PASSIVE INTERMODULATION AND PEAK INSTANTANEOUS POWER:

THE IMPORTANCE OF TEST TECHNIQUES FOR OPTIMIZED ANTENNA DESIGN AND PERFORMANCE

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Author: Dr. Jawad Abdulnour, Director of Engineering

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PASSIVE INTERMODULATION (PIM)

PIM OVERVIEW:

- Multitone intermodulation distortions (also referred to as Passive InterModulation or PIM) are caused by the nonlinear behavior of devices when two or more signals are present at the input.

- In linear devices, the output is linearly proportional to the input. When two signals at different frequencies F1 and F2 are mixed, the result at the output is two signals at F1 and F2. Ideally, no other frequency components are generated. (see figure 1 below)

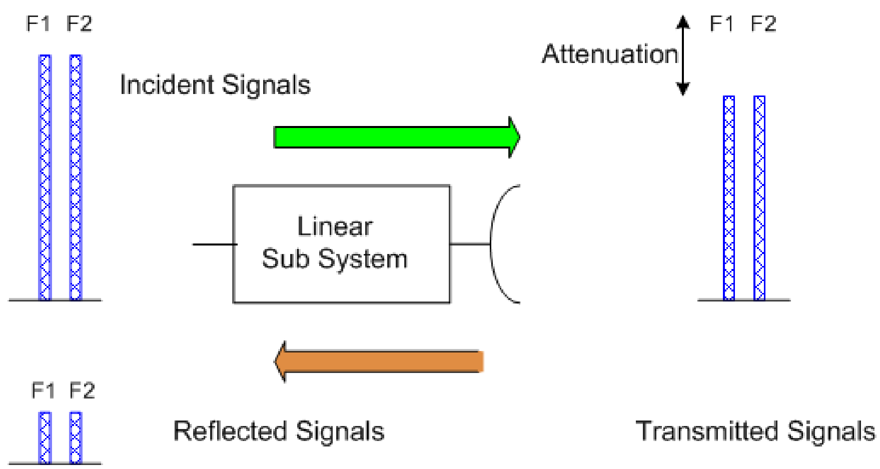


FIGURE 1: ATTENUATION AND REFLECTION IN LINEAR SYSTEMS

- In non-linear devices (see figure 2 below), when two signals at different frequencies F1 and F2 are mixed at the input, the result is a series of harmonics and high-order frequency components at the output:

nF1± mF2; n,m = 0,1,2,3,4,…

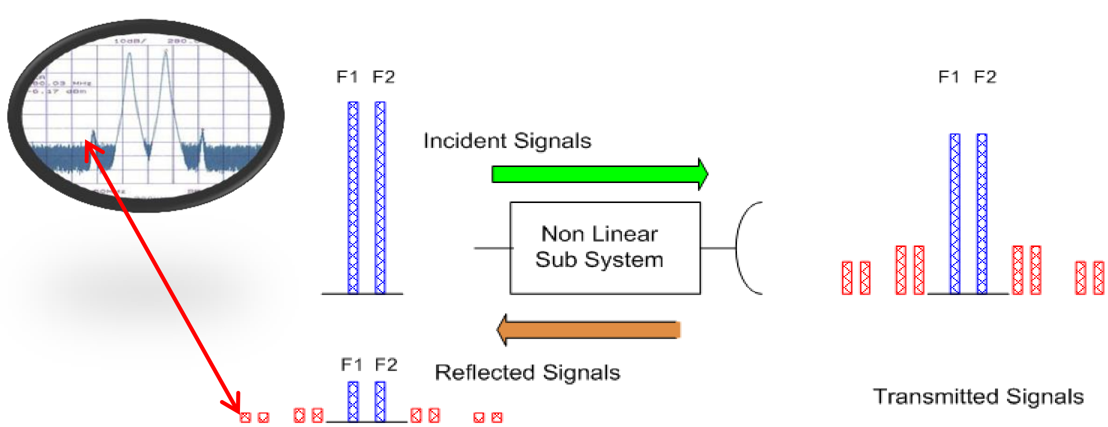


FIGURE 2: HIGH-ORDER FREQUENCY COMPONENTS GENERATED BY NON-LINEAR SYSTEMS

These new frequency components become a source of interference and therefore need to be carefully controlled.

- The 3rd order intermodulation (2F1-F2) is the strongest product. The 5th order PIM product is about 15 dB lower than the 3rd order and the 7th order is lower by an additional 15 dB. The PIM figure increases as well with increased input power levels by an approximate 2:1 ratio. (when the input power is increased by 3dB, the PIM figure will be increased by approximately 6dB)
- When the 3rd, 5th or higher order mix fall within the RX band, the level must be below the squelch point. If not, it will cause significant **desense (receiver desensitization) issues.**

ACTIVE VS PASSIVE:

- Active devices such as amplifiers require sources of energy (e.g. DC biasing) in order to operate whereas passive devices do not. Typically, active devices are non-linear and thus, the main source of intermodulation distortions and spurious emissions in RF systems.
- Under certain conditions, the linear passive devices that are supposed to be linear show non-linear behavior that results in minor distortions, commonly referred to as Passive InterModulation (PIM) distortions. Previously, PIM was of little concern to the telecom system engineers, but it is now presenting major challenges to the wireless industry. Modern systems indeed require much tougher frequency plans, and with the use of higher transmitter power levels and more sensitive receivers, PIM manifests as an **interfering signal which may degrade the performance of the receiver.**

MAIN CAUSES OF PIM:

- Passive InterModulation (PIM) occurs anywhere in the following systems:
  - Antennas
  - Couplers
  - Filters
  - Feeders and cables
  - Connectors
  - Lightning arresters
- Environmental influence and elements outside the system that are generating PIM:
  - Tower modules and components
  - Bolts
  - Brackets
  - Nearby metallic objects and obstacles

- The following can play a role in generating PIM by acting as diodes in mixing signals. This is mainly caused by:
  - Poor contact junctions
  - Materials that exhibit levels of hysteresis (ferromagnetic materials)
  - Contamination
  - Loose connections
  - Corroded objects

COMPROD'S INTERMODULATION TEST PROCEDURES:

- PIM cannot be predicted by simulation. The only way to find out the level of PIM generation is to measure it.

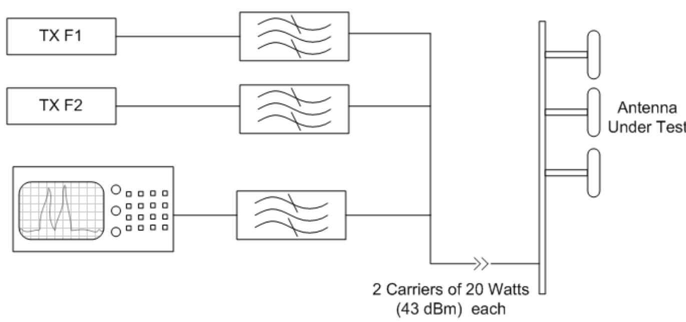


FIGURE 3: PIM TEST SETUP

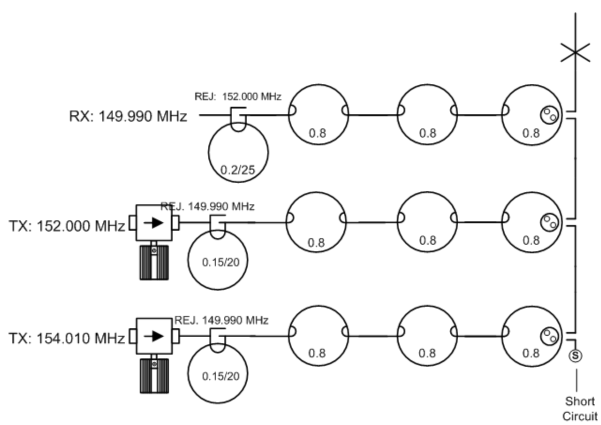


FIGURE 4: TYPE OF FILTERING SYSTEM USED IN THE PIM SETUP
FEATURING THE X-PASS EXPANDABLE TRANSMIT/RECEIVE MULTICOUPLER TECHNOLOGY

FIGURE 5: PIM TEST EQUIPMENT FOR VHF

FIGURE 6: COMMERCIAL PIM TEST EQUIPMENT

COMPROD’S PIM TEST CONDITIONS:

- PIM testing is performed using two 20 Watt (43dBm) transmitters. The signals are filtered and combined. The level of intermodulation product is measured with a **spectrum analyzer**.

- The **X-Pass Expandable Transmit/Receive multicoupler technology** is used for VHF and UHF frequencies. The test beds for these frequencies are developed and manufactured by Comprod. For higher frequencies (e.g. 700/800/900 MHz), a commercial test setup is used.

- All parts, components, cables and connectors in the test setup are **certified low PIM.** PIM performance of the setup is verified prior to each measurement by replacing the antenna with a low PIM load. Our standard specification for low PIM antennas is -150 dBc and we always ensure that our test bed has a residual InterModulation (IM) that is 10 dB below this value in order to offer a reliable measurement.

- Passive devices such as filters, cable/connector assemblies, etc. (where the signal is confined within the structure) are very lightly affected by electromagnetic signals existing in the environment because of the shielding structure that is protecting these devices.

- By contrast, because of radiative properties, antennas are highly affected by external sources. A strong isolation from the environment is therefore required - hence the importance of using an **anechoic chamber.**

FIGURE 7: COMPROD'S PIM TESTING ANECHOIC CHAMBER

- Comprod's antennas are tested in an anechoic chamber which is equipped with **custom-developed absorption panels specifically designed for PIM testing**. Ferrite materials are not allowed. In addition, special shaping and configuration are used to handle the power at frequencies as low as 138 MHz. This is achieved by maintaining a suitable size for each absorber. As the shielding structure does not contain any ferromagnetic materials, it results in a shielding level that is better than 100 dB.

- Omnidirectional, quasi-omnidirectional and directional antennas with very high directivity can be tested in this chamber, from 138 MHz up to 18 GHz.

COMPROD'S MEASURES TO AVOID PIM GENERATION:

- Comprod implements a series of measures, from design all the way to manufacturing, to avoid or reduce to the lowest possible level the potential sources of PIM:
    - Careful selection of materials
    - Use of high-performance cables and connectors
    - Highest quality of welding as well as appropriate torque and alignment during the assembly process to avoid poor mechanical contacts or loose mechanical junctions
    - Complete elimination of contaminated surfaces and gaps (parts cleaned in an ultrasonic bath)
    - Perfectly smooth metal surfaces that are free of cracks, distortions, flakes or shavings
    - Sealed points of contact so as to avoid corrosion

PEAK INSTANTANEOUS POWER (PIP)

PIP OVERVIEW:

- In modern digital multi-carrier communication systems, amplitude and phase modulations are combined in complex envelop waveforms. The peaks of in-phase signals will be added and the result is a **significant rise in voltage occurrences**. This creates a serious Peak Instantaneous Power (PIP) handling issue in devices and modules such as antennas. The peak can be high enough to create arcing across junctions and gaps in sensitive areas.

- The ratio of the signal peaks to the average power level is usually expressed as **Peak to Average Power Ratio (PAPR).** Higher data rates lead to higher PAPR.

- The following diagram shows the impact of modern modulation schemes on the PAPR which is increasing from approximately 3.5 dB in the 3G wireless networks and up to 8.5 dB in the 4G networks. The average transmitted power level generally remains the same, as this determines the distance (range) of the RF transmission.

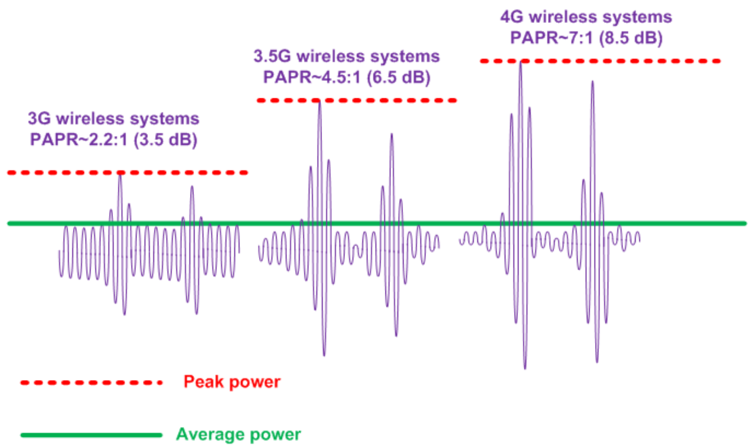


FIGURE 8: IMPACT OF MODERN MODULATION SCHEMES

For *N* channels with *V* voltage amplitude each, the PAPR is given by the following expression:

$$PAPR(dB) = 10\,log\left[\frac{V(Maximum\ Peak\ Value)}{N \times V(RMS)}\right]^2$$

The previous formula leads to:

$$PAPR(dB) = 10\,log\left[\frac{PIP}{N^2 \times 2 \times P_{carrier}}\right]$$

As a result, PIP is given by:

$$PIP = 2 \times N^2 \times P_{carrier} \times 10^{\frac{PAPR(dB)}{10}}$$

\ If we know the Peak to Average Power Ratio (PAPR in dB) of the modulation scheme as well as the Continuous Wave (CW) power of each carrier (Pcarrier in Watts), this formula gives a good approximation of the peak instantaneous power in Watts.

INSERTION LOSS EFFECT:

\ The insertion loss could come from the combining network, feeders or other passive components. The following formula allows taking into account the effect of this loss. (In this formula, the Insertion Loss IL should be a negative value in dB)

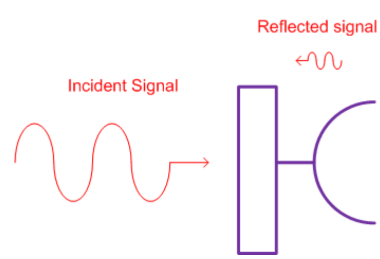
$$PIP = 2 \times N^2 \times P_{carrier} \times 10^{\frac{PAPR(dB)+IL(dB)}{10}}$$

Modulation PAPR ratio	Number of channels	TX power per channel	Insertion Loss	PIP (KW)
0 dB (P25 P1)	12	20 Watts	3.2 dB	2.8
2.6 dB (P25 P2, TETRA)	12	20 Watts	3.2 dB	5.0
3.5 dB (3G)	12	20 Watts	3.2 dB	6.2
6.5 dB (3.5G)	12	20 Watts	3.2 dB	12.3
8.5 dB (4G)	12	20 Watts	3.2 dB	19.5

TABLE 1: EXAMPLE OF CALCULATION
(FOR A SITE WITH 12 CHANNELS COMBINED, 20 W POWER PER CHANNEL,
3.2 DB INSERTION LOSS, 1.3:1 ANTENNA VSWR, THE PEAK INSTANTANEOUS POWER
PIP GENERATED IN AN ANTENNA FOR DIFFERENT MODULATION SYSTEMS)

REFLECTION EFFECT:

Residual reflection due to mismatch occurs in all communication systems. It is represented by the reflection coefficient r which is related to the power and Voltage Standing Wave Ratio (VSWR) in the following formula:



$$\rho = \frac{Amplitude\ of\ reflected\ signal}{Amplitude\ of\ incident\ signal} = \frac{\sqrt{P_r}}{\sqrt{P_i}} = \frac{VSWR - 1}{VSWR + 1}$$

The amount of peak power reflected (in Watts) is given by:

$$PIP_{reflected} = PIP_{incident} \times \left[\frac{VSWR - 1}{VSWR + 1}\right]^2$$

\ For an antenna of 1.4:1 VSWR, around 3% of the incident power is reflected. This power should be added to the incident power when analyzing the PIP handling of the antenna.

\ For an antenna of 1.5:1 VSWR, around 4% of the incident power is reflected. This power should be added to the incident power when analyzing the PIP handling of the antenna.

\ If we take the PIP value of our example and add the reflection effect, we obtain two different VSWR values:

PIP without RL effect	*VSWR*	*PIP with RL effect*
2.8 (KW)	*1.5:1*	*3.0 (KW)*
5.0 (KW)	*1.5:1*	*5.4 (KW)*
6.2 (KW)	*1.5:1*	*6.7 (KW)*
12.3 (KW)	*1.5:1*	*13.3 (KW)*
19.5 (KW)	*1.5:1*	*21.1 (KW)*

PIP without RL effect	*VSWR*	*PIP with RL effect*
2.8 (KW)	*1.2:1*	*2.8 (KW)*
5.0 (KW)	*1.2:1*	*5.1 (KW)*
6.2 (KW)	*1.2:1*	*6.3 (KW)*
12.3 (KW)	*1.2:1*	*12.5 (KW)*
19.5 (KW)	*1.2:1*	*19.9 (KW)*

TABLE 2: REFLECTION EFFECT ON PIP

COMPROD'S MEASURES TO AVOID PIP BREAKDOWN:

\ PIP is responsible for breakdown **(arcing)** in the antenna. This is different from the Continuous Wave (CW) power responsible for temperature rise. When arcing occurs in the antenna, the surface is damaged and the interior gets contaminated. This is a destructive process which leads to major failure in the antenna.

\ Knowing that breakdown in the air occurs at 3000 KV/m, Comprod's engineers developed **3D simulation techniques** to represent with precision the distribution of electric field strength radiated by a dipole. The mechanical construction of the dipole is reproduced in this simulation and source excitation normalized to 1 Watt is considered.

- This enables us to accurately calculate the amplitude in V/m produced by the peak power in the system.

- When designing antennas and feed networks, we reduce the mismatch to the lowest possible level.

- Design and manufacturing processes are carefully monitored in order to eliminate any residual imperfections and avoid charge accumulation as well as high-density currents in critical areas.

- Our PIP-rated antenna is designed to support a maximum of 25KW peak power. A margin is also considered to overcome the effects of temperature, humidity and altitude.

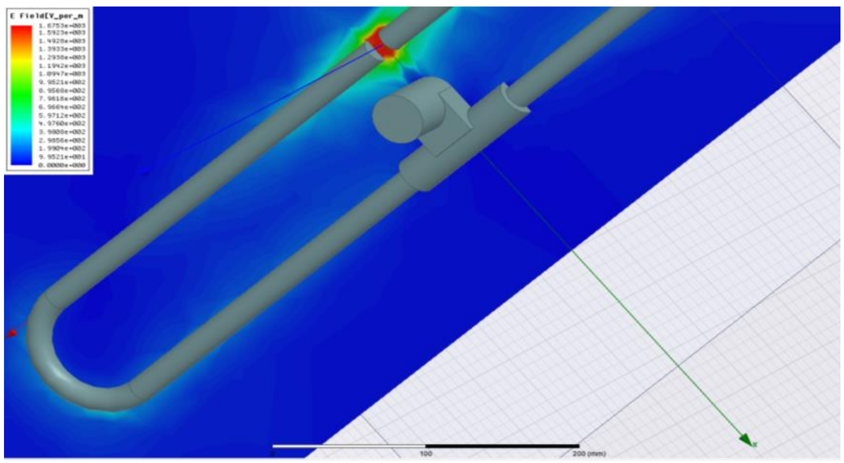
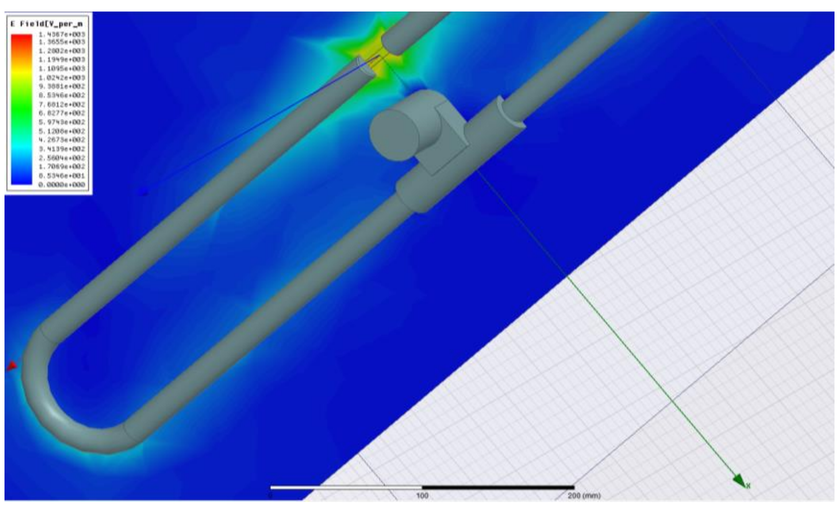


FIGURE 9: 3D SIMULATION
TO REPRESENT THE DISTRIBUTION OF ELECTRIC FIELD AROUND A FOLDED DIPOLE



- This simulation shows the effect of the geometry on the intensity on electric fields. This kind of simulation is performed on all Comprod’s antennas to prevent the arcing with a comfortable margin for improved PIP rating.

CONCLUSION

Understanding and minimizing the detrimental impact of Passive InterModulation (PIM) and Peak Instantaneous Power (PIP) is critical to ensure the optimal performance and efficiency of your RF networks. Special considerations for testing, prevention and measurement of these two parameters are therefore needed to ensure that your key communications network components, such as antennas and filtering solutions, do not contribute to network performance degradation.

As a leader in RF solutions, Comprod has leveraged its forty years of experience in the field to establish and apply a set of best practices - from the careful selection of materials and sophisticated RF design practices, combined with strict quality control during the manufacturing processes all the way through to rigorous testing procedures performed using its own anechoic chamber as well as field testing - to deliver unmatched low PIM characteristics products (better than -155 dBc) and guarantee sustained product specifications over time.

In addition, Comprod employs powerful 3D simulation design techniques to accurately assess the impact of PIP, and thus prevent arcing and possible premature component failures in antenna systems. Designed to support a maximum of 25KW peak power, its PIP-rated antennas are manufactured to the highest standards so as to eliminate any residual imperfections and avoid charge accumulation as well as high-density currents in critical areas.

We hope that this overview will serve as a useful guide and that it will assist you in the selection of antenna components in the planning and design of your wireless network. Please contact us at sales@comprodcom.com should you wish to receive additional information or discuss your specific requirements.

ABOUT THE AUTHOR

Dr. Jawad Abdulnour joined Comprod in 2013 as Director of Engineering. In his role, he is responsible for overseeing all aspects of R&D and new product development.

Mr. Abdulnour has over 20 years of experience in the wireless industry, having previously worked for leading microwave and RF solution providers such as EMS Technologies and Mitec Telecom.

Prior to joining Comprod, he was Director of Engineering and CTO at SDP Telecom, where he played a key role in driving the product strategy and growing the business.

During the course of his career, he has acquired expertise in the field of satellite technologies and participated in a major program to develop satellite transponders and RF modules for the International Space Station.

Mr. Abdulnour holds a Bachelor of Science (B.Sc.) degree from the Lebanese University in Beirut, a Master of Science (M.Sc.) degree from Quebec University in Trois Rivières as well as a Ph.D. from the National Institute of Scientific Research of Quebec.

As a Postdoctoral Fellow, Research Associate and Visiting Assistant Professor at École Polytechnique and École de Technologie Supérieure (ETS) in Montreal, he has authored over 50 scientific articles and conference papers on electromagnetic theory and related numerical methods.