.10 MHz. This signal can key up the .70 machine, which will then repeat both the .31 machine *and* the simplex conversation. We will disregard the other IM products that are generated.

Case 2: The simplex station is off the air. The .31 machine is repeating, and the input to the .70 repeater drops, but the output is still up. An IM signal is produced: 146.70 − 145.31 + 144.71 = 146.10 MHz. The .70 machine will now repeat the signal from the .31 repeater until someone overrides the IM signal — provided that the .70 repeater doesn't time out beforehand. If the system gain is adequate, the repeater could feed back on itself with a resulting characteristic audio howl.

Case 3: The .31 repeater shuts down. The input to the .70 machine drops, but the output is up and *stays* up. You may hear another signal on the output, or the repeater may break into oscillation. Why? You find a strong signal at 147.30 MHz that is overloading the repeater receiver, causing it to be nonlinear. The strong signal mixes with the second harmonic of the repeater: 2(146.70) − 147.30 = 293.40 − 147.30 = 146.10 MHz. This signal falls on the .70 repeater input.

These cases use the popular 2-meter band for illustration. Keep in mind that intermodulation can occur on *any* band, and can entail an endless combination of frequencies.

Receiver as the Culprit

Usually, the first stage of a receiver is the one most likely to overload, causing susceptibility to intermodulation. In some cases, however, later stages may be at fault. Receiver front-end nonlinearity occurs at relatively low input voltage levels, so the signal power involved is small. Therefore, the IM products generated there are also low in amplitude. These signals are fed to the receiving antenna and are radiated. If you track down these weak IM signals, they will lead you back to the receiver site!

There is a big temptation to use a preamplifier to increase the sensitivity of a receiver or the range of a repeater. The use of these devices in repeater service is strongly discouraged. Preamplifiers may not have the dynamic range that early stages of communications receivers have, and they usually lack the front-end selectivity found on well-designed receivers. Therefore, they are red-hot candidates for intermodulation. Preamplifiers may generate signals on the input frequency of the repeater, and users have to override these signals in order to be heard. The use of a preamplifier can sometimes *degrade* system performance!

Reducing Receiver IM Susceptibility

It is important to realize that it takes only *one* signal, located anywhere in the spectrum, to drive a circuit into nonlinearity, which could produce IM products when one or more other signals are present. In order to minimize intermodulation, your receiver circuitry should provide great attenuation to all frequencies except the band of interest. The receiver dynamic range should also be as large as possible. For this idealized case, only a huge signal in the passband could possibly cause overload and nonlinear operation. Any resulting IM signals falling outside of the receiver passband would be severely attenuated.

Transmitter as the Culprit

Serious intermodulation problems can be generated by transmitters when other strong signals present on the antenna (and coupled to the final amplifier) mix with the fundamental and its harmonics. Here the voltage and power levels are much greater than those associated with receiver circuits, so relatively strong IM signals may be coupled to the transmitting antenna and be radiated. The transmitter final amplifier is essentially an rf switch, and unless it is operating Class A (which is uncommon) it will be a nonlinear stage. Class C operation is more likely to cause intermodulation than Class AB1 — because it is more nonlinear. Wide-band, solid-state amplifiers with low-Q circuits tend to be more susceptible to intermodulation than are narrow-band, high-Q configurations.

Reducing Transmitter IM Susceptibility

Fm transmitter final amplifiers are quite nonlinear, and intermodulation can occur if other signals mix in this stage. The Q of most final stages is not high, even for tuned final amplifiers, so the resulting bandwidth is wide. Increasing circuit Q helps the IM problem, but it may be undesirable for other reasons. Eliminating intermodulation in transmitters is, therefore, more difficult than in receivers. The use of a *circulator* is effective because it presents a very low impedance to signals going from the transmitter to the antenna, but high attenuation to signals going from the antenna to the transmitter. Since the circulator must carry full transmitter power, it is an expensive cure for intermodulation. When duplexers are used at repeater sites, a degree of attenuation is introduced for out-of-band signals, but this alone may not be sufficient if other transmitters are nearby.

Conclusions

In-band intermodulation products will degrade or destroy your station performance, in addition to interfering with other amateur communications. Out-of-band IM products may play havoc with non-Amateur Radio services. Furthermore, transmitting spurious signals, such as IM products, is illegal. Conscientious operators are knowledgeable about intermodulation and ensure that their stations are free from it. QST

David W. Potter, W2GZD, is a spokesman for the Long Island GAME Association (Group Against Malicious Emissions). If it sounds like a hunting club, you're right! The group is engaged in tracking down interference for local repeater clubs. David's inspiration to write this article came about as a result of his involvement with the group. Persons interested in working with the GAME Association are invited to contact him.

Strays

At the 1982 New England Division Convention, ARRL General Manager K1ZZ (left) had the pleasure of presenting awards to the top-scoring W/VE entrants on both modes in the 1982 ARRL DX Contest: K1ZM, operating W1ZM on phone, and K1GQ, operating his own station on cw. Both are members of the Yankee Clipper Contest Club. *(W1VRK photo)*

KERCHUNK!

☐ Advice from a New York photographer to ladies on how to compose their mouth to gain "some advantage to their appearance" when sitting for a picture: ". . . If she wishes to look mournful, she must say 'Kerchunk'. . ." — *Quincy* (Massachusetts) *Patriot*, Dec. 3, 1887 as reprinted in *The New Yorker; tnx W9IWI*