Input Third Order Intercept Point for Crystal Filters

By Dennis Layne

A key performance requirement for crystal IF filters is the linearity of the filter.

Introduction

The heart of a dual conversion super heterodyne receiver is the Intermediate frequency (IF) filter or filters. This filter has to be approximately one channel wide. Crystal IF filters are typically used in order to achieve this bandwidth. A key performance requirement for crystal IF filters is the linearity of the filter. The IF filter is often subjected to multiple strong signals that are not in the pass band of the filter. In order to predict the receiver's linear dynamic range it is common to calculate the overall cascaded input third order intercept point (IIP3). From this value an estimate of the receiver intermodulation rejection can be calculated. Since crystal filters are passive components and by design, the interfering signals are not in the pass band of the filter, it is very challenging to measure the IIP3 of a crystal filter.

Third Order Intercept Point

The "third order intercept point" is the imaginary extrapolated point where the amplitude of a desired signal output from a device is equal to the amplitude of an unwanted output. The output intercept point equals the input intercept point plus the device gain. If the distortion products at the output are known for one particular input level then the intercept point can be predicted as follows:

$$IP_n = A + \frac{\Delta}{n-1}$$

IPn = n^{th} order intercept point

A = Signal power level at the input for IIP3 or output for OIP3 (dBm)

Δ = difference between desired signal and unwanted distortion (dB)

n = order of distortion

Two Tone Test

The Two-Tone test measures the third-order distortion products produced by a non-linear device when two tones closely spaced in frequency are fed into its input. In the case of an IF crystal filter, the two tones may be spaced the same as the industry standard intermodulation rejection test. These tones are outside of the filter passband. As a result of frequency spacing, the difference between the "test signal" and the "unwanted distortion" cannot be measured directly in one step.

The power of the distortion product is only meaningful at the output of the device under test and the gain of the device is defined as the loss in the passband of the filter. Therefore the power in the "test signal" in this case is defined as the power of one of the two test tones at the filter input minus the passband loss of the filter.

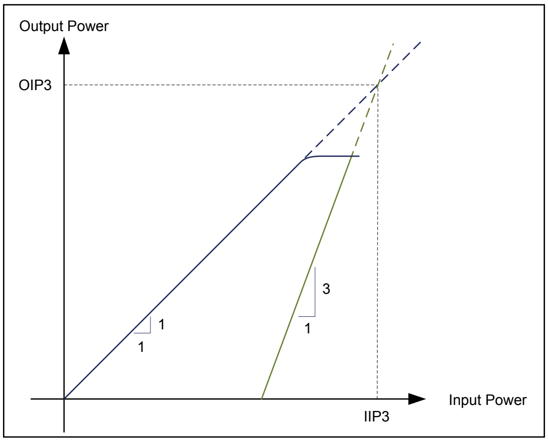

Figure 1 • Graphic definition of Intercept Point.

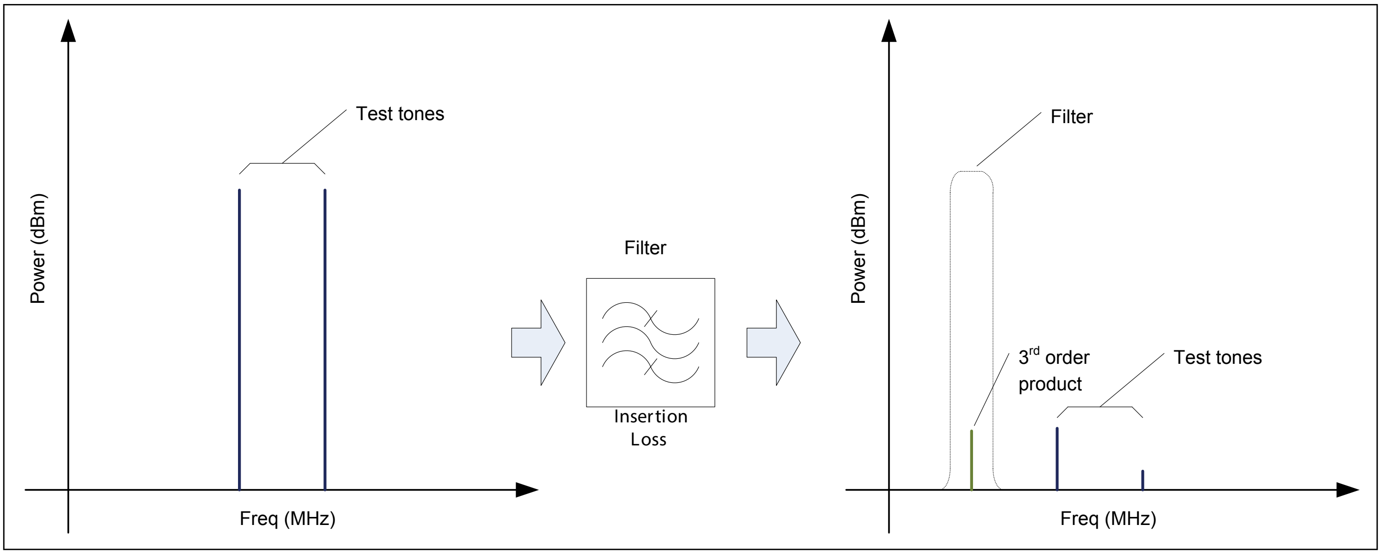

Figure 2 • Spectrum before and after Bandpass filter.

Δ (delta) = $(P_{test\_tone} - I_{loss}) - P3_{rd\_OP}$

For example: $P_{test\_tone} = -20$ dBm
$I_{loss} = 5$ dB
$P3_{rd\_OP} = -100$ dBm
Δ (delta) = -20 - 5 - -100 = 75 dB

Or, conversely if one considers the 3rd order product that would be imagined present at the input, then the power in the 3rd order product would be higher at the input of the filter by the insertion loss.

Δ (delta) = $P_{test\_tone} - (P3_{rd\_OP} + I_{loss})$

For example: $P_{test\_tone} = -20$ dBm
$I_{loss} = 5$ dB
$P3_{rd\_OP} = -100$ dBm
Δ (delta) = -20 – (-100 + 5) = 75 dB

Either way the result is the same.

Test Equipment Configuration

The goal when configuring the test setup is to get the lowest loss combining network that provides the best isolation between the signal generators and the best broad band termination at the input and output of the fixture. The setup is optimized so that the output power of the signal generators is as low as possible. In order to achieve this, there are two possible combining networks. First, one may use an isolator on the output of each signal generator. This will provide isolation between the signal generators with a low loss of signal to the filter under test. It is also best to use a hybrid combiner for the addition isolation between the inputs. Resistive attenuators are used at the input and output of the fixture for broadband termination. The output of the signal generators should be set to the lowest power that will result in a third order product within the dynamic range of the spectrum analyzer that is used.

An alternate combining network uses high isolation lab amplifiers at the output of each signal generator. This allows the signal generator to operate at a low output power but still have excellent isolation. The addition of

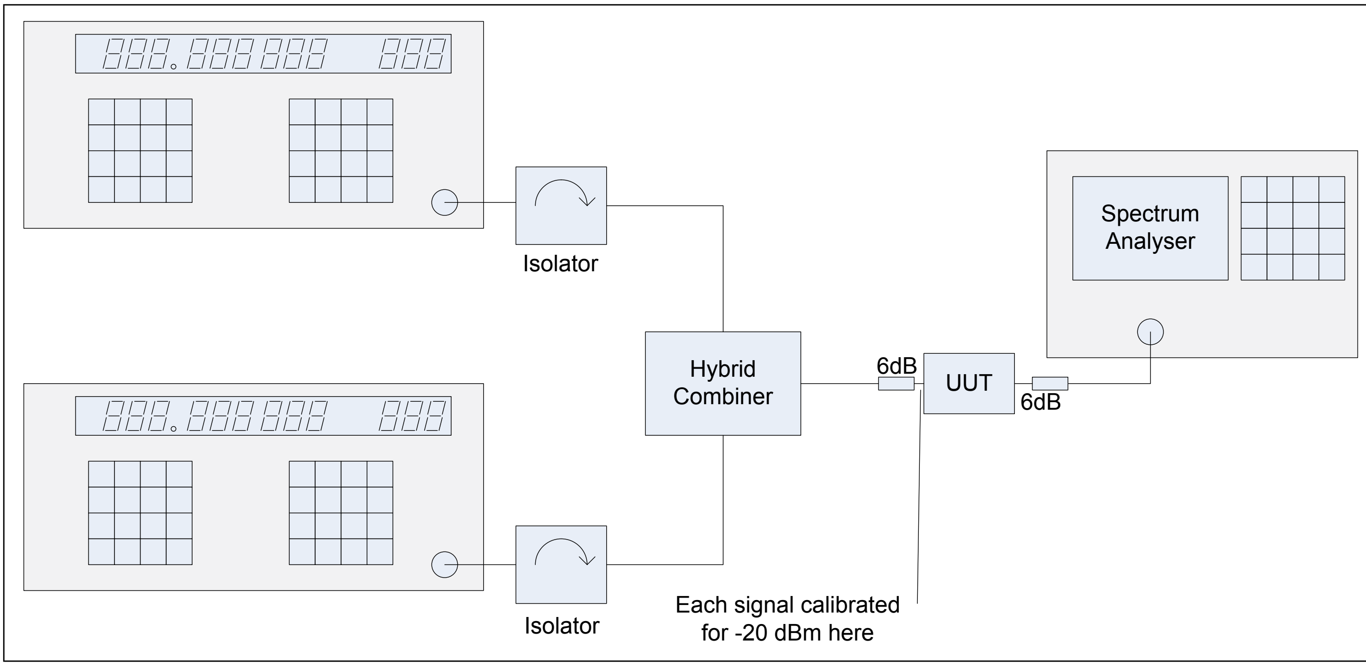

Figure 3 • Passive combining network.

low pass filters helps to remove harmonics from the generators and the amplifiers.

Note that the isolators on the signal generators have ~ 30 dB of isolation. The combiner is an M/A-Com H-8-4 hybrid combiner and has ~25 dB of isolation. The 6 dB attenuators on either side of the fixture ensure a broadband termination to the filter under test.

Crystal Filter Input Third Order Intercept Point Test Procedure

1. Apply a signal at the IF frequency that is calibrated to be -20 dBm at the input to the filter (UUT).
2. Measure the output of the UUT and set a reference marker (this offsets the delta marker by the insertion loss).
3. Apply signals at even channel frequency offsets (i.e. 2 channels and 4 channels) above the filter center frequency (IF frequency). Or some other uniform spacing may be chosen as long as the signals are evenly spaced apart. These are also calibrated to –20 dBm at the input to the filter.
4. Measure the power of the resulting third order product at the center frequency (IF frequency) of the filter. The delta marker now reads the change in filter output power from the signal generators and the third order product at the output. This is the “delta”.
5. Apply signals at even channel frequency offsets below the filter center frequency (IF frequency). Repeat step 4. The third order product with the highest power reading is the worst case. Use it to calculate the input third order intercept point.

Then the input third order intercept point

$$= IIP_3 = Pin + \frac{\Delta}{2}$$

So, if the delta is 100 dB then the IIP3 = -20 dBm + (0.5 * 100 dB) = +30 dBm

If the insertion loss is 5 db then the output intercept point would be = Pout + 0.5* delta = -25 dBm + (0.5 * 100 dB) = +25 dBm

Test Setup Linearity

In order to determine if the test equipment is operating in a linear mode, one can test the response of the intermodulation product to changes in input power. Reduce the power of the “test signals” by on e dB. This should result in a three dB drop in the intermodulation product power on the spectrum analyzer. Repeat this test by increasing the “test signals” by one dB and observe a 3 dB increase in the intermodulation product power. If the intermodulation product does not change by exactly three (3) dB then some component of the measurement network is producing distortion.

Conclusion

With careful attention to the power levels in each part of the test network, the dynamic range of the measurement system can be optimized. This allows for accurate measurement of the device. This is challenging to achieve because non-linearity in any element of the

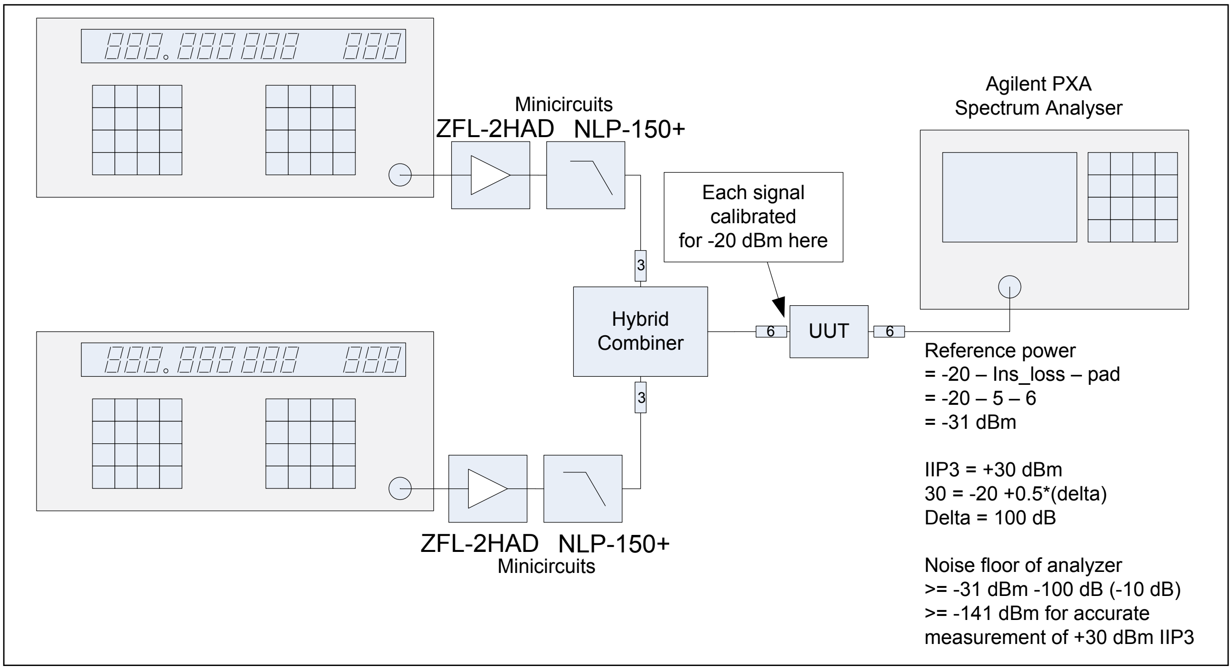

Figure 4 • Active combining network.

test network is difficult to distinguish from nonlinearity of the device under test. Once the input third order intercept point is accurately measured then the overall IIP3 cascade will result in an accurate Intermodulation rejection performance calculation.

About the Author:

Dennis Layne is a Principal RF Engineer at Harris Corp. Dennis has a BS in Physics from Lynchburg College in Virginia and has designed Land Mobile Radio receivers for 17 years.