Multi source signal generator simplifies intermodulation testing

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Intermodulation distortion, is a common problem in a variety of areas of electronics. In RF communications it represents a difficult challenge to designers who face demanding requirements on component and sub system linearity. This trend is driven in part, due to an increase in radio spectrum congestion. This paper aims to identify the mechanisms responsible for generating intermodulation distortion and examine some of the methods which may be used to measure the problem.

Intermodulation distortion is the result of two or more signals being present in a non- linear device producing additional signals. These additional signals, (intermodulation products), appear mainly at the output of devices such as amplifiers and mixers, but to a lesser extent they also occur in passive devices such as can be found in many transmission systems. For example, RF connectors on transmission feeds may become corroded over time resulting in them behaving like non linear diode junctions.

For two signal frequencies f_1, f_2, the intermodulation products occur at the sum and difference of integer multiples of the original frequencies as described by the following equation

$$mf_1 \pm nf_2 \quad \text{where, m and n are integers} \geq 1$$
$$f_1 \neq f_2$$

The order of the intermodulation product is the sum of m+n. The 'two tone' third order components, ($2*f_1-f_2$ and $2*f_2-f_1$) are particularly important because unlike 2nd order distortion, i.e. harmonic distortion, $2*f_1$ or $2*f_2$, they can occur at frequencies close to the desired/interfering signals and so cannot be easily filtered. Higher order intermodulation products are less important because they have lower amplitude and are more widely spaced. Additional 'single' tone third-order intermodulation products are seen at $3f_1$ and $3f_2$, otherwise know as 3rd harmonics. The remaining third order products, $2f_1+f_2$ and $2f_2+f_1$, like harmonics do not generally present a problem.

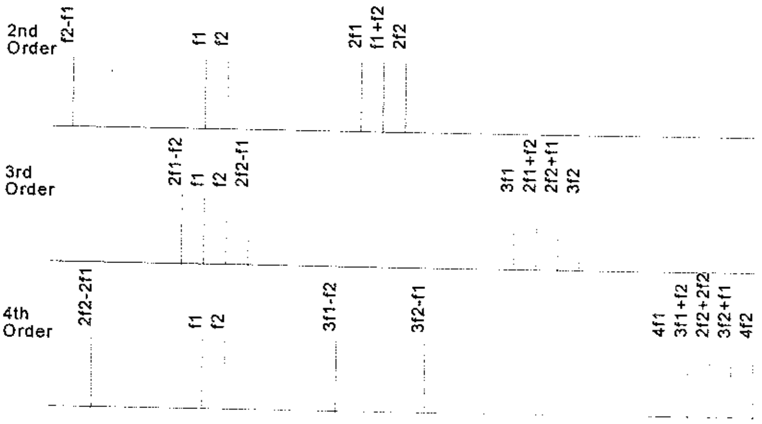

Figure 1 Distribution of Intermodulation products.

Example *If two signals, f_1 and f_2, at 90 MHz and 95 MHz respectively are applied to an amplifier, any non linearity of the device will result in two tone third order intermodulation products at 85 MHz ((2 x 90) - 95)) and 100 MHz ((2 x 95) - 90), plus two further signals at 275MHz and 280MHz. 2nd order harmonics at 180MHz and 190MHz and additional 3rd order intermodulation products (or 3rd harmonics), at 270MHz and 285MHz.*

The magnitude of IM products cannot easily be calculated but usually their amplitude is proportional to the power of their order. Third order IM products have an amplitude proportional to the cube of the input signal whereas second order components have an amplitude proportional to the square of the input signal. Thus if two input signals, equal in magnitude, each rise by 1 dB then the third order IM products rise by 3 dB, and the 2nd order components by 2dB. Higher order terms behave accordingly. However, although they increase at higher rates, their levels are initially very small compared to lower order components which generally dominate. The rf level dependency leads to a simple test to establish the mechanism responsible for various distortion products, i.e. 2nd order or 3rd order effects.

Receiver Intermodulation

Receiver front end designs include both mixers and amplifiers. A measure of receiver linearity is the intermodulation immunity in the presence of two interfering RF tones lying within the preselector bandwidth, (see figure 2). The interfering tones themselves do not fall inside the IF passband, but their intermodulation products do. The interference due to intermodulation is primarily of interest at the limits of receiver sensitivity in the presence of relatively large interferers. At these levels the following useful relationship can be used.

$$P_{imp} = 2P_A + P_B - 2P_{IP3}$$

Where P_{imp} = level of the intermod product in dBm
P_A = level of the nearest interfering tone.
P_B = level of the furthest interfering tone.
P_{IP3} = Third order intercept point.

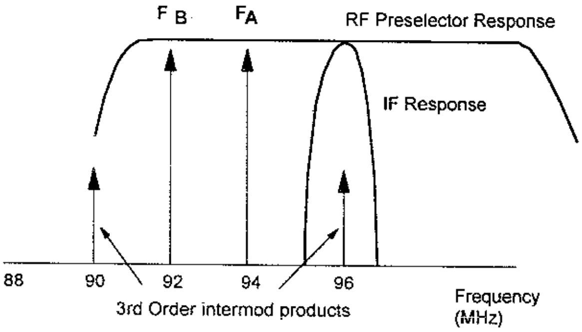

Figure 2. Receiver Intermodulation rejection

The frequency spacing of the two tones used in tests is chosen to be greater than the receivers I.F. bandwidth to ensure that the measurement is not affected by the selectivity characteristics of the receiver. In particular the measurement is designed to ensure that the intermodulation product falls within the receivers IF bandwidth. For example in AMPS (Advanced Mobile Phone System), receiver intermodulation tests are performed with interferers spaced 60kHz and 120kHz away from the in channel signal, which equates to 2 and 4 channels offset. AMPS radios are also tested with 300kHz and 600kHz spacings.

Second and Third Order Intercept Point

If the levels of fundamental, 2nd order and 3rd order components are plotted against input level, then theoretically the second order and third order levels will intercept the fundamental. These points are known respectively as a SOI, second order intercept point and TOI, third order intercept point (otherwise known as IP3). In reality, the amplifier reaches compression first. From the graph, TOI or SOI are found by extrapolation. Figure 3 shows an example TOI.

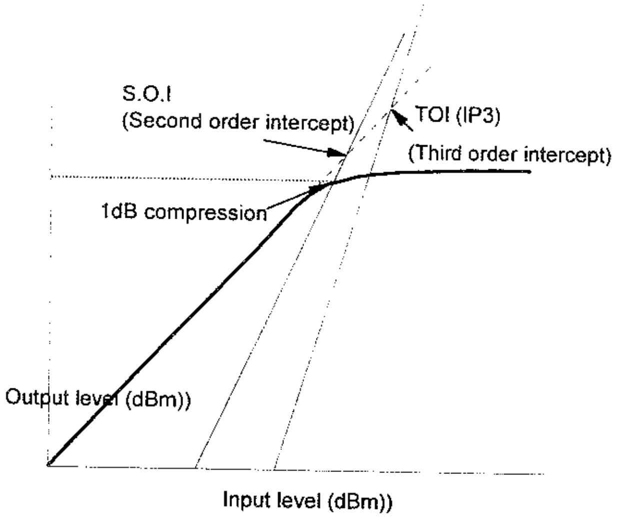

Figure 3. Graph of S.O.I and T.O.I

The third order intercept point is used as a means of rating different amplifiers and mixers, allowing a comparison of the devices independent of their input level, unlike specifications for intermodulation distortion levels.

In the absence of any specified value given for IP3, it may be estimated from the specified 1dB compression point. In typical amplifiers the third-order intercept point is approximately 10 dB higher than the 1 dB compression point for systems operating at high frequencies and 15 dB higher for systems operating at lower frequencies.

From a single intermodulation measurement IP3 can be estimated using the following formula;

$$IP3 = P + A/2$$

where P is the input or output power in dBm

A is the difference in dB between P and the third order product

The value of A must be measured using a spectrum analyser taking great care. The value will only apply to one set of operating conditions, i.e. temperature, frequency and power level.

Three tone intermodulation distortion

The effect of intermodulation distortion may differ with the introduction of further interfering signals. With three signals present at the input of an amplifier or mixer, three sets of IM products are produced (caused by f1&f2 combining, f1&f3 combining and f2&f3 combining), this is shown in figure 4. A total of 15 different third order product may be generated (including 3rd harmonics) of which 6 are important. For equally spaced tones, 2 of these 6 occur at the same frequency as two of the interfering tones, (C and D in figure 4 below). The phase relationship between these intermodulation products and the associated interfering signal modifies their combined level. This in turn results in a change in the level of the other intermodulation products generated. When making three tone measurements it is essential that the phase of tone F_1 is varied for worst case intermodulation product.

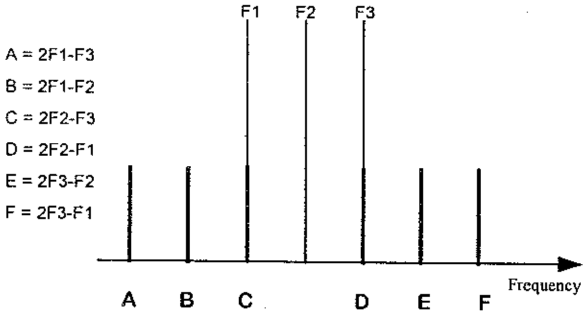

Figure 4. Three tone intermodulation products.

Measuring IM Distortion Products

The level of intermodulation products may be dependant on many variables including; the input frequency, amplitude and terminating impedance. Therefore any measurement of third order IM distortion products must be done under specific conditions.

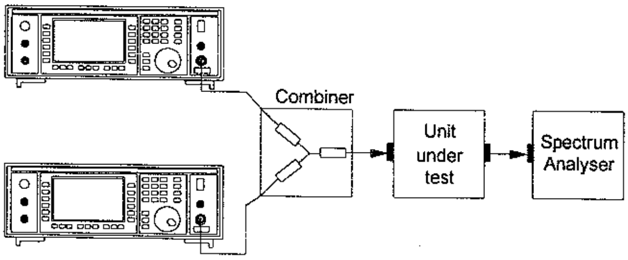

Figure. 5. Basic test set up for intermodulation testing

The standard means of measuring IM products is to combine the output of two or more signal generators, as in figure 5. The signal generators are used to control the individual components of the combined signal. This combined signal is then fed into either an amplifier, receiver, component or mixer. The output of the device is then monitored on a spectrum analyser.

IM measurement problems

There are a number of problems associated with IM product measurement. These relate to how the signals are combined and the proper use of measuring equipment.

Figure 5 illustrates a very simple test set up using a star network resistive combiner. In principle this would work but in practice the combiner does not give significant isolation (6dB) between the signal generators. This means that the signal from one generator will be injected into the output of the other. However, the combiner does ensure that the generators are correctly matched.

The presence of the signal from one generator, A, at the output of the other signal generator, B, will cause its output level to modulate. If the other signal is within the signal generator's Automatic Level Control (ALC) bandwidth it will try to remove it by generating AM onto the desired signal, cancelling the modulation caused by the foreign signal. This means that the signal generator no longer produces a single signal at the required frequency but also side bands (beat notes) at an offset from this signal. This offset is equal to the difference between the desired and unwanted signals which makes them indistinguishable from IM products that may be generated by the device under test.

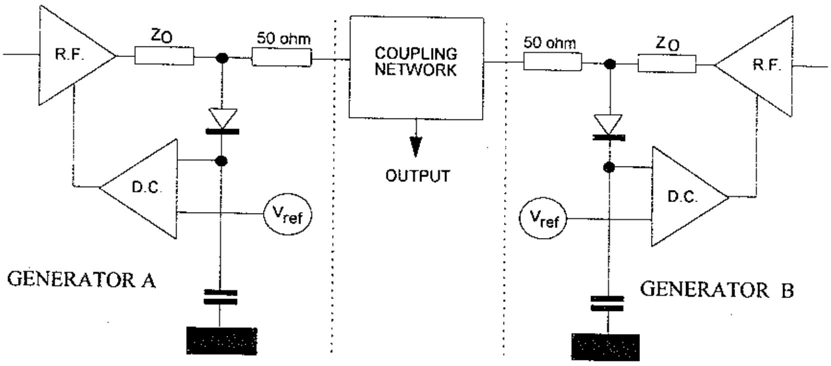

Figure 6. Equivalent circuit of two combined signal generators

There are a number of different ways in which the test set-up can be altered in order to minimise the distortion problems. For example reactive combiners can be used in place of resistive combiners. This gives better isolation (>30 dB typically) and lower insertion loss (<4dB typically) but over a limited narrow frequency range, offering 24 dB improvement in isolation over simple resistive combiners.

Isolation between the signal generators can be further enhanced by including a 3-port circulator, employed as an isolator, between the combiner and signal generator but once again this is a narrowband solution.

2026 multi source signal generator

The process of making IM distortion measurements has been greatly simplified with the introduction of the Marconi Instruments 2026 multi source signal generator. This eliminates much of the equipment required for traditional IM distortion measurement by supplying up to three RF sources in one instrument with a built in combiner. The design ensures that when the rf signals are combined to one port of the generator the intermodulation products are very low. Internally generated IM products are < -80 dBc at 0dBm. The process is further simplified by providing pre-defined test set-ups for the measurement of amplifier and receiver IM distortion. The 2026 multisource generator consists of two or three versatile 2.4GHz signal generators within a single 19 inch rack mounting case. The three source version is useful for measuring intermodulation distortion of mixers and for making three tone measurements. In the latter case one tone can be phase modulated at 10 Hz rate in order to generate the worst case intermodulation product.

All generators share a common frequency standard supplied by an oven controlled crystal oscillator which can also be locked to an external frequency reference if desired. A simplified block diagram of the 2026 is shown in Figure 7.

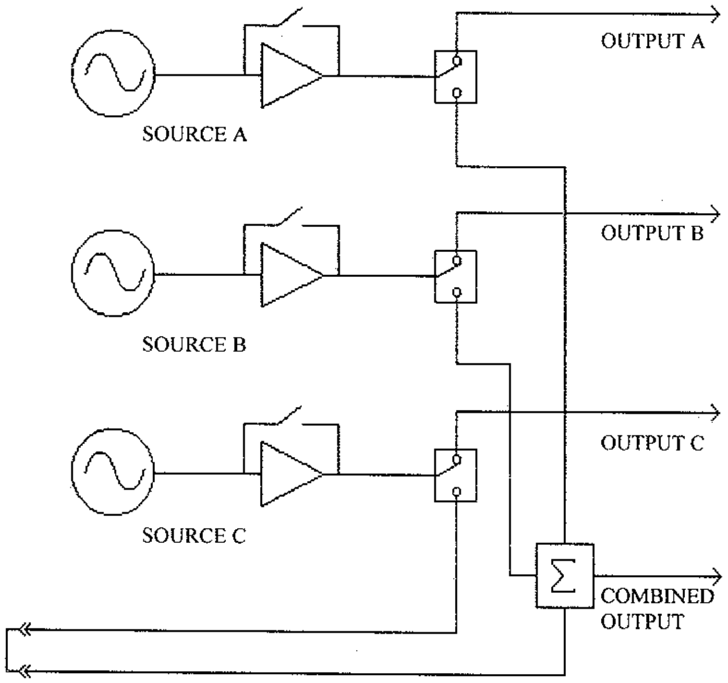

Figure 7 2026 block diagram.

Each generator is fitted with a switched amplifier to produce +24dBm to 1.2GHz and +20dBm to 2.4GHz. To simplify various kinds of test requiring multiple sources, a summing output is provided to combine the generators together with low intermodulation over the entire frequency range of the generators (10KHz to 2.4GHz).

The amplifiers at the output of each generator reduce the influence generators have on each other by increasing the isolation between the output levelling loops of each generator. Switches select whether signals will appear at individual outputs or at the combined output. All four outputs of the instrument are calibrated to compensate for cables, switches and combiner losses thus eliminating the need for user compensation.

A link on the rear panel of the instrument connects the third generator output through to the combiner. When connected to the combiner, the third generator's output is routed via a link on the rear panel of the instrument. Alternatively this link may be removed allowing an external generator to be connected to the internal combiner of the 2026 instead of the third generator.

Signal combination.

As many test requirements involve combined sources of RF a means of combining multiple signals over a range of 10KHz to 2.4GHz with as much isolation between inputs as possible was required for the 2026. Hybrid combiners offer low loss with good isolation but they are narrowband devices and the isolation varies greatly with load VSWR. Resistive combiners are extremely broadband by comparison but have higher loss and less isolation. However the isolation does not depend so much on load VSWR. Isolators can be used to increase the isolation between sources but these devices are also quite narrowband and are expensive. The resistive type of combiner was used in the design of the 2026 because of its simplicity and bandwidth.

A classic 3 way star combiner is shown in Figure 8

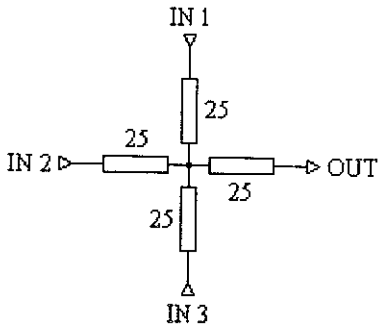

Figure 8 Classic 3-way star combiner.

The 2026 however uses a modified type of star combiner shown in Figure 9 which gives broad bandwidth together with much greater isolation than the traditional star network.

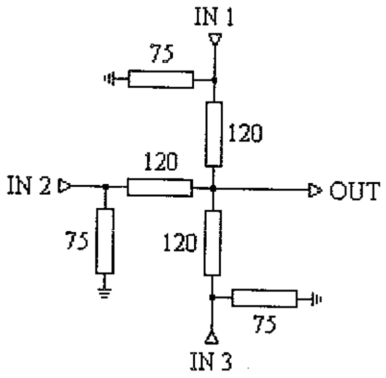

Figure 9 High isolation 3-way combiner.

With this type of combiner the combining loss is slightly more than the three way star combiner being 14dB compared to 9.5dB. The isolation between the input ports however is much greater than with the star configuration giving 28dB as opposed to 9.5dB. When these figures are taken into account it is evident that an improvement in third order intermod of 9.5dB can be achieved by using the 2026 combiner. This allows the 2026 to achieve higher levels of performance than setups using classic star combiners.

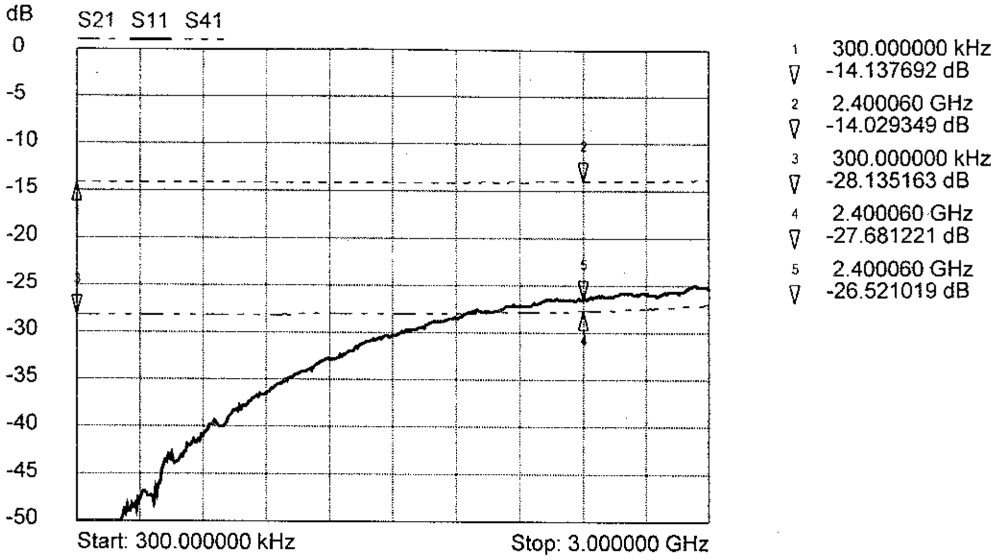

Figure 10 Combiner insertion loss, isolation and return loss

Figure 10 shows measurements of the combiners key parameters. It is implemented on G200 using surface mount T805 resistors. As can be seen the combiner achieves near theoretical performance. Its insertion loss only exhibits 0.1 dB frequency response. The very low return loss, < -26dB, ensures that there is minimal mismatch error in the power level calibration of the 2026. This allows the 2026 to achieve a power accuracy setting of < 1 dB.

Conclusion

An overview of intermodulation distortion has been presented. Traditional measurement techniques were described and their limitations identified. The MI 2026 multi source signal generator was shown to overcome the signal source limitations through architecture improvements and a broadband high isolation combiner.