Measuring 3rd order Intercept Point (IP3 / TOI) of an amplifier

Why measuring IP3 / TOI?

IP3 is an important parameter for nonlinear systems like mixers or amplifiers which helps to verify the quality / linearity of the device.
It is a measure of the receiver performance in the presence of strong nearby signals.
It can be used to define the upper limit of the dynamic range of an amplifier.

Devices with nonlinear transfer functions generate harmonics. In the presence of two sine wave signals with a small frequency distance intermodulation products are generated. The mathematics looks like this:

Pout =	A1f1 + A2f2 +	Fundamentals @f1 and f2
	A3(f1+f2) + A3(f1-f2)+	2nd order IM
	A4(2*f1+f2) + A4(2*f1-f2) +	
	A5(f1+2*f2) + A5(f1-2+f2) +	3rd order IM
	A6 (2*f1+2*f2) + A6(2*f1+2*f2) +	4th order IM
	A7(.....	

Second and Third Order Intermodulation Distortion
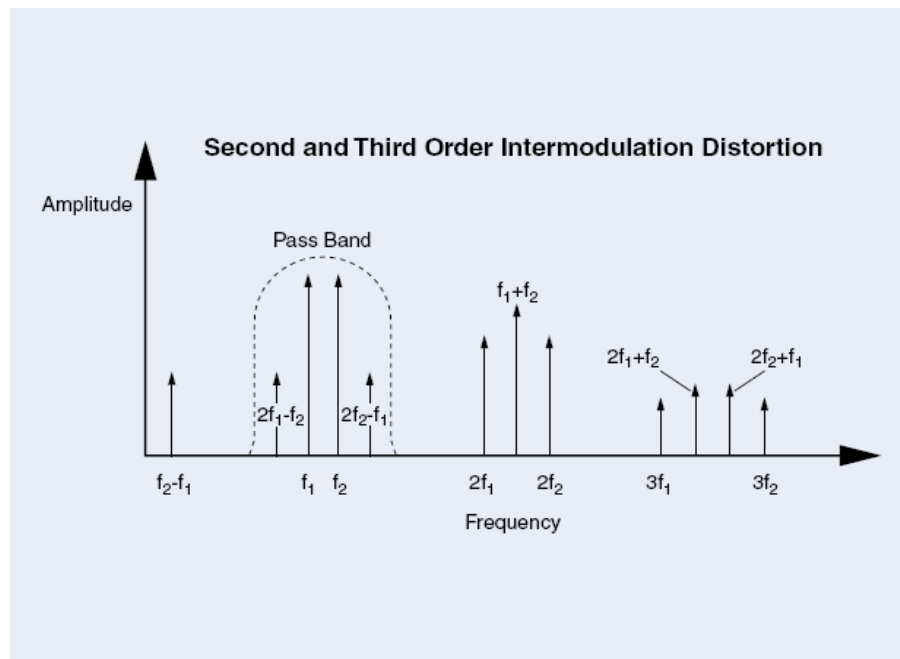
It can be seen that the 3rd order Inter-Modulation (IM) products are located directly beside the two fundamentals all the other are far away and do not disturb (most of the time). The 3rd order products lie within the range with is marked as pass band and exactly this frequencies will harm for example the adjacent communication channel. That's one of the reasons why we look on IP3. Another one is that the two-tone approach has the advantage that it is not restricted to broadband devices and is commonly used for radio receivers.

Why the two-tone approach is commonly used to test radio receivers?

The main advantage is that can also be used for measurements on devices with smaller bandwidth and the method is simple and the requirement for the test equipment is not that high.

How to determine the TOI or IP3 point of an amplifier?
The problem is that the value cannot be measured directly as the amplifier comes into suppression before the IP3 point is reached. It is an extrapolated convergence of intermodulation distortion products in the desired output. It can be done graphically by expanding the transformer curve with the ideal linear behavior.
The cross point between the two lines of fundamental and 3rd order product is the IP3 point.

The relation between the 1 dB compression point and the IP3 point can be summarized with the rule of thumb that the third-order intercept point is roughly 10 dB above the 1dB compression point.

How to select the right parameters for frequency and power?
1.) The used power settings should be far enough below the 1dB compression point of your device
2.) Use frequencies which are near enough together to reduce the influence of different transmission function. Usually, the test frequencies are about 20 to 30 kHz apart
3.) Select frequencies of the two test frequencies that fall within your real application values.

Measurement and IP3 determination:

Please follow the example with the graph below:

We use an Amplifier with 20 dB gain. The graph shows the input power and the output power. The red line shows the corresponding curve of our PA (incl. compression)

The blue line shows the 3rd order IM product. It can be seen that if the input power is changed by on 1dB the out power of 3rd order IM product is changed by 3 dB, compared to the fundamentals with have a 1dB/1dB slope.
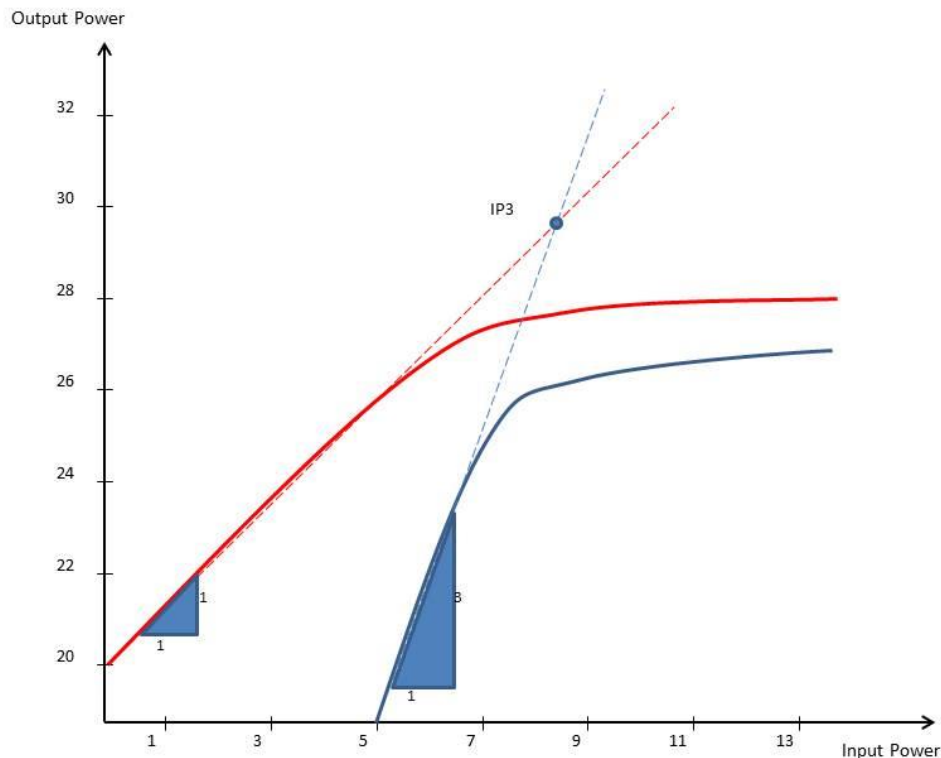
IP3 point is located at the input power level where the output power of the fundamental and the output power of the 3rd order IM product is the same.

It can easy be calculated when you have the measurement result of the output power of both signals fundamental and 3rd order IM product.

IP3 out = P1 + ½ (P1 – P3)

Test Setup and Measurement:

## Creating a two-tone sine wave signal for DG4000 (DG5000) with the use of Ultra Station software

Frequencies @ 10.000 MHz and 10.001MHz (1kHz spacing)

Prerequisites:

- Installation of Ultra Sigma
- Installation of Ultra Station
- Connected and recognized Rigol DG4000 or DG5000 series Generator

Step-by-step guidance:
- Start, if not already done, Ultra Sigma Software
- Rigol Generator should appear in the list on Ultra Sigma
- Right click on the VISA resource name -> Start Ultra Station from appearing menu
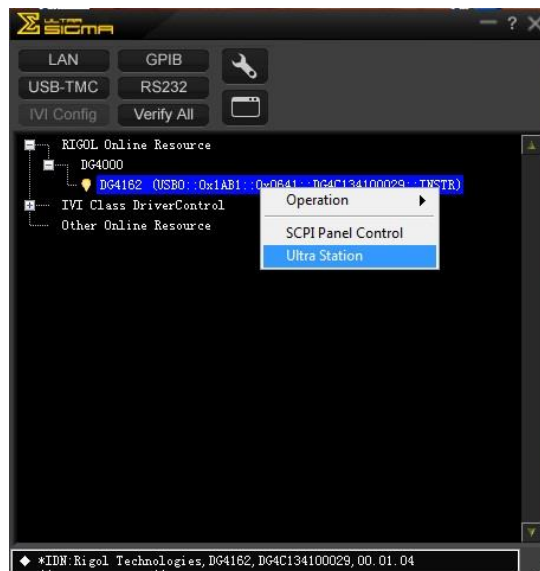
Ultra Station Setup steps:

- Create new Waveform file
- In the appearing dialog set the frequency to the value which will be the lowest frequency step size you need. In this example 1kHz because of the need to be able to set the 1kHz spacing
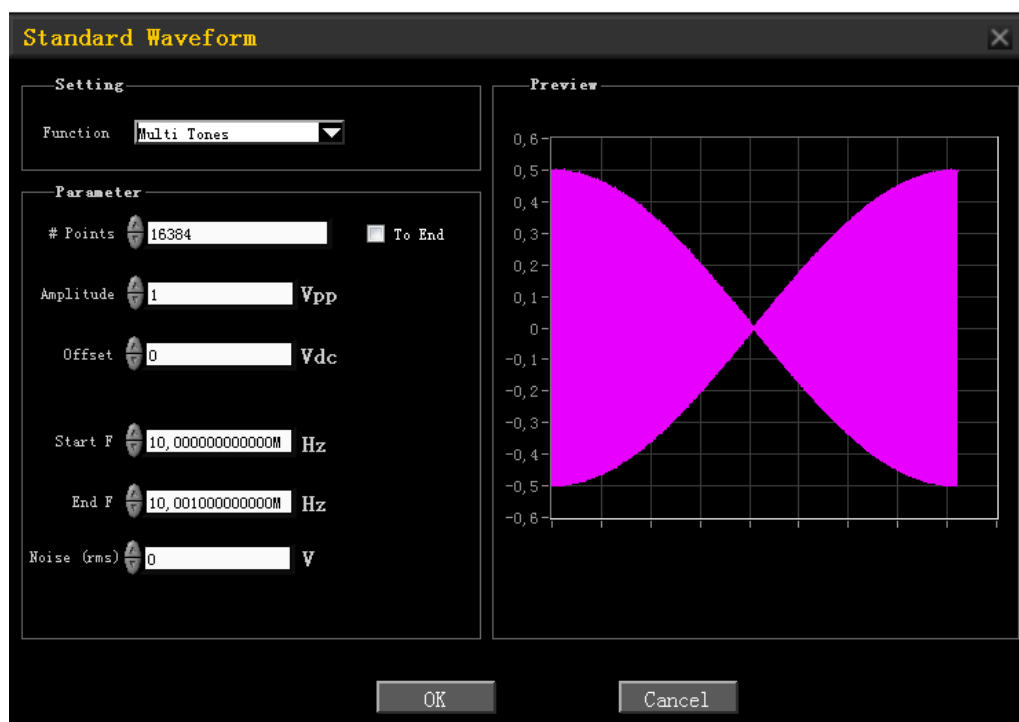
- Tab Waveform -> press button Insert Standard waveform
- Set Function to Multi Tones
- Set Start Frequency to 10.000 MHz
- Set Stop Frequency to 10.001MHz

Because of our first frequency setting (1kHz) the result is that only two frequencies will be generated. (equal Start and Stop freq.) If Stop freq. would be 10.002MHz a three tone signal will be generated.

- Download this Arb.-file to the instrument
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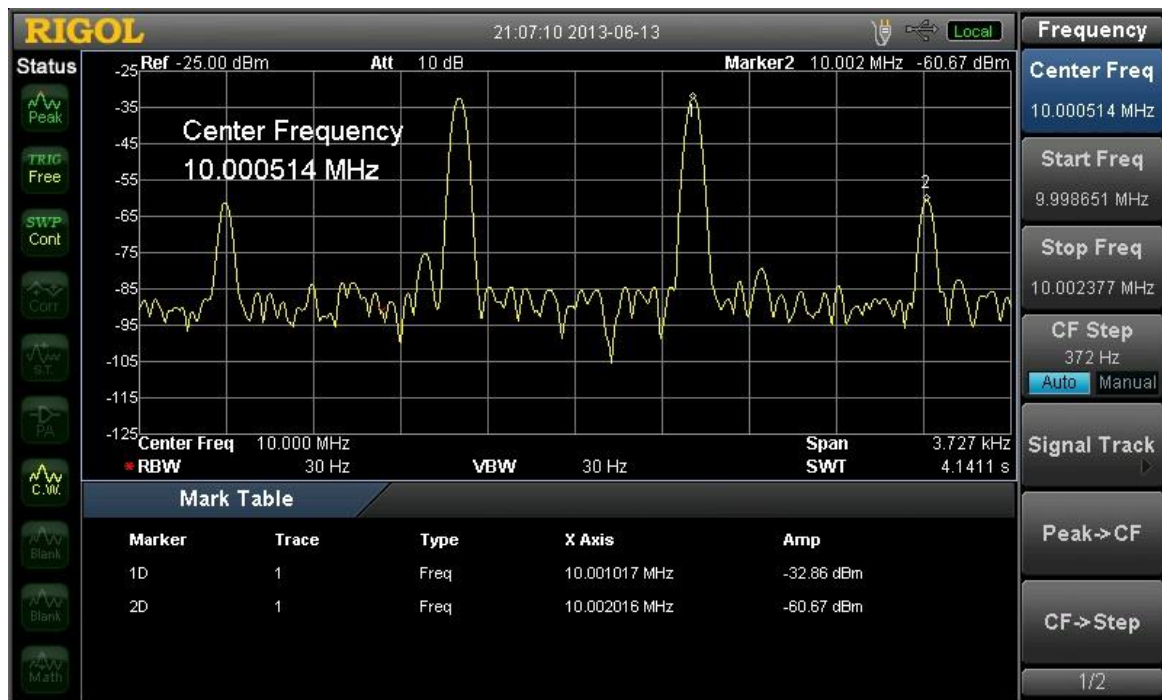**Connect to Spectrum Analyzer and setup the test**

- First directly connect the DG4000 to the DSA and check if the arbitrary file works as wanted.
- Set DG4000 to 50 Ohm Load, set frequency to 1kHz and output level to -20dBm
- Switch on the DG4000 and set the DSA as seen in the picture below.
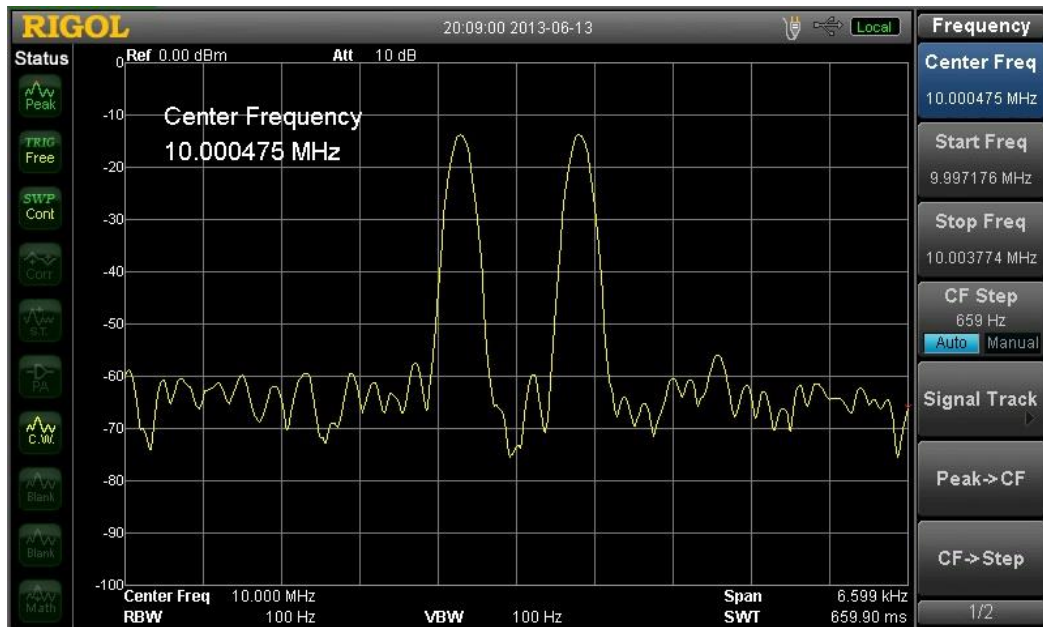
Setup the measurement including the PA in between. See picture below:
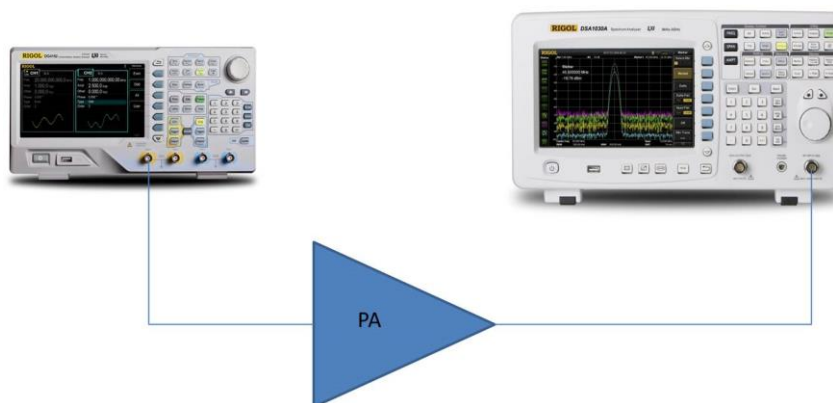
Set the corresponding center frequency and span. Activate two markers and set one on the fundamental (upper or lower) and the second one on the corresponding 3rd order IM product.

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IP3 = -32.66 dBm + ½ * (-32.66 dBm – (-60.67 dBm)) = -32.66 dBm + 14.01 dB = -18,66dBm

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