BY HAROLD KINLEY

The next level of intermodulation

Here's what to do when dealing with amplifier signals that are unequal

In the April edition, we lightly touched on the subject of intermodulation (I-M) and small-signal radio frequency amplifiers. We discussed how two equal-level tones (RF signals), A and B, when applied to the amplifier input, are used to produce third-order intermodulation products at the output of the amplifier. We left the reader hanging, somewhat, with the question: "What if tones A and B are not equal?" In this article, we provide the answer.

First, a little background about interconnecting the test equipment and the device under test (DUT) is in order. Two signal generators labeled A and B are used to generate the two continuous wave tones, A and B. The outputs of the two signal generators are combined and fed to the input of the DUT (a small-signal RF amplifier in this case), and the frequency and output level of the two generators are adjusted to produce third-order I-M products at the output of the RF amplifier. The test setup is shown in Figure 1.

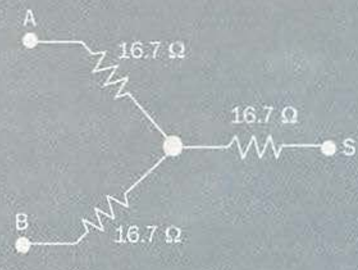
A hybrid combiner is preferred over a simple resistive combiner. A resistive combiner like the one shown in Figure 2, while providing proper impedance matching, offers little isolation between signal generators. A high degree of isolation between combiner ports A and B is necessary to prevent interaction between the signal generators. Don't even think about using a simple Tee connector as a combiner for this test. A hybrid combiner is made up of an RF transformer and resistor network. The isolation between ports A and B is achieved by cancellation of signals at opposite ports.

For example, the signal at port A arrives at port B via two separate paths. One path is through a transformer, and the other path is through a resistor. The path through the RF transformer is 180° out of phase with the signal through the resistor. With the signals being equal—or nearly so—cancellation occurs. The same is true for the signals traveling from port B to port A. Referring to Figure 1, RF isolators can be used with hybrid combiners for additional isolation. But they must be used with resistive combiners in order to achieve the required degree of isolation.

Another important point to note is that having a good 50 ohm load at the sum (S) port is necessary to optimize the isolation between ports A and B. A mismatch at the S port will adversely affect the isolation between ports A and B, possibly resulting in undesirable interaction between the signal generators. An attenuator pad connected as shown can improve the isolation figure.

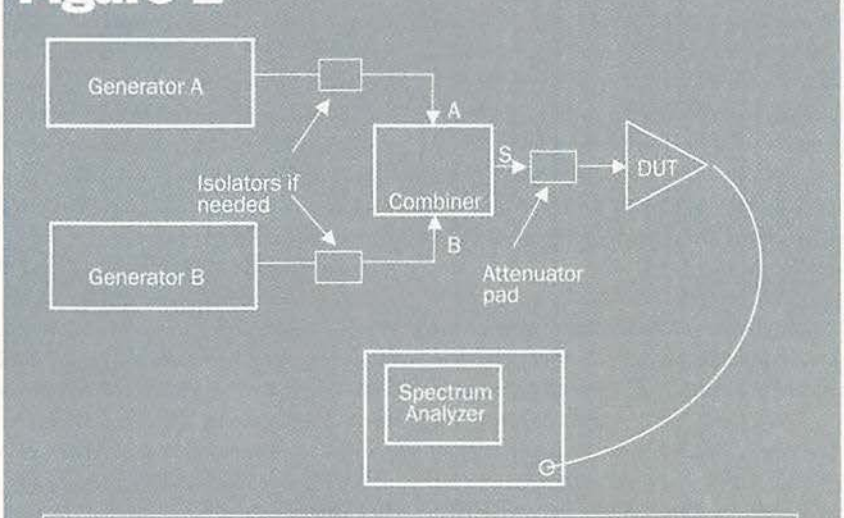
In order to check for interaction between signal generators, vary the output level of generators A and B by ±10 dB and observe the effect on the opposite signal on the spectrum analyzer. For example, increase and decrease the level of generator A by 10 dB while closely monitoring the level of signal B on the spectrum analyzer. If the level of signal B is affected by changes in the level of generator A, there is insufficient isolation between the two signal generators. Also, make sure that I-M signals

Figure 2



A resistive combiner such as this could be used to combine the signals from two signal generators. However, not enough isolation would be provided between the signal generators. Additional means of isolation would be required.

Figure 1



This test setup is used to check the intermodulation distortion (IMD) performance of the DUT (device under test), a small-signal RF amplifier. See text for full discussion.

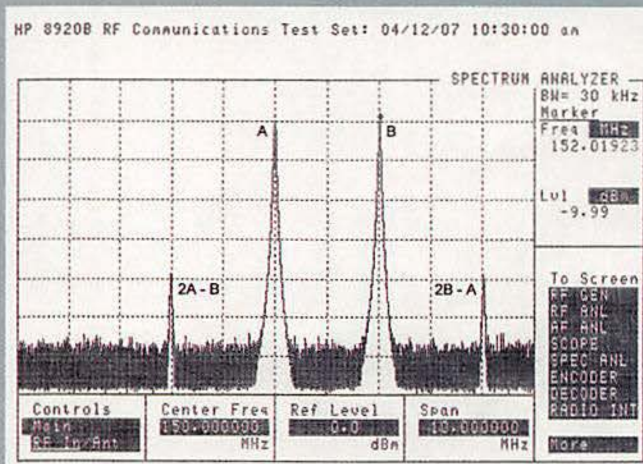
are not being formed in the signal generators. You can check this by changing the attenuation in the pad between the DUT and the combiner. If you see a dB-for-dB change in the I-M signal on the spectrum analyzer, the I-M signal is being formed at a point prior to the attenuator pad. If you see a 3-for-1 dB change in the third-order I-M signal on the spectrum analyzer, the I-M signal is being formed at a point after the attenuator pad.

Suppose that the amplifier in Figure 1 has a third-order intercept point (TOIP) of +10 dBm. Signal generators A and B are set to 150 MHz and 152 MHz, respectively. The output levels of generators A and B are set to produce a level of -10 dBm for each tone (A and B) at the input to the DUT (amplifier). Since both of the fundamental tones are equal in amplitude, the two third-order intermodulation products also are equal in amplitude. In Figure 3, each horizontal scale division on the spectrum analyzer represents 1 MHz. Thus, the 2A-B intermodulation product is at 148 MHz, and the 2B-A intermodulation product is at 154 MHz. Notice that the levels of the I-M products are each at -50 dBm. Also note in Figure 4 that the fundamental tones, A and B, are not of equal level. This results in I-M products that are not of equal level. The frequency spacing remains unchanged.

Figure 5 on page 48 is a nomogram that can be used to determine the output level of the third-order I-M products, given the amplifier's third-order intercept figure and the level of fundamental tones, A and B, at the output. First, a description of the scales of the nomogram is in order. The first scale on the far left is used to represent the level of the second-order term. The second scale is used to represent the level of the first-order term. In the expression 2A-B, A is the second-order term, and B is the first-order term. Conversely, in the expression 2B-A, B is the second-order term, and A is the first-order term. The third scale is used to adjust the TOIP of the amplifier. If the TOIP of the amplifier is 0 dBm, no adjustment is necessary.

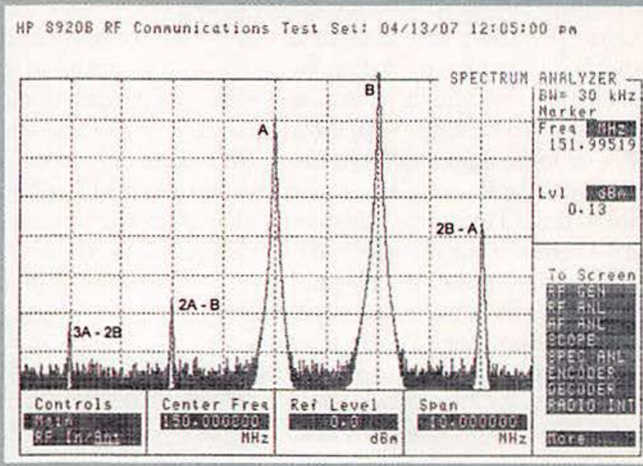
Now, let's do an example on the nomogram. Suppose that an amplifier has a TOIP of +25 dBm. The level of the fundamental tone A at the output is -20 dBm and the level of the fundamental tone B at the output is -30 dBm. Now, we want to determine the level of the two third-order I-M products at the output, 2A-B and 2B-A. First, we will determine the level of the 2A-B intermodulation signal. The blue dashed line on the nomogram in Figure 5 represents this procedure. Start on the left scale for the second-order term at -20 dBm, represented by point 1 on the blue-dashed line. Move straight over to the second scale repre-

Figure 3



This spectrum analyzer display shows the two CW tones (A and B) and the resultant third-order I-M products (2A-B and 2B-A). See text for details.

Figure 4



Here, tones A and B are unequal. Tone B is at 0 dBm and tone A is at -10 dBm. This results in the unequal I-M products as shown in the display. Notice, too, that a fifth-order I-M product appears on the left in the display. See text for full discussion.

Figure 5

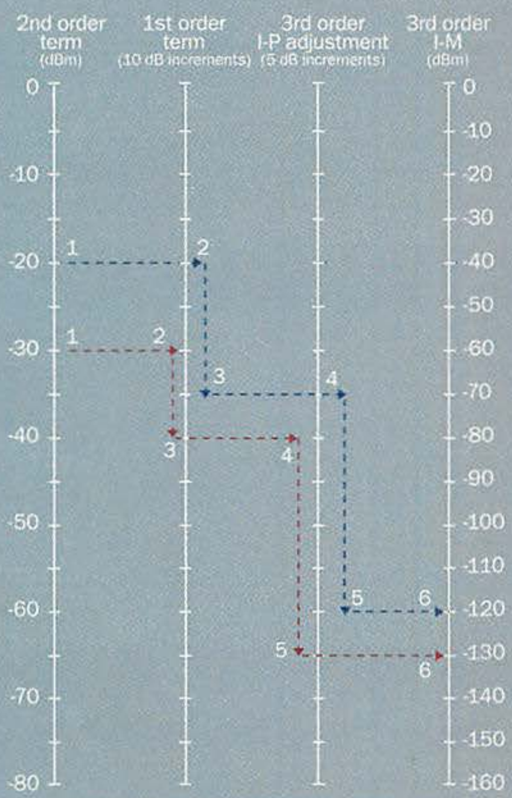


Figure 5: This nomogram can be used to determine the level of the third-order intermodulation product produced in the output of an amplifier, given the output level of the fundamental tones, A and B, and the third-order intercept point of the amplifier.

senting the first-order term at point 2. Since the first-order term is -30 dBm, we move downward by three increments to point 3 on the second scale. Next, move directly over to the third scale representing the third-order intercept adjustment at point 4. If the TOIP was 0 dBm, we would not need to make any adjustment. But, since the third-order intercept point is +25 dBm, we must move downward by five increments to point 5 on the third scale. Then, move directly over to the fourth scale at point 6, which represents -120 dBm for the third-order I-M level. Thus, the level of the 2A-B intermodulation product is -120 dBm. The level of the 2B-A intermodulation product is determined the same way, as depicted by the red dashed line on the nomogram.

The nomogram in Figure 5 is very intuitive, and in studying it, several things become apparent. For example, notice that a 10 dB change in the second-order term will change the third-order I-M level by 20 dB. A 10 dB change in the first-order term will change the third-order I-M level only by 10 dB, while a 10 dB change in both terms (in the same direction) will result in a 30 dB change in the output I-M level (in that direction).

Note that on the third scale—the TOIP adjustment—each increment represents a 5 dB change and that a 5 dB change in the third-order intercept point will result in a 10 dB change in the third-order I-M level. For a given output level of the fundamental A and B tones, increasing the TOIP results in a decrease in the I-M signal level. This is why it is important to use an amplifier with a very high TOIP figure to keep the resultant I-M signal levels low. The formulas for calculating the third-order I-M levels can be found in Equation 1.

It is important to note here that this discussion centers on the output TOIP and uses the tone levels, A and B, at the output of the amplifier. Thus, the figure listed is the output TOIP. The input TOIP would be less than the output TOIP by an amount equal to the gain of the amplifier. (Typically, RF amplifiers are rated in terms of the output TOIP figure.)

It is important to remember, too, that the TOIP point is an extrapolated figure based on the point at which the third-order I-M product is equal to the level of one of the two equal fundamental tones, A or B. This point occurs at a point 15 dB (plus/minus a few decibels) above the 1 dB compression point. Since it is well beyond the point of compression, the TOIP can't be reached in a practical amplifier. Still, the figure is useful in determining low signal-level performance of an RF amplifier.

Until next time—*stay tuned*!

Equation 1

$$P_{(2A-B)} = 2P_A + P_B - 2P_{I3}$$

$$P_{(2B-A)} = 2P_B + P_A - 2P_{I3}$$

where: $P_{(2A-B)}$ and $P_{(2B-A)}$ = power level of I-M signal in dBm
P_A and P_B = power level of signals A and B, respectively, in dBm
P_{I3} = power level of TOIP in dBm.