Fundamentals of Passive Intermodulation and Distance-To-PIM

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April 2012
Intermodulation

Active versus Passive Intermodulation

- Intermodulation is caused when 2 or more RF carriers are mixed in an active system and form unwanted signals.
- When passive components containing non-linear elements those are the source of this interference.
- We refer it in this case as Passive InterModulation (PIM).
Intermodulation

Non-Linear “Diode Effect” at ferromagnetic metals

A low signal operating in a linear region and a large signal operating in the non-linear region of a ferromagnetic metal is creating additional spectral components in the output signal.
### Intermodulation

#### Intermodulation mathematics

<table>
<thead>
<tr>
<th>Order</th>
<th>Frequencies</th>
<th>Tone 1</th>
<th>Tone 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Order</td>
<td>$f_1$</td>
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</tr>
<tr>
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### Intermodulation

#### Intermodulation Orders

| Order: | 15 | 13 | 11 | 9  | 7  | 5  | 3  | 1  | 1  | 3  | 5  | 7  | 9  | 11 | 13 | 15 |
|--------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| f1:    | 8  | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
| f2:    | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
**Intermodulation**

PIM is a result of signal mixing at nonlinearities

- IM3 PIM non-linearity increases, in theory, at a ratio of 3:1 (PIM to signal)
- A 1 dB increase in carrier power correlates to a theoretical increase of 3 dB in PIM signal power.
- In practice, the actual effect is closer to 2.3-2.5 dB as the thermal noise constant -174 dBm/Hz becomes an error contributor.
Intermodulation

PIM are clogging up complete RF bands

- **PIM multiplies bandwidth**
  - If bandwidth of \( f_1 \) and \( f_2 \) is 1 MHz then
  - \( BW_{IM3} = 3 \text{ MHz} \)
  - \( BW_{IM5} = 5 \text{ MHz} \)
  - \( BW_{IM7} = 7 \text{ MHz} \)
PIM impacts UL-bands of other services

A real scenario result and it’s spectrum

<table>
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<tr>
<th>System</th>
<th>Intermodulation Products</th>
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<tr>
<td>GSM 900</td>
<td>3rd order in GSM 900 → 2 × GSM 900 TX - 1 × GSM 900 TX</td>
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<tr>
<td>PCN</td>
<td>3rd order in PCN → 2 × PCN TX - 1 × PCN TX</td>
</tr>
<tr>
<td>UMTS</td>
<td>7th order in GSM 900 → 4 × UMTS TX - 3 × UMTS TX</td>
</tr>
<tr>
<td>Tri-band System</td>
<td>2nd order in GSM 900 → 1 × PCN TX - 1 × GSM 900 TX</td>
</tr>
<tr>
<td>GSM 900, PCN, UMTS</td>
<td>4th order in UMTS → 3 × GSM 900 TX - 1 × GSM 900 TX</td>
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PIM impacts UL-bands of other services

A real example – TELSTRA Next G™ UMTS 850

Example

- $f_1 = 887$ MHz, 5 MHz UMTS TX
- $f_2 = 935$ MHz, 200 kHz GSM TX
- $f_{IM3} = 839$ MHz, CDMA RX
PIM Summary

Summary of the phenomenon

PIM is of particular concern when

- PIM products fall in the RX band
- Two or more transmitter channels share a common antenna
- TX signal levels are high
- RX sensitivity is high
- TX and RX are diplexed
PIM Summary

Summary of the phenomenon

PIM is measured

- acc. to IEC 62037 Ed. 1 1999 - RF connectors, connector cable assemblies, and cables intermodulation level measurement
- Standard specifies the use of two 20 watt carriers (2 x +43 dBm)
- Typical IM3 value is $\geq -165$ dBc
Passive Intermodulation

PIM Causes

Non-Linearities take two different forms

- Contact Non-Linearity
- Material Non-Linearity
Passive Intermodulation

PIM Causes - Contact Non-Linearities

Causes of contact Non-Linearities

- Junction capacitance due to thin oxide layer between conductors
- Impurities on metal surface
- Semiconductor tunnel / schottky effect at point of contact
- Contact resistance caused by two dissimilar metals
Causes of material Non-Linearities

- Hysteresis effect in ferromagnetic materials (nickel, iron, steel)
- Thermal Heating due to poor conduction rate (torque, corrosion, cracks)
Passive Intermodulation

Root Causes of PIM in a real RF environment

- Loose and/or inconsistent metal to metal contacts
  - Not enough contact pressure.
  - Cracked solder joints
  - Cold solder joints
  - Scratches or dents at mating interfaces
  - Burrs
  - Metal flakes, chips, dust
  - Improperly formed or sized parts
  - Misaligned parts
  - Rough mating surfaces (saw cut)
  - Loose metal to metal contacts
  - Loose or rusty bolts
- Ferromagnetic materials (steel, nickel, etc.)
- Contamination
  - Trapped between mating surfaces
  - Trapped between plating layers
  - Solder splatters
  - Dirt or debris
- Surface Oxides
- Insufficient thickness of plated metal causing RF heating
- Too much or too little torque at connections
Passive Intermodulation

Field Examples

- Ferromagnetic materials
- Cracked solder joints
- Antenna showing oxidation within the power divider
Passive Intermodulation
Field Examples

Poor cable preparation

Dirt / trash
Passive Intermodulation

Field Examples

LDF4-50A RF-Repeater feeder cable
- -10 dB Return Loss after installation
- no Repeater operation possible due to high noise level in Donor-Site RX band
- -35 dB Return Loss after connector swap
A common PIM field failure in hardware is not PIM at all, it is arcing.

Arching produces a wide-band noise signal that covers a much broader band than intermodulation.

Arcing, because it is wide-band, raises the whole receive noise floor.
PIM sources within the RF interconnection
Co-Siting GSM 900 / GSM 1800 / UMTS
PIM sources within the RF interconnection

Co-Siting 3 Op GSM 900 / GSM 1800 and 4 Op UMTS

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Passive Intermodulation

Does it matter at what frequency I test at?

- PIM is not frequency selective
- If the antenna system can pass
  - PIM test equipment frequencies and intermodulation frequencies
  - Then test at those frequencies

- If there are frequency limiting
  - antennas
  - TMAs
  - lightning arrestors
  - combiners/duplexers
  - Then pick frequencies in pass band
Passive Intermodulation

PIM Levels - Figures for practice

The PIM level at which repairs must be made depends on a number of factors:

- PIM level near to -110 dBm
  - RX will begin to compete with Cell Phones
- assuming TX carriers at +43 dBm, the threshold becomes
  - -110 dBm or -153 dBC
- due to RX Diversity PIM problems on a single RX branch can be tolerated
  - for ~ 10 - 15 dB above the -153 dBC
  - -143 to -138 dBC
  Beyond this point the BTS begins to lose receive diversity and call quality suffers
Passive Intermodulation

PIM performance of DIN 7/16 connectors

The PIM level of a connector depends on material, power and torque

► DIN 7/16 coax cable connectors
  ► typically PIM values of -140 to -168 dBc
  ► recommended torque (IEC) 35 Nm, in practice often 25 - 30 Nm

► Example: PIM difference between hand-tightened and torque specified
  ► 900 MHz band signals with 25 MHz tone separation and each 10 W carrier power
  ► hand-tightened connector → IM3 = -115.3 dB
  ► 25 Nm torque-tightened connector → IM3 = -173.1 dB
Passive Intermodulation

PIM of a connector cable assembly

- Coaxial cables together with connectors are the major source of PIM in communications systems
  - Comparison of 2 commercial PCS 1900 BTS feeder cables with 7/16” connectors
  - IM3 PIM was measured with 2 CW tones each with +40 dBm power
  - It was said that connectors are $P_{IM3} < -120$ dBm
Passive Intermodulation

Conventional way to measure PIM
Indicators of PIM in a Cellular Network

- Intermodulation products generated by TX signals can interfere in the RX band,
- The common result is that these IM's can “over-power” receive channels.
  - Calls are dropped or
  - Channels are believed to be occupied and being used by the BTS
  - Loss of Air Time and thus ARPU
  - Cell Coverage shrinks
  - Data Transmission rate drops
  - RX control loop shows no problem
  - Antenna sweep detects no issue
  - RX Noise Level is high
PIM Measurements

Can you detect PIM with a Sweeper?

- No, because
  - a single signal does not create mixing,
  - RF TX level too low,
  - Dynamic Range is too low

- You need a tool to identify PIM
  - with respect to level
  - Noise Floor
  - source
  - and location

- A tool to verify the quality of installation and discrete component performance
Anritsu PIM Master™ on Box
The Fastest Way to Pinpoint the Source of PIM

Available PIM Master models

<table>
<thead>
<tr>
<th>Model</th>
<th>RF Band</th>
<th>RF range for $f_1$ and $f_2$</th>
<th>Power Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW8219A</td>
<td>PCS</td>
<td>1930 - 1990 MHz</td>
<td>20, 30, 40 W</td>
</tr>
<tr>
<td></td>
<td>AWS</td>
<td>2110 - 2155 MHz</td>
<td></td>
</tr>
<tr>
<td>MW8209A</td>
<td>E-GSM</td>
<td>925 - 960 MHz</td>
<td></td>
</tr>
<tr>
<td>MW8208A</td>
<td>US Cellular</td>
<td>869 - 894 MHz</td>
<td></td>
</tr>
</tbody>
</table>

Handheld models supporting PIM Master

- Site Master™
  S332E, S362E
- Spectrum Master™
  MS271xE, MS2721B, MS272xC
- Cell Master™
  MT8212E, MT8213E
- BTS Master™
  MT8221B, MT8222B
Passive Intermodulation Measurements

Measure PIM level and location

Run PIM Test
Is there a problem?  Yes!

Run DTP Test
Troubleshoot largest PIM source
Amplitude Scale 75-100 dB

DUT 26 m cable with PIM Sources @ 3.1 m, 10.7 m, 25.9 m
Passive Intermodulation Measurements

Finding of hidden and unknown PIM sources

- Using Distance-to-Fault to Verify Antenna Location
- Using Marker and Delta Marker to Identify Distance-to-PIM beyond the Antenna
Passive Intermodulation Measurements

Prior way to measure PIM levels (example)
Passive Intermodulation Measurements

Examplified principle on how to measure DTP
Passive Intermodulation Measurements

Summary Statement

- PIM = reduces site performance

- PIM sources can be eliminated / minimized through:
  - Careful construction techniques
  - Use of low PIM components
  - Careful site design

- PIM testing should be dynamic (not static)

- PIM testing AND VSWR testing are needed to verify system performance.