the necessary trigonometric identities shows that a product can be produced from this combination of interfering frequencies that has a frequency of exactly f_0 — the same frequency as the desired signal! (The higher-order terms of the sidebar's equation for sinusoid signals can also produce products at f_0, but their amplitude is usually well below those of the third-order products.)

Thus we have two interfering signals that are not within our operating bandwidth so we don't hear either by themselves. Yet they combine in a nonlinear circuit and produce a signal exactly on top of our desired signal. If the interfering signals are within the passband of our first IF and are strong enough the IM product will be heard.

As the strength of the interfering signals increases, so does that of the resulting intermodulation products. For every dB of increase in the interfering signals, the third-order IM products increase by approximately 3 dB. Fifth-order IM increases by 5 dB for every dB increase in the interfering signals, and so forth. Our primary concern, however, is with the third-order products because they are the strongest and cause the most interference.

Third-order IMD dynamic range (*3IMD_DR*) is the difference between a receiver's MDS and the input level of two interfering signals that create an IMD product on the same frequency and as strong as a desired signal. (The complete test is described in the **Test Measurements and Instruments** chapter and in the book by Allison.) The test is performed with the interfering signals at different spacings (usually 2, 5, and 20 kHz) and with the desired signal at several different levels. The ARRL uses a signal at the MDS, at S5 (–97 dBm) and 0 dBm. For *QST* Product Reports, the test is performed on the 3.5, 14, and 50 MHz bands. All of these conditions must be specified and no single number characterizes 3IMD_DR performance entirely.

This dynamic range is particularly important to the contest and DX community since they often need to copy very weak signals with very strong signals on an adjacent channel or just a few kHz away. Combined with reciprocal mixing, band noise, and spurious emissions from transmitters, third-order IMD products can make for very difficult reception. Note that SDR receivers do not specify this dynamic range because their circuitry does not behave the same as analog superheterodyne receivers as discussed the sections below.

INTERCEPT POINT

Intercept point describes the IMD performance of an individual stage or a complete receiver. For example, in an analog heterodyne receiver, third-order IM products increase at the rate of 3 dB for every 1-dB increase in the level of each of the interfering input signals (ideally, but not always exactly true). As the input levels increase, the distortion products seen at the output on a spectrum analyzer could catch up to, and equal, the level of the two desired signals if the receiver did not begin to exhibit blocking as discussed earlier. Remember that SDR equipment will behave differently.

The input level at which this occurs is the *input intercept point*. **Figure 12.3** shows the concept graphically, and also derives from the geometry an equation that relates signal level, distortion and intercept point. The intercept point of the most interest in receiver evaluation is that for third-order IM products and is called the *third-order intercept point* or IP_3. A similar process is used to get a second-order intercept point for second-order IMD. A higher IP_3 means that third-order IM products will be weaker for specific input signal strengths and the operator will experience less interference from IM products from strong adjacent signals.

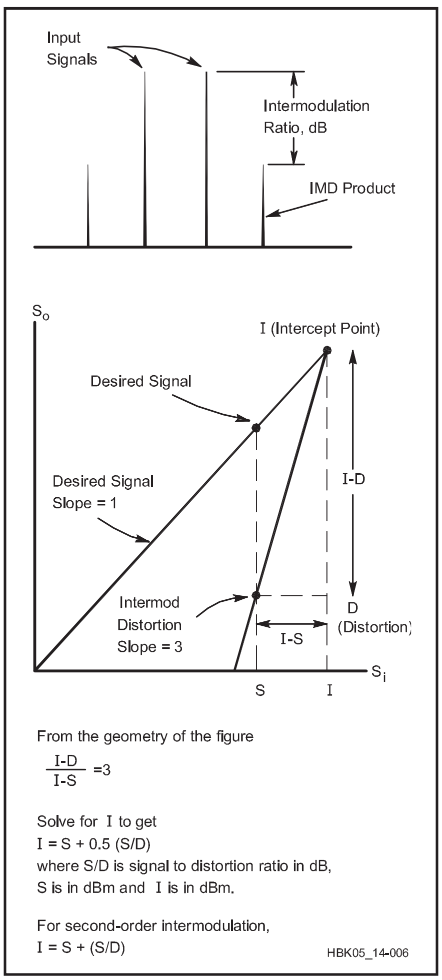

Figure 12.3 — Graphical representation of the third-order intercept concept.

Testing and Calculating Intermodulation Distortion in Receivers

Second and third-order IMD can be measured using the setup of **Figure 12.B1**. The outputs of two signal generators are combined in a 3-dB hybrid coupler. Such couplers are available from various companies, and can be home-made. The 3-dB coupler should have low loss and should itself produce negligible IMD. The signal generators are adjusted to provide a known signal level at the output of the 3-dB coupler, say, –20 dBm for each of the two signals. This combined signal is then fed through a calibrated variable attenuator to the device under test. The shielding of the cables used in this system is important: At least 90 dB of isolation should exist between the high-level signal at the input of the attenuator and the low-level signal delivered to the receiver.

The measurement procedure is simple: adjust the variable attenuator to produce a signal of known level at the frequency of the expected IMD product ($f_1 \pm f_2$ for second-order, $2f_1 - f_2$ or $2f_2 - f_1$ for third-order IMD).

To do this, of course, you have to figure out what equivalent input signal level at the receiver's operating frequency corresponds to the level of the IMD product you are seeing. There are several ways of doing this. One way — the way used by the ARRL Lab in their receiver tests — uses the minimum discernible signal. This is defined as the signal level that produces a 3-dB increase in the receiver audio output power. That is, you measure the receiver output level with no input signal, then insert a signal at the operating frequency and adjust the level of this input signal until the output power is 3 dB greater than the no-signal power. Then, when doing the IMD measurement, you adjust the attenuator of Figure 12.B1 to cause a 3-dB increase in receiver output. The level of the IMD product is then the same as the MDS level you measured.

There are several things I dislike about doing the measurement this way. The problem is that you have to measure noise power. This can be difficult. First, you need an RMS voltmeter or audio power meter to do it at all. Second, the measurement varies with time (it's noise!), making it difficult to nail down a number. And third, there is the question of the audio response of the receiver; its noise output may not be flat across the output spectrum. So I prefer to measure, instead of MDS, a higher reference level. I use the receiver's S meter as a reference. I first determine the input signal level it takes to get an S1 reading. Then, in the IMD measurement, I adjust the attenuator to again give an S1 reading. The level of the IMD product signal is now equal to the level I measured at S1. Note that this technique gives a different IMD level value than the MDS technique. That's OK, though. What we are trying to determine is the *difference* between the level of the signals applied to the receiver input and the level of the IMD product. Our calculations will give the same result whether we measure the IMD product at the MDS level, the S1 level or some other level.

An easy way to make the reference measurement is with the setup of Figure 12.B1. You'll have to switch in a lot of attenuation (make sure you have an attenuator with enough range), but doing it this way keeps all of the possible variations in the measurement fairly constant. And this way, the difference between the reference level and the input level needed to produce the desired IMD product signal level is simply the difference in attenuator settings between the reference and IMD measurements.

Calculating Intercept Points

Once we know the levels of the signals applied to the receiver input and the level of the IMD product, we can easily calculate the intercept point using the following equation:

$$IP_n = \frac{n \times P_A - P_{IM_n}}{n-1} \quad \text{(A)}$$

Here, n is the order, P_A is the receiver input power (of one of the input signals), P_{IMn} is the power of the IMD product signal, and IP_n is the nth-order intercept point. All powers should be in dBm. For second and third-order IMD, equation A results in the equations:

$$IP_2 = \frac{2 \times P_A - P_{IM_2}}{2-1} \quad \text{(B)}$$

$$IP_3 = \frac{3 \times P_A - P_{IM_3}}{3-1} \quad \text{(C)}$$

You can measure higher-order intercept points, too.

Example Measurements

To get a feel for this process, it's useful to consider some actual measured values.

The first example is a Rohde & Schwarz model EK085 receiver with digital preselection. For measuring second-order IMD, signals at 6.00 and 8.01 MHz, at –20 dBm each, were applied at the input of the attenuator. The difference in attenuator settings between the reference measurement and the level needed to produce the desired IMD product signal level was found to be 125 dB. The calculation of the second-order IP is then:

$$IP_2 = \frac{2\,(-20\text{ dBm}) - (-20\text{ dBm} - 125\text{ dB})}{2-1}$$

$$= -40\text{ dBm} + 20\text{ dBm} + 125\text{ dB} = +105\text{ dB}$$

For IP_3, we set the signal generators for 0 dBm at the attenuator input, using frequencies of 14.00 and 14.01 MHz. The difference in attenuator settings between the reference and IMD measurements was 80 dB, so:

$$IP_3 = \frac{3\,(0\text{ dBm}) - (0\text{ dBm} - 80\text{ dB})}{3-1}$$

$$= \frac{0\text{ dBm} + 80\text{ dB}}{2} = +40\text{ dBm}$$

We also measured the IP_3 of a Yaesu FT-1000D at the same frequencies, using attenuator-input levels of –10 dBm. A difference in attenuator readings of 80 dB resulted in the calculation:

$$IP_3 = \frac{3\,(-10\text{ dBm}) - (-10\text{ dBm} - 80\text{ dB})}{3-1}$$

$$= \frac{-30\text{ dBm} + 10\text{ dBm} + 80\text{ dB}}{2}$$

$$= \frac{-20\text{ dBm} + 80\text{ dB}}{2}$$

$$= +30\text{ dBm}$$

Synthesizer Requirements

To be able to make use of high third-order intercept points at these close-in spacings requires a low-noise LO synthesizer. You can estimate the required noise performance of the synthesizer for a given IP_3 value. First, calculate the value of receiver input power that would cause the IMD product to just come out of the noise floor, by solving equation A for P_A, then take the difference between the calculated value of P_A and the noise floor to find the dynamic range. Doing so gives the equation:

$$ID_3 = \frac{2}{3}(IP_3 + P_{min}) \quad \text{(D)}$$

where ID_3 is the third-order IMD dynamic range in dB and P_{min} is the noise floor in dBm. Knowing the receiver bandwidth, BW (2400 Hz in this case) and noise figure, NF (8 dB) allows us to calculate the noise floor, P_{min}:

$$P_{min} = -174\text{ dBm} + 10\log(BW) + NF$$

$$= -174\text{ dBm} + 10\log(2400) + 8$$

$$= -132\text{ dBm}$$

The synthesizer noise should not exceed the noise floor when an input signal is present that just causes an IMD product signal at the noise floor level. This will be accomplished if the synthesizer noise is less than:

ID + 10 log (BW) = 114.7 dB + 10 log (2400) = 148.5 dBc/Hz

in the passband of the receiver. Such synthesizers hardly exist.

— Dr Ulrich L. Rohde, N1UL

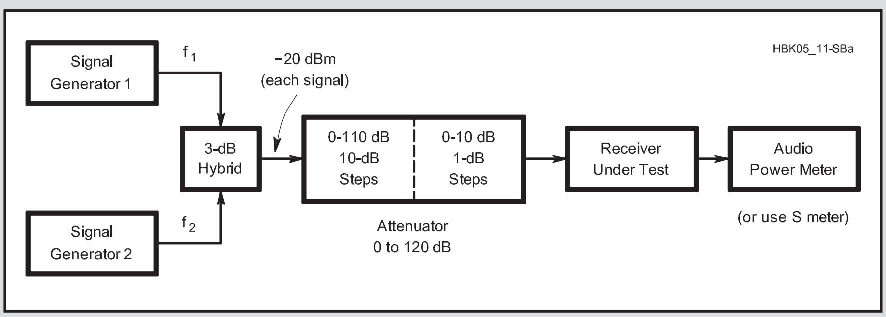

Figure 12.B1 — Test setup for measurement of IMD performance. Both signal generators should be types such as HP 608, HP 8640, or Rohde & Schwarz SMDU, with phase noise performance of –140 dBc/Hz or better at 20 kHz from the signal frequency.