

# Performing Sensitive Two-Tone Mixer Measurements With Existing Equipment

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When sensitive mixer intermodulation measurements are needed and sensitivity is of paramount importance; you don't want to bother with an automatic test stand for a small number of measurements; or your test equipment isn't the greatest, and your equipment budget got shot down — then the ideas in this paper can help you attain this sensitivity, step-by-step.

## Two-tone IM and third order intercept point

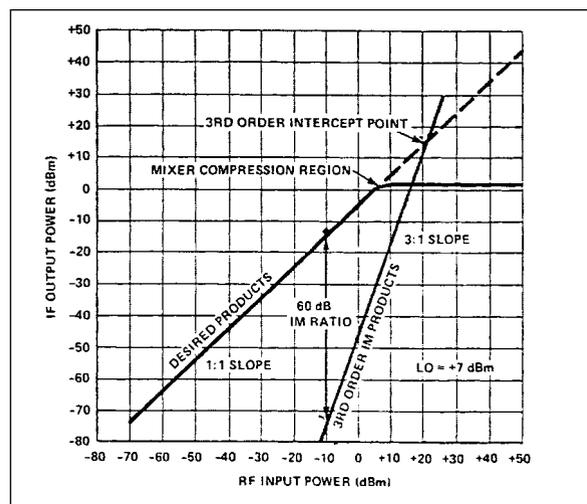
When two RF signals,  $f_1$  and  $f_2$ , are simultaneously applied to a mixer, they will combine with the local oscillator frequency,  $f_L$ , producing the normal terms  $f_L \pm f_1$  and  $f_L \pm f_2$ , as well as distortion products  $f_L \pm nf_1 \pm mf_2$ , where  $n$  and  $m$  represent integers. The first distortion products of interest here are  $f_L \pm (2f_1 - f_2)$  and  $f_L \pm (2f_2 - f_1)$ , which are usually referred to as third order IM products. ("Third" refers to the three RF factors involved, e.g.  $2RF_1 + 1RF_2$ .)

The two-tone IM ratio is the ratio of a third order IM product to an IF output level, at a specified power level for the two RF inputs.

When the output products versus RF input power are plotted on a log-log graph, as in Figure 1, the third order IM products have a 3:1 slope and the IF outputs have a 1:1 slope. The extrapolations of these two slopes meet at the third order intercept point. Figure 2 shows the basic test set-up. An analysis of the major elements of this set-up follows.

## RF sources

**RF Signal Purity** — For reliable results, the two RF signals should be as pure as possible. The second harmonics of the desired signals are of prime concern here, because they can direct-



▲ Figure 1. Diagram of the third order intercept point (IP3).

ly contribute to the level of the intermodulation products that are under test. If possible, it is desirable to have them at least  $-60$  dBc.

Frequency synthesizers are good RF sources. If necessary, lowpass filters following the source can be used to reduce the unwanted harmonics at the expense of test set-up bandwidth. If one suspects that a subharmonic is causing problems, then a bandpass filter would be required. For simplicity, just one filter can be placed at the output of the combiner that adds the two RF signals. However, see the paragraph on the IM between the two generators.

**IM between the two RF generators** — The two RF generators can interact with each other to cause intermodulation, but inserting isolation between them can reduce this effect. For the combiner, a hybrid device can be chosen to pro-

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vide at least 20 dB of isolation. For lower frequencies, a ferrite combiner such as M/A-COM's H-8-4 can provide greater than 20 dB of isolation over the wide frequency range of 2 to 2,000 MHz.

Attenuators and filters on each arm of the combiner can also improve isolation. The filters can prevent unwanted products coming out a generator from interacting with the other one. The trade-off with attenuators is that the output level of each generator must be correspondingly raised, which in turn might cause the harmonic level from the generators to increase. The ultimate RF signal combination can be fed directly into a spectrum analyzer in order to test this self-IM level.

**Separation of the 2 RF signal frequencies** — The closer together the 2 RF frequencies, the tighter the output IM frequency pattern, and therefore the smaller the required frequency span setting on the spectrum analyzer. This allows for a faster sweep.

Standard separations seen in the literature are 10, 5, and 2 MHz. If the 2 IM products were unequal or unstable, one fix would be to increase the separation. (Also, see the spectrum analyzer discussion.)

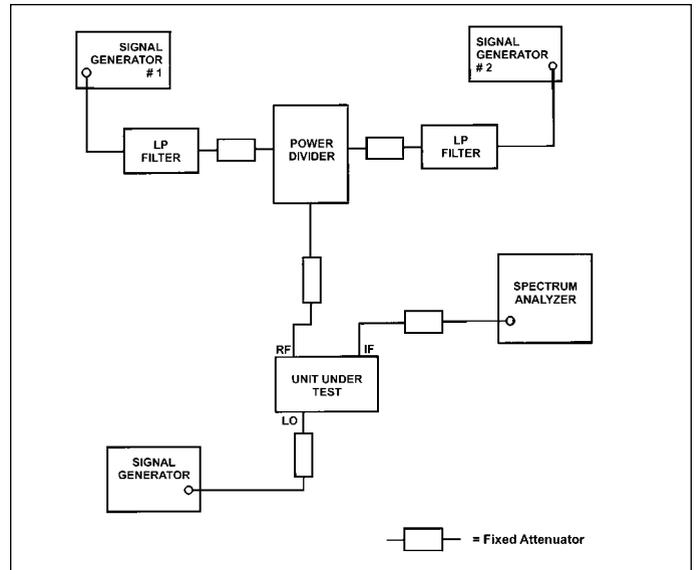
**RF signal power levels** — In the linear region, the third order IM level increases 3 dB for every 1 dB increase in RF signal, thus giving a 3:1 slope. As the RF levels increase above the linear region, most often the IM levels don't keep up with their normal pace, thus giving a slope something less than 3:1. This actually yields an apparent  $IP_3$  which is higher than the true value, when you extrapolate from one of these points.

It is also possible to go further and encounter a slope greater than 3:1, thus giving an ICP that is lower than the true value [1]. At times, linear region measurements necessitate a power level so low that large IM ratios must be measured requiring a very sensitive set-up. As an alternate, one could provide IM ratio data at power levels that the end user is likely to encounter.

## LO source

**Harmonics in the LO signal** — By pushing the generator and possibly an amplifier to a higher power level as needed for the LO signal, it is probable that the second harmonic as well as other harmonics and subharmonics will be present at significant levels. For example, it would be possible for the second harmonic to be only -35 dBc. Depending on the mixer type used, these strong harmonics may still have minimal effect on the IM performance. To test it out, one can add a filter to cut out the strongest harmonics. Also add more padding (attenuation) and/or a circulator between the filter and the mixer in order to reduce reflections, off the filter, of spurious products coming out of the LO port of the mixer. Then make some careful measurements and compare with the no-filter case to see if the inconvenience of a filter is really justified for the mixer type under test.

**LO power level** — The LO power is typically set in



▲ **Figure 2. Two tone IM ratio test set-up.**

accordance with the applicable requirement or with the listed mixer LO range. In the LO power range where performance is "well behaved," increased power gives increased IM suppression. However, this effect loses steam at higher levels and under certain conditions can even reverse itself.

## IF path

**"Pads," etc.** — In most mixers, the greatest sensitivity to mismatch is at the IF port [3]. If possible, a 10 dB pad, minimum, is recommended here. The tradeoff is with the increased noise floor. A filter should not be used at the IF for this test set-up unless a very strong signal is coming out of the mixer that might cause distortion in the spectrum analyzer. If either the allowable padding is low or a filter is required, then an isolator would help. The sequence, leading from the mixer, is pad, isolator, and filter. Thus the isolator and the pad reduce reflections of spurious mixer products off of the filter or any other reactive mismatch. Of course, a good low noise IF amplifier can be inserted to improve the signal to noise ratio. Make sure the amplifier has a good input match so that it is not altering the performance of the mixer that we are trying to test. Also make comparison tests to assure that the amplifier is not making its own contribution to the IM levels.

**Spectrum analyzer** — What if you have a good set-up, but the IM products to be tested are close to noise floor of the analyzer? This is where the sensitive measurement techniques come in. Reduction of the resolution bandwidth and video bandwidth will reduce the noise level, to allow a better view of the desired product. However, if the sweep time of the analyzer is ganged to the bandwidths, as it should be, then the narrower bandwidths yield longer sweep times.

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If you would like the noise level to be at least 10 dB below the IM product, this might make for a very slow sweep. Narrowing the spectrum analyzer frequency span as much as possible can speed up things. This is why it was suggested in the RF section to bring the two test tones fairly close together. Also, the span could be narrowed to the extent that only one IM signal is in view at one time, although you should still monitor both IM signals. This inconvenience can be compared to that of the slow sweep.

Video bandwidth (VBW) is typically set equal to or less than resolution bandwidth (RBW) to test these sine wave signals. Noise present with the signals is a good reason to reduce the VBW below the setting of the RBW. This smooths out irregularities caused by the noise [3].

Figure 3 illustrates the spectrum analyzer settings in Table 1. As seen, if the VBW is reduced, then the sweep time will increase, but the visible dynamic range will also increase. Generally, the input attenuator of the analyzer is left at the 10 dB default setting, which in most cases eliminates the possibility of distortion within the analyzer itself. If the low level signals seem to have some "bounce" or vary from sweep to sweep, and if it is proving difficult to eliminate this situation with signal separation adjustments, or BW adjustments, then one trick is to manually increase the sweep time by one step.

## IM vs. frequency

IM performance varies with frequency, even in a perfect 50 ohm test environment. Depending on the mixer and the test conditions, IM variation can be anywhere from a few dB to greater than 20 dB. This is good reason to test at more than just one frequency.

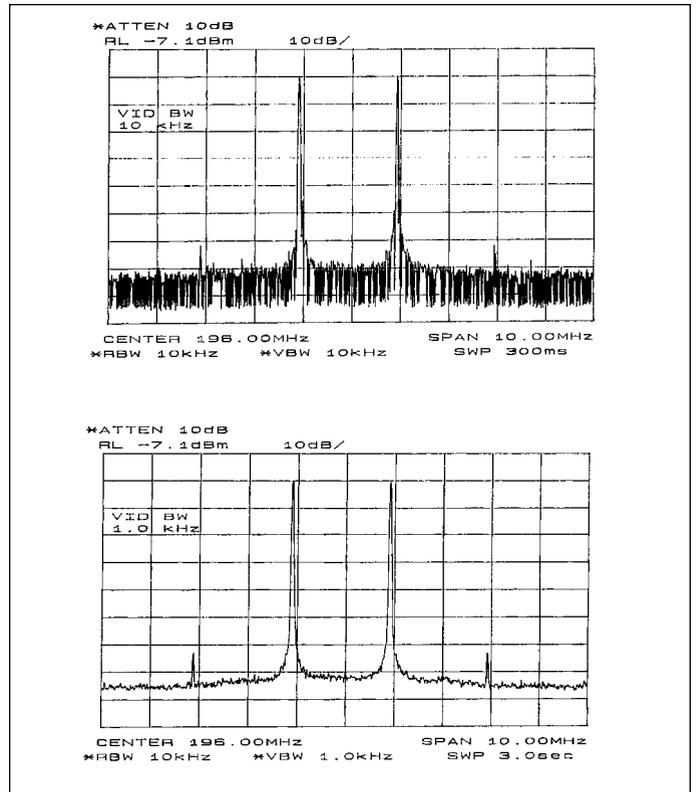
Computer controlled automatic test equipment (ATE) would be the first choice for testing vs. frequency, allowing for precisely set power as well as frequency at each step across the band. Even so, the appropriate test components must be used.

If an ATE is not in the cards, one can manually step the LO and two RF generators through the frequency band in such a way as to give a constant IF frequency which will keep the IM frequency pattern on the spectrum analyzer screen. The step sizes should be truly equal for all three generators. Also check the power level of each generator as it sweeps across the band. If variations are greater than  $\pm .5$  dB, try to find another generator, or break the sweep down into narrower bands.

Another set-up for IM swept measurements is described in detail in a referenced article [4], offering good dynamic range and the ability to display the IM response vs. frequency. The set-up illustrated covers the RF/LO frequency band of 100-500 MHz. ■

## References

1. D. Cheadle, "Selecting mixers for best intermod performance (Part 2)," *Microwaves*, December 1973.



▲ Figure 3. Spectrum analyzer displays showing two different video bandwidths. Two-tone IM of prototype mixer #M189-2H3T. RF = 1800 and 1802 MHz at 0 dBm. LO = 2000 MHz at +23 dBm.

	(1)	(2)
RBW	10 kHz	same
VBW	10.0 kHz	1.0 kHz
Center Frequency	196 MHz	same
Span	10 MHz	same
Sweep time	0.3 Sec.	3.0 Sec.

▲ Table 1. Spectrum analyzer settings.

2. P. Will, "Reactive Loads-The Big Mixer Menace," *Microwaves*, April 1971.

3. M. Engelson, "Distortion Measurements Using the Spectrum Analyzer," *RF Design*, March 1995.

4. R. Snyder, "Sweep Dynamic Range Into Mixer Measurements," *Microwaves*, May 1978.

## Author information

Bob Severance received a BA in Physics in 1958 and an MA in Physics in 1961 from Williams College. During his career, he has designed microwave devices for Mitre, Raytheon, Adams Russell and Piconics Inc. He has been with the RF & Microwave Components group of M/A-COM since 1997, specializing in RF mixer development. He may be reached at severanceb@tycoelectronics.com.