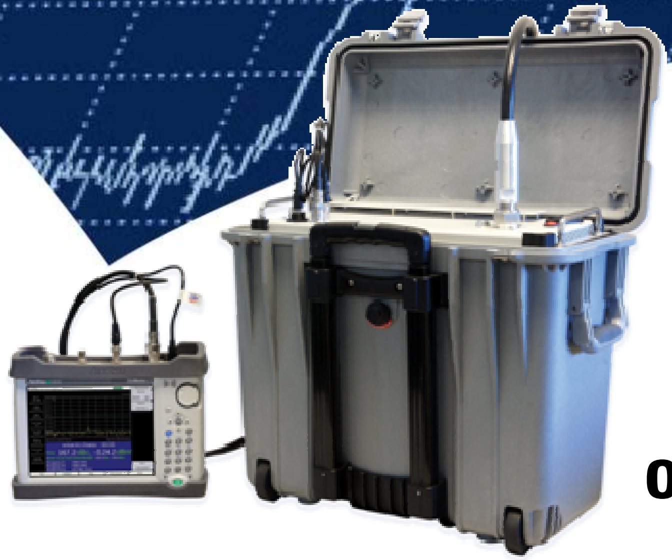
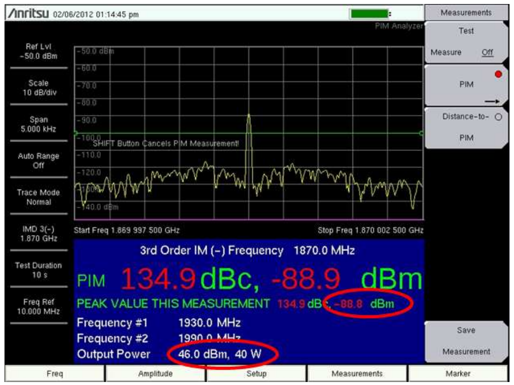


Fundamentals

of Passive Intermodulation and

Distance-To-PIM



Ferdinand Gerhardes, Anritsu

April 2012

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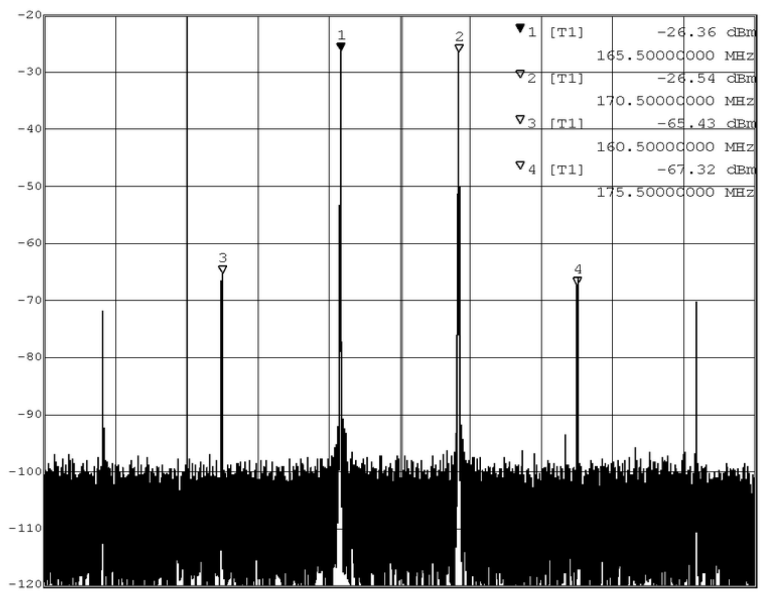
Intermodulation

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)**



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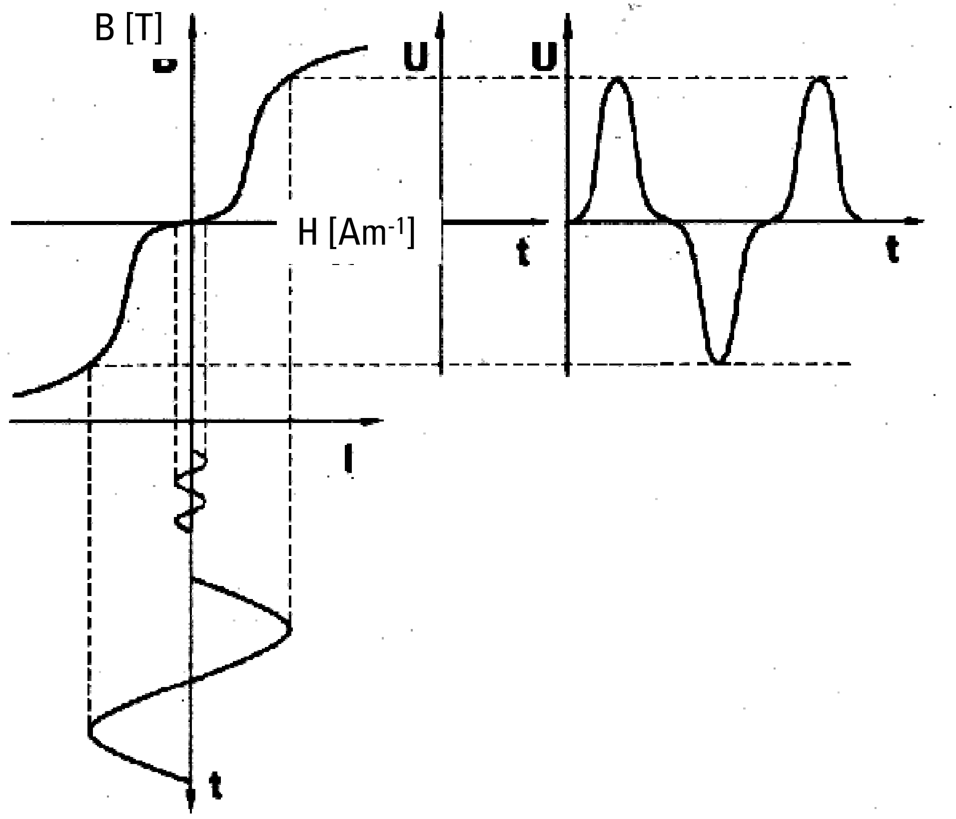
Intermodulation

Non-Linear "Diode Effect" at ferromagnetic metals

- A low signale 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

Order	Frequencies		Tone 1	Tone 2
1st Order	f_1	f_2	100 MHz	101 MHz
2nd Order	f_1+f_2	f_2+f_1	201 MHz	1 MHz
3rd Order	$2f_1-f_2$	$2f_2-f_1$	99 MHz	102 MHz
	$2f_1+f_2$	$2f_2+f_1$	301 MHz	302 MHz
4th Order	$2f_2+2f_1$	$2f_2-2f_1$	402 MHz	2 MHz
5th Order	$3f_1-2f_2$	$3f_2-2f_1$	98 MHZ	103 MHz
	$3f_1+2f_2$	$3f_2+2f_1$	502 MHz	503 MHz
7th Order	$4f_1-3f_2$	$4f_2-3f_1$	97 MHz	104 MHz
	$4f_1+3f_2$	$4f_2+3f_1$	…	…
9th Order	$5f_1-4f_2$	$5f_2-4f_1$	96 MHz	105 MHz
	$5f_1+4f_2$	$4f_2+3f_1$	…	…
e.t.c.				

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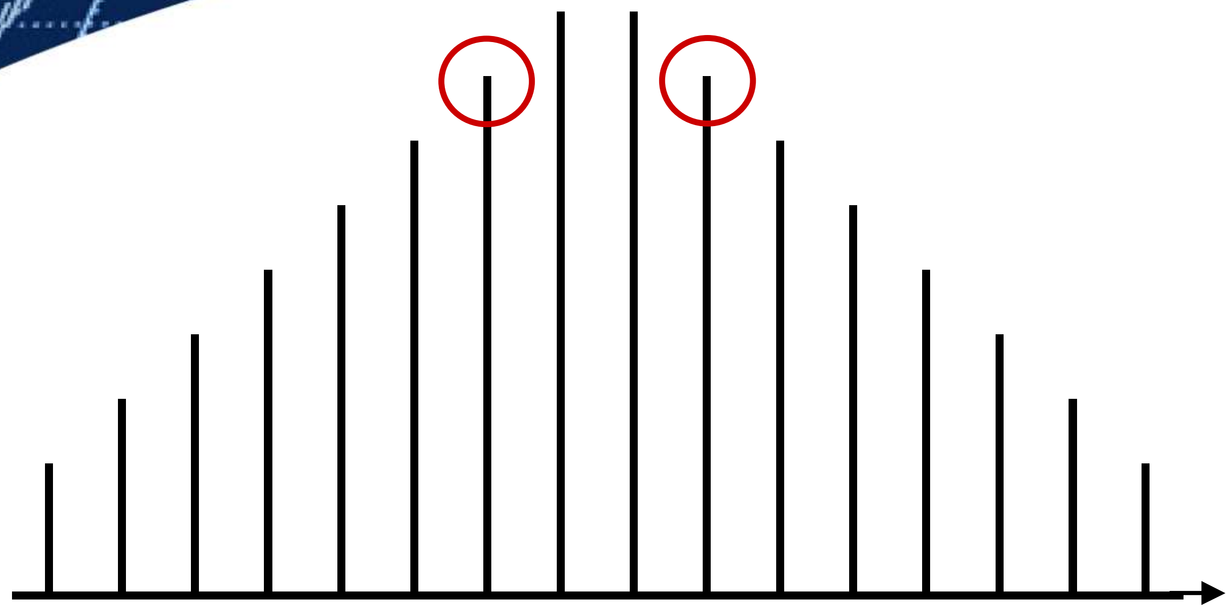
e.t.c.				

Intermodulation

Intermodulation Orders

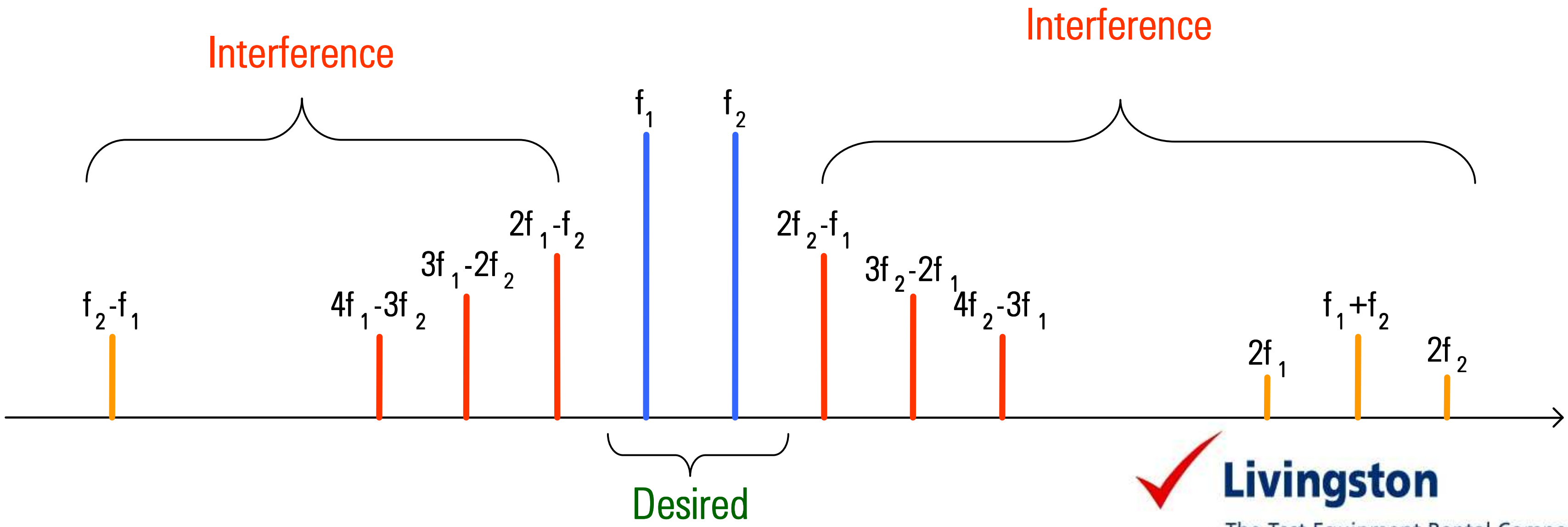


f1:	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7
f2:	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8
Order:	15	13	11	9	7	5	3	1	1	3	5	7	9	11	13	15

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.**



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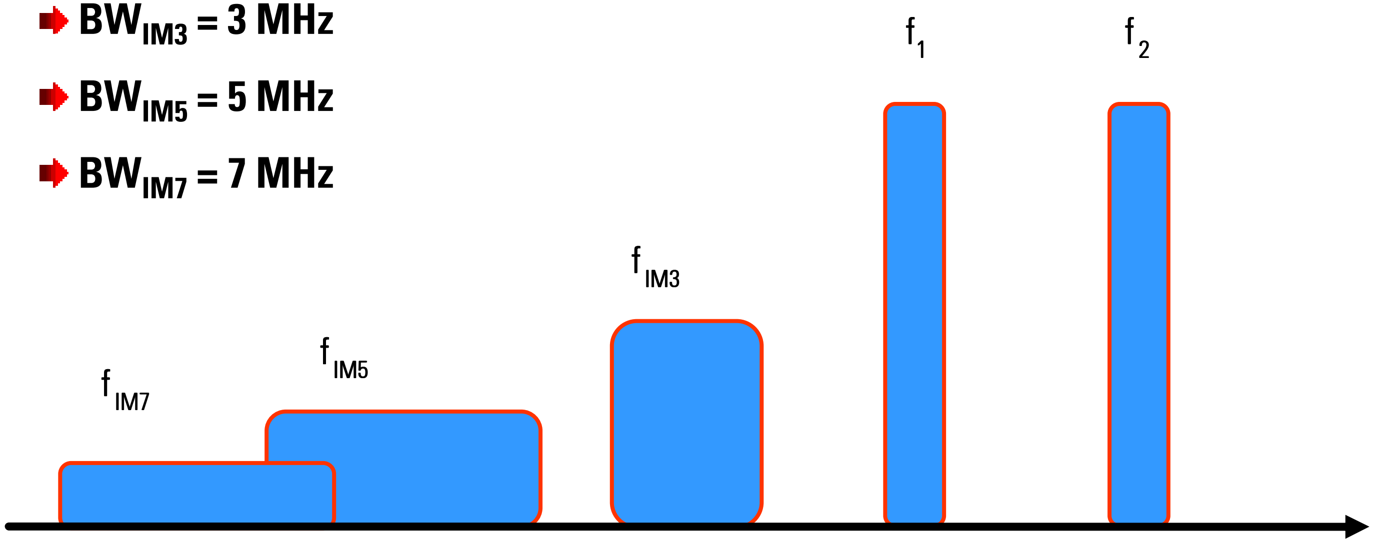
Intermodulation

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 MHz**
  - **BW_{IM5} = 5 MHz**
  - **BW_{IM7} = 7 MHz**



PIM impacts UL-bands of other services

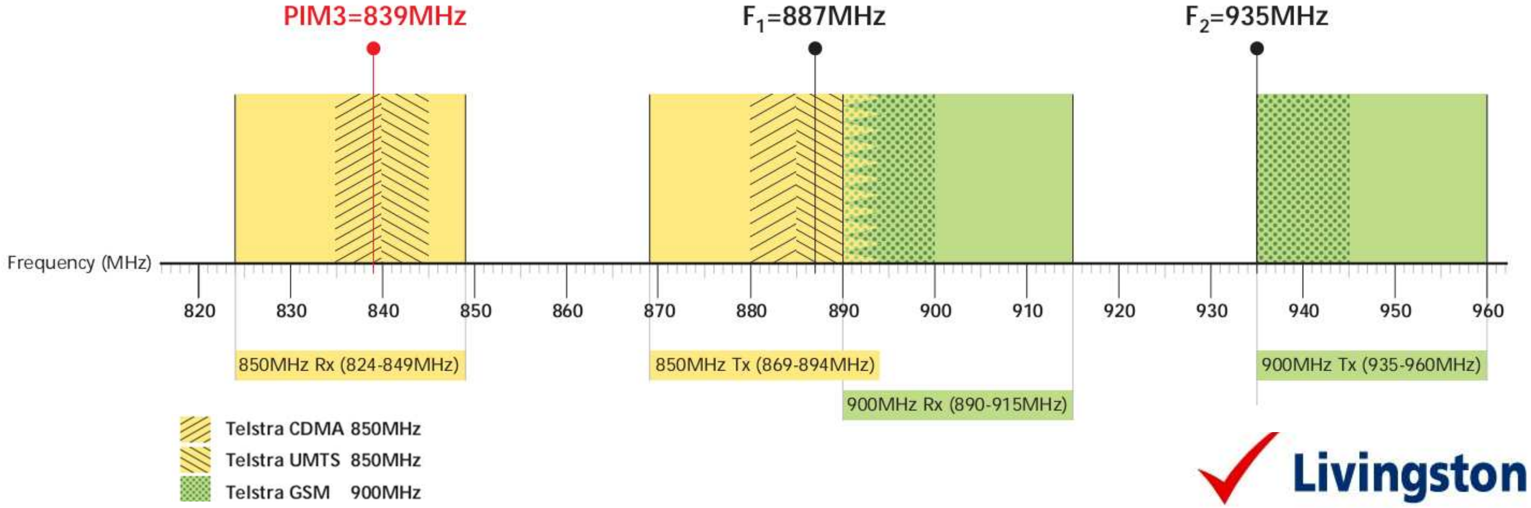
A real scenario result and it's spectrum

System	Intermodulation Products
GSM 900	3rd order in GSM 900 ⟶ 2 x GSM 900 TX - 1 x GSM 900 TX
PCN	3rd order in PCM ⟶ 2 x PCN TX - 1 x PCN TX
UMTS	7th order in GSM 900 ⟶ 4 x UMTS TX - 3 x UMTS TX
Triband System	2nd order in GSM 900 ⟶ 1 x PCN TX - 1 x GSM 900 TX
GSM 900, PCN, UMTS	4th order in UMTS ⟶ 3 x GSM 900 TX - 1 x GSM 900 TX
	3rd order in UMTS ⟶ 2 x PCN TX - 1 x PCN TX

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**

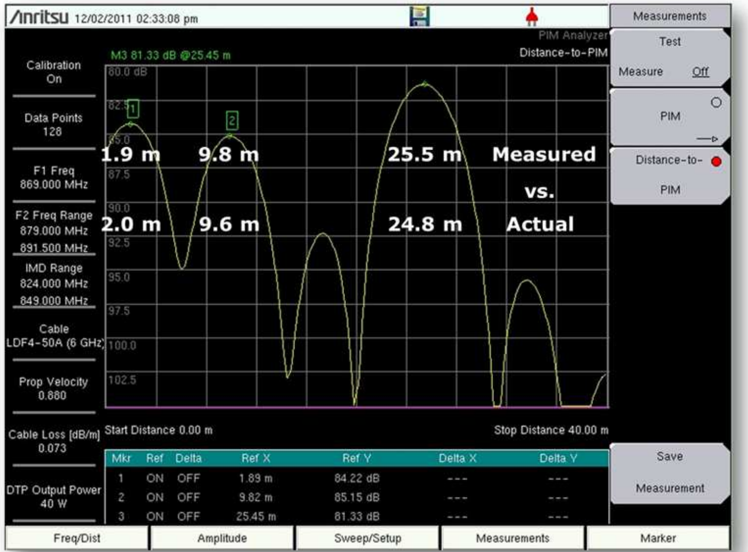


PIM Summary

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**



Distance-to-PIM (DTP) screenshot showing a measurement at 850 MHz.

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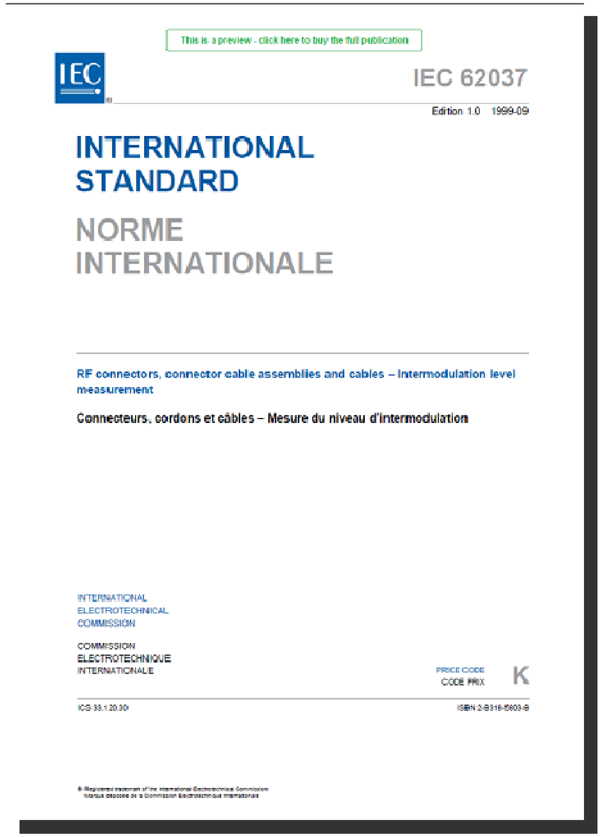
PIM Summary

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 ≥ -165 dBc



This is a preview - click here to buy the full publication

IEC 62037

Edition 1.0 1999-09

INTERNATIONAL STANDARD

NORME INTERNATIONALE

RF connectors, connector cable assemblies and cables – Intermodulation level measurement

Connecteurs, cordons et câbles – Mesure du niveau d'intermodulation

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

PRICE CODE
CODE PRIX K

ICS 33.120.30

ISBN 2-8318-5603-8

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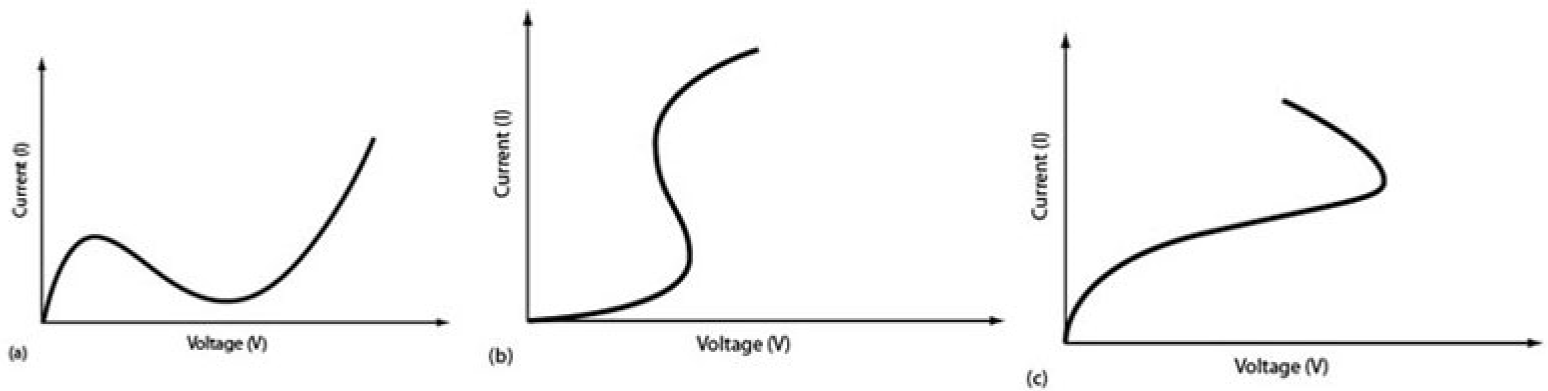
Passive Intermodulation

PIM Causes

Non-Linearities take two different forms

- **Contact Non-Linearity**
- **Material Non-Linearity**



Passive Intermodulation

PIM Causes - Contect 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 restistance caused by two dissimilar metals

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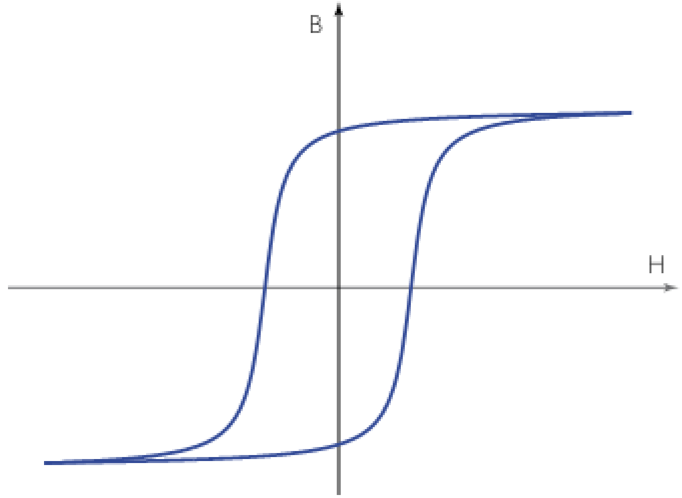
Passive Intermodulation

PIM Causes - Material Non-Linearities

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

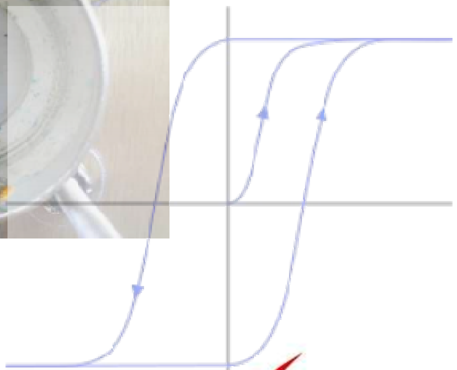
Root Causes of PIM in a real RF environment

- 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



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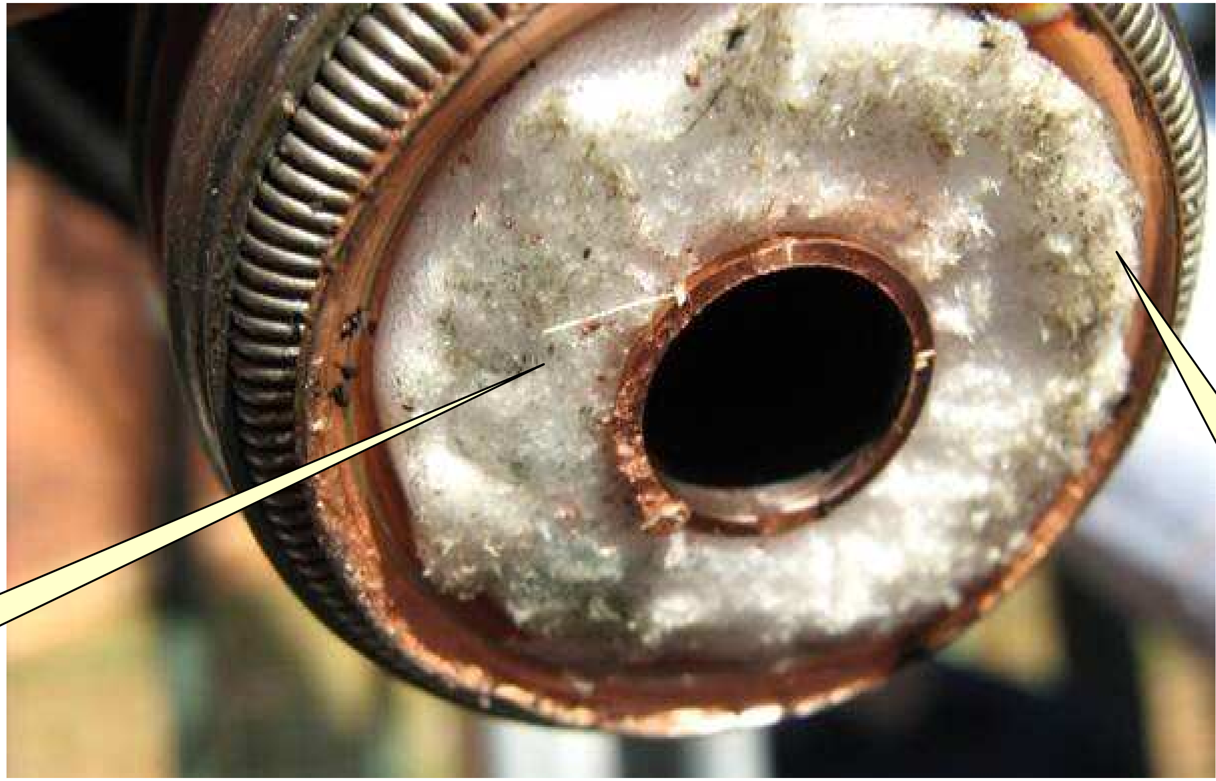
Passive Intermodulation

Field Examples



Poor cable preparation

Dirt / trash

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Passive Intermodulation

Field Examples

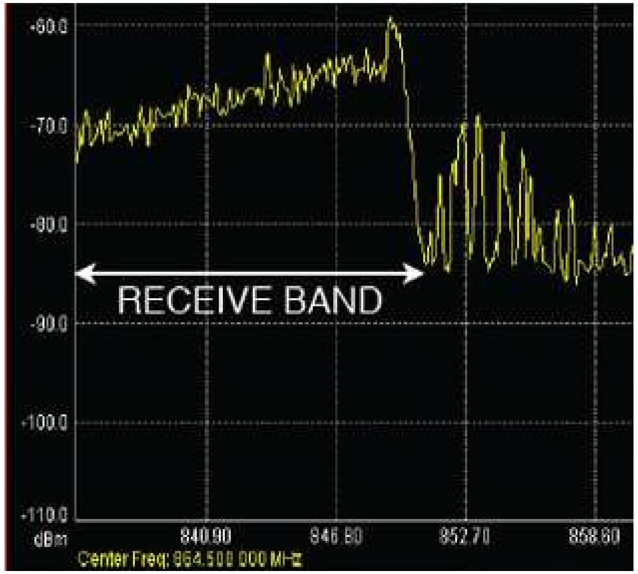
LDF4-50A RF-Repeater feeder cable

- -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

Passive Intermodulation

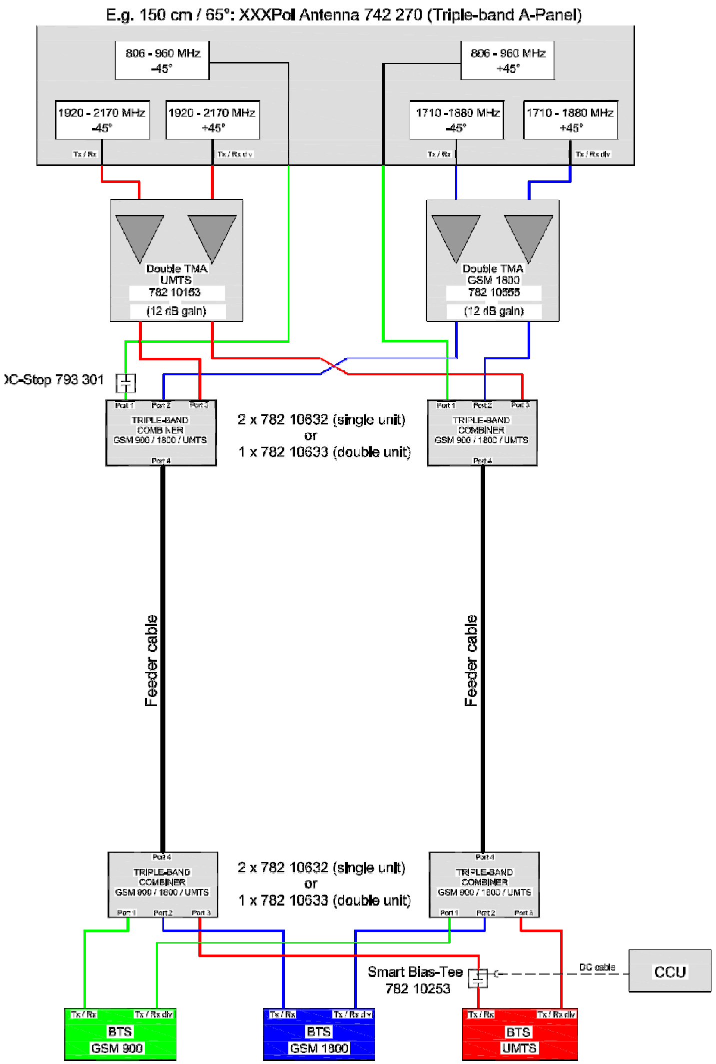
PIM versus Arcing

- 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



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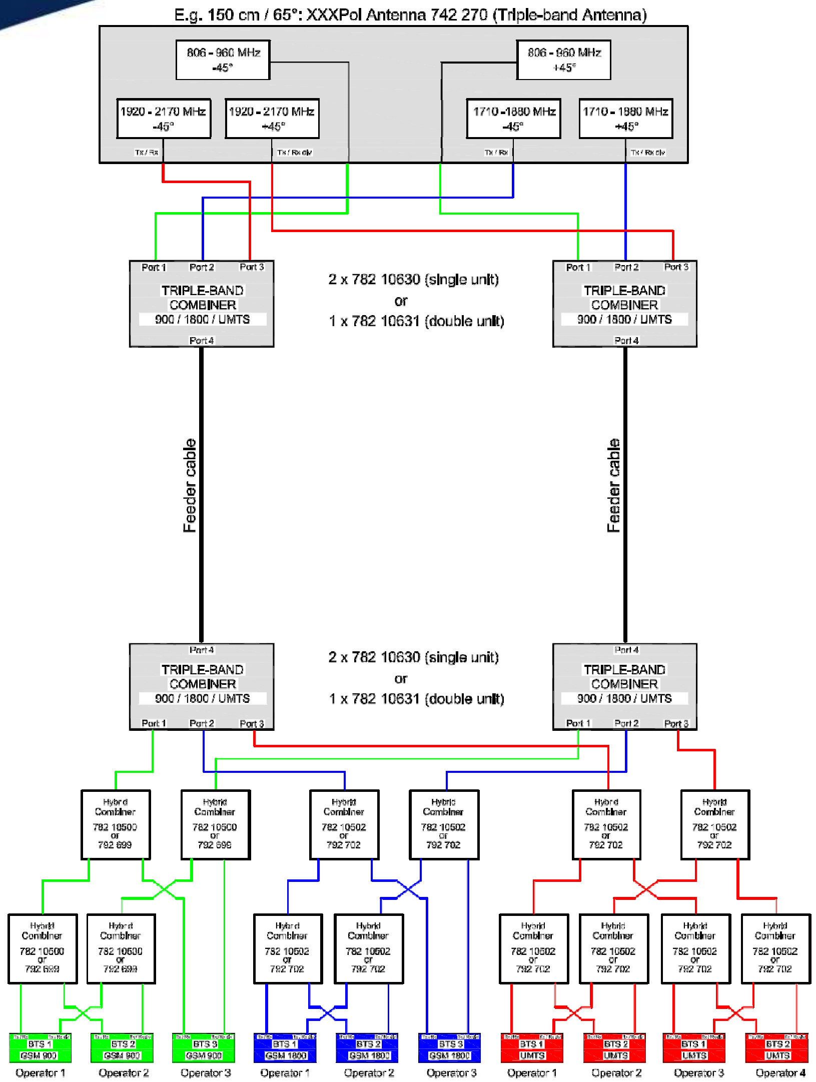
PIM sources within the RF interconnection

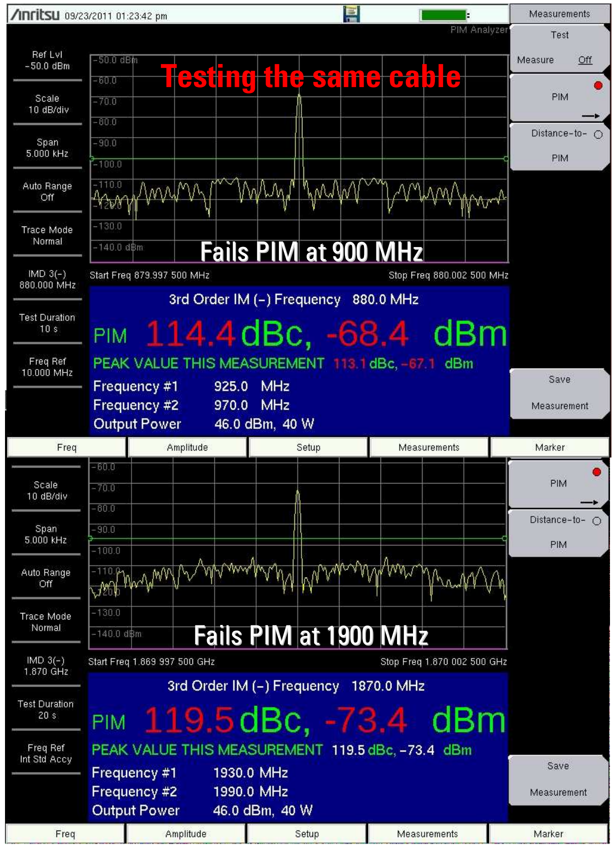
Co-Siting 3 Op GSM 900 / GSM 1800 and 4 Op UMTS



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 limitating**
  - **antennas**
  - **TMAs**
  - **lightning arrestors**
  - **combiners/duplexers**
  - **Then pick frequencies in pass band**



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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

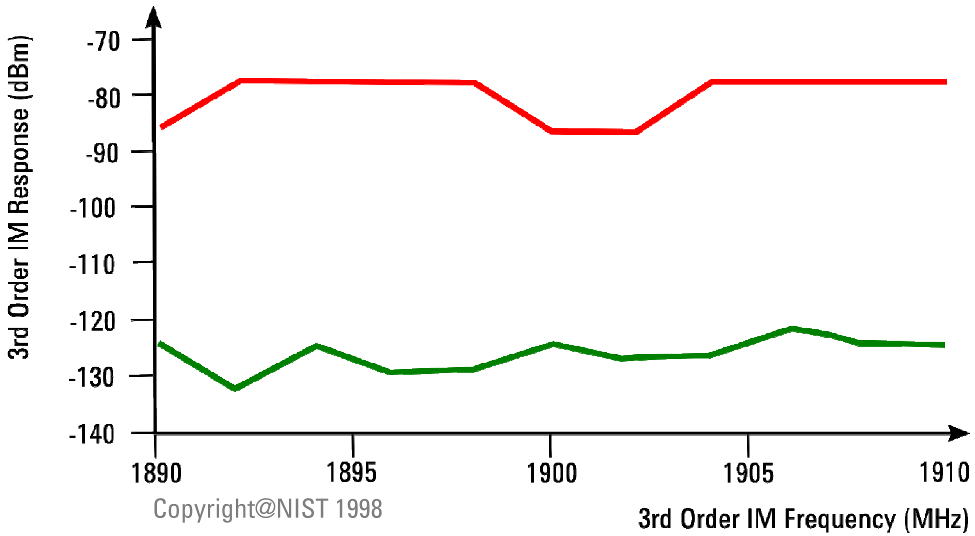
- **DIN 7/16 coax cable connectors**
  - **typically PIM values of -140 to -168 dBc**
  - **recommended torque (IEC) 35 Nm, in practice often 25 -30 Nm**

- **Example: PIM difference between hand-tightend 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**
  - **Comparision 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**



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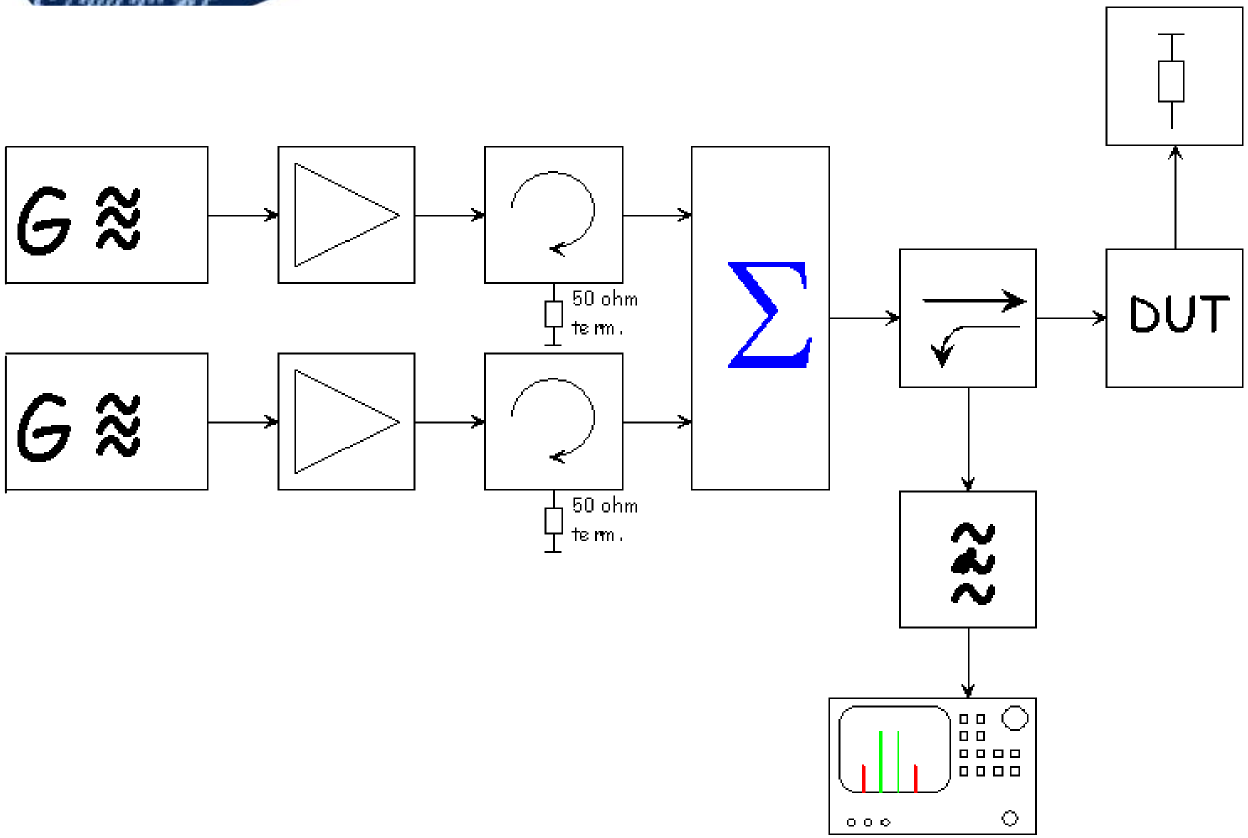
Passive Intermodulation

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 Measurments

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™

The Solution Box

The Fastest Way to Pinpoint the Source of PIM

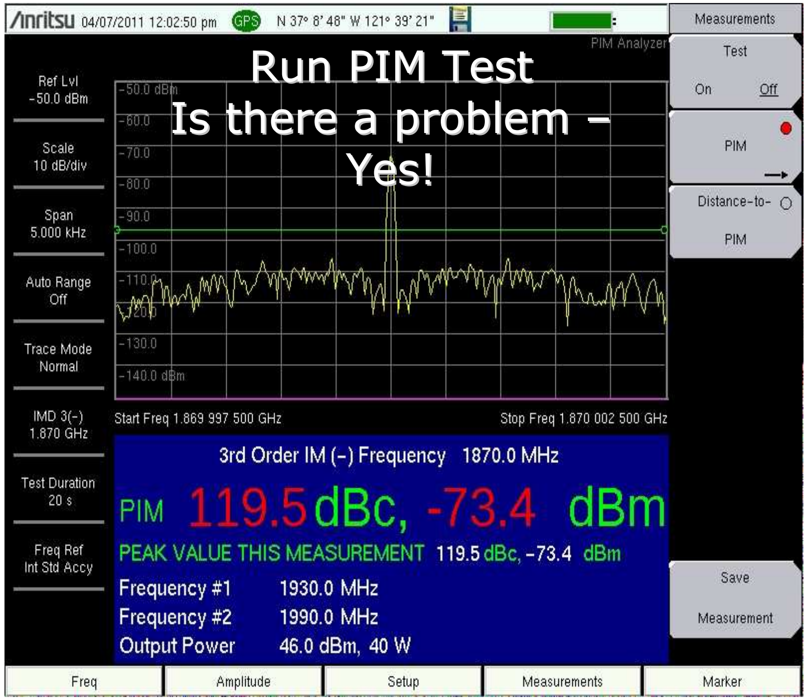
- **Available PIM Master models**

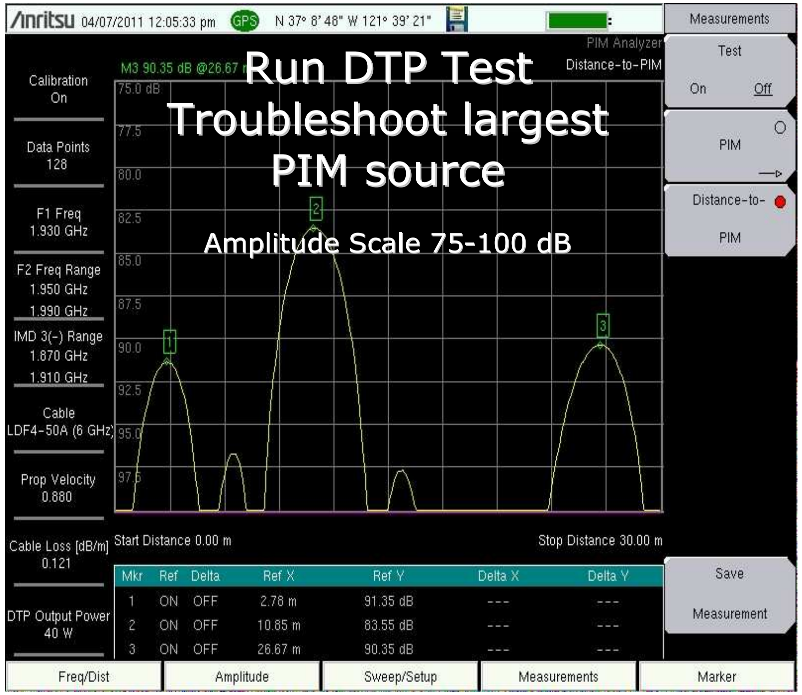
Model	RF Band	RF range for f_1 and f_2	Power Levels
MW8219A	PCS	1930 - 1990 MHz	20, 30, 40 W
	AWS	2110 - 2155 MHz	
MW8209A	E-GSM	925 - 960 MHz	
MW8208A	US Cellular	869 - 894 MHz	

- **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





- **DUT 26 m cable with PIM Sources @ 3.1 m, 10.7 m, 25.9 m**

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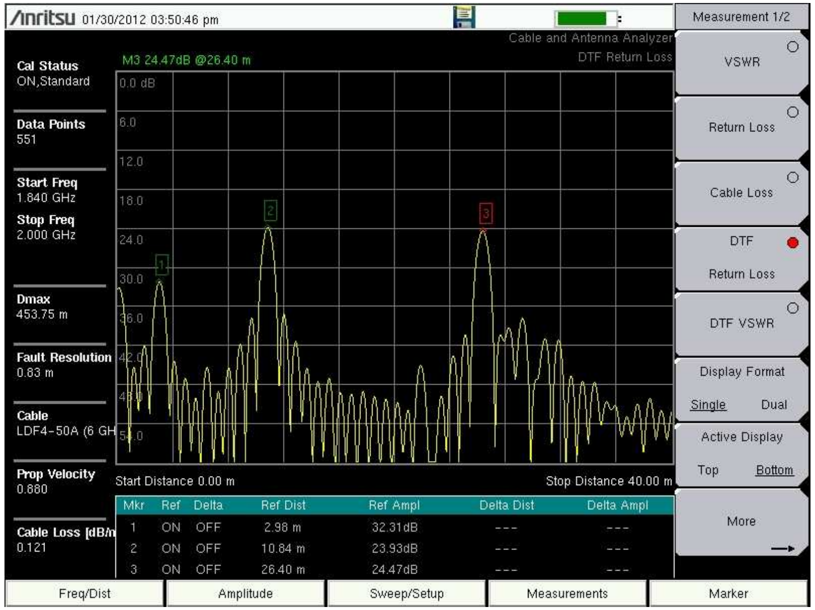
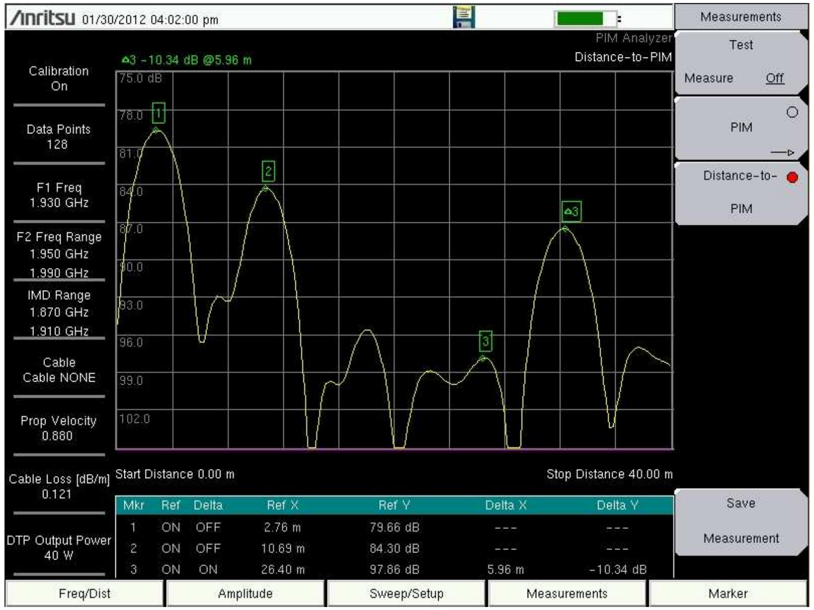
Passive Intermodulation Measurements

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**





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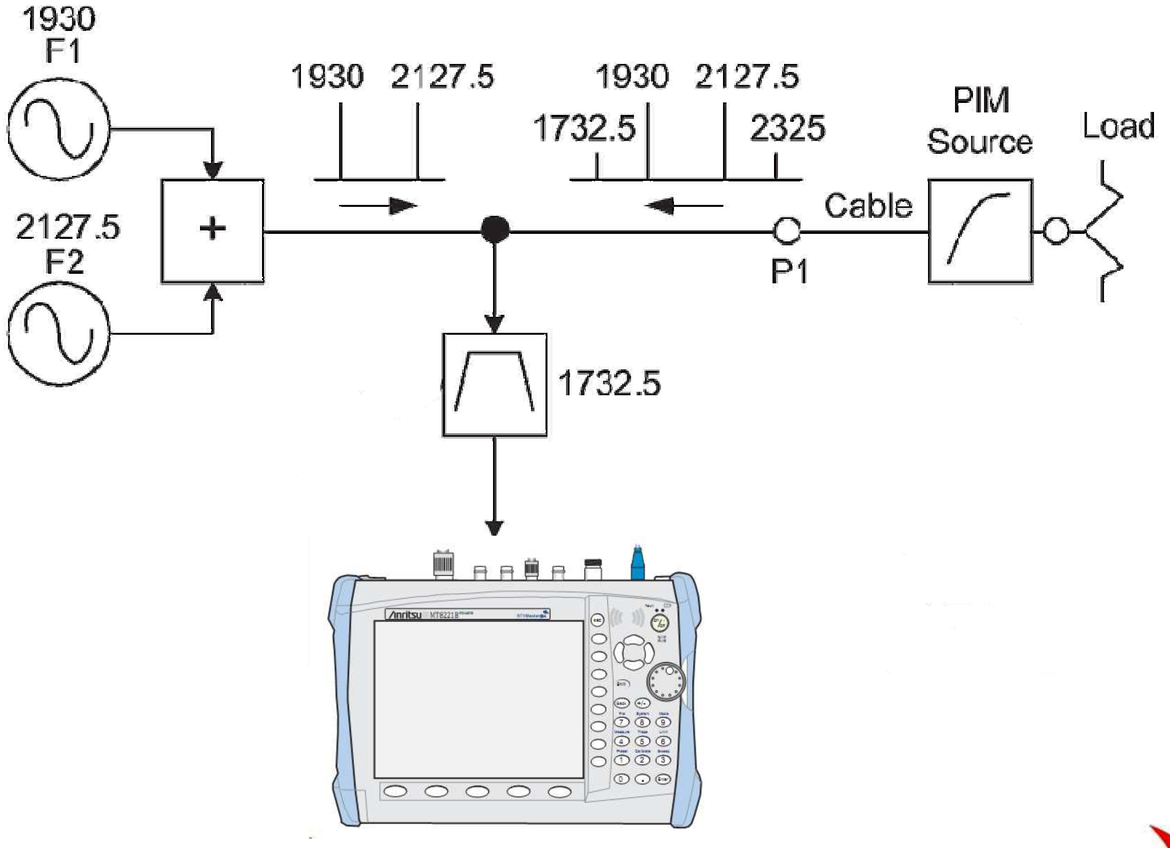
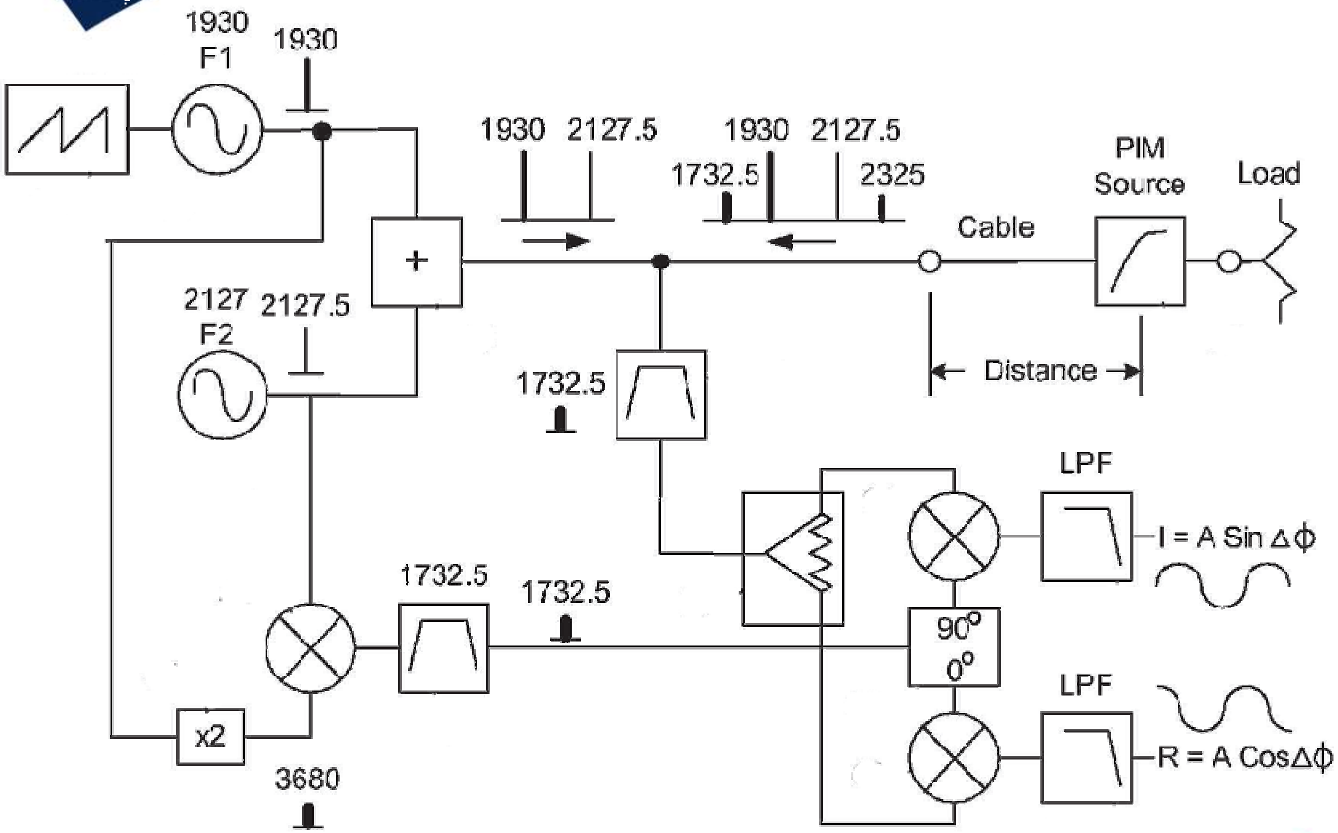
Passive Intermodulation Measurements

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.

Discover What's Possible™