Technology Guide for Intermodulation on Coaxial Switching Products

Definitions

Z_C: System's characteristic impedance (Ω)

P: Power in watts

IMD: Intermodulation distortion

IMP: Intermodulation products

PIM : Passive intermodulation products

FDD : Frequency Division Duplex

RAMSES : RAdiall Modular System for Electromechanical Switches

MM :. Metal/metal contact

MIM :. Metal/insulator/metal contact

Introduction to PIM

As the growth of wireless communications systems continues, the need to minimize interference between channels, and systems operated in parallel, is taking on greater importance. A significant part of this interference is created by the mixing of multiple transmission frequencies in components with nonlinear characteristics.

The 5G technologies required sensitivity levels increasing. A main technical limitation encountered by these new systems is weakness introduced by passive intermodulation products. The cables and connectors are the main sources of interference such as passive intermodulation. Components such as switches are also affected. PIM introduces distortion in the analog signal of a communication. These disturbances in the analog signal generate errors in the digital signal.

The intermodulation product is essentially due to the imperfections of the transmission channel, and more precisely its non-linearity.
When you send, two signals on two carriers at frequencies F1 and F2, you receive both carriers F1 and F2, and also their intermodulation product: F_{mn}= m.F1 + n.F2 (Figure 1).
Intermodulation product amplitude is decreasing: PIM3 > PIM5 > PIM7…Usually, in telecommunications product, we use the third order intermodulation products (Figure 1).

Figure 1 : Product of intermodulation, ideally and real case.

In the FDD (Frequency Division Duplex) system, PIM caused by the transmitted signals could fall in the receiver band and cause the performance degradation of the received signal. For example, in GSM1800, the IM3 and IM5 of transmitted signal fall in the receiver band (Figure 2).

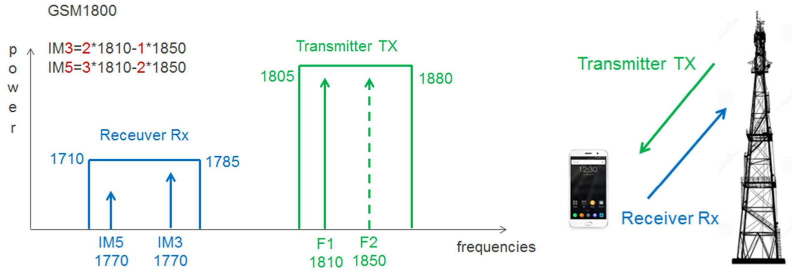


Figure 2: example of intermodulation product for GSM1800.

Mechanism of contact

In order to understand PIM, it is necessary to understand the mechanism of contact. Poor electrical contact is a source of non-linearity and therefore produces a high level of PIM.
The type of contact is strongly dependent on the roughness of the material but also the contact forces, as well as the cleanliness of the area.

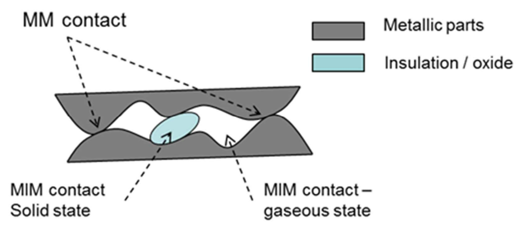


Figure 3 : type of contact MM (Metal to Metal contact) or MIM (Metal, Insulator, Metal)

*Perfect metal/metal contact (**MM contact - Figure 3**): better contact for PIM*

The PIM level of this type of contact is exclusively dependent on the nature of the materials (coating in case of plated device). A ferromagnetic material (for example: nickel) will be of low performance compared to non-ferromagnetic materials (for example: silver).

*Contact Metal/insulator/metal (**MIM contact Solid state - Figure 3**) : case of solid state insulation*

These contacts occur if there is insulating material (could be created by oxidation or corrosion depending on the nature of coating) between the two metal parts. The insulation thickness must be under 10nm to have a mechanism of conduction. It is known that several mechanisms could appear. The most common is the tunneling effect, but it isn't the only one (mechanism of Fowler-Nordheim, mechanism of Poole-Frenkel). All of these mechanisms have the same effect; they allow the flow of current through the layer of insulation creating a non-linear system.
When the oxidation layer is larger, the insulation finds its entire role and prevents conduction current. There is no more non-linear effect.

*Contact Metal/insulator/metal (**MIM contact gaseous state - Figure 3**) : case of gas state insulation*

Other mechanisms must be taken into account. Big and small air gaps between the two metal parts can generate PIM. Micro-discharges between the metal parts can create oxide and micro-cracks in coating layers.

Switch application

The electrical junction to consider is the contact area where an electrical current flows (areas in red on the attached picture below - Figure 4).

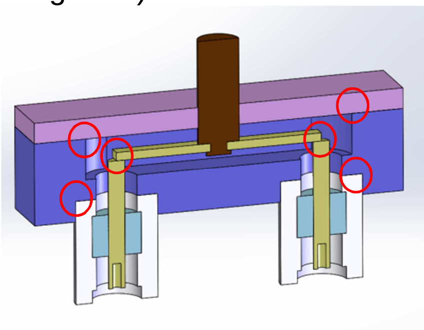


Figure 4: Contact area in coaxial relay.

Current density is higher in the center contact. So the center contact of connector is the main contributor to the PIM.

It is important to differentiate between static and dynamic levels of PIM is the intermodulation product inherent to the product. The dynamic level is the PIM stability of a moving product. It's the case for electromagnetic switches or relays where the RF blade moves inside of the waveguide cavity.

Static PIM

The main parameters impacting Static PIM in coaxial switch or relay are (in decreasing order):

- The nature of the coated or plated surface
- The efforts made by petals of socket on pin contact (link to contact force and / or to coupling torque)
- The coating thickness (due to the skin effect, depending on the nature of the coating and of the frequency)

First implementation

During the first switch cycling, the PIM values increased.

For example, on a DPDT with an N type connector without switching, we distributed power at two frequencies (1805 MHz and 1880 MHz), and then we measured the 3rd PIM and recorded each 2 seconds for 3 minutes. We waited for 5 minutes and then started again.
The optimal PIM value occurs after 10 minutes. Contact stress and plastic deformation are released.

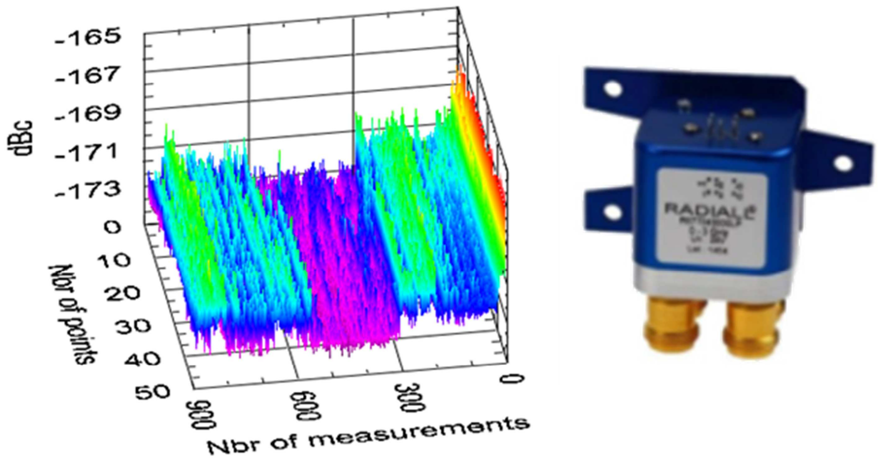


Figure 5: 3rd PIM measurement on DPDT switch with N type connectors

Dynamic PIM

The main parameters impacting Dynamic PIM in coaxial switch or relay are (in decreasing order):

- The nature of the coated or plated surface
  The unique design of RAMSES is based on the suppression of friction, in order to improve reliability and avoid electric contact and RF characteristics degradation. In general, traditional switches operate by moving a rectangular section contact reed inside of a rectangular cavity. These contact reeds are linked to dielectric material “transmission pushers” and directed by guides made of insulated material. During the switching sequences, these dielectric parts rub against the reeds and in the transmission holes, and generate insulating particles in the RF cavity that pollute the contacts, ultimately causing running defects and insertion loss increasing and PIM problems.

- The repeatability of the transmission.
  The patented RAMSES polarized linear actuator has been manufactured for several years by Radiall. Our linear actuator uses high-energy magnets, and can be incorporated in both failsafe and latching models. The actuator also produces a locking force and above all, contact forces that far exceed those of traditional actuators. The actuator has the added advantage of very low magnetic leakage, allowing actuators to be used in close proximity to one another without degradation of performance.
  The attachment of the only moving part of the actuator (see Figure 5) on two parallel cantilever beams, suppresses the friction surfaces between the housing and the moving parts of the actuator. This improvement, associated with the mounting of the second moving part (reed contact), which is suspended between the two spring blades, eliminates all friction inside of the RAMSES switches. This transmission allows increased microwave and PIM repeatability.

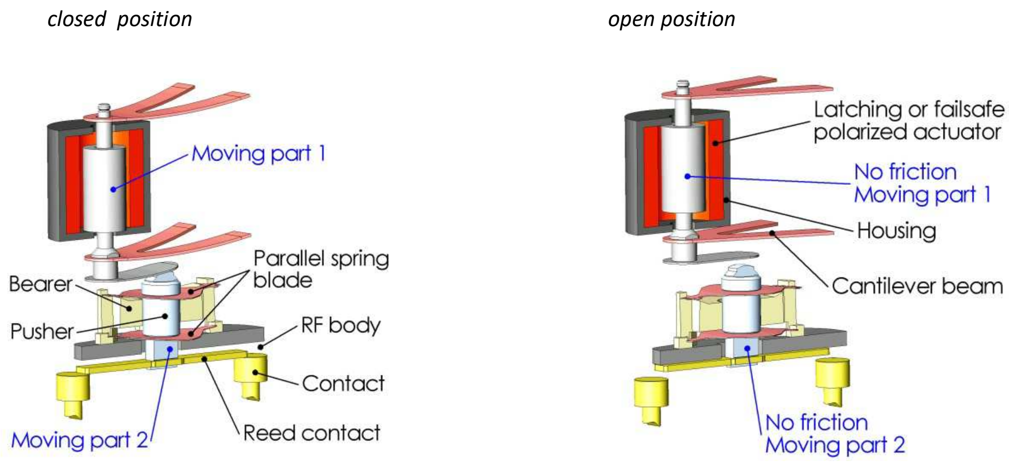


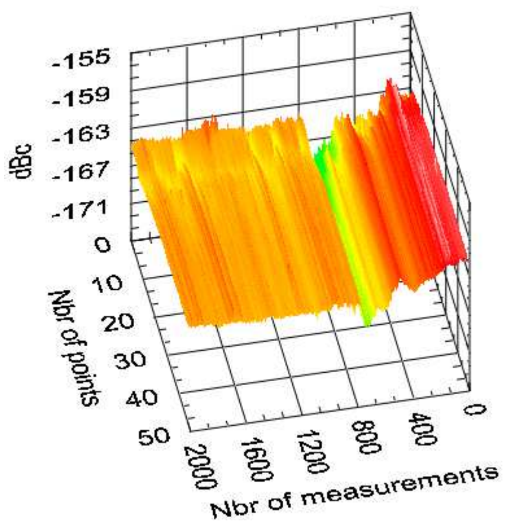
Figure 6: RAMSES switch kinematics

- The contacts forces
  The particular suspension system ensures strong steady contact force, perfect geometric positioning of the reed in the RF line, and exceptional contact cleanliness switching cycle after switching cycle.

Switching cycle

During the first measurements PIM values increased until stables values.

For example, on an SPDT with SMA type connectors without switching, we distributed power at two frequencies (1805 MHz and 1880 MHz), and then we measured the 3rd PIM and recorded every 2 seconds for 3 minutes. The switching frequency rate is at 5 cycles per second (Ton 25ms / Toff 175ms).
The optimal PIM value occurs after 400 switching cycles. Contact stress and plastic deformation are released.



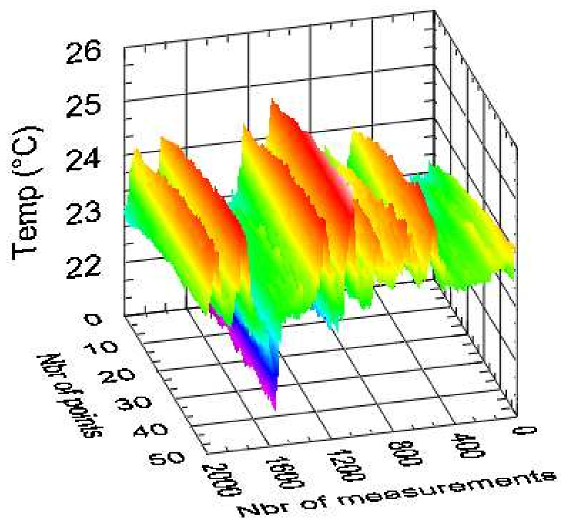


Figure 7: 3rd PIM measurement (1730MHz). **Figure 8: Temperature.**

The unique design of RAMSES (RADIALL Modular System for Electro mechanical Switches) is based on the suppression of friction, in order to improve reliability and avoid electric contact and degradation of RF characteristics.
The primary difference between the RAMSES design and classic designs is its exceptional electrical life expectancy. The design allows users to perform life tests successfully without RF contact resistance failure or switching time variation over the entire operating temperature range.
All RAMSES devices incorporate the same modular patented system comprised of parallel spring blades suspended from a barrier located outside of the RF body.
The typical intermodulation product of Ramses is around -165 dBc for all types of connector options and will perform past 2 million cycles.

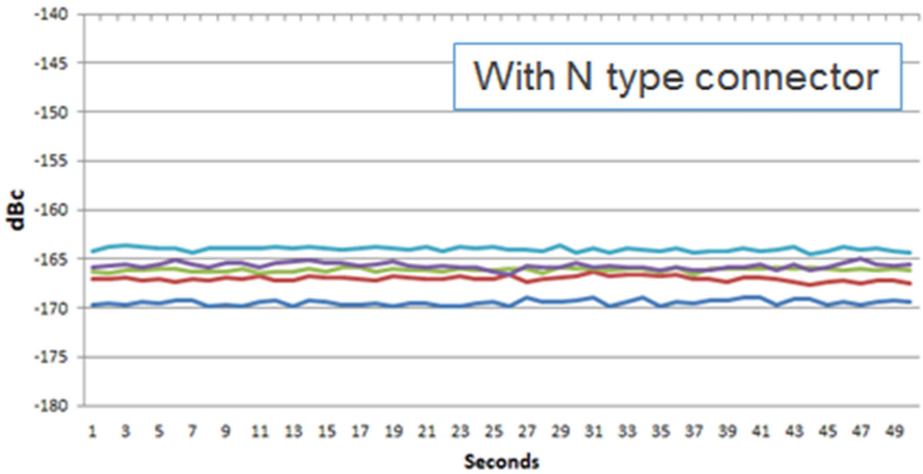


Figure 9: Typical PIM measurements for SPDT fitted with N and SMA type connectors

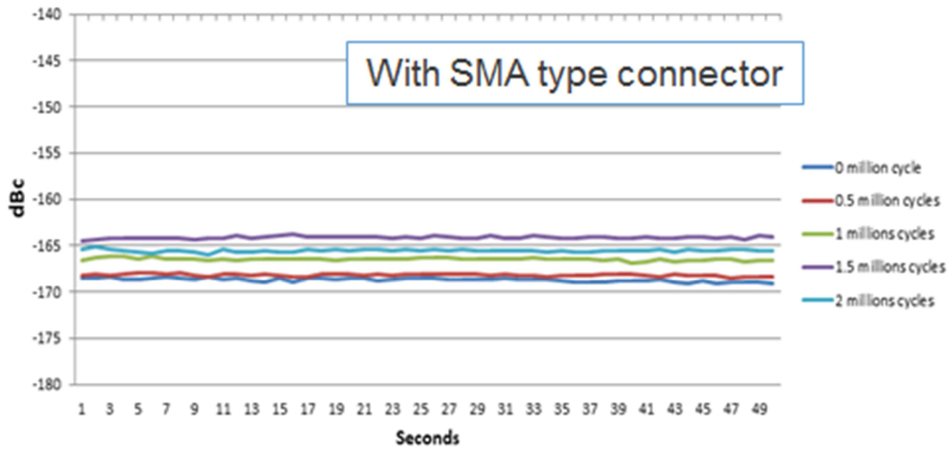


Figure 10: Typical PIM measurements for SPDT fitted with N and SMA type connectors

Nature of coating or plating

The first rule is to avoid ferromagnetic materials like Nickel. Due to the magnetic hysteresis phenomenon, this material stimulates a non-linear junction.
As a function of the behavior of the coating (conductivity, hardness, type and facilities to generate oxide), the coating could be more or less high level performance for PIM. For coaxial switches, Silver is a very good candidate for low PIM (Figure 6), but some interesting coatings could be used, like HeP²R (a Radiall plating innovation).

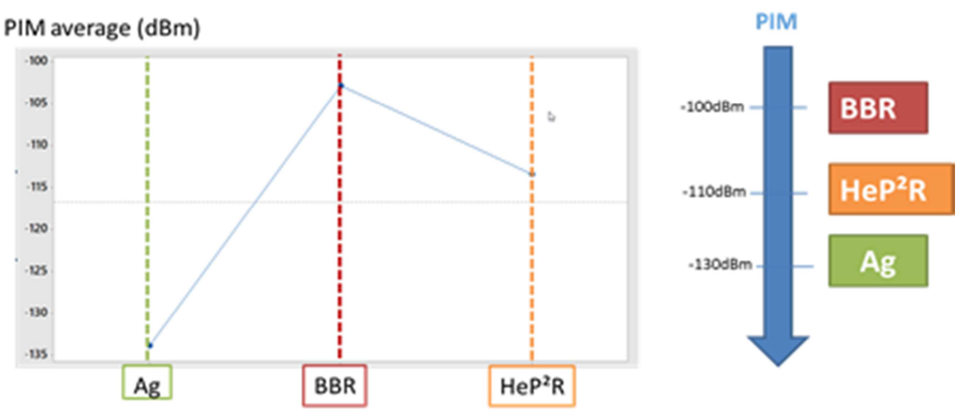


Figure 11: nature of coating versus PIM level

In function of design and product, the level of PIM could be evaluated. Some products done with a silver coating could have a PIM level of -145dBm and, with a HeP²R coating the level could be around -135 dBm.

Contact force / torque

We can identify 3 areas of influence of the contact force (to modulate according to the hardness of the materials in the presence – Figure 12):

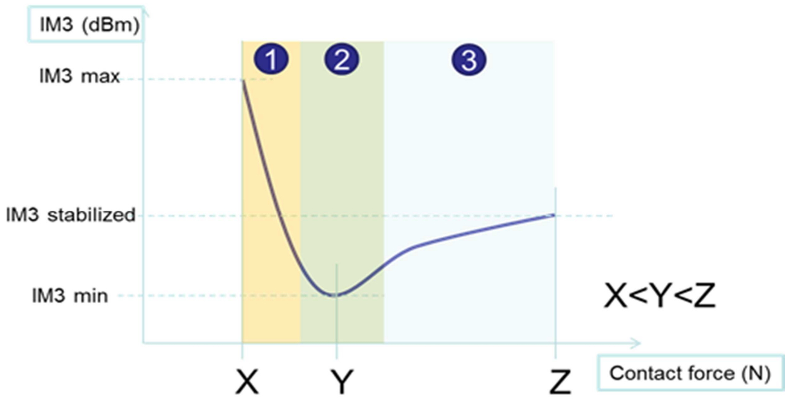


Figure 12: influence of contact force on PIM level.

- Area 1: low contact pressure, all areas of non-linear contact is expressed. This is the most unstable area.
- Area 2: average pressure, this is the area with the least of non-linear contact area. The pressure is sufficient to create large contact area straight metal/metal, oxide deposits break. This area is for only a small change in contact pressure. This area is difficult to achieve due to the phenomena of relaxation of metals.
- Area 3: pressure, this is the most stable area. The oxides are completely fractured. Metal/metal contact areas are free. Appearance of tunneling mechanisms, which are so dominant.

Through the control of the coaxial connector, tightening torque of third-order PIM power level values were measured from 100 to 380 Ncm for the SPDT fitted with N type connectors and from 40 to 140 Ncm for the SPDT fitted with SMA type connectors

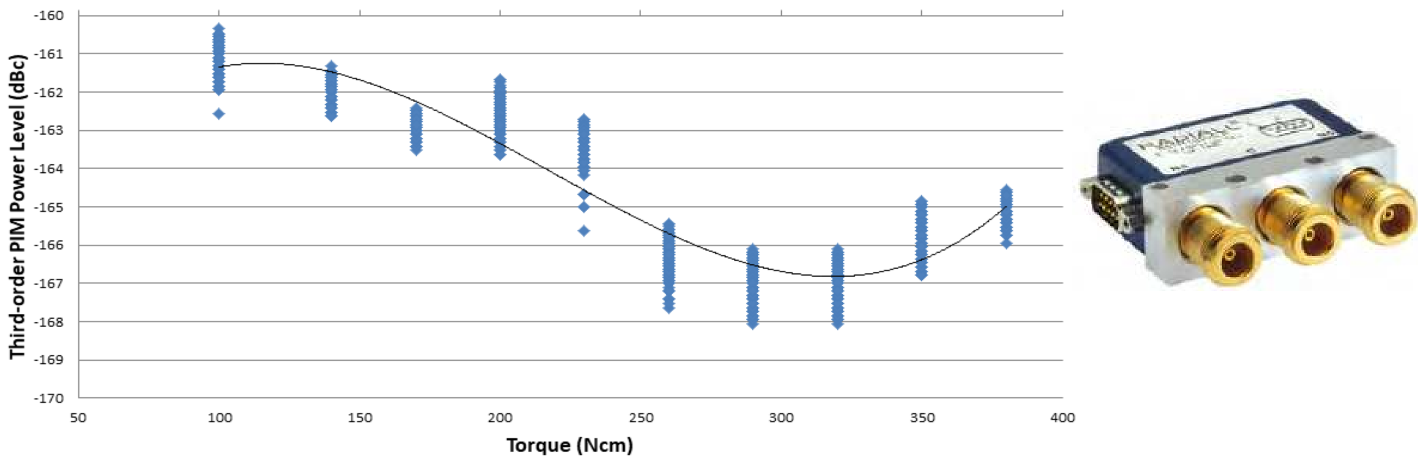


Figure 13: Effect of tightening Torque on PIM. SPDT fitted with N type connectors

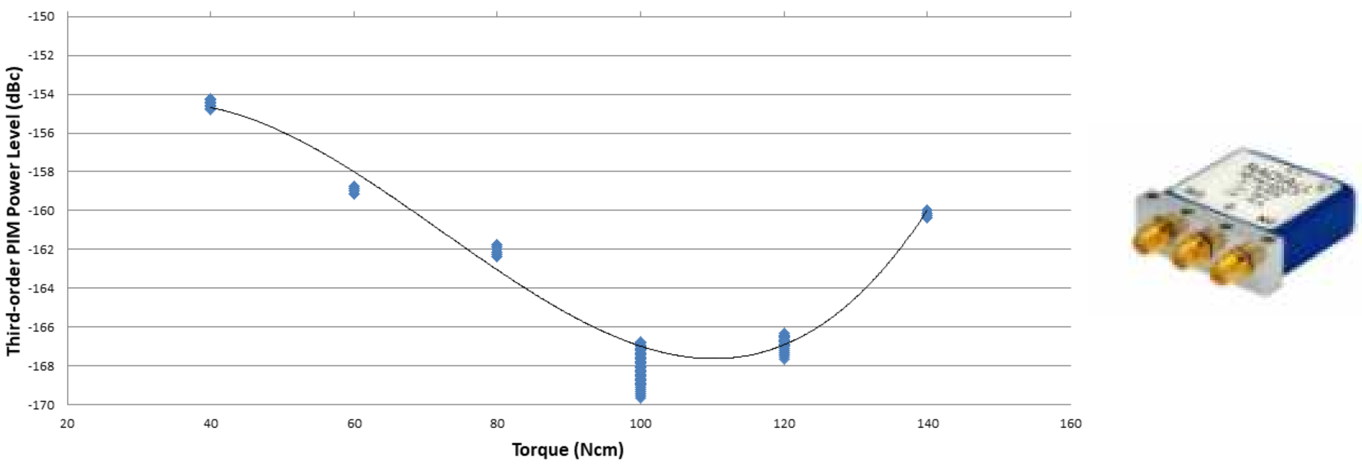


Figure 14: Effect of tightening Torque on PIM. SPDT fitted with SMA type connectors

As the tightening torque increases, the area of contact surface of the coaxial connector is increased, while the PIM value is reduced. However, when the tightening torque is over 300 Ncm for N type or 120 Ncm for SMA type, the contact stress is over the limit, and plastic deformation occurs. The PIM is deteriorative.

The result indicates that the optimal tightening torque is 300 Ncm on an N type coaxial connector and 120 Ncm for SMA type.

Thermal effect

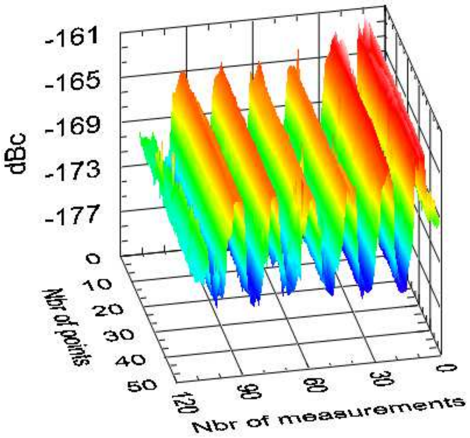
This heating will generate a relative displacement of the materials thus modifying the contact areas and therefore levels of intermodulation. Creating an unstable phase of intermodulation until thermal stabilization.

In addition, the increase in temperature and more precisely the temperature deltas will be generators of thermoelectricity between two materials of different nature, which can promote intermodulation. (See Beck effect)

During the first temperature cycles between -25°C to +75°C the PIM values increased.

For example, on a DPDT with N type connectors without switching, we distributed power at two frequencies (1805 MHz and 1880 MHz), and then we measured the 3rd PIM and recorded every 2 seconds for 3 minutes. We waited for 5 minutes, and then started again for a temperature between -25°C to +75°C.
The optimal PIM value occurs after the second temperature cycle. Contact stress and plastic deformation are released.

Between -25°C to +75°C PIM variation is -177dBc up to -165dBc (Δ 12dB)



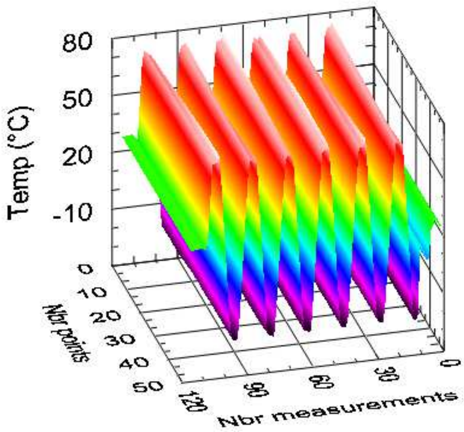


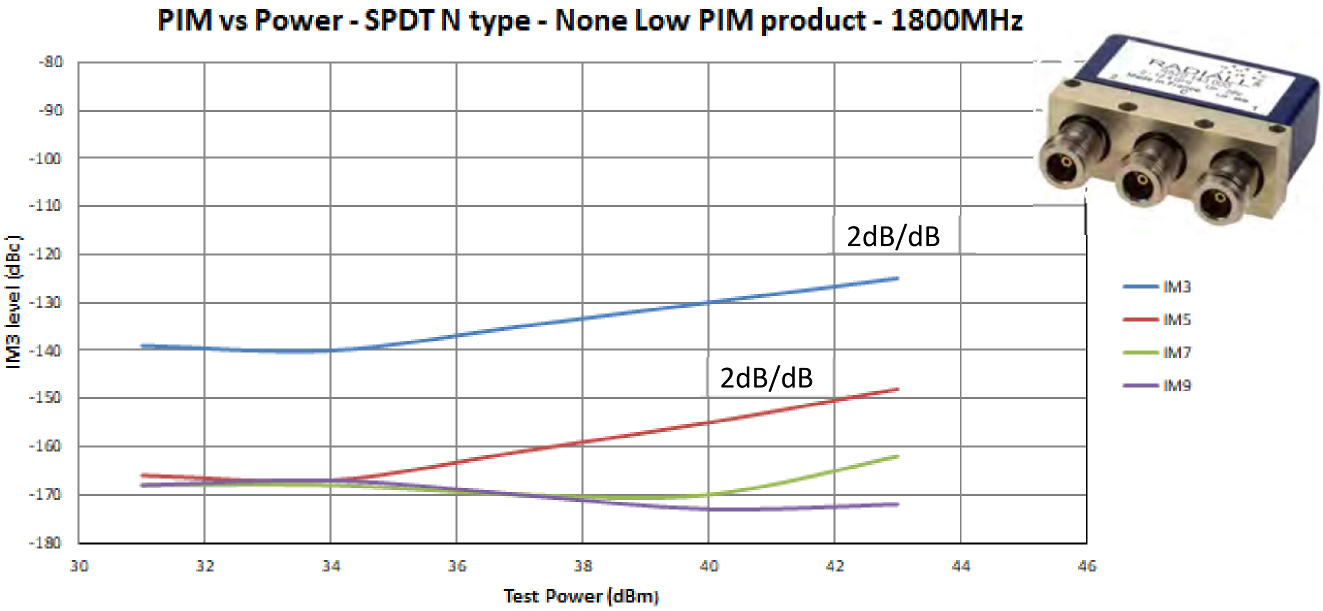
Figure 15: 3rd PIM measurement (1730MHz). Figure 16: Temperature (-25°C up to +75°C).

PIM level variation as a function of TX power

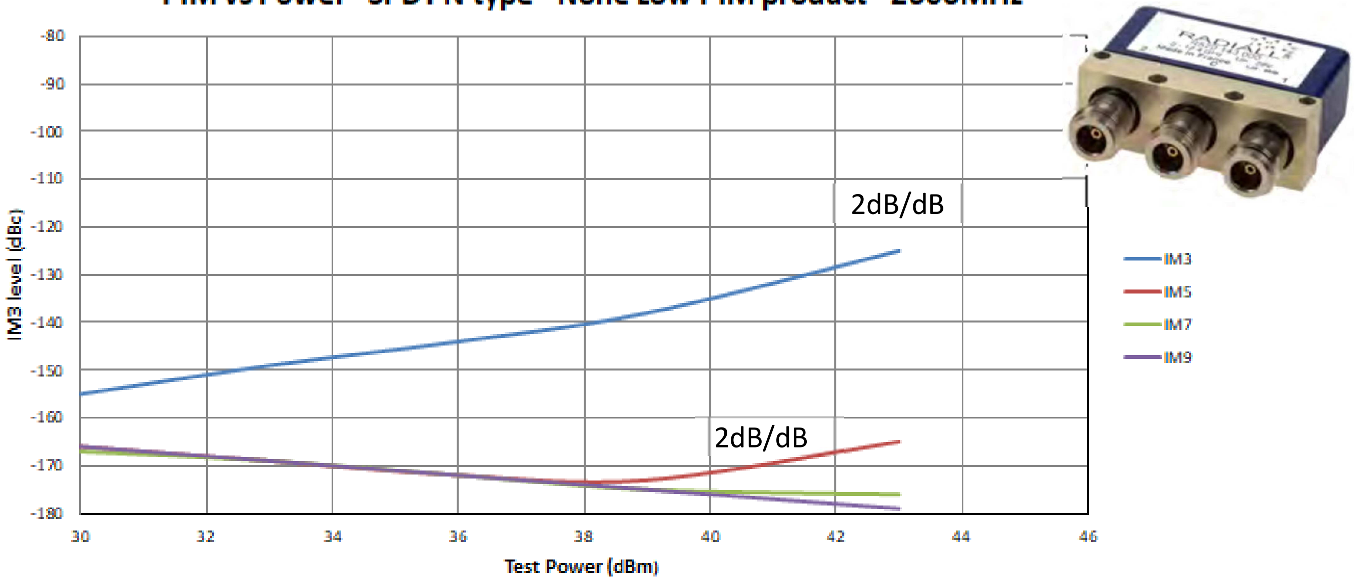
The increase of the PIM level as a function of the input power was studied in different test campaigns performed on RF switches. Generally, the PIM slope observed is between 2 dB of PIM/dB of Power for a non-low PIM switches and 1 dB of PIM / dB for a Low PIM switches.

On Radiall electromechanical switches, results show that the 3rd order PIM seems to have the same slope than the 5th, and 7th order PIM.

PIM results were obtained by increasing the RF power of two carriers by steps of 3 dB per carrier simultaneously.



PIM vs Power - SPDT N type - None Low PIM product - 2600MHz



PIM vs Power - SPDT N type - Low PIM product - 2600MHz