
# * Passive Intermodulation (PIM) in the RF Path
# * Remote Electrical Downtilt (RET)

PSCR – Boulder, CO
2 December 2010

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# Agenda

- Introduction to Passive Intermodulation (PIM)
- Why is it especially a concern for LTE systems
- Typical Component Specifications
- Overview of PIM Causes
- Test Equipment Considerations
- Antenna Measurements
  - Outdoor testing
- Cable and Connector Measurements
  - Cable preparation and connector fit
  - Proper Connector Torque
- Entire RF Path Measurement Considerations
- Merits of Remote Electrical Downtilt (RET)

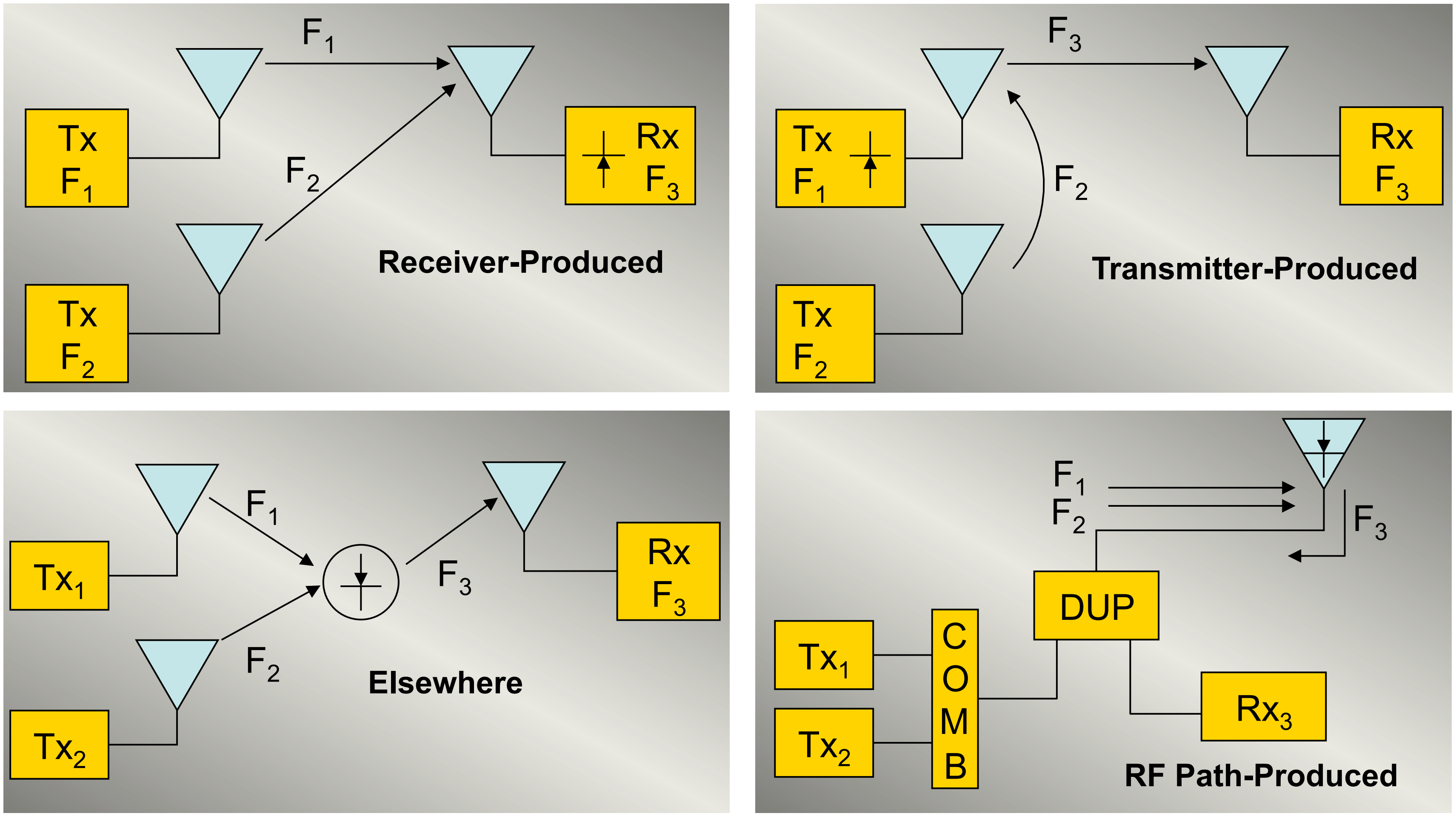
# Definition: Passive InterModulation Distortion (PIM)

- PIM is the mathematical mixing of two or more desired signals creating a family of undesired signals, sometimes interfering with the Base Receiver
    - Third order PIM gives the highest level of interference, followed by 5$^{th}$ and 7$^{th}$ order.
    - 3$^{rd}$ order spreads by 3X the channel BW, so PIM generated by 10 MHz LTE signal would interfere over at least 30 MHz. 5$^{th}$ order is 5X, 7$^{th}$ order is 7x, etc.
- In the past, careful frequency assignments could be made to avoid worst case PIM interference
    - With Next Generation Network (NGN) broadband signals such as LTE, the probability of interference is greater
- The following slides will show two-carrier “swept” PIM results.

**PIM is a challenging Network issue**

# Intermodulation Interference

## Where?

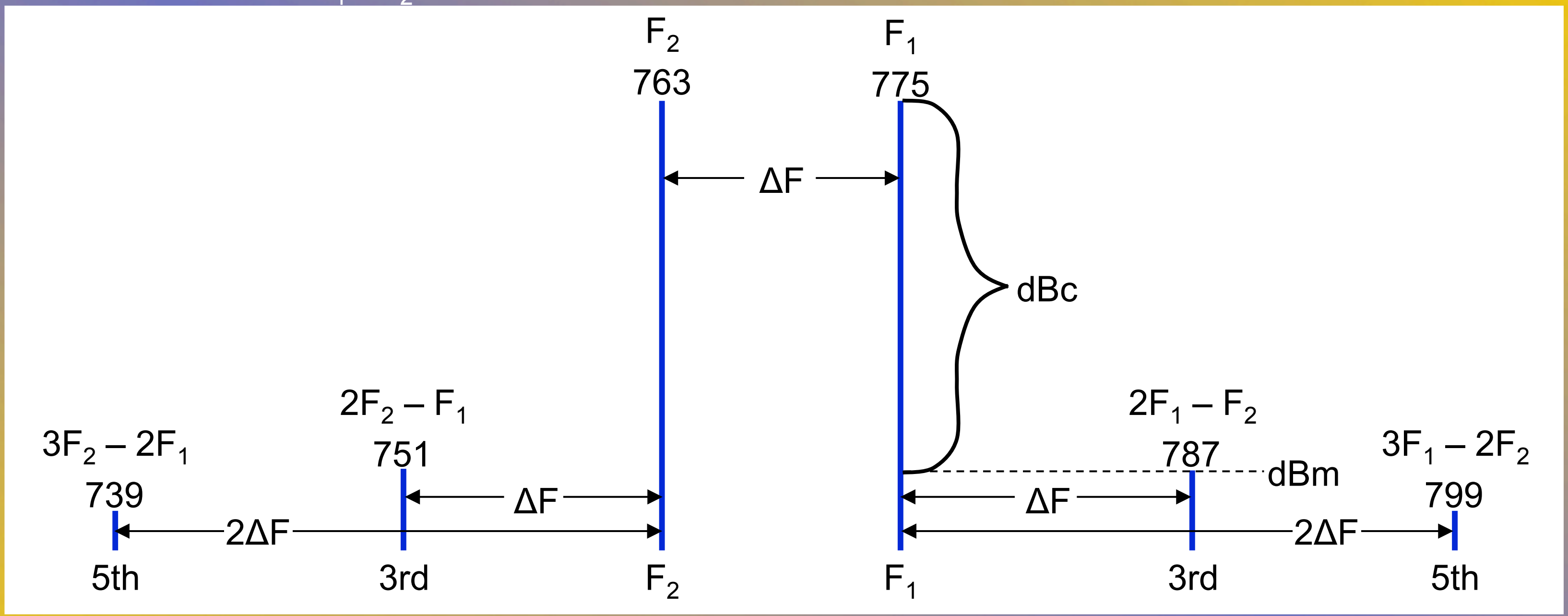


# Two-Signal PIM

## Odd-Order Difference Products

Example: $F_1$ = 775 MHz; $F_2$ = 763 MHz

$\Delta F = F_1 - F_2 = 12$




Third Order: $F_1 + \Delta F$; $F_2 - \Delta F$

Fifth Order: $F_1 + 2\Delta F$; $F_2 - 2\Delta F$

Seventh Order: $F_1 + 3\Delta F$; $F_2 - 3\Delta F$

*Higher than the highest – lower than the lowest – none in-between*

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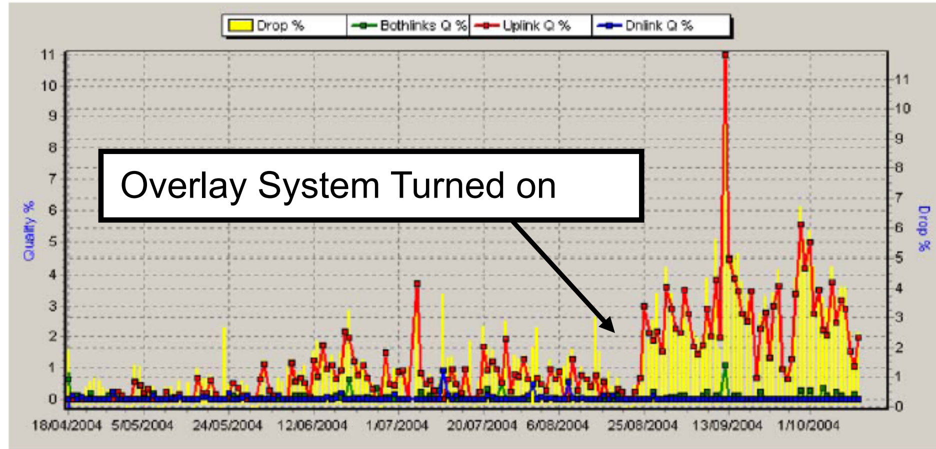
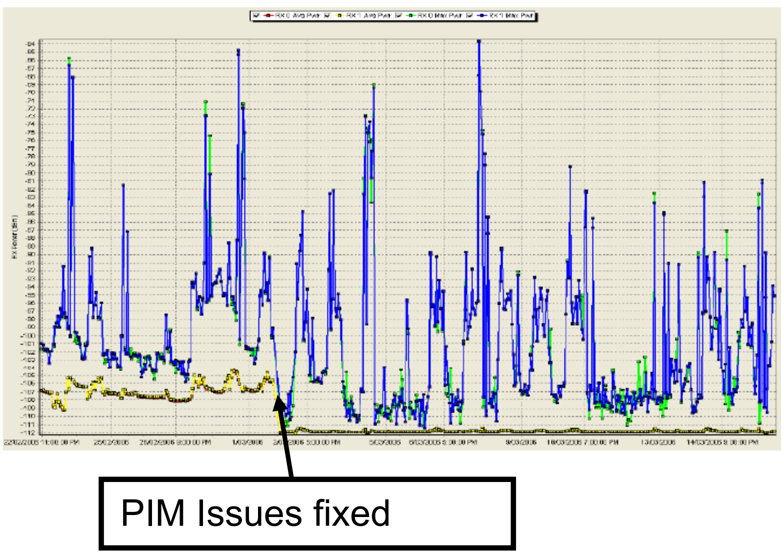
# PIM Degrades System Noise Floor and Performance

- Poor PIM performance caused increase in dropped calls when overlay system was turned on
- Significant concern when sharing RF path between two systems



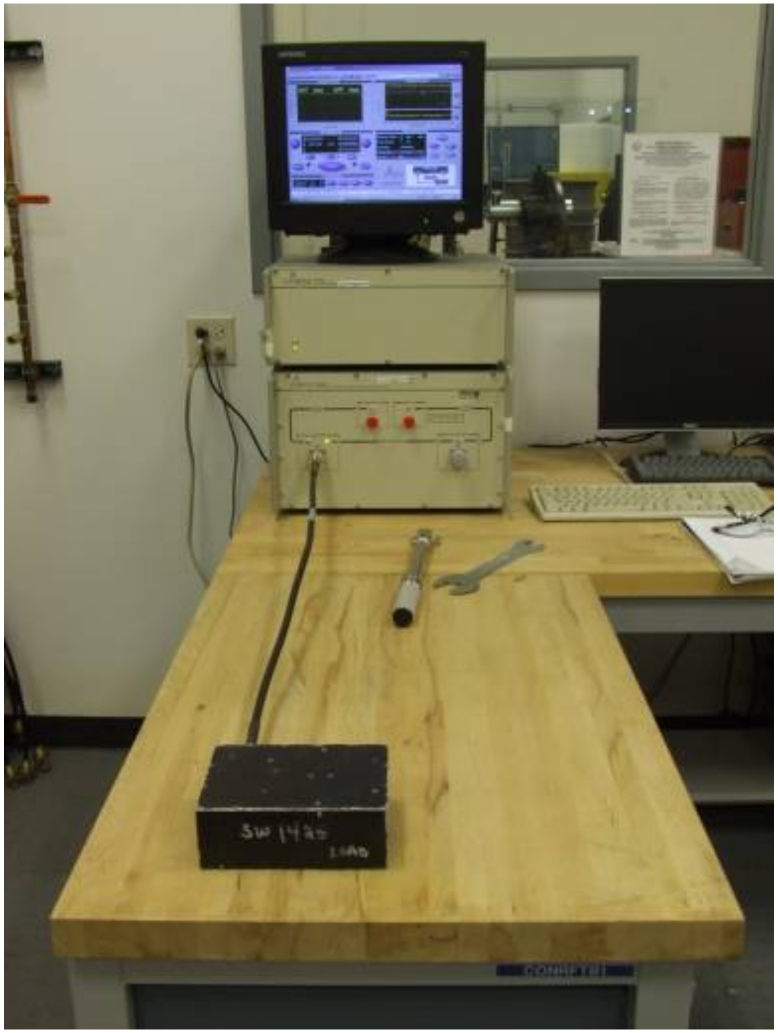

- When PIM issues were fixed, the noise floor of the system dropped to pre-overlay levels
- High quality components and installation are essential for network performance

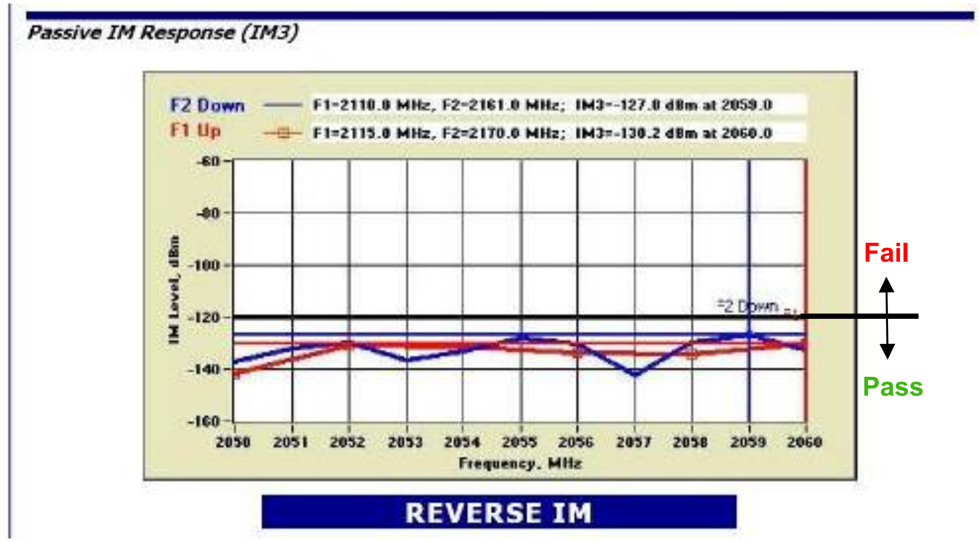
Source: Triasx white paper

# PIM Causes

- **Site**
  - Guy Wires
  - Steel Tower
  - Other Sites IMD
  - Lighting
- **Installation**
  - Poorly torqued connectors
  - Scratches
  - Contamination on conducting surfaces
  - Contamination left in dielectric material
- **Components**
  - Poor quality of components
  - Poor component durability
- **Materials**
  - Hysteresis
  - Rust
  - Ferromagnetic materials
  - Semi-Conductive Films
  - Poor Quality Plating
- **Test Equipment**
  - Poor Quality Loads
  - Low Quality or Damaged Jumpers, Adapters, and Connectors
  - Handling and usage causing deterioration
- **Other**
  - Microphonics
  - Welders
  - Contact Pressure

# Verify Test Equipment Performance






- Must first validate the test equipment
- Use of low IM of jumper cable, load and adapters is important
- Minimize number of adapters
- Connector faces must be undamaged
- Connectors must be tight
- There should be no mechanical strain on the connectors
- True verification of low IM requires swept frequency equipment
- **RF Power is Normally 20 watts (+43 dBm) per Carrier**

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# PIM measurements – some observations

- On-Site Antenna Measurements with iQA2000 Portable PIM
  - Clear sky RF field of view required to avoid excitation of secondary PIM sources which could cause false PIM failures. Retest in other positions to confirm failure.
  - Ex.: HBX-6516-R2M, **Typical Antenna 3rd Order PIM Spec-150 dBc = -107 dBm**

**Clear Sky**
**-123 dBm (-166 dBc)**

**Person nearby with phone, keys, adapters, badge**
**-94 dBm (-137 dBc)**

**Point At Fence**
**-102 dBm (-145 dBc)**

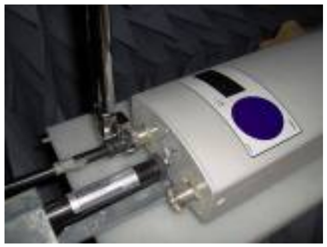
**Towards Forklift**
**-84 dBm (-127 dBc)**

**Near Shelter**
**-102 dBm (-145 dBc)**

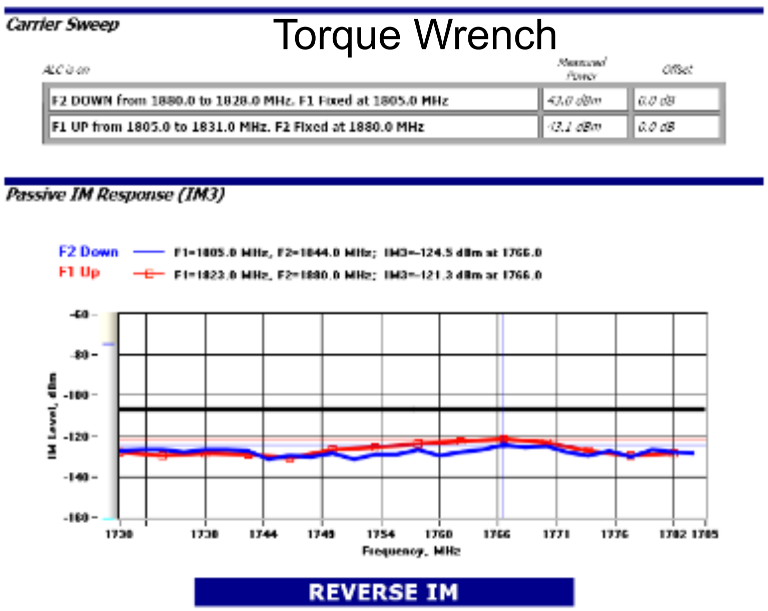
**Near Cabinet and Test Equipment**
**-96 dBm (-139 dBc)**

# PIM Measurement with Properly Torqued Connections

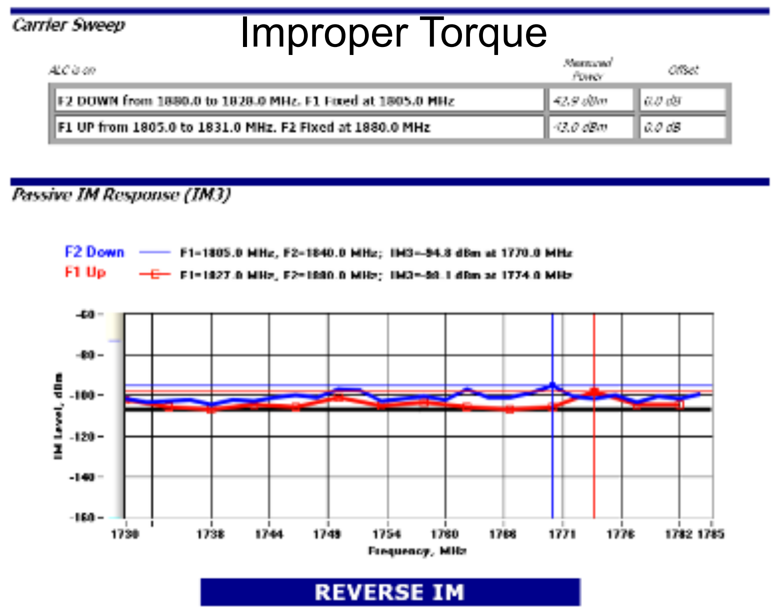
- Hand-tightening of connectors can provide unstable and non-repeatable measurements.  Use torque wrench with connector manufacturer recommended settings.



Note: Use 2 wrenches where necessary



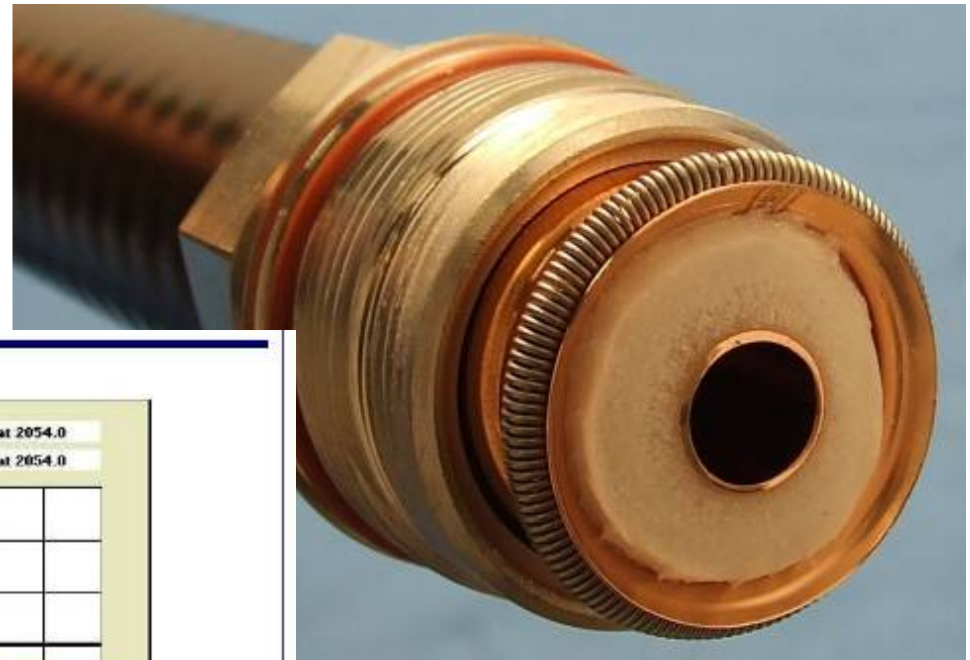

Torque Wrench

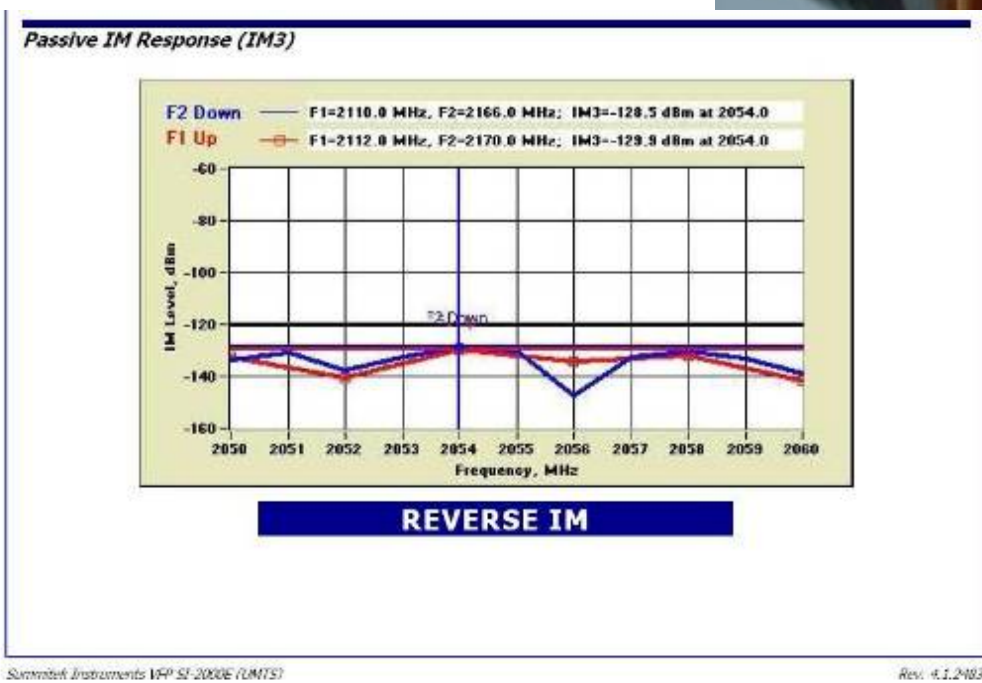



Improper Torque

# Correct cable preparation is critical

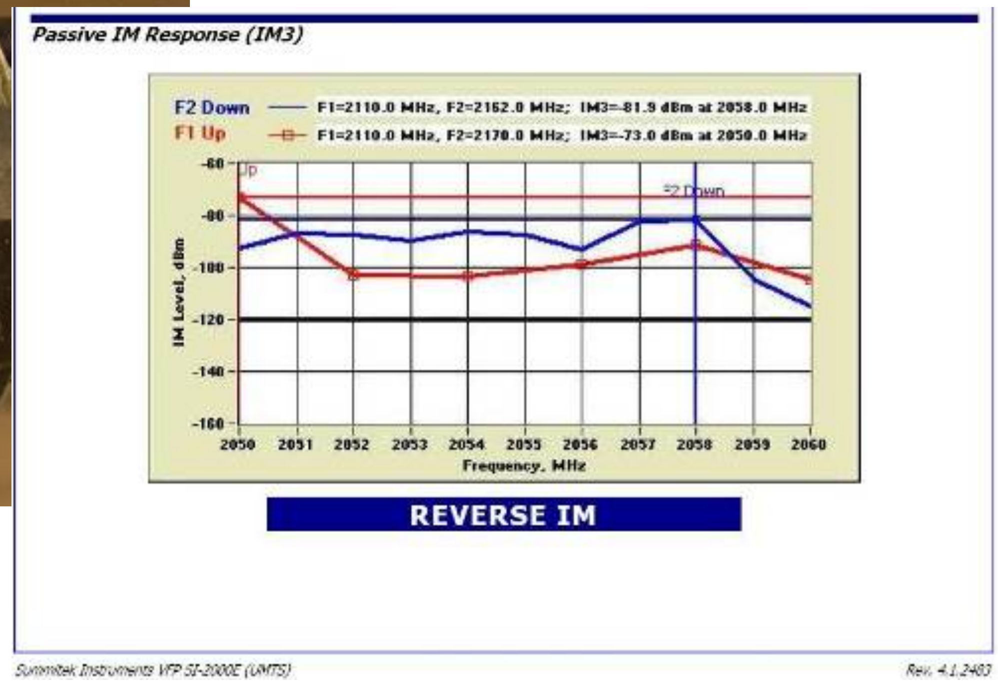
- A  clean, square, properly de-burred and debris-free cable preparation is needed for low IM performance
- Always use the correct cable preparation tools






**Typical Cable/Connector**
**3rd Order PIM Spec -163 dBc = -120 dBm**

# Make sure the initial cable cut is straight


- An angled cut will give uneven contact and high or erratic IM
- A hacksaw cut must be done with care
- Prep tools guarantee a straight cut

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# PIM for complete system

- PIM levels for individual components combine to give a system PIM level.
- Combination is similar to the case of system VSWR, except that feeder and jumper losses provide more "padding" for far end components because of the non-linear nature of PIM generation (typically 2.5 dB variation per 1 dB of carrier variation for 3rd order).
- For example, a 2dB feeder loss will improve the apparent antenna return loss as seen on the ground by ~4 dB, but will improve the apparent PIM by about 7 dB.
- PIM contributions from the various components will usually combine in random phase for a typical system level, which can be calculated.
- But there can be favorable or unfavorable phase combinations to give variations up to a worst case value.

# System PIM Calculator

## System 3rd Order PIM Calculator

| | |
|---|---|
| Frequency (MHz): | 850.00 |
| PIM Power (w each Carrier) | 20 |

Version 1.7 03/10/09

*Industry Standard is 2x20w*

Test Equipment (TE) Noise Floor (dBm) = -130

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| Component Used? | System Component | Component PIM Spec (dBc, 2x20w) | Cable Type / Component Loss (dB) | Cable Length (m) | Cable Length (ft) | Ins Loss w/2 Conn (dB) | Attn to bottom (dB) | Power to Componen t (dBm) | Effective* PIM Value (dBm) | PIM Value @ bottom dBm | % of Est. System | Power at input (pW) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Antenna or Load** | -150.00 | | | | | 2.7529 | 40.25 | -113.88 | -116.64 | 10.3% | 0.0434 |
| Yes | **Jumper** | -159.00 | FSJ4-50B | 1.83 | 6.00 | 0.25 | 2.5003 | 40.50 | -122.25 | -124.75 | 1.6% | 0.0067 |
| Yes | Tower Mounted Amp | -155.00 | 0.20 | | | 0.20 | 2.3003 | 40.70 | -117.75 | -120.05 | 4.7% | 0.0198 |
| Yes | Jumper | -159.00 | LDF4-50A | 1.83 | 6.00 | 0.18 | 2.1228 | 40.88 | -121.31 | -123.43 | 2.2% | 0.0091 |
| Yes | Top Diplexer or Bias Tee | -160.00 | 0.20 | | | 0.20 | 1.9228 | 41.08 | -121.81 | -123.73 | 2.0% | 0.0085 |
| Yes | Jumper | -159.00 | LDF4-50A | 1.83 | 6.00 | 0.18 | 1.7454 | 41.25 | -120.36 | -122.11 | 2.9% | 0.0123 |
| Yes | **Main Feed Line** | -159.00 | LDF7-50A | 31.00 | 101.71 | 0.74 | 1.0042 | 42.00 | -118.51 | -119.51 | 5.3% | 0.0224 |
| Yes | **Jumper** | -159.00 | LDF4-50A | 1.83 | 6.00 | 0.18 | 0.8268 | 42.17 | -118.07 | -118.89 | 6.1% | 0.0258 |
| Yes | Bias Tee | -159.00 | 0.10 | | | 0.10 | 0.7268 | 42.27 | -117.82 | -118.54 | 6.7% | 0.0280 |
| Yes | Jumper | -159.00 | LDF4-50A | 1.83 | 6.00 | 0.17 | 0.5548 | 42.45 | -117.39 | -117.94 | 7.6% | 0.0321 |
| Yes | **Surge Suppressor** | -155.00 | 0.10 | | | 0.10 | 0.4548 | 42.55 | -113.14 | -113.59 | 20.8% | 0.0875 |
| Yes | Jumper | -159.00 | LDF4-50A | 1.83 | 6.00 | 0.18 | 0.2774 | 42.72 | -116.69 | -116.97 | 9.6% | 0.0402 |
| Yes | Bottom Diplexer or Duplexer | -160.00 | 0.10 | | | 0.10 | 0.1774 | 42.82 | -117.44 | -117.62 | 8.2% | 0.0346 |
| Yes | **Jumper** | -159.00 | LDF4-50A | 1.83 | 6.00 | 0.18 | 0.0000 | 43.00 | -116.00 | -116.00 | 11.9% | 0.0502 |
| | | | | | | | | | | | 100.0% | |

* Effective PIM3 at the component is reduced by ~2.5 dB for every dB below 20w. (Theory predicts x3 but practice measures x2.2 to x2.8 range)

Value <10 dB above TE noise floor

| Legacy Jumper / TL Cables | Andrew | CommScope |
|---|---|---|
| 1/2 inch Superflexible Copper | FSJ4-50B | |
| 1/2 inch Foam Copper | LDF4-50A | CR 540 |
| 1/2 inch Superflexible Aluminum | | SFX 500 |
| 1/2 inch Foam Aluminum | | FLX 540 |

| Legacy Transmission Lines | Andrew | CommScope |
|---|---|---|
| 7/8 inch Copper | LDF5-50A | CR 1070 |
| 1 1/4 inch Copper | LDF6-50 | CR 1480 |
| 1 5/8 inch Copper | LDF7-50A | CR 1873 |
| 7/8 inch Very Flexible Copper | VXL5-50 | |
| 1 1/4 inch Very Flexible Copper | VXL6-50 | |
| 1 5/8 inch Very Flexible Copper | VXL7-50 | |
| 7/8 inch Virtual Air Copper | AVA5-50 | |
| 1 5/8 inch Virtual Air Copper | AVA7-50 | |
| 7/8 inch Aluminum | AL5-50 | FLX 780 |
| 1 1/4 inch Aluminum | | FLX 1480 |
| 1 5/8 inch Aluminum | AL7-50 | FLX 1873 |

| | |
|---|---|
| Estimated Conn Loss (2per cable) | 0.028 |
| Typical System PIM Voltage (uV): | 4.5850 |
| Typical System PIM (dBm) | -106.8 |
| Typical System PIM (dBc): | -149.8 |
| Worst Case System PIM Voltage: | 16.2067 |
| Worst Case System PIM (dBm) | -95.8 |
| Worst Case System PIM (dBc): | -138.8 |
| Total Insertion Loss (dB): | 2.75 |

Return Loss to VSWR converter

| Return Loss (dB) | VSWR |
|---|---|
| 17.00 | 1.33 |

Feet to meters converter

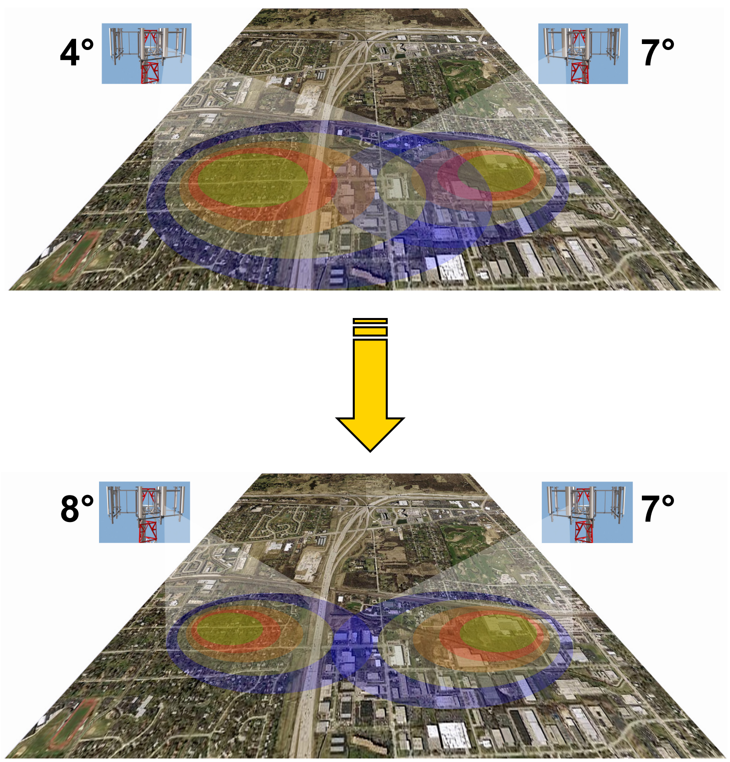
| Feet | meters |
|---|---|
| 100.00 | 30.48 |

# Summary

- Passive Intermodulation Distortion (PIM) exists at some level in all passive systems
  - When poor quality parts are used, or the installation process is not followed, this distortion can result in system performance degradation
- PIM is a very sensitive measurement, and can be degraded by objects found in the proximity of the site.
  - A good antenna will suddenly fail if objects come in the vicinity of the antenna, in the main beam
  - PIM is a good measure of the linearity of the RF path.
  - PIM test results can indicate a false failure because of interfering signals
- When testing antennas, caution must be used in selecting only in-band transmit carriers to avoid interference with Neighboring Systems.
- Use the recommended tools for cable preparation and connector installation.
- A Torque Wrench is required to correctly tighten connectors.

# Merits of Remote Electrical Downtilt (RET)

## Network Optimization




- Closes coverage holes
- Reduces interference
- Decreases dropped calls
- Increases throughput and capacity
- Is necessary when adding sites
- Adjusts network configuration to subscriber movements
- Should be done remotely and immediately
- Needs to be done often and quickly
- Is most efficient with an Antenna Network Management System

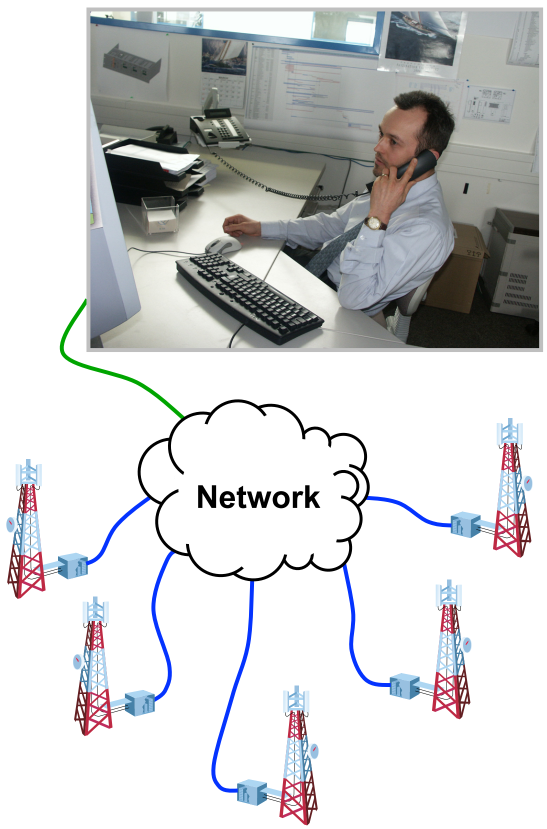
# Agile Systems Optimization

## Optimization – Did you know . . .

- 25–30% of network optimization exists with beamtilting.
- Audits show that 40% of sites are out of specification with the original site requirements on boresite and tilt angle.
- One average tower climb costs around US$4,500.
- An average rooftop climb costs around US$1,350.
- Frequent site visits to make adjustments on the site location are time consuming, weather dependent, and costly with traditional antennas.
- Manual tilting is inaccurate and results in less frequent optimizations, high costs, and delays.
- Manual optimization for a 200 site market generates around 50 tons of carbon dioxide and costs around US$10,000 in gasoline per year.

# Optimization — The New Way

**Remote Access (New Way)**




- For every antenna configuration change:
  - Nobody needs to drive to the site.
  - Nobody needs to climb the tower.
  - The antenna does not need to be moved.
- No site access issues or paperwork.
- Convenient modifications made from the office.
- Independent from bad weather.
- Full network visibility.
- Almost no running costs.
- Quick and immediate real-time execution.
- Optimization changes can be scheduled and executed several times a day.
- Teletilt is GREEN and saves tons of $CO_2$

***Thank You !***

# Backup Slides

# 700 MHz Band Example

## Product Frequencies, Two-Signal IM

$F_{IM} = nF_1 \pm mF_2$

Example: $F_1$ = 775 MHz; $F_2$ = 763 MHz

| | | | | |
|---|---|---|---|---|
| 1 | 1 | Second | $1F_1 + 1F_2$<br>$1F_1 – 1F_2$ | 1538<br>12 |
| 2 | 1 | Third | $2F_1 + 1F_2$<br>*$2F_1 – 1F_2$ | 2313<br>787 |
| 1 | 2 | Third | $2F_2 + 1F_1$<br>*$2F_2 – 1F_1$ | 2301<br>751 |
| 2 | 2 | Fourth | $2F_1 + 2F_2$<br>$2F_1 – 2F_2$ | 3076<br>24 |
| 3 | 2 | Fifth | $3F_1 + 2F_2$<br>*$3F_1 – 2F_2$ | 3851<br>799 |
| 2 | 3 | Fifth | $3F_2 + 2F_1$<br>*$3F_2 – 2F_1$ | 3839<br>739 |

*Odd-order difference products fall in-band.

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# Theoretical Effects of Interference on LTE Data Rates

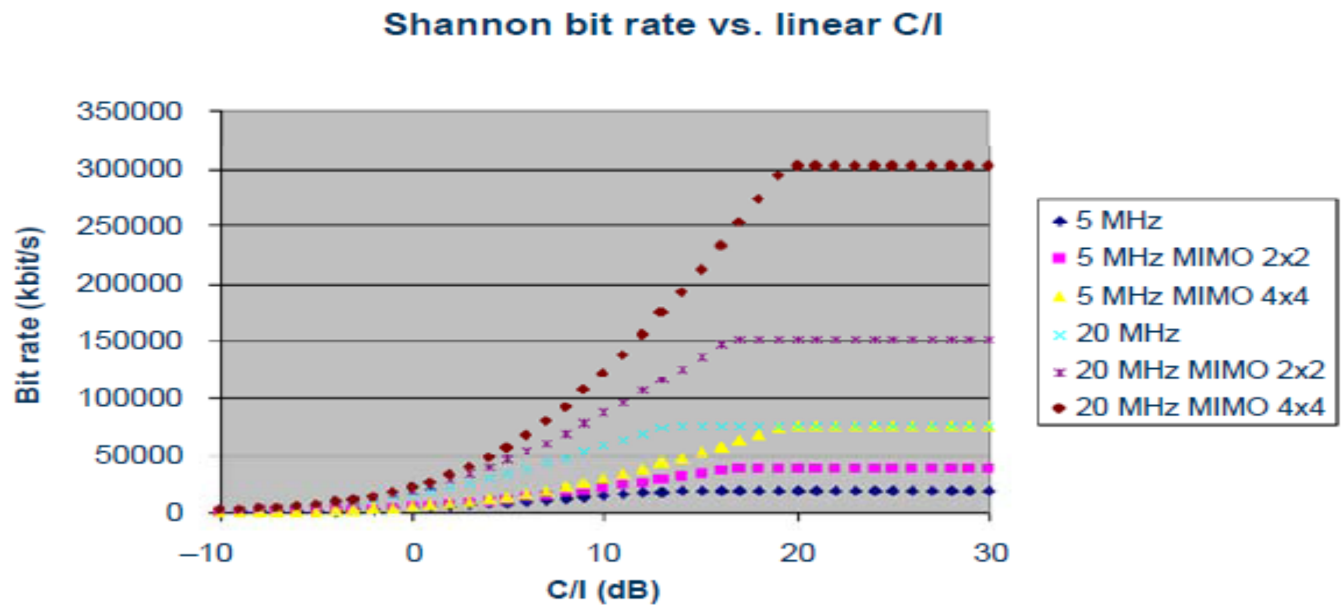
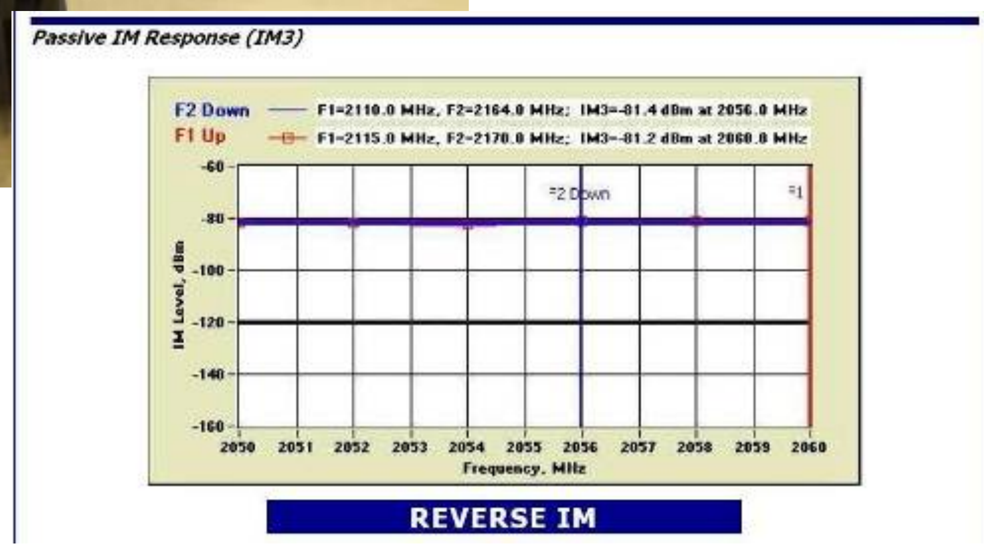



Figure 3. Theoretical maximum LTE bit rates as functions of C/I. Note that this is still based on Shannon, *not* on simulations; a fixed (25%) overhead is assumed, with no margins whatsoever and no inter-stream interference. The maximum bit rate is thus limited solely by the channel rate.

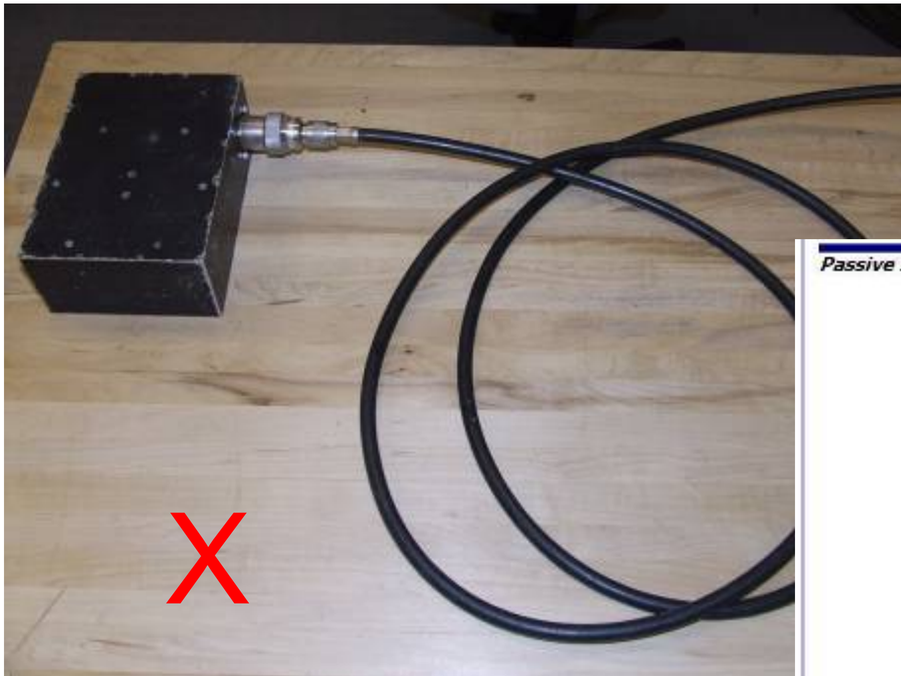
Even though the C/I-to-bit rate mappings given here are exaggerated (since no attempt is made to model the properties and effects of the radio channel, and since no exact overheads are calculated), the diagram shows the importance of bandwidth as well as the potential improvements obtainable with spatial multiplexing techniques.

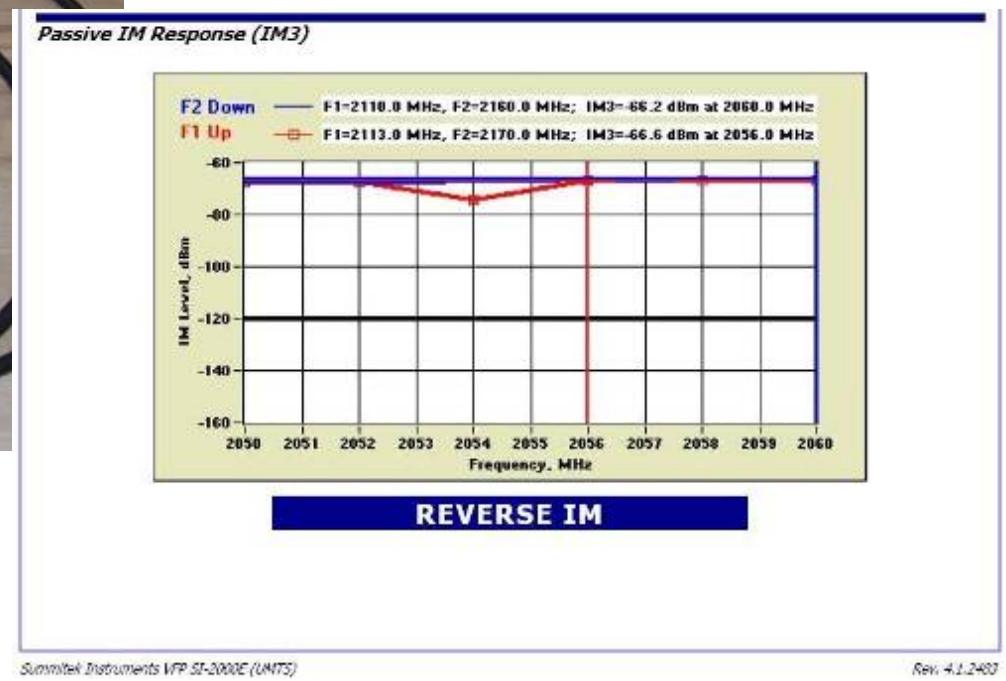
# Only use a load with low PIM


- A regular high power load has poor IM because of the absorbing element
- Use a low IM load from the supplier of the IM test equipment

# Avoid using a braided cable jumper




•Most braided cables have poor IM performance because of a loose braid weave

• Some may be good initially but can worsen with repeated flexing

•Use a jumper with a continuous outer conductor (e.g. Heliax®)

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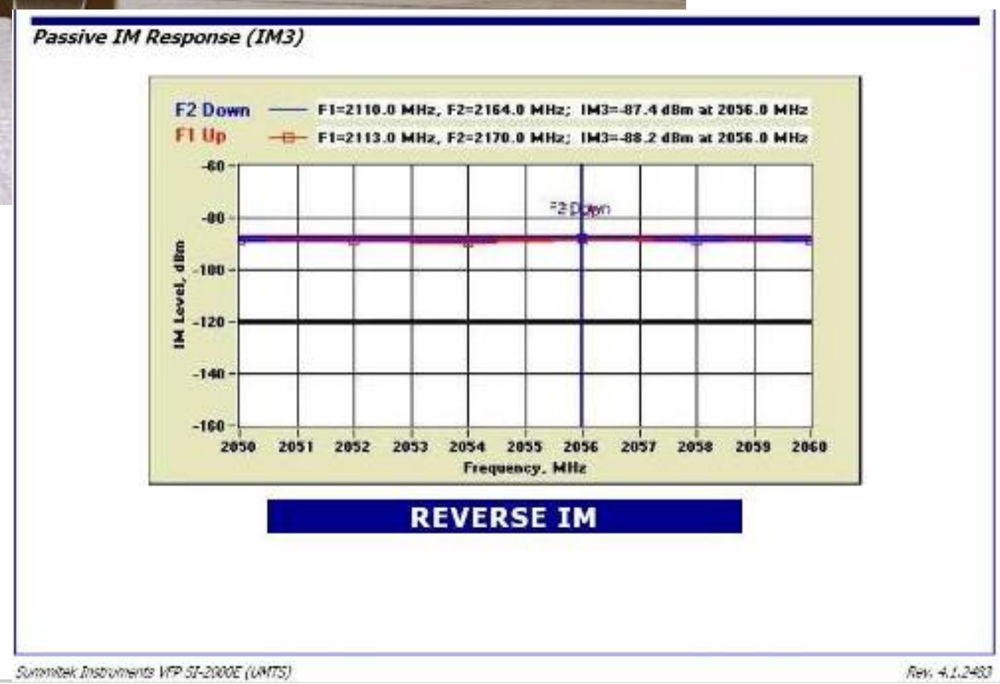
# Do not use old or worn adapters




- All connections must be clean and tight at both inner and outer conductors
- A loose contact is an IM generator, especially at the inner conductor
- Minimize the number of adapters

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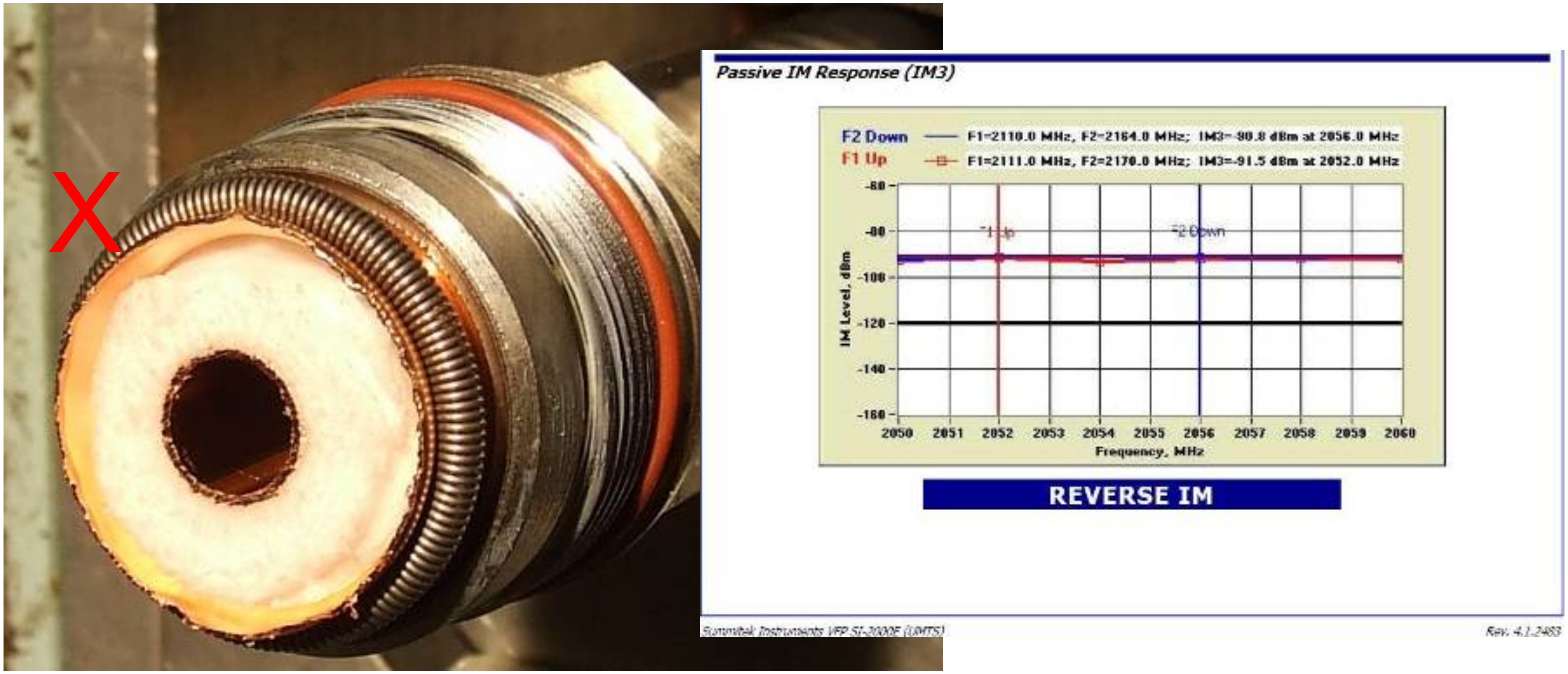
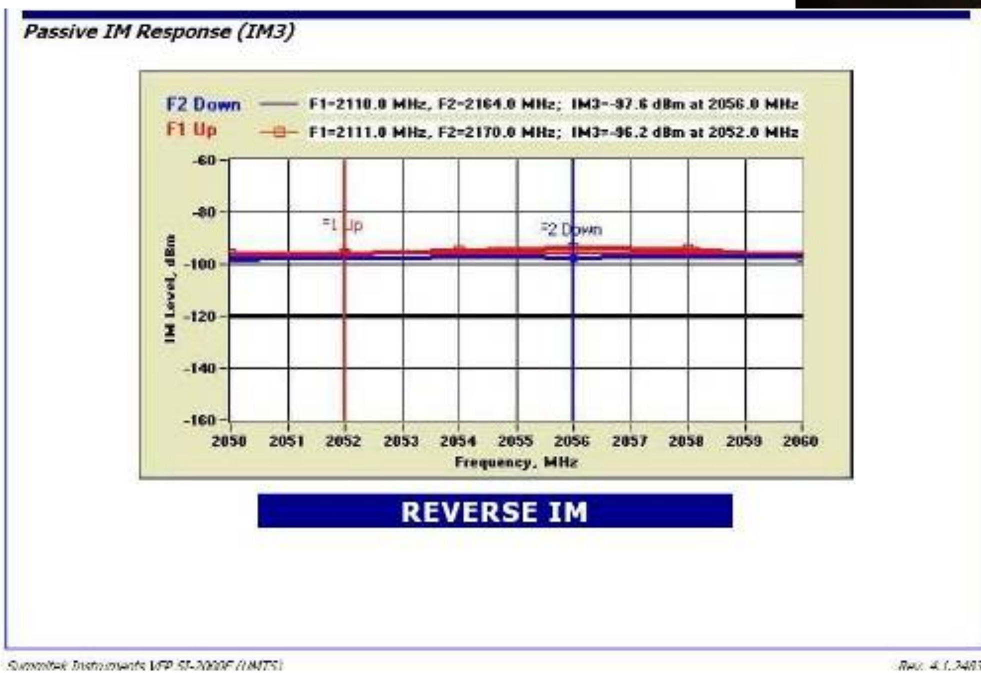
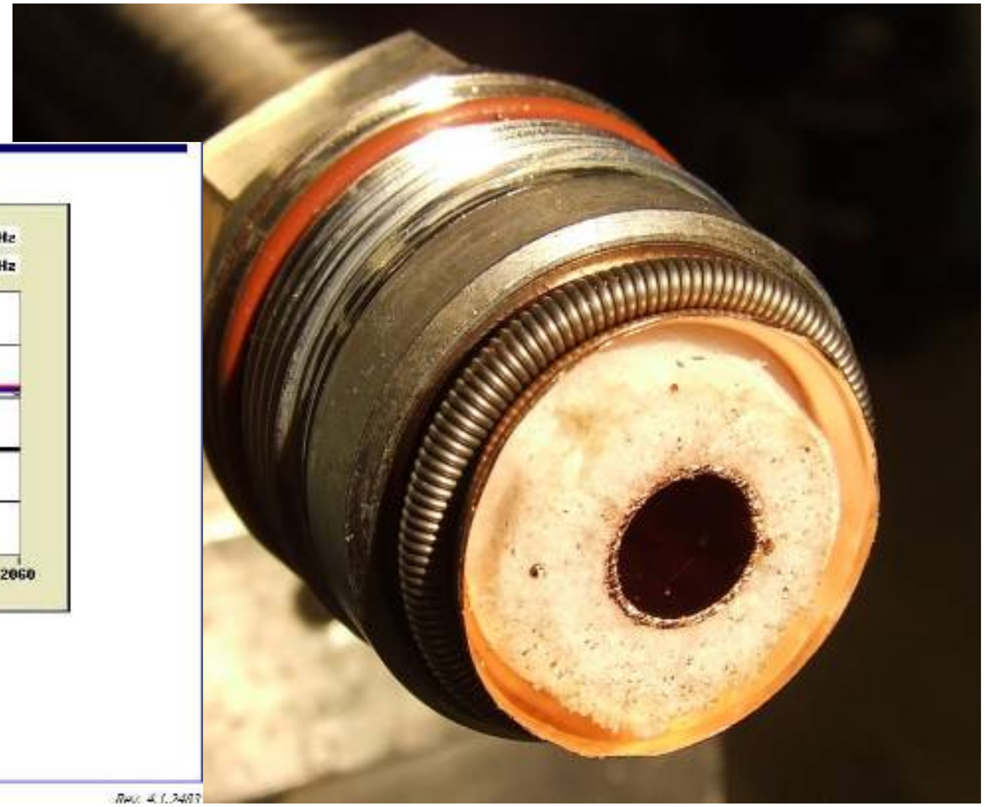
# De-burr both inner and outer conductors




- Burrs, ragged edges, folds etc. in either inner or outer cause uneven contact and poor IM
- Make sure blades in prep tools are sharp

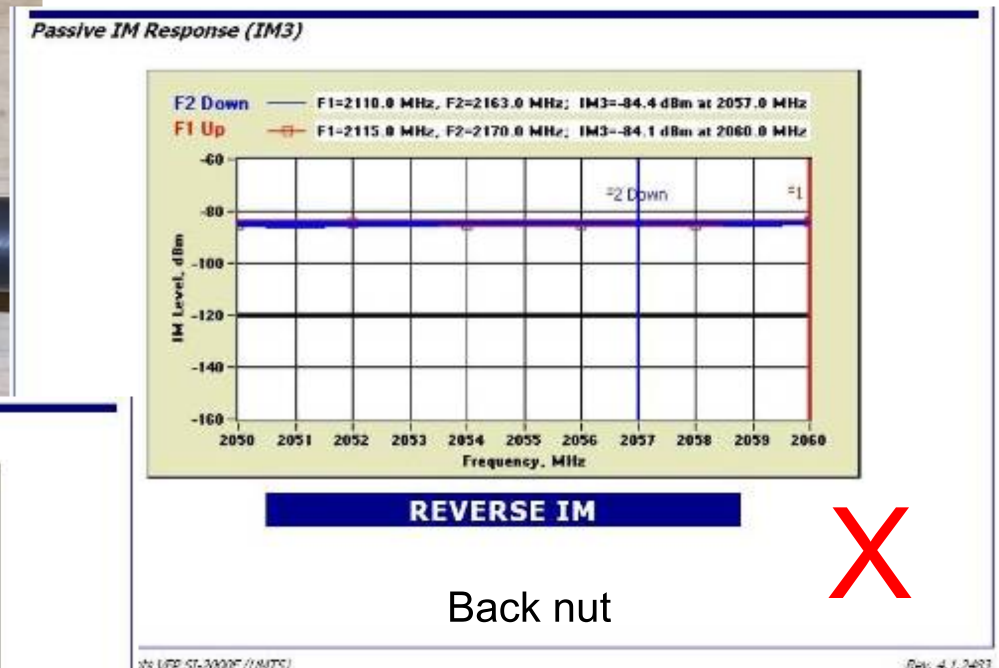
# Clean metal chips from the foam



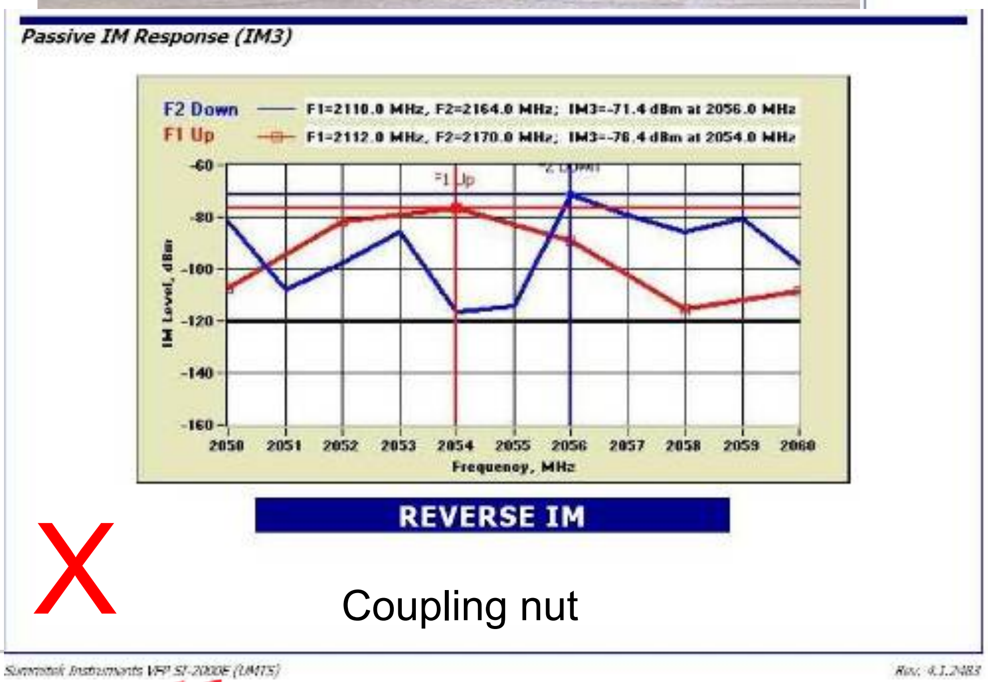



- Small metal particles can result from cable preparation and are IM generators
- Clean these thoroughly from inside and outside the prepared cable end

# Connector back nut and coupling must be tightened to the correct torque




Back nut




Coupling nut

- Test equipment traces show consequences of loose back nut and coupling nut
- Poor contact pressure is a cause of IM