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Intermodulation in RF Coaxial Connectors

Introduction

The increased demand from the mobile communication industry to provide greater channel capacity coupled with the increased sensitivity of receivers has exposed a condition within RF Coaxial Connectors referred to as Intermodulation Distortion (IMD). This condition occurs when non-linearities within the connectors act as imperfect diodes to generate other frequencies known as Intermodulation Products (IMP). Some of these frequencies appear within the receive band and effectively block the channel. The purpose of this application note is to outline the basic causes of Intermodulation and the techniques M/A-COM has undertaken to minimize this condition.

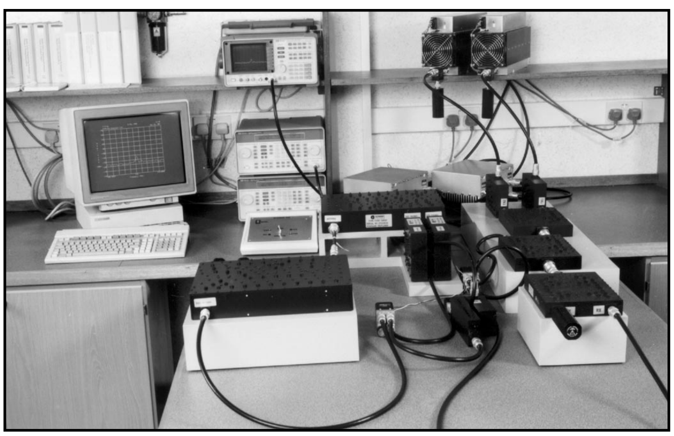
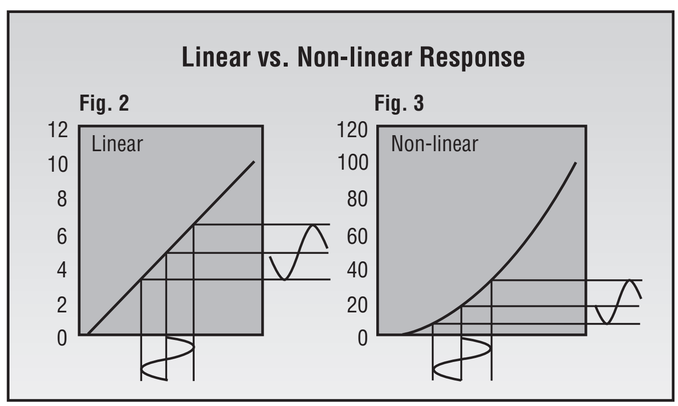


Fig. 1 M/A-COM Intermodulation Test Lab

IM Basics

Modern developments in base stations for GSM, DCS 1800 and PCS 1900 have necessitated the use of “7-16”, “4.1/9.5” and “N” connectors due to the increased power requirements. The requirements for performance are typically in the order of -160 dBc to -163dBc (when working in dBc) or -120dBm (when working in dBm), both with 2 x (+43dBm) tones. The requirement is so stringent because the connectors are used in post-filtering sections of the transmit path (between the diplexer and the antenna) and also because the system is a full duplex system where the multiple-carrier transmit path is also the receive path. In a truly linear system, the output is directly proportional to the input, following the form of y=mx+c (see fig. 2). Coaxial connectors have traditionally been viewed as following this pattern. In reality, there have always been non-linearities present in coaxial connectors. These were not readily apparent as the resultant IM products were significantly below the noise floor of the system due to relatively weak carrier signals. This situation becomes apparent when the incident power is raised above 30 dBm.



The small non-linearities have a characteristic similar to a square-law (see Fig 3). The distortion to the waveform is evident, the positive 1/2 cycle being significantly greater in amplitude than the negative 1/2-cycle. When converted to the frequency domain, this waveform consists of the desired fundamental plus a decaying series of related harmonics that, in themselves, interact with other carriers present on the transmission line.

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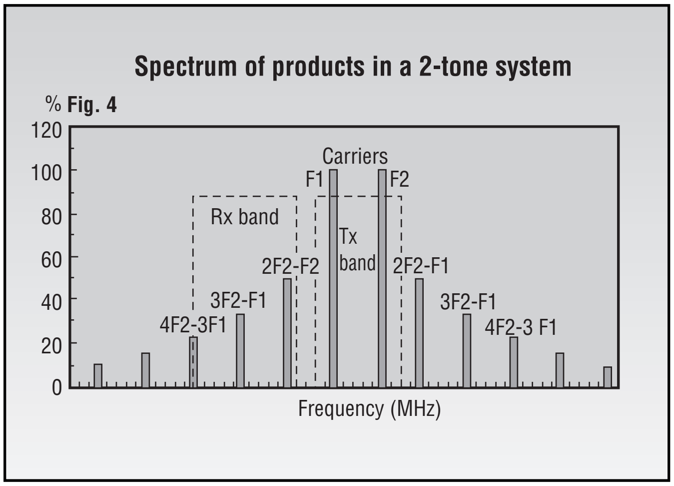
The effect of this interaction produces additional frequencies, some of which occur where they are least wanted (see fig. 4). The 2F1-F2 (3rd order IMP, IMP_3), 3F1-F2 (5th order IMP, IMP_5) and 4F1-F2 (7th order IMP, IMP_7) products can all manifest in the receive band and, if sufficiently large, effectively block a channel by making the base station receiver think that a carrier is present when one is not.



Potential Causes of IM in Coaxial Connectors

There are numerous factors which can affect intermodulation performance in RF coaxial connectors. Identified below are the most likely sources of concern:

- Contaminated plating solution
- Insufficient plating thickness
- Corrosion
- Dissimilar metals in intimate contact
- Magnetic materials in the signal path
- Low contact pressure
- Less than 360-degree contact
- Poor surface finish
- Debris and dust within the connector
- Convoluted signal path

Remedies for IM in RF Coaxial Connectors

To combat the above identified IM sources, M/A-COM undertakes precautions during the design and manufacture of the product, as summarized below:

- High quality plating to 6µm for IM-sensitive products

  The plating must also be free from contaminants and properly passivated with a chromate passivate. Silver has been the preferred plating material as it possesses the lowest practical resistivity thereby minimizing interface contact resistances. M/A-COM also offers a unique White Bronze plating finish which provides excellent durability, tarnish resistance and non-magnetic properties ideal for low inter-modulation. During testing with a system noise floor of -145 dBm, the difference in performance between silver-plating and M/A-COM's new White Bronze finish is not discernible (refer to White Bronze Application Note ID1014).

- Restrict materials to copper and its alloys.

  This ensures maximum plating adhesion and minimum electrochemical potential difference between the base materials and their over-platings.

- Avoid the use of stainless steel, nickel, ferrites, etc. in the signal path

  Magnetic and para-magnetic materials will only compound non-linearites and give poorer interface contact resistances. During experimentation, M/A-COM discovered a degradation in performance of 20dB when nickel plate was used. The presence of magnetic or para-magnetic materials will also cause the forward IMP figure to differ from the reverse IMP.

- Quality machining

  Surface finish is paramount. The signal propagates within a "skin" if this skin is too rough, the signal will repeatedly transition through metal and surface oxide layers, thereby creating the same effect as a poor panel contact (see fig. 5). For IM-sensitive designs M/A-COM ensures 0.4 µm is the maximum.

- Contact design

  This primarily affects the connector interface. Repeated matings can generate small amounts of plating from the individual parts. These oxidize and interfere with the mechanical (and therefore electrical) mating of connectors. The oxidized debris gives further rise to metal and surface oxide junctions and consequently, higher IM products.

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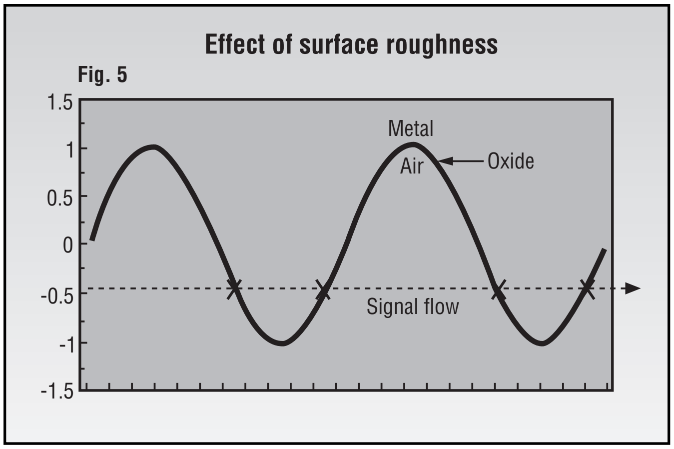

• Ensure, by design, a properly defined contact interface at connector, panel and contact interfaces

Insufficient contact force will give rise to metal to oxide junctions. The classic rectifiers were metal oxide by composition.

Axial maximum material condition at the connector interface is critical in order to ensure minimum mismatch and maximum potential of a butt-contact. Panel interfaces generally concern the physical contact of the connector body to the panel. In this case, it has been determined that a protruding feature as close as possible to the body bore will give the best IM performance. The applied mounting force is concentrated in the surface area of the protrusion which, on engagement with the panel, punctures the existing oxide layer to give a metal-to-metal, gas-tight junction.

• Avoidance of crimps

Crimps, by nature, can only give multiple point-contact rather than 360-degree contact and also cause a variability in the position of electrical contact during dynamic testing. IM products will therefore be greater. It has been found that soldered center contacts and clamp/solder outer contacts give the best static and dynamic IM performance.

Improving IM Connector Design

M/A-COM continues to pursue design techniques which improve intermodulation performance to address emerging telecommunication market needs. A state of the art intermodulation test facility and participation on the international (IEC SC46D WG5) committee to develop standard test practices ensures our commitment to the understanding of intermodulation characteristics. This applied technology base is instrumental in developing innovative low intermodulation products for 7-16, Type N, SMA and OSP interfaces.

Most Commonly Asked Questions Regarding Intermodulation

1. Why is intermodulation such a concern for cellular infrastructure equipment?

The primary concerns for cellular service providers today are channel efficiency and clarity of transmission. Growth in demand for mobile communications has created a need to operate equipment at greater capacities and reliability to service the competitive market. Intermodulation degrades or limits the ability of the service provider to operate at optimal levels of performance and may ultimately cause subscribers to experience poor call quality. Intermodulation has become an important factor in system selection to ensure the best possible network service.

2. Where is intermodulation most likely to occur in cellular infrastructure equipment?

Intermodulation is typically of greatest concern between the filtering elements of the system and the antenna. The introduction of higher power levels for the transmit side of the equipment creates greater potential for intermodulation to occur. This is why the majority of focus for intermodulation concerns 7-16, type N, SMA and 4.1/9.5 connector interfaces.

3. Is intermodulation a recent development?

Intermodulation has always been inherently present in RF coaxial connectors but may be relatively imperceptible in some devices for a variety of reasons. The amount of power applied to an RF connector determines the relative IM threshold which can be observed. Intermodulation is therefore more likely to cause concern in a higher power system, for example, utilizing a 7-16 connector interface rather than an equivalent low power OSX solution. The trend toward higher power digital cellular systems creates the need for greater intermodulation sensitivity.

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4. What is the best method of cable attachment for IM sensitive cable assembly applications?

Soldering and clamping are preferred methods due to the 360-degree point of contact created at the cable to connector interface. Such intimate contact improves the overall contact resistance leading to improved IM characteristics. In addition, it is also better to solder the center conductor of the connector to the cable versus crimping due to the improved contact resistance path and elimination of voids.

5. Are there ways to test for intermodulation in an RF coaxial connector?

Yes, very sophisticated methods are needed to test for intermodulation in RF connectors. The test system must utilize extremely sensitive filtering or clean amplification so that the equipment itself has a very low intermodulation noise floor. There is not yet a standardized approach to testing, although an international committee has been formed in the connector industry to address the situation. M/A-COM has a state of the art test facility where our designs are optimized for low intermod performance and where further analysis on the effects of this phenomena can be studied.

6. Is intermodulation in coaxial connectors frequency dependent?

No. Because coaxial connectors are broadband devices there is no frequency dependency. Some apparent variability can be detected during testing but this is not due to the connector. The impedance matches of the output diplexer/triplexer and terminations are the causes of the variations and should not be incorrectly attributed to the connector/assembly. M/A-COM Interconnect Business Unit has demonstrated that by varying the impedance match of the test station termination, a DUT can show 15dB better IMP_3 than exists in reality.

7. IMP_3 in mixers follows a 3dB/dB relationship. What is it for connectors?

The relationship is identical. Taking the 3rd order (2F1-F2): varying the power of F2 gives an IMP_3 relationship of 1dB/dB whereas varying the power of F1 gives a relationship of 2dB/dB as the IMP is derived from the 2nd harmonic of F1. This gives a total of 3dB/dB when symmetrically varying both carrier powers.

8. I am buying a complete cable assembly from M/A-COM. How do I interpret the IMP result now?

With caution! It is M/A-COM's policy when testing devices to move away from the normal static test to a dynamic test where the cable termination interfaces are mechanically exercised during live IM conditions. It is also a good indicator to customers of the build quality of the assemblies. A dynamic evaluation has shown 15dB degradation in IMP performance for poor assemblies and even as much as 50dB for bad ones.

It is therefore strongly advisable that IM performance figures are stated in the context of a dynamic measurement.

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