Characterization of Passive Intermodulation (PIM) in Space Communication Antennas

Joakim Johansson
Lead Engineer, Antennas

RUAG Space AB
Solna, November 15, 2018

Together ahead. RUAG

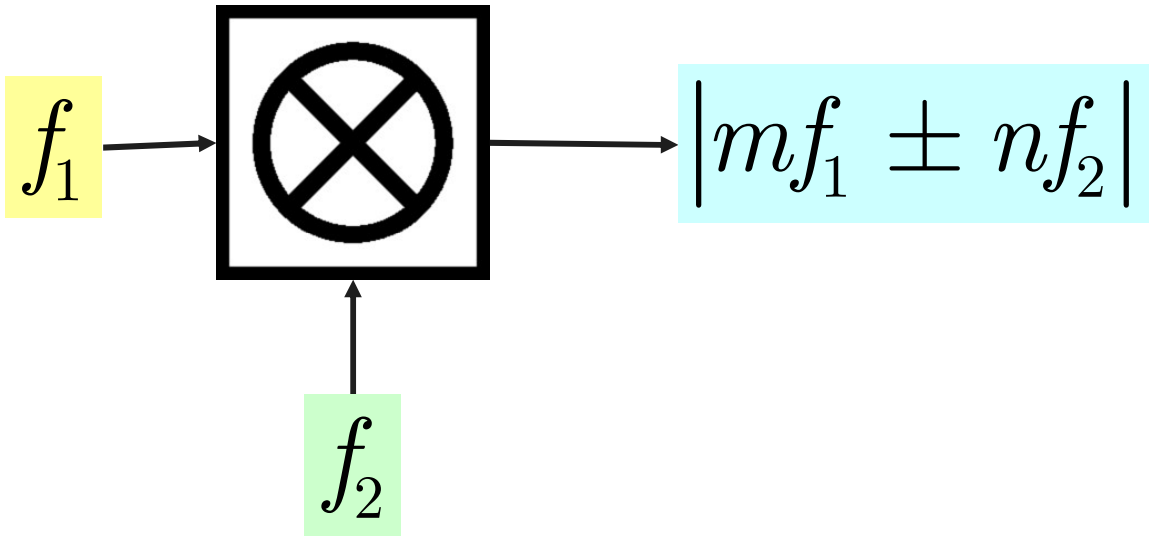
Project
Involved Parties

- Academia:
  - Department of Microtechnology and Nanoscience – MC2
    Chalmers University of Technology
  - PI: Docent Dan Kuylenstierna
  - Ph.D. student recruited Q4 2018

- Industry:
  - RUAG Space AB
    Product Unit Antennas
  - PM: Joakim Johansson

What is Passive Intermodulation (PIM)?
Frequency mixing

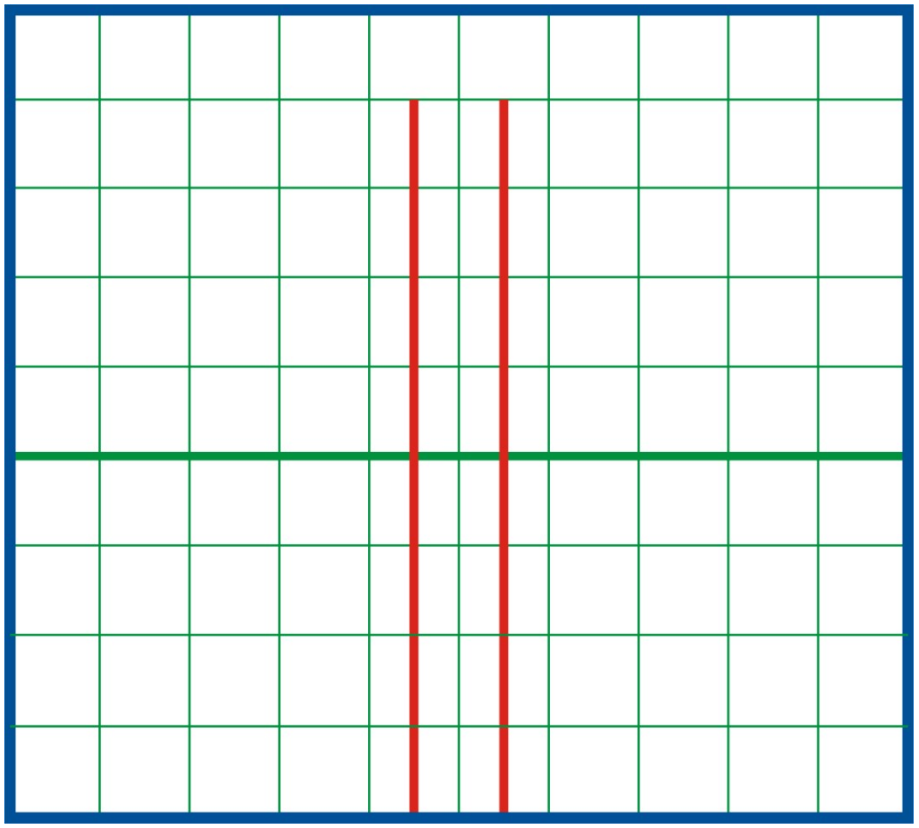
- When two signals of different frequency combine in a non-linear component, other frequencies are produced
  - Intentional in frequency converters
  - Sometimes unintended and undesired



What is Passive Intermodulation (PIM)?
Fundamentals

- Assume two carriers

$$f_1 = f_o - \Delta f$$
$$f_2 = f_o + \Delta f$$

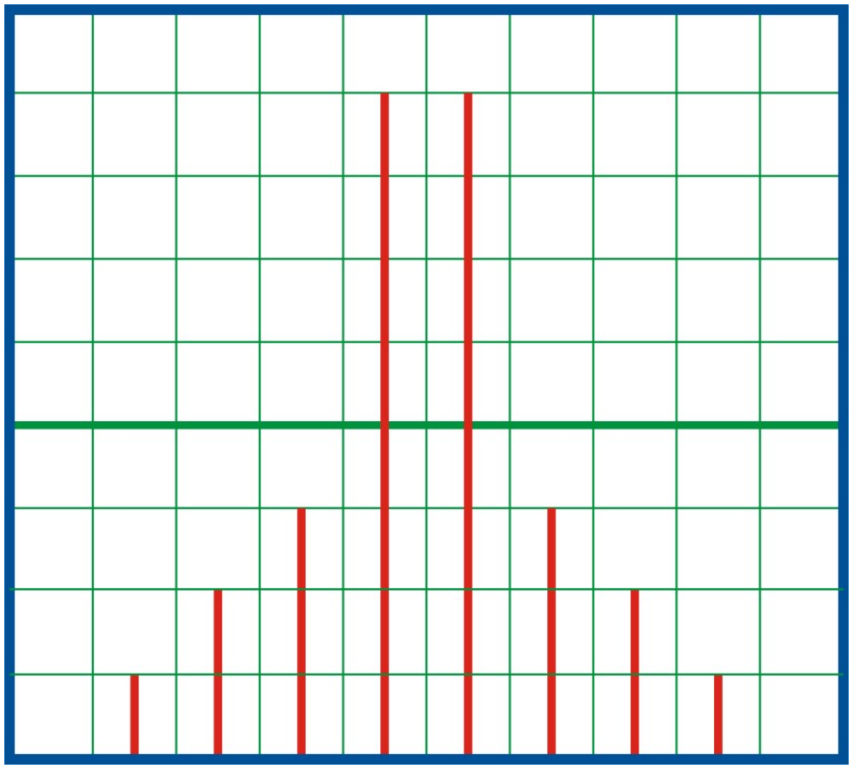


$$f_o \pm \Delta f$$

What is Passive Intermodulation (PIM)?
Fundamentals

- Any non-linearity will then produce a forest of unwanted frequencies
  - Intermodulation!

- Common in high power amplifiers
  - Strongly dependent on the input power



$$f_o \pm (m+n)\Delta f$$

Together ahead. RUAG

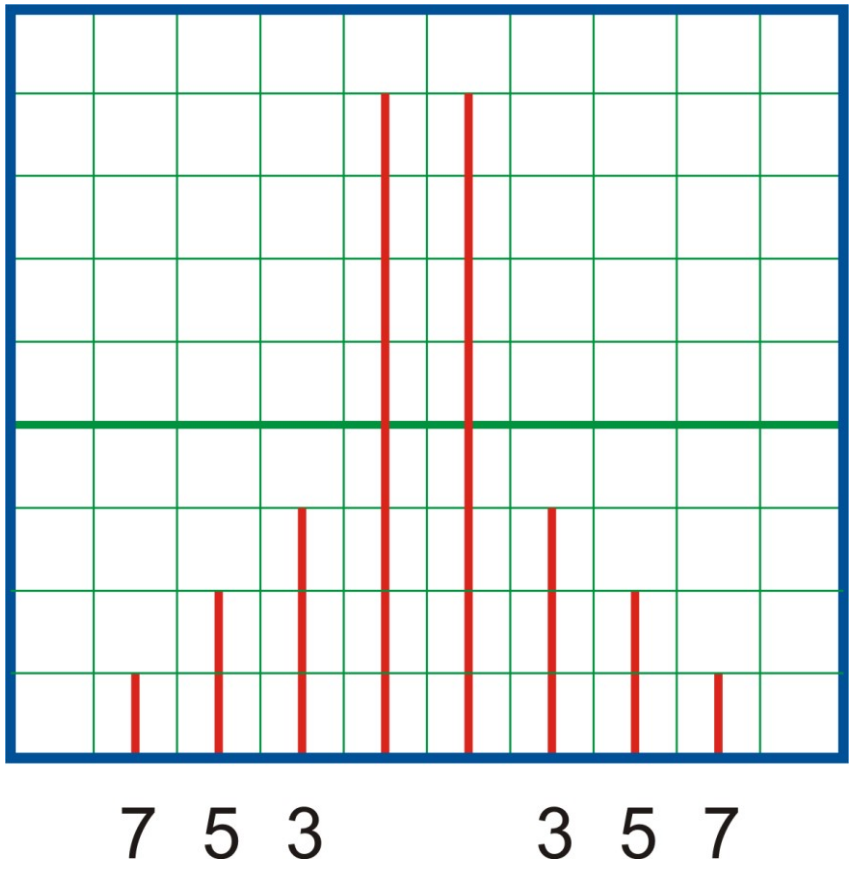
What is Passive Intermodulation (PIM)?
Fundamentals

- The **order** of the intermodulation is defined as

$$m + n$$

- The odd order intermodulation is located close to the carriers

- Even order intermodulation is typically located far off



What is Passive Intermodulation (PIM)?
Fundamentals

- Intermodulation can occur in passive circuits, not only in amplifiers
  - Passive Intermodulation (PIM)

- From a phenomenological point of view, PIM sources are various, but they all have some kind of RF non-linearity involved
- Some potential causes are:
  - Semiconductor-to-metal contacts
  - Metal-to-metal contacts (similar or dissimilar, as well as with an oxide layer in between)
  - Ferromagnetic materials
  - Metallurgical imperfections
  - Corona and multipactor breakdown

What is Passive Intermodulation (PIM)?
Mechanisms

- PIM is poorly understood
- Some of the fundamental mechanisms that have been suggested are:
  - Band-gap non-linearities
  - Field emission
  - Tunneling
  - Constriction resistance effects
- Ultimate limit imposed by electro-thermal effects

What is Passive Intermodulation (PIM)?
Methodology & Mitigation

- PIM analysis has to a large degree been restricted to prediction of intermodulation product frequencies, as well as identifying the high field or current regions of a design that could be potential PIM sources
- Highly empirical!

- Typically, the PIM mitigation approach has been:
  - Follow certain guidelines
  - 'Hope for the best'
  - Verify the performance by test

- The problem is of course that this approach leads to risks in terms of late re-designs (or even failure to achieve compliance)

PIM in Satellite Communication Systems
Increasing…

- Passive intermodulation is a problem area within space radio communication technology that is increasing in importance
- The trend towards co-location of ***antenna farms*** with various transmit and receive functions for communications equipment and *e.g.* active and passive instruments, as well as the drive towards increased RF power levels and multiple carriers exacerbates the problem

PIM in Satellite Communication Systems
Mitigation

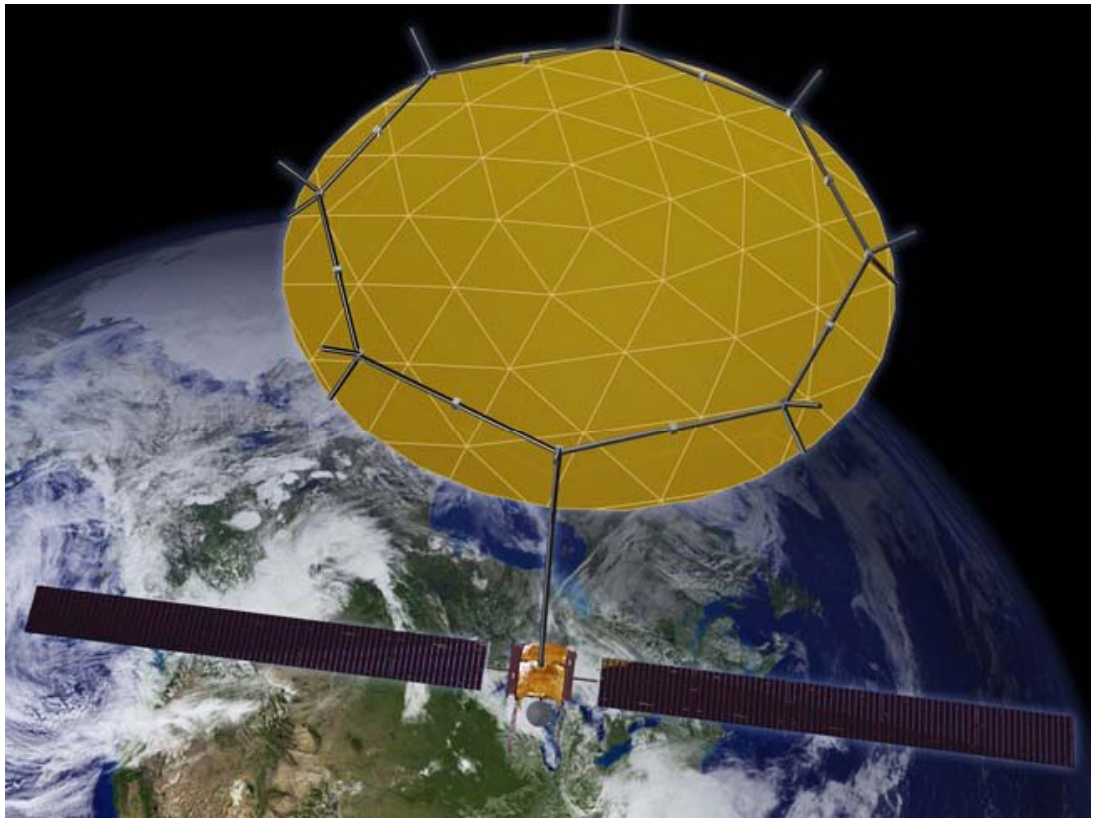
- Typical guidelines in space antenna design:
  - Avoidance of ferromagnetic materials
  - Avoidance of semiconducting materials
  - Avoidance of certain coatings
  - Avoidance of dissimilar metal contact
  - Avoidance of metal-to-metal contact without enough contact pressure
  - Avoidance of mechanical designs with joints in high field / current regions
  - Usage of insulating dielectric films

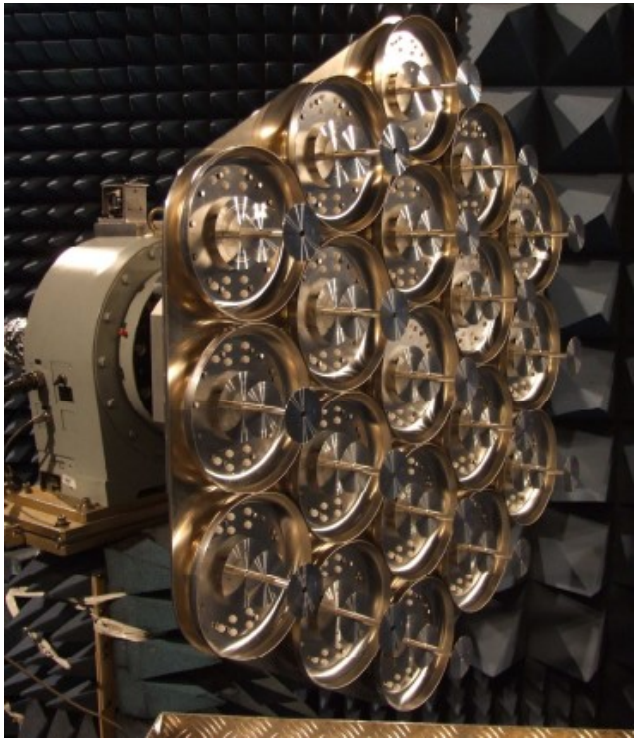
PIM Mitigation
Conflicting requirements

- Several of the typical PIM mitigation methods can be in direct contradiction with other design drivers for space antennas:
  - ESD (space charging of dielectrics)
  - Structural integrity
  - Thermal design
  - Multipactor breakdown

PIM Mitigation
Conflicting and demanding requirements

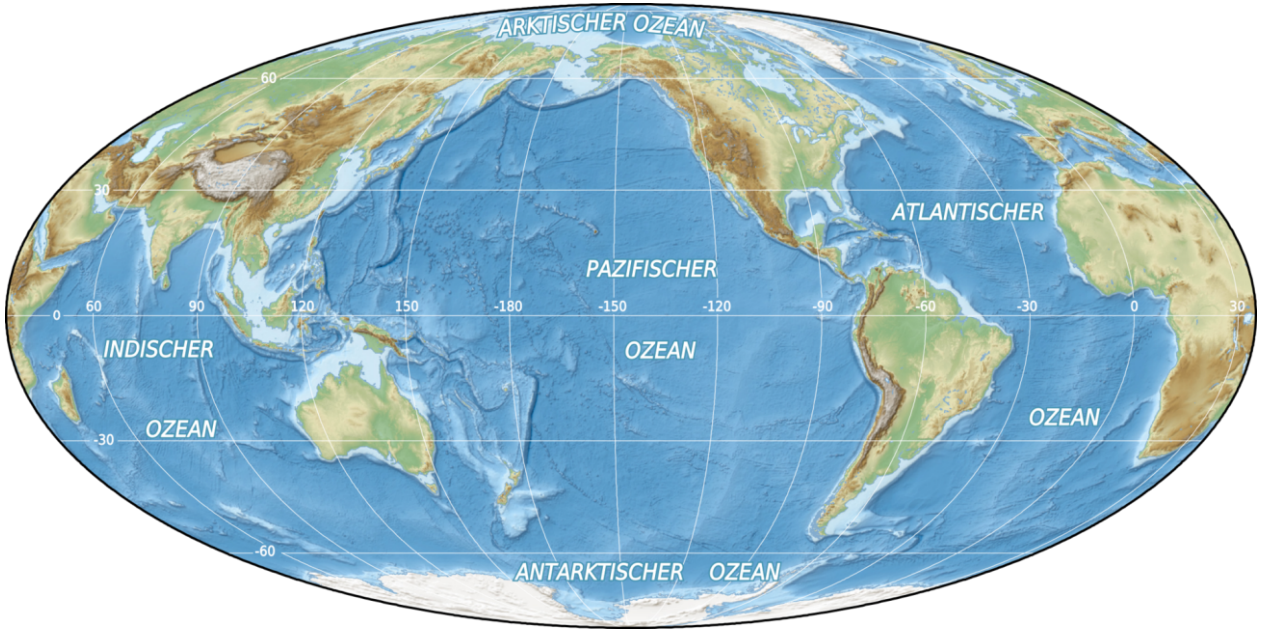
- RUAG Space has gained considerable experience in PIM mitigation, especially for Patch Excited Cup (PEC) array elements
  - But the requirements are getting tougher…





Tougher Requirements
A magnitude comparison

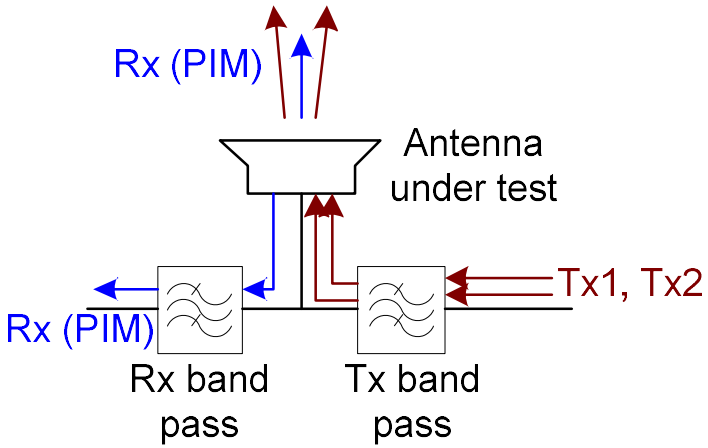
- In some extreme cases the requirements on PIM suppression can be 190 dB!
- The measurement dynamic range then needs to be 200 dB (= 10^{20})
  - Compare a bucket of water to the total volume of water in all oceans…



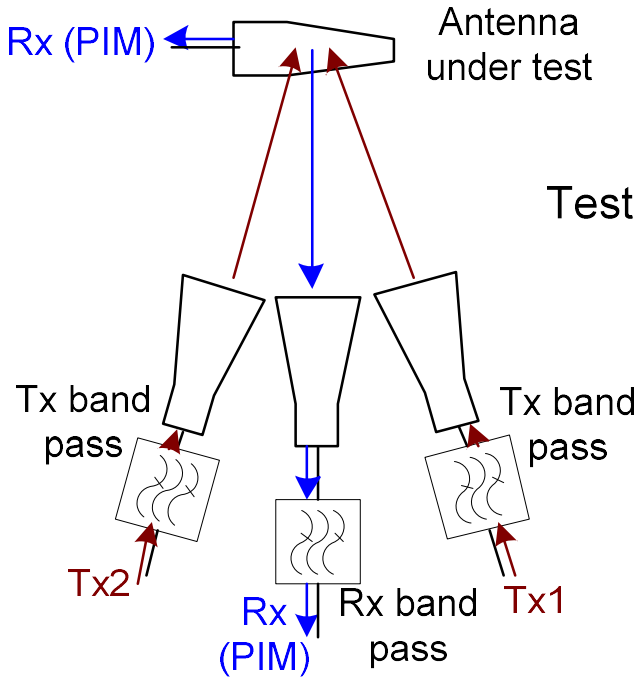
Together ahead. RUAG

PIM Measurements
Reflected or radiated PIM

- Typical measurement setups



Test setup type 1



Test setup type 2

Together ahead. RUAG

PIM Measurements
RUAG Space PIM facility

- L-/S-/X-band
- 500 – 1000 W
- Thermal cycling

Goals for the NRFP Study

- A deepened understanding of how materials, surface treatments, joining methods, *etc*. affect the PIM performance of space communication antennas
- Recommendations for the selection of materials, surface treatments, and joining methods to minimize PIM in space communication antennas
- PIM measurement systems with improved dynamic range
- New methods and models for the prediction of PIM when designing antennas and beam forming networks for space communications
- Non-linear behavioral models that enable analysis of the impact of antenna PIM on modern communication signals