Passive intermodulation (PIM)

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Intermodulation is a system characteristic, where new frequencies in the output are created. A common technical realisation for intermodulation is to use non-linear components, such as diodes.

While intermodulation is important for certain applications, it is not in every case. One important example is a communication system, where transmission and reception paths are combined. In this case, no distortion of the received signal by the transmission signal is expected. Unfortunately, perfect linear components do not exist. Even passive components do not behave perfectly linearly. In this case, the term Passive Intermodulation (PIM) is used.

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What is passive intermodulation (PIM)?

Passive Intermodulation is generated in a system, if it is non-linear. This causes the shape of the output signal to be changed. Figure 1 shows that positive components of the amplitude are much more strongly amplified than negative ones.
This signal also differs in its frequency spectrum.

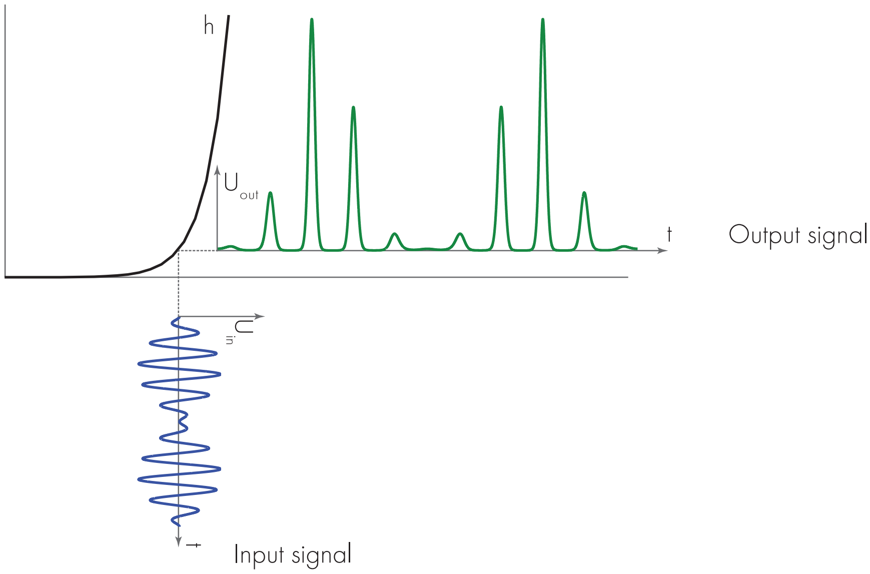

Figure 1:
Non-linear system characteristic

Mathematically, we can explain this as follows: let h be a non-linear system, then the output is given as

$$u_{out} = h\,(u_{in}) \qquad (1)$$

To understand why additional frequencies are generated, it is helpful to look at the Taylor expansion:

$$u_{out} = \sum_{i=0}^{N} \alpha_i u^i_{in} \qquad (2)$$

For the input signal, we use a two tone signal u_{in}:

$$u_{in} = a \cos(\omega_1 t) + b \cos(\omega_2 t) \qquad (3)$$

By substituting u_{in} in (2) we get the following terms:

$$\begin{aligned} u_{out} = {} & \ldots \cos(\omega_1 t) + \ldots \cos(\omega_2 t) + \\ & \ldots \cos(2\omega_1 t - \omega_2 t) + \ldots \cos(\omega_1 t - 2\omega_2 t) + \\ & \ldots \cos(3\omega_1 t - 2\omega_2 t) + \ldots \cos(2\omega_1 t - 3\omega_2 t) + \\ & \ldots \end{aligned} \qquad (4)$$

We recognise the following relationship:
$\cos(n\omega_1 t - m\omega_2 t)$ where n and m are integers

This leads us to the definition of order of a PIM signal:
$|n|+|m|$

Where and why is PIM a problem?

Whenever a high power and a low power signal is transmitted at the same time but with slightly different frequencies, PIM may become a problem. It is a problem, for example, in a full duplex radio base station but not in a radar application. (because transmission and received signals are not simultaneous)

In order to reduce the number of components, it is desirable to use the antenna and cabling for both transmission and received signals. It is the case that the amplitude of the transmitted and received signals differ in order of many magnitude where the received signal is the lower. This means that even the slightest non-linear behaviour would create intermodulation from the transmission signal of the same order of magnitude as the reception signal.

If the received signal and intermodulation signal fall into the same frequency band, the communication is distorted. Thus this band cannot be used, which reduces the capacity of a communication site. With increasing bandwidth demand, this becomes a major problem for the operator.

PIM-sensitive components are mainly critical between diplexer and antenna. PIM-caused signals created before the diplexer are filtered out by the filter system and should have no influence on the reception path.

Figure 2 shows an example where PIM frequencies fall into the reception band

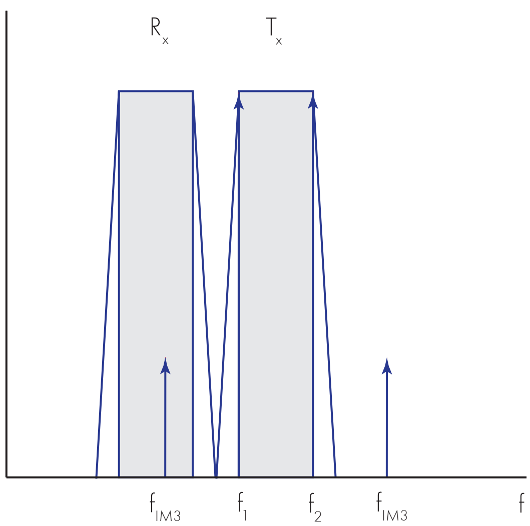

Figure 2:
PIM causing receiver de-sence at f_{IM3}

What causes PIM?

In the previous section, we mentioned non-linearity as a root cause of PIM. As a manufacturer of low PIM components, it is important to understand all possible sources of non-linearity.

Material and plating

Both dielectric and metallic materials could cause PIM, if they show any non-linear behaviour. In practice, dielectrics are not a big problem as typical plastics behave very well. Only exotic materials could cause problems, e.g. semi-conducting materials. In special and/or very high power applications, corona discharge and multipaction can be a problem.
Metallic conductors are more critical if they contain ferro- or ferri-magnetic materials (Fe, Ni or Co).
These materials have a non-linear magnetic flux density (B) as a function of its magnetic field stimulus (H). Figure 3 shows the familiar magnetisation loop of ferromagnetic materials. At first glance, the solution is trivial – just avoid these materials. Unfortunately, the slightest contamination of ferromagnetic material in brass causes significant PIM.
For platings, the above is also true. Therefore, silver is a very good plating with regard to PIM. The only aesthetical issue is tarnishing of silver, but it is not a technical one. Gold itself is also a very good plating. In this case, the underplating has to be taken into consideration. Nickel is often used as an underlayer for gold platings. Nickel is a ferromagnetic material that causes PIM. Fortunately, some connector manufacturers have developed a solution with a non-magnetic diffusion barrier. (e.g. SUCOPRO from HUBER+SUHNER). Trimetal platings (e.g. SUCOPLATE) also have premium PIM performance.

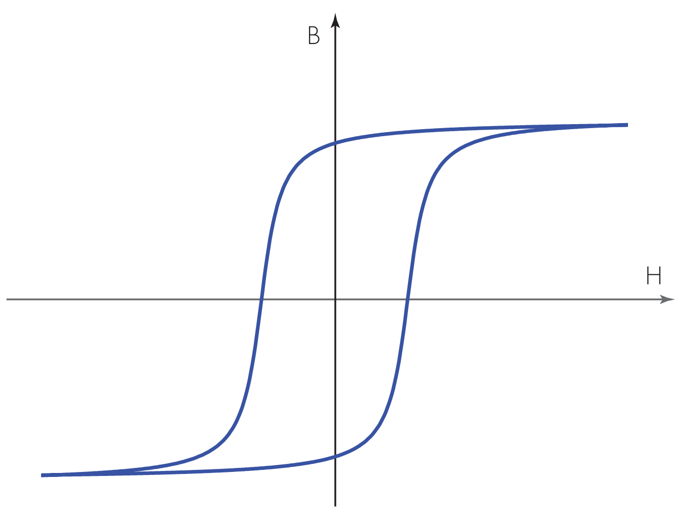

Figure 3:
Ferromagnetic magnetisation loop

Galvanic contacts

The contact parts of a connector are particularly sensitive to PIM, because of the high current densities in this region.
Spring contacts typically found on centre conductors have only one mechanical contact point (green in figure 4) per contact finger. The electrical conducting area (red in figure 4) is a fraction of the contact area, which itself is a fraction of the contact finger area.

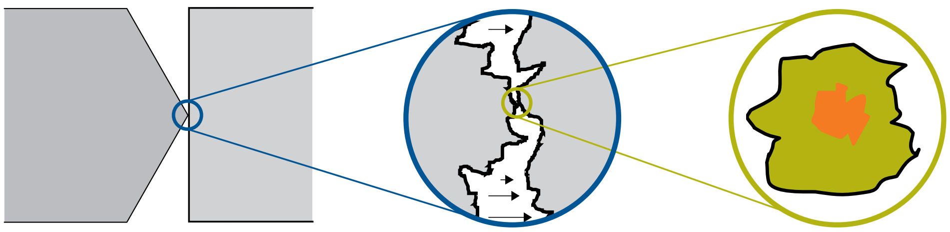

Figure 4: A-spot

Close to the conducting area, electron tunnelling is possible in the thin dielectric coating, which is highly non-linear.
The a-spot area has a very high current density and therefore quite a lot of joule heating is generated in the close proximity of the a-spot. This is non-linear and highly dependent on (instantaneous) power.
PIM performance is also highly dependent on the contact force. The smaller the contact force, the smaller the contact area and a-spots become. This results in even higher current densities. If contact fingers can move, transient distortion results, which has the same effect as non-linearities.
In conclusion, the design of the connectors, but also the surroundings of the RF line, should be stable (no movement).

Solder joints

Soldering is a very good joining technology for cable assemblies with regard to PIM. The main drawback is the very high requirements on the manufacturing process. Connector bodies have high mass and must be heated fast and accurately. Otherwise, the flux does not have enough time for the chemical reactions to take place or it is oxidised before the solder is applied and molten. Another aspect is to choose a design where metal salts in the residual flux are not exposed to the electrical field, as they behave non-linearly.
The advantage is that once a solder joint is made and successfully tested, it is reliable over time.

Screwing connections

Many connector parts are screwed together and if the design is good, PIM performance is not a concern. As general rule, a thread must never be exposed to the electrical field. Contact force has a great influence on PIM. Therefore, it is very important to tighten threads with the specified torque.

What is done against PIM?

Knowing the potential sources of PIM is not enough – we also need to know how to design a component to prevent PIM.

Material and plating

On the material side, we use high quality and very pure base material. If problems occur, we have the option to easily measure contamination and magnetism, in order to locate the source of problem.
HUBER+SUHNER SUCOPRO plating uses a non-magnetic diffusion barrier. Silver plating is technically the best solution and can be used if cosmetic aspects are not critical. SUCOPLATE is a good and economical alternative.

Galvanic contacts

One of the most important design goals is to have sufficient contact force at every contact spot. Therefore, the female contact design requires special attention. With screwed interfaces, the captivation is so robust that contacts do not move when mechanical load is applied. With snap-on connectors, the situation is quite different and care must be taken that contact spots remain stable (no movement). Quick lock connectors like QN have special design features to ensure good PIM performance also under dynamic conditions.
The number of contacts is another important design parameter. On one hand, fewer contacts reduce the risk of a bad contact. And the weakest link in a chain determines the performance. On the other hand, if all contacts were replaced by e.g. solder joints, all mechanical movement is applied to the last, left (interface) contact, causing problems there.
Within the interface, more contact spots in parallel reduce the current density and this is therefore an improvement, as long spring contacts can build up enough contact force.

As discussed, an optimised balance is the key to a well-performing contact.

What must be considered for low PIM products?

In the previous chapter, we discussed techniques we apply for low PIM designs. As for those high performance products, correct handling by the user is essential to achieve the performance. Here are some recommendations on how you can optimise the performance of the product.

Cleanness

Any dirt within the signal path is a performance killer. Non-conducting substances on contact spots decrease the number and size of a-spots, which results in poor PIM performance.
Dirt can enter the interface when it is not mated. Therefore, never touch the inner parts of the connector and always fit protection caps. If the interface is exposed to dust and liquids, use special metallic protection caps, as they are rated for the same tightness as the interface. Compressed air is not a helpful way of cleaning, because it can contain oil and does not remove dirt – it just moves it somewhere else. Tiny vacuum pencils are more effective for removing dust.
Metallic particles cause high local field strength, which causes non-linear behaviour as discussed earlier. A typical source of these particles is the thread of a connector if it is used over many mating cycles (test & measurement applications). Interfaces are rated for several hundreds of mating cycles, but this requires cleaning. Use isopropanol with a lint-free cloth. Another important factor is mating torque. Always use a high quality and calibrated wrench for torqueing. If a thread is tightened with a too low torque, the contact force is insufficient, which may cause PIM and, if the torque is too high, parts of the connector may be damaged and swarf may peel off.

Connector care

While mating and demating, it is essential only to rotate the nut. If both connectors are rotated against each other, swarf can peel off. Make sure that no dirt and especially liquids can enter the interface when demating. Clean the connector first before demating.
In order not to damage the connector, always tighten with the specified torque. At the side on which the nut is attached, ensure the correct rotation direction for demating.
As described in this paper, there are many sources of PIM. By following certain design rules and handling instructions, PIM can be prevented and a better and more reliable RF connection can be achieved.

Conclusion

Some applications are very sensitive to intermodulation products. Although passive components are considered to be linear in theory, such components exhibit some non-linearity in practice. We have discussed several physical phenomena, which are root causes. The most important aspects are non-linear magnetisation of ferromagnetic materials and a-spots in galvanic contacts. A careful design is a prerequisite, but correct connector care – such as a clean environment and correct torque – are also important.

Author

Adjan Kretz received a MSc degree in electrical engineering from the Swiss Federal Institute of Technology ETH in 2005. He holds the position of Head of Microwave Connector Development. His activities are focused on Test+Measurement and High Speed Baseband Signal transmission.

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