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How Much Receiver Performance Does a Contester *Need*? — Part 2

Part 1 of this series examined the effects of external noise on the minimum signal levels that most amateurs will be able to receive. Other receiver parameters affect the ability to receive weak signals, however (at this stage, we'll ignore poor *transmitted* signals). Selectivity enables you to "separate" signals that are close in frequency; it's produced by filters of various forms. But before filters, we need to consider the performance of the receiver's stages in the presence of a multitude of strong signals.

Cross Modulation

Cross modulation was an effect first noticed in the late 1920s and early 1930s, in which modulation from a station well removed in frequency to the desired frequency was superimposed upon the signal of the desired signal. This was caused by the nonlinearity of the early stages of the receiver, especially where AGC (then known as "automatic volume control" or AVC) was used. Reducing the gain of the early stages to handle the desired signal likewise reduced the capability to handle the strong unwanted signal. Many older textbooks will gravely inform us that the effect was cured by the introduction of variable *mu* tubes, where the gain fell off more slowly as the bias voltage was increased. This was only partially true, although for broadcast sets, it was near enough! The advent of SSB on the amateur bands and the ensuing greater band occupancy showed that cross modulation was still considered to be a problem — except there was no carrier upon which to superimpose errant modulation. Most of the problems were actually caused by a related phenomenon — intermodulation.

Intermodulation

If two signals are applied to an amplifier or other device that does not have a truly linear relationship between input and output, the output will contain mixing products (see Figure 1). So, if a receiver is tuned to, say, 7,190 kHz, and two strong broadcast stations are on 7,250 and 7,310 kHz, intermodulation (IMD) in the receiver of 2 × 7,250 – 1 × 7,310 will yield an interfering signal on 7,190 kHz. This is known as "third-order intermodulation," because it is $2f^1 \pm f^2$. There are higher orders of IMD, but not all of the odd-order mixing products cause problems; that depends upon where they fall relative to the tuned frequency of the receiver. Even-order products, such as $f_1 - f_2$, falling on the receive frequency are less common, since they are removed by a band-pass filter that is less than one octave wide. Where there are a lot of signals, there are a lot more products (see Figure 2).

A bit of mathematics says that if there are *n* signals, then for any order, there will be 0.5 ($n^2 - n$) products that can fall within the receiver's passband. With multiple signals, the effect sounds like noise and effectively raises the noise floor of the receiver.

In the classical analog receiver, IMD products change with input level, and the

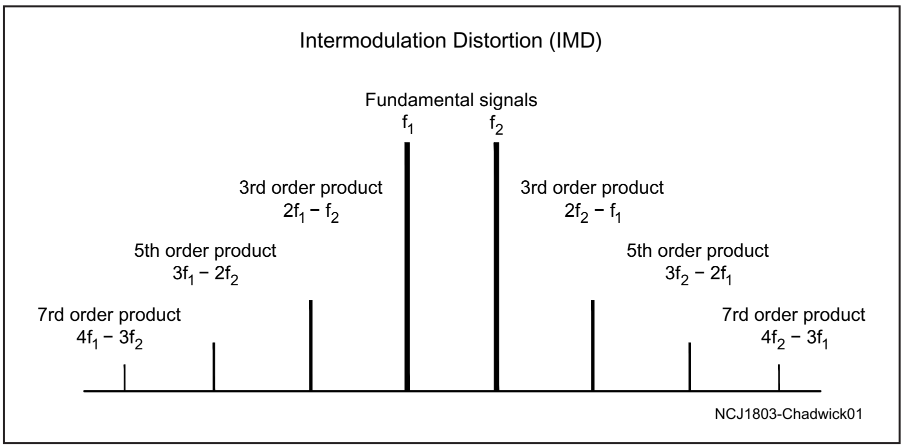

Figure 1 — Intermodulation distortion

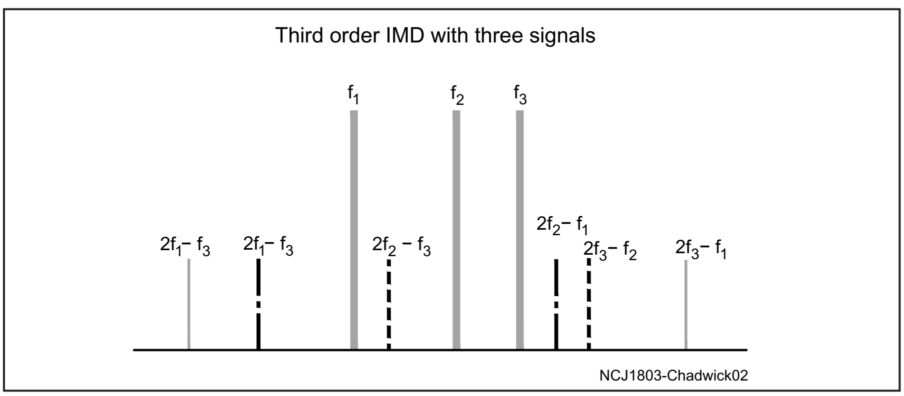

Figure 2 — Intermodulation with multiple signals

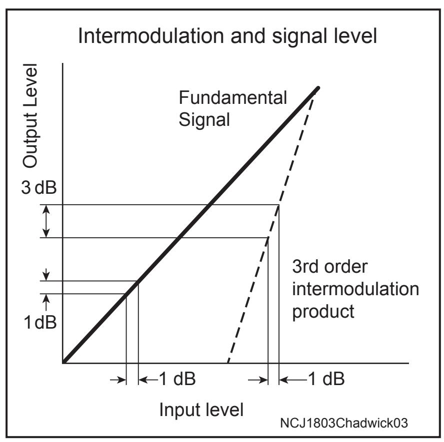

Figure 3 — Intermodulation and signal level

rate at which they so do depends on the order, so third-order IMD varies such that for every 1 dB increase in input level, the 3rd-order product rises by 3 dB in theory, and usually somewhere between 2 and 4 dB in practice (see Figure 3).

It may be seen from Figure 3 that a theoretical point exists — never reached in practice — where the IMD level is equal to the signal level. This is known as the *Intermodulation Intercept Point* or IP3 for the third order, IP5 for the fifth order, and so on.

TABLE

Inp Level – dBm	IMR $2f_1 - f_2$	IP^3 dBm	IMR $2f_2 - f_1$	IP^3 dBm
30	80	+10	66	+3
40	64	–8	56	–12
50	56	–22	44	–28
60	50	–35	33	–34

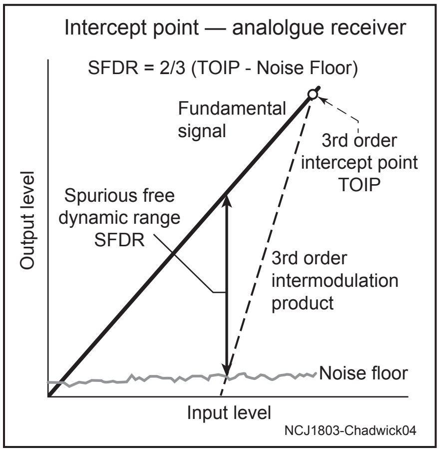

Figure 4 — Spurious free dynamic range

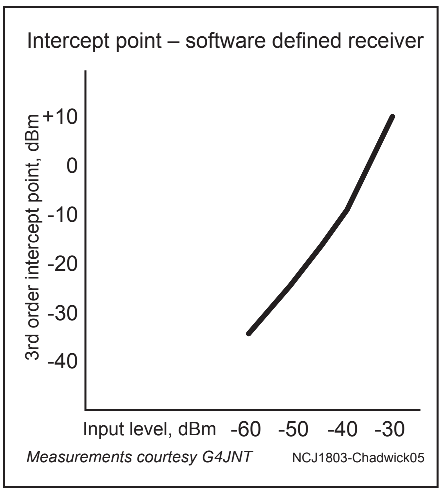

Figure 5 — SDR intercept point

Dynamic Range

If the lowest signal level that can be detected is at the receiver's noise floor, then IMD that is equal to the noise floor will degrade effective receiver sensitivity by 3 dB; the ratio between the noise floor and the signal level producing an IMD product that is equal to the noise floor is known as the *Spurious Free Dynamic Range* (SFDR). An interesting question is, "How much SFDR do we need?" Articles in *QEX*[1] and *NCJ*[2] suggest that for the average amateur station in the UK and by extrapolation, probably in Western Europe, 95 to 100 dB of SFDR is all that is required on 7 MHz, which is probably the worst-case band. For stations with very good antennas and/or very low-noise locations, another 6 or even 10 dB of SFDR may be useful. It may be shown that the SFDR is 2/3 of the difference in dB between the receiver noise floor and IP^3 (see Figure 4).

Because the IP^3 is fixed but the noise floor is dependent upon the receiver bandwidth, the SFDR is greater for a narrower bandwidth. Where the receiver noise floor is determined by external noise, as it is for an increasing number of amateurs these days, the usable SFDR may, in fact, be rather less.

The measured SFDR is also a function of the spacing between the signals, and as the signals used for measurement get closer to the tuned frequency, the SFDR can be expected to decrease, partly because IF selectivity allows more signal into the IF — analog filters are not "brick wall." In a multiple-conversion receiver, the signal levels into the second and/or third mixers can lead to some IMD there. It can be argued that, at least on SSB, the IMD products of most amateur *transmitters* — especially the majority of those with solid-state PA stages — are far worse than that of the receiver, and so will dominate.

IMD performance is measured with two signal generators and a suitable combining network, which is not that easy for measuring high-performance receivers, as the combining network has to provide substantial isolation between the two generators. This frequently means the use of a fixed attenuator between the combiner and the receiver under test. However, once we look at SDR receivers (depending on the architecture in use), this traditional measurement method can yield results that are not easily comparable with analog radios. Figure 5 shows the results of traditional measurement on an SDR radio: The intercept point is a function of input level. This means that, in order to get meaningful comparisons, depending on the architecture of the SDR, we require some different measurement methods.

Examination of the measurements from which Figure 5 was derived (see Table 1) shows that the equivalent input level of the IMD product stays at a relatively constant level as the input signal is varied. The significant difference between the products $2f_1 - f_2$ and $2f_2 - f_1$ has not been explained, however, and may be a function of the measurement system.

Meaningful comparison with analog systems may require testing with a wideband noise input signal, with a notch on the measurement frequency, as was done with the old FDM (frequency division multiplex) analog telephone systems.

Notes

[1] HF Receiver Dynamic Range — How much do we really need? Peter E. Chadwick, G3RZP, *QEX* May/June 2002, p 36 et seq.

[2] Receiver Parameters for Contesters, Peter E. Chadwick, G3RZP, *NCJ*, March/April 2007