Intermodulation

Everybody is justifiably talking about intermodulation these days. So what then is intermodulation, often shorted to IM, and its extension PIM? Here we discuss this phenomenon, its effects and how to gain a measure of control over IM.

The expression intermodulation is formed from the two Latin words inter, meaning between and modulus, meaning measure. Broadly speaking intermodulation is the interaction between two or more frequencies passing through an active or passive non-linear circuit or a component which generates new unwanted frequencies in other places in the frequency spectrum.

These frequencies are mathematically related and will appear anywhere in the spectrum within the actual band where the system that will generate intermodulation is active, as well as outside this frequency band.

To begin with we have two signals f1 and f2 of different frequencies, from which intermodulation products (IP) and harmonics are generated. The products can be classified as follows (fig 1):

- Harmonics , 2f1, 3f1, 4f1 etc. and 2f2, 3f2, 4f2 etc.
- IP2 , second order IP, (f1 – f2,f1 + f2)
- IP3, third order IP, (2f1-f2, 2f2- f1)
- IP5, fifth order IP, (3f1-2f2,)
- Etc.

As you will see this will generate a chorus of signals, but we shall mainly concentrate on IP3 as it is the most significant product. Higher order intermodulation products such as IP5, IP7, etc. also have an influence but they usually only have a magnitude some 10-20 dB lower and will hence not have such a strong influence, especially in passive systems.

An important factor not to forget is that intermodulation products will rise faster in the spectrum than the original signals. If the 1st tone (f1 or f2) is increased by 1dB the IP3 will increase 3dB and IP5 will increase 5dB etc.

In other words in a severely non-linear circuit there will be a lot of strong products of higher order throughout the spectrum. There will also naturally be intermodulation products between intermodulation products and so on.

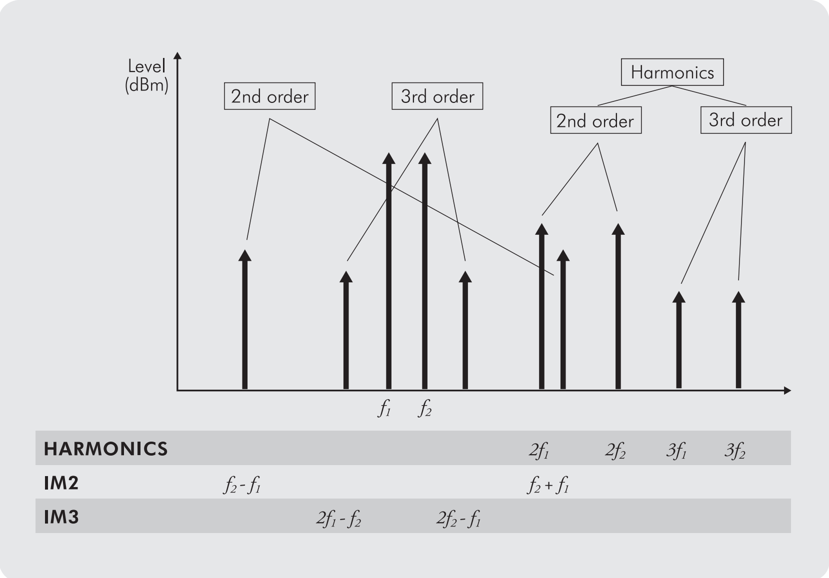
In the active parts of transmission systems such as transmitters and receivers, benefits are gained from intermodulation. Harmonics and 2nd order of IP for instance (such as in mixers) are used to generate new frequencies etc. internally in the transmission systems.

What causes intermodulation?

Intermodulation is generated when a signal passes through a non-linear component or circuit, where the transfer function is non-linear or better, and/or where the attenuation or the amplification of a circuit is not constant with respect to the signal level. (Fig 2)

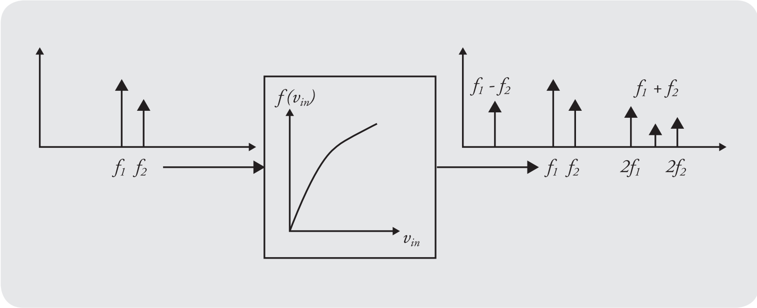
One brief example is an amplifier, where the output level is a function of input level and the amplification factor (Vout

Fig. 1



= Vin x A) causes the input to go so high that the resulting output level will try to exceed the supply voltage. In this case the circuit is saturated, and will go into a non-linear mode and hence produce harmonics (IP2). If the signal is complex higher intermodulation products (IP3 etc.) will also be generated.

Fig. 2



PIM is an abbreviation of the words Passive InterModulation. As it says, the expression describes a certain area of intermodulation. IM can be generated in passive or active components. Active components can be amplifiers, mixers etc, where the signal is in one way or another processed. In passive components the signals pass without any 'processing', as with cables, antennas etc. Intermodulation generated in such components can be expressed as PIM.

In other words PIM will appear at most places in a system from the transmitter up to the antenna top. It can be very hard to define in practice as it tends not to originate from one single source. To make matters worse, passive intermodulation is very difficult to measure in complete systems and is hard enough to measure in single components. When measured it can be quite tricky to find and isolate the source. Often the problems will affect the margins of a specified system and as a combination of a number of minor PIM generators.

We can separate components into three categories where PIM is generated:

1 Connectors, combiners, cables and filters.

2 Magnetic components such as circulators.

3 External factors such as Antennas, towers, cable ladders, metal construction details of houses, etc.

Some main factors will generate intermodulation in all of the above categories, such as bad connection (low contact pressure), 'diode effect' originating from oxidation, corrosion or different material combinations, magnetic materials, micro-arcing due to bad contact surfaces or unparallel surfaces etc.

New signals

In general PIM will generate new signals in the spectrum out of the original usable signals, resulting in these signals interfering and distorting the usable signals.

If some intermodulation products fall within a receiving channel of, for instance, a telephone network, and the IM level is high enough, it will block out or distort the receiver information. The reception of the telephones in the far regions of the cell will be lost or of low and 'slow' quality, hence increasing the amount of interruptions. The ability to serve at traffic-peaks will be reduced. Another serious effect is the risk of interference with other services in other frequency bands such as broadcast, public rescue networks etc.

A delicate procedure

Measuring IM and PIM is mainly achieved with a two-tone test by introducing two (or more) power signals of equal levels and different frequencies into the device to be tested. After passing the resulting signals are analysed with a spectrum analyser. The level of the stimulus is set to + 43dBm (20W) each. The practical set-up is somewhat more complex.

The devices to be tested can be either '1 port' devices such as antennas or loads, '2 port' devices such as cables, filters, combiners, splitters, etc.

Two tests

Because of this there are often calls for two fundamentally different ways of testing a device – forward and reflected tests. The two methods have different advantages but both require the necessary amount of ports available on the tested device.

The forward test, where the signal passes the device in only one (forward) direction, is frequency independent and therefore non-dependent on cable lengths etc.

The reflected mode test is more complicated, as the interaction between different reflected signals will return at different phases and can be added or subtracted, thereby giving results depending of frequency vs. cable lengths or delay in the tested device.

The difference between the two modes in summary:

Reflected test mode:

- Variation in level as a function of the frequency is a result of interaction between IM products of the same frequency that is generated at different positions in the device under test.
- The variation can result in minimums at more than one frequency, where the distance is depending of the

mechanical/electrical distance between the positions at the device under test where the IM is generated.

Forward test mode:

- The frequency of the test signal vis-à-vis the tested device.
- The dimension of the tested device, attenuation.

In order to increase the validity of a measured result a test system with swept frequency generation has been developed. This will give the operator the opportunity to make a validation and calculation with respect to maximum, minimum, nodes and peaks etc of the resulting swept intermodulation pattern.

The demands on the test set-up are very high. Put into relation, 142dB corresponds to the distance to the sun measured in cm. We measure differences in levels of up to 170dB when talking about passive intermodulation.

The instrumentation itself must generate lower residual intermodulation products, than it is intended to measure. As an example, the filtering of the receiver input must be able to isolate the stimulating signals to avoid intermodulation in the receiver itself.

All test cables and internal cables in the instrumentation must be of low IM quality. This also stands for all terminations used. Resistive terminators cannot be used. It seems the best results are gained by using the attenuation in a high quality cable short-circuited in the far end, such as 'Semi-rigid' cables.

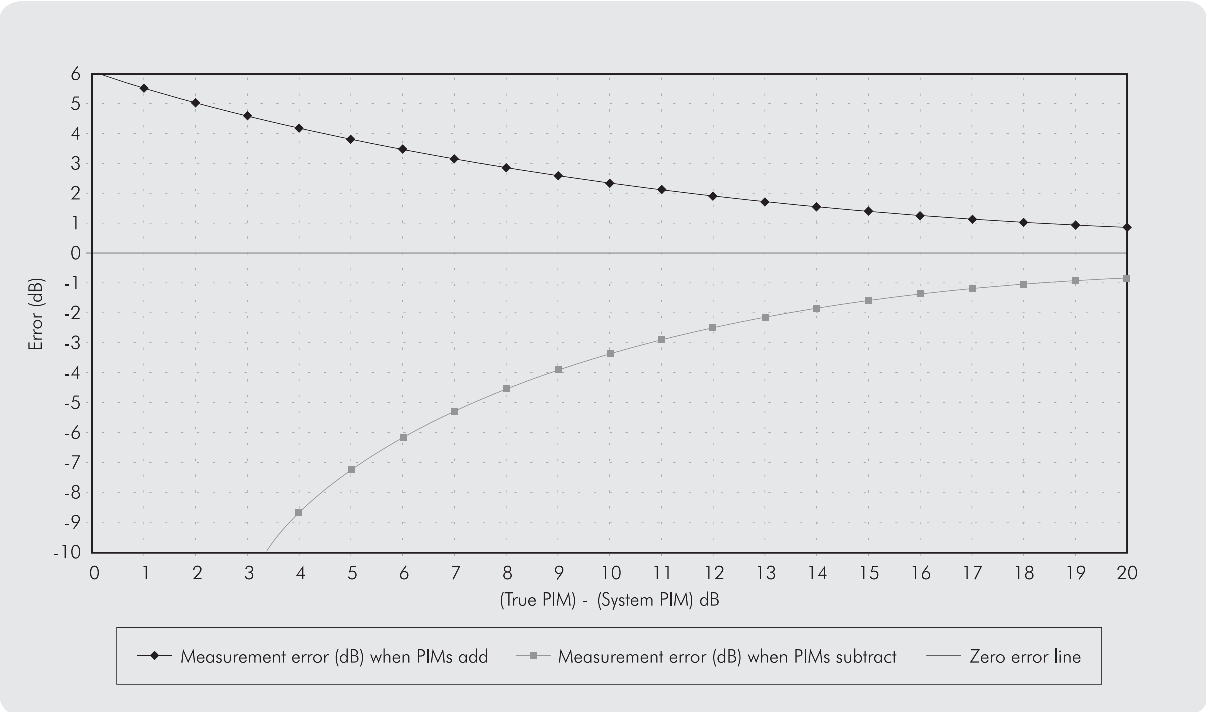
The residual IM of a test system, such as the instrument/generators and termination should have a good margin to the expected result. The figure illustrates the relation between expected measure failure rate and the difference between real and residual PIM.

As can be seen, if the relation residual and real PIM is small the failure rate of the test result will be high. (Fig 4) At the start of every test session it is mandatory to check the test system with the failure diagram in mind, specifically instrumentation, cables, connectors, adaptors and terminations to find the actual status and replace or clean connectors etc.

A single test of a single sample will never conclusively give the whole picture about intermodulation characteristics, though it can give a sufficient result. It is always safer to take a series of tests on different samples to find a significant and representative value by averaging maximums and minimums. A good average is to test at least 10 samples of a device and 20 or 30 is even better. Often you will get slightly different results from the same sample, especially if you conduct dynamic tests.

Practice has shown that a connection will often present a better result over time. This indicates that a sample needs some time to stabilize before the results are logged. In other words testing IM will take time. One explanation for this is that the connecting surfaces migrate under contact pressure over time.

Fig. 3

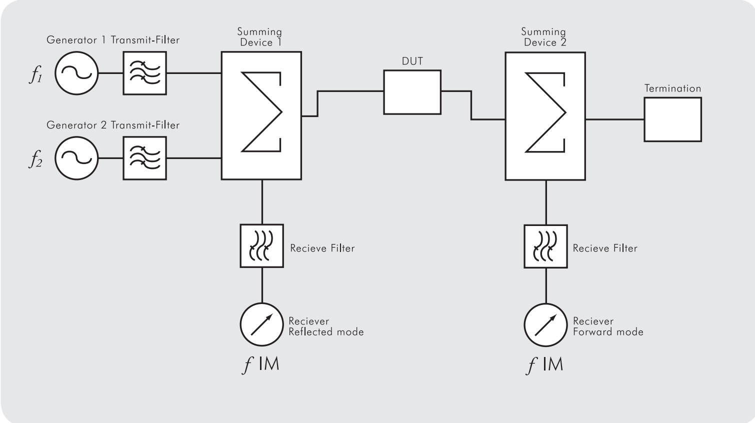


Static and dynamic tests

In practice PIM tests are divided into two categories – static and dynamic. The static measurements are performed within a stable environment, with no temperature variations and no mechanical stress etc. A static measurement gives a more or less electrical evaluation of the sample. It is easier to compare static results.

Dynamic measurements are performed with the influence of the environment, such as thermal variations in combination with humidity, mechanical stress such as vibration, chock and repetition of some specified stress. The dynamic test tries to duplicate reality, or perhaps better, the worst case of environmental stress. To achieve a common and comparable test situation some dynamic tests have been developed, for example the cable/connector defined rotation test which simulates the most common stresses that usually affects a connector.

'Tapping' is a method that has been developed in which the sample is exposed to a specified beat from a special hammer. In the laboratory environment 'tapping' is a very effective method of locating an IM source and of getting an opinion of the status of a component. Use a small hammer and search the IM source over the component or a system with the help of light hits. Sensitive spots will always result in increased IM response on the test instrument.



This is a set-up suggested by IEC. In the case of reflected mode the 'summing device 2' and termination is excluded. The set-up can be formed to measure either the forward 'transmitted' IM or the 'reflected' IM. At Forward mode measurements are taken via a directional coupler after the sample. In the Reflected mode the measurement is taken via a directional coupler at the input side of the sample.

When using the Forward mode the tested device must have two ports or more. Reflected mode gives the possibility to test one port devices. If two or more port devices are to be tested all unmeasured ports should be properly terminated with a low IM load which is capable of handling the power.

Standards

Since the 19th century work has been going on to establish some sort of international standard in order to have a common language when specifying and comparing components.

As previously mentioned, it is not actually possible to compare test results from tests with, for instance, different stimulation power levels. We know that if the stimulation power is increased by 1dB the third order IM product will increase by 3dB and the fifth by 5dB. This is found not to be true in practice. One of many reasons for this is the influence of higher order of IM products and summation of reflected products with different phase relations etc.

A working group under IEC (WG 46) have formed a standard, the IEC 62037, which was accepted in September 1999. This specification covers intermodulation in connectors, connector cable assemblies and cables and describes test set-up, equipment and principles of test procedures. When introduced it was a theoretical standard and did not specify the tests.

A new draft including appendix have been published, but not yet accepted. These additional appendixes define test methods, set-ups and tools for measuring PIM in cable assemblies, connectors, cables, filters and antennas. In these added appendixes the power levels for the stimulating signal are recommended to 2* 20W (43dBm).

To summarise, it is important and helpful to have a common way of specifying and measuring intermodulation, both from the designer's point of view and the customer's. In the case of intermodulation, it is often not reliable to compare the results from measurements with different stimulus levels and/or different intermodulation demands. In other test situations such comparisons can usually be possible to achieve by calculations.

Exir Broadcasting & Telecom has decided to comply to this specification and set their stimulus accordingly to 43dBm (2x20W) and a maximum IM3 level of –156dBc as a default. Other higher order of products shall of course not exceed this level. Components and assemblies are tested according to these methods and with the specified tools, both in the developing process and in the production.

Improving figures

What can we do to improve intermodulation figures in components and systems?

Over the years research and experience have isolated some important sources of intermodulation in passive devices. We can divide the problem into categories: materials, contact junction and handling.

Materials

There are some obvious materials that affect intermodulation characteristics dramatically.

Metal oxides that can occur on surfaces exposed to aggressive environments can behave as 'diodes', this phenomena was for instance used in metal oxide rectifier in the past. Rusty joints in masts and installations and acids from the human skin are other examples.

Ferromagnetic metals such as steel, nickel, cobalt will act non-linear when saturated and hence generate intermodulation. An increase of up to 40dB has been traced due to the use of nickel plating. Contact between different materials can create non-linearity due to the same phenomena as metal oxides.

The use of gold or silver plating, preferably silver, will improve circuit conductivity and prevent contact between dissimilar materials. However, care must be taken to prevent exposing the silver plating to atmospheric corrosion that may tarnish the silver surface and cause bad contact.

Contact junction

The quality of the contact junction is naturally of the highest importance. The junction must have a high pressure to guarantee absolute connection over the whole surface and achieve maximum migration between surfaces. Don't disturb this migration but instead create an environment that will make a connecting surface that is very stable.

The connection must be stable in order to avoid microsparks, high contact resistance and again prevent penetration of moisture etc. which in the long term will degrade the junction. This also calls for stable nuts with low friction so the energy put into assembling will be used to form contact pressure and not be consumed in friction. It should also be able to withstand bending forces introduced from the cable etc.

Handling

Connectors must be handled as delicate components. The active connecting surfaces must always be kept clean and care taken not to damage their surfaces in any way. Dirt, dust and moisture as well as oils must be kept away. Even the thinnest film will increase intermodulation dramatically. This calls for great efforts in hygiene to achieve the cleanest possible environment when assembling. It is also important to keep the contact surfaces free from water and moisture, which is why tight connectors etc. are compulsory.

High contact pressure is essential to avoid many of the problems mentioned. It will also prevent penetration of anything between the contact surfaces.

Another thing to bear in mind is when a 'small' connector is installed on a 'heavy' cable, say a DIN7/16 connector on a 1 5/8" cable. One should always remember that it is the cable that determines the mechanical circumstances. It is the cable that is fixed into the structure and a flexible jumper-cable must be installed between a 1 5/8" connector and other fixed equipment. ■