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Passive Intermodulation in Distributed Circuits with Cascaded Discrete Nonlinearities

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Abstract: The principle aspects of passive intermodulation (PIM) characterisation in distributed printed circuits with cascaded lumped nonlinearities are presented. Mechanisms of PIM generations have been investigated experimentally and modelled using the formalism of X-parameters. The devised equivalent circuit models are applied to the analysis of microstrip lines with distributed and cascaded lumped sources of nonlinearity. The dynamic measurements have revealed that PIM generation rates in straight and meandered microstrip lines differ and significantly deviate from those expected for the respective discrete sources of nonlinearity. The obtained results indicate that multiple physical sources of nonlinearity contribute to PIM generation in printed circuits. Finally, it is demonstrated that the electrical discontinuities can have significant effect on the overall PIM response of the distributed passive circuits and cause PIM product leakage and parasitic coupling between isolated circuit elements.

Keywords: intermodulation distortion; passive intermodulation (PIM); distributed nonlinearity; X-parameters, interference

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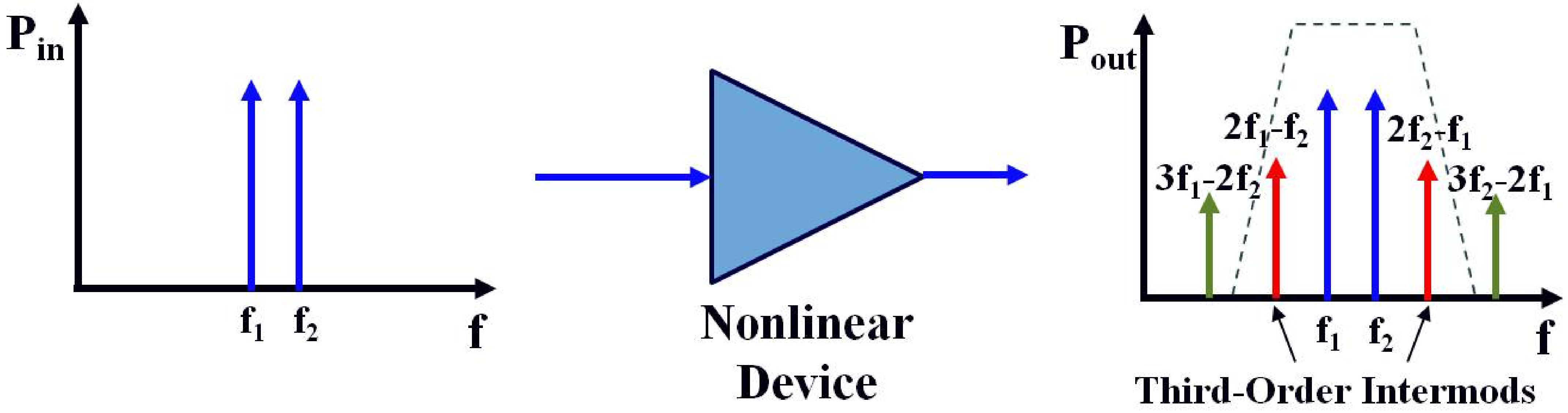
Passive Intermodulation (PIM)

PIM manifests itself in appearance of additional spectral components at output of passive devices, beamforming networks and antennas



Basic PIM sources

- Localised: contact effects, soldered joints
- Distributed: nonlinear resistivity of signal tracks
  substrate polarisability in printed circuits

Typical passive RF devices contain combinations of distributed and lumped nonlinearities of transmission lines (TLs), discontinuities, contact junctions, etc.

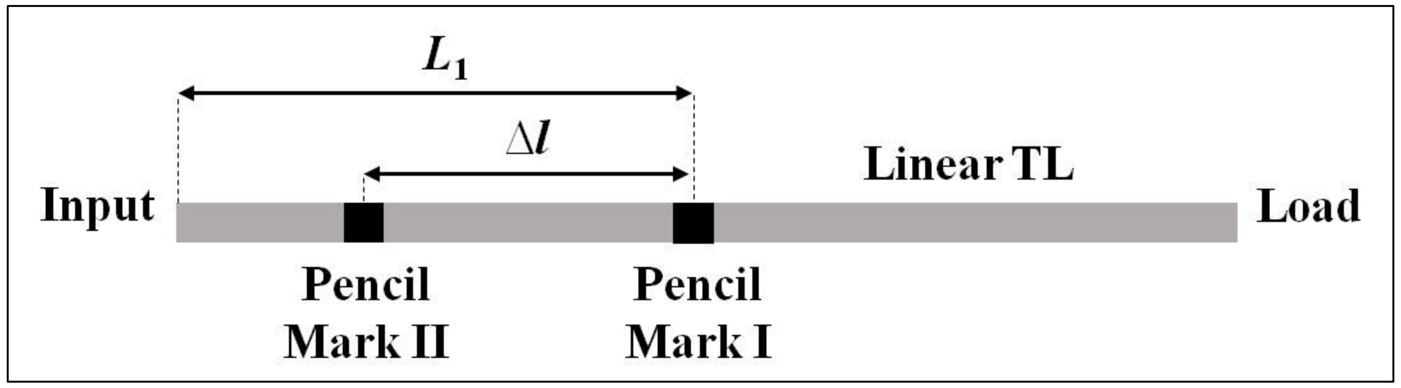
Objective: Incorporate the PIM analysis into the design process and develop predictive models of distributed and localised PIM generation

Challenges:

- Characterisation of the basic passive components with localised and distributed nonlinearities
- Identification and description of physical sources of nonlinearity

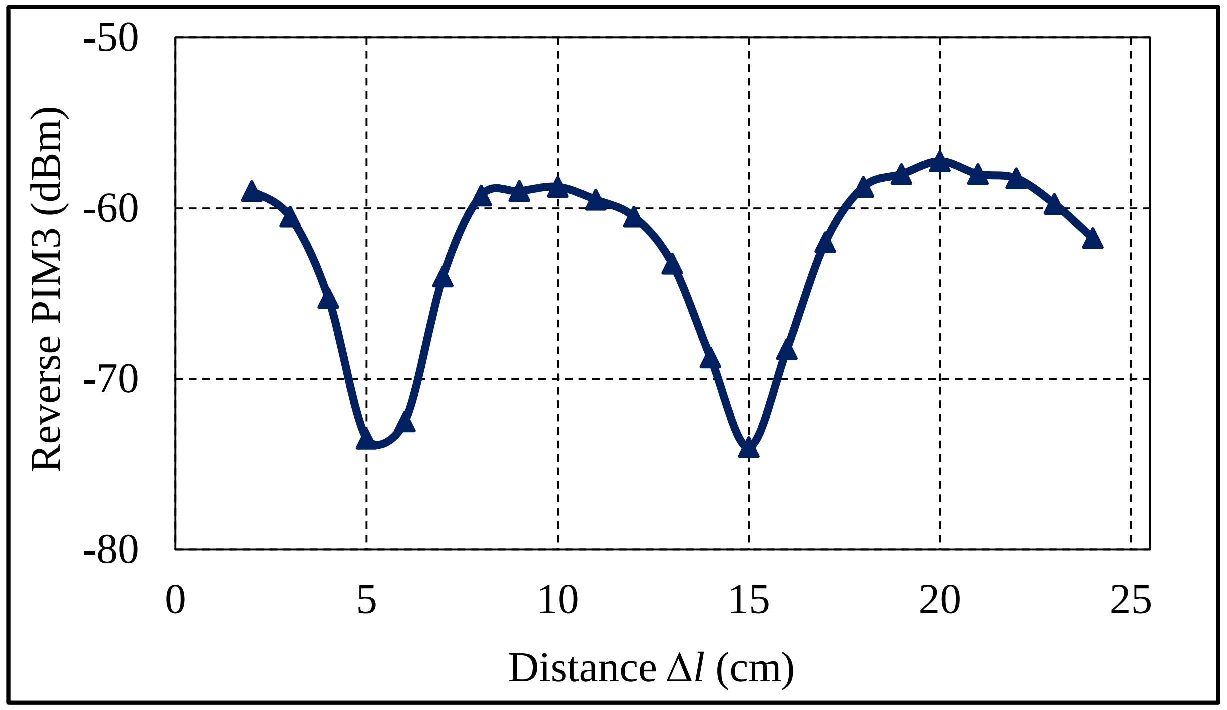
Cascaded Lumped Nonlinearities

Lumped nonlinearities were emulated by small pencil marks on a paper sheet placed over the tested microstrip line



f_1 = 935 MHz and f_2 = 960 MHz
P_0 = 43 dBm / tone
Length L_1 = 30 cm

Magnitude of reverse PIM3 products



Test specimens are printed on PCB TLG-30:

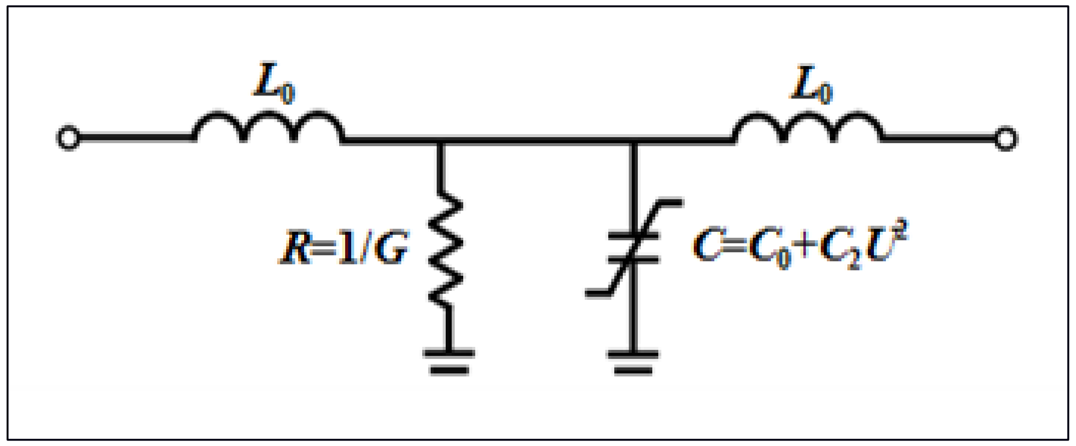
Laminate thickness:	***h = 0.76 mm;***
Permittivity:	***ε_r = 3.0;***
Dissipation factor:	***tanδ = 0.0026;***
Low-profile copper	***t =17.5µm;***

Wavelength λ = 21.2 cm at PIM3 frequency $2f_1 - f_2$ = 910 MHz)

Maxima and minima of PIM3 level in the microstrip line are offset for ~ λ/4 at PIM3 frequency– interference pattern

Distributed PIM Generation in Nonlinear TL

Nonlinear TL can be analysed as a cascade of unit cells, described by the X-parameters



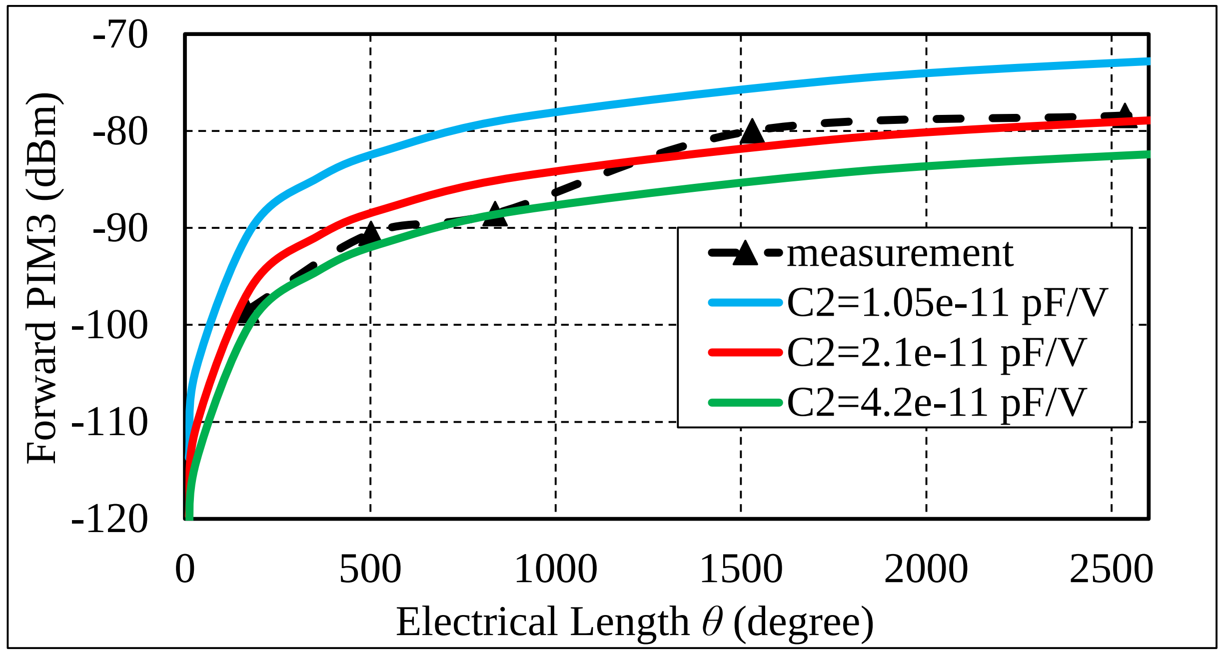
f_1 = 935 MHz and f_2 = 960 MHz

P_0 = 43 dBm / tone

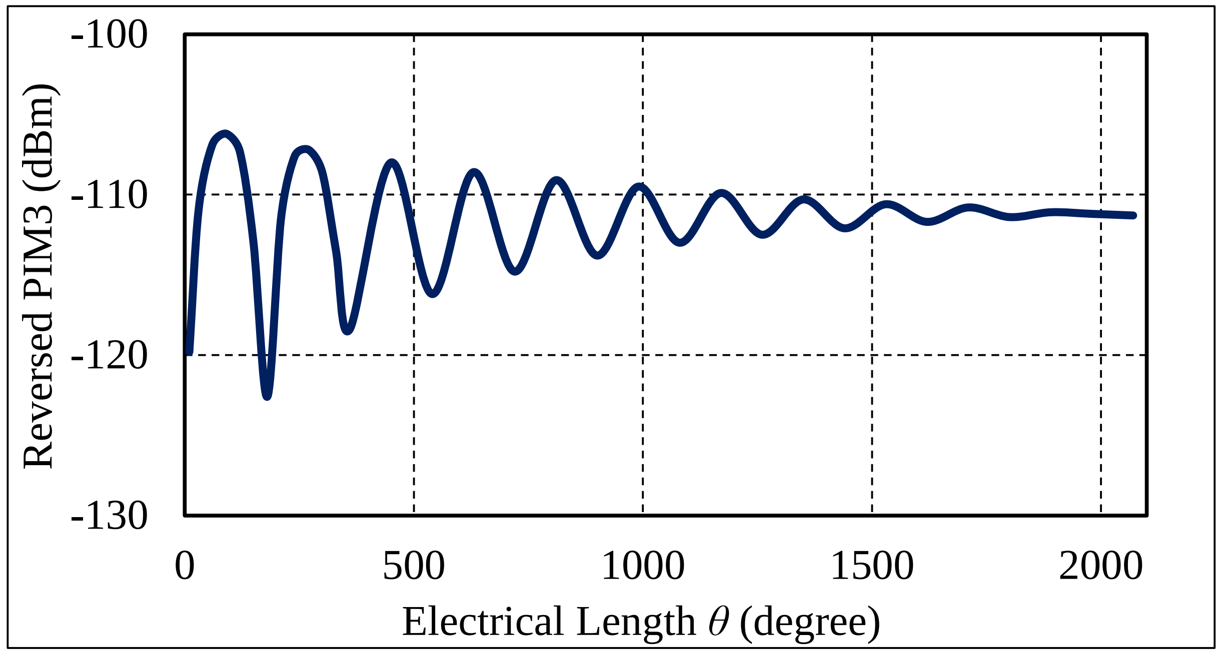
Unit cell electrical length at $2f_1 - f_2$: $\theta = 2°$

L_0 = 0.154 nH, G = $3{*}10^{-5}$ S, C_0 = 0.123 pF.

Magnitude of forward PIM3 products



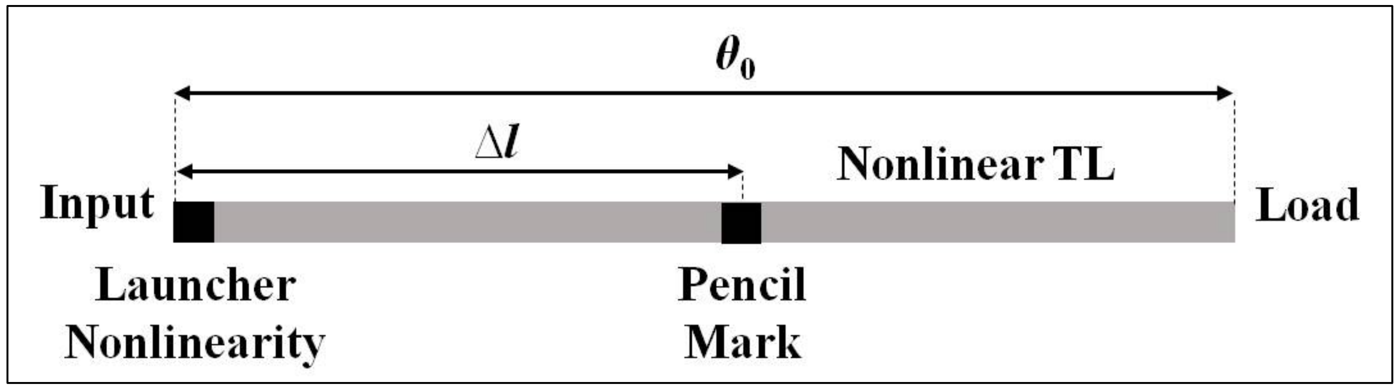
Magnitude of reverse PIM3 products



- **Cumulative growth of the PIM3 level at the TL output (Forward PIM)**
- **Periodic undulations of the PIM3 level at the input (Reverse PIM)**

Lumped and Distributed Nonlinearities in TL

A weak lumped nonlinearity is assumed in input microstrip launcher



f_1 = 935 MHz and f_2 = 960 MHz

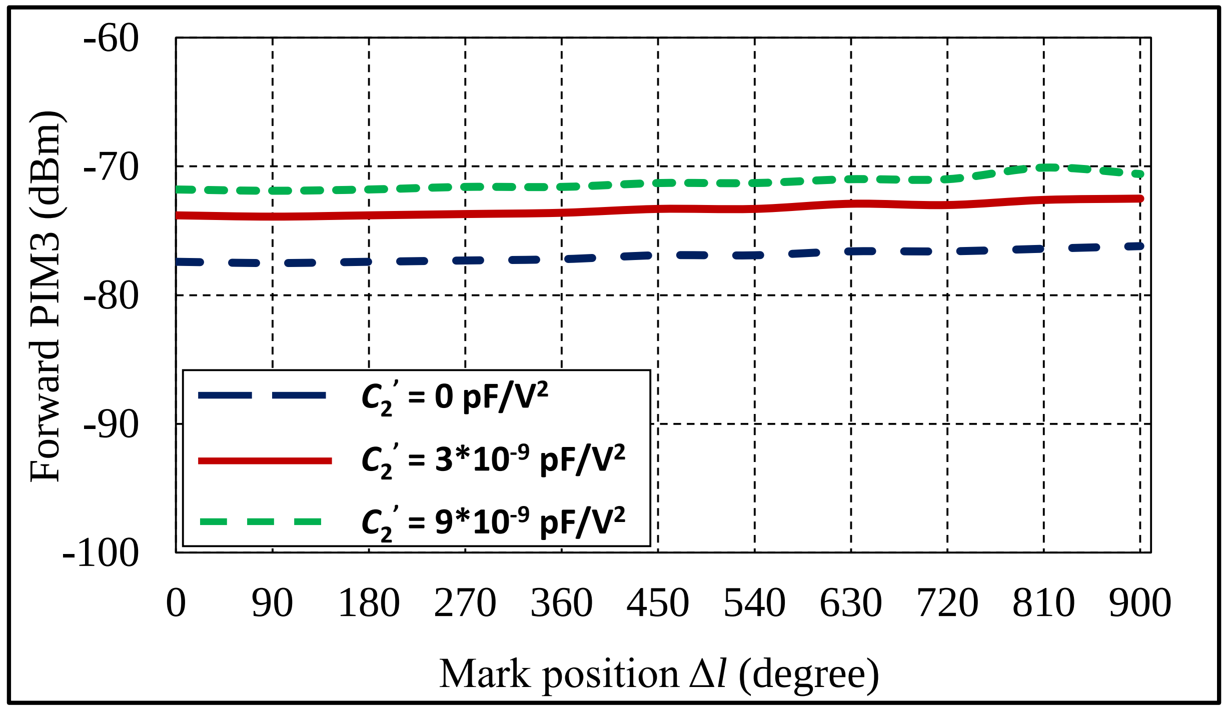
P_0 = 43 dBm / tone

TL electrical length θ_0 = 900° at frequency $2f_1 - f_2$

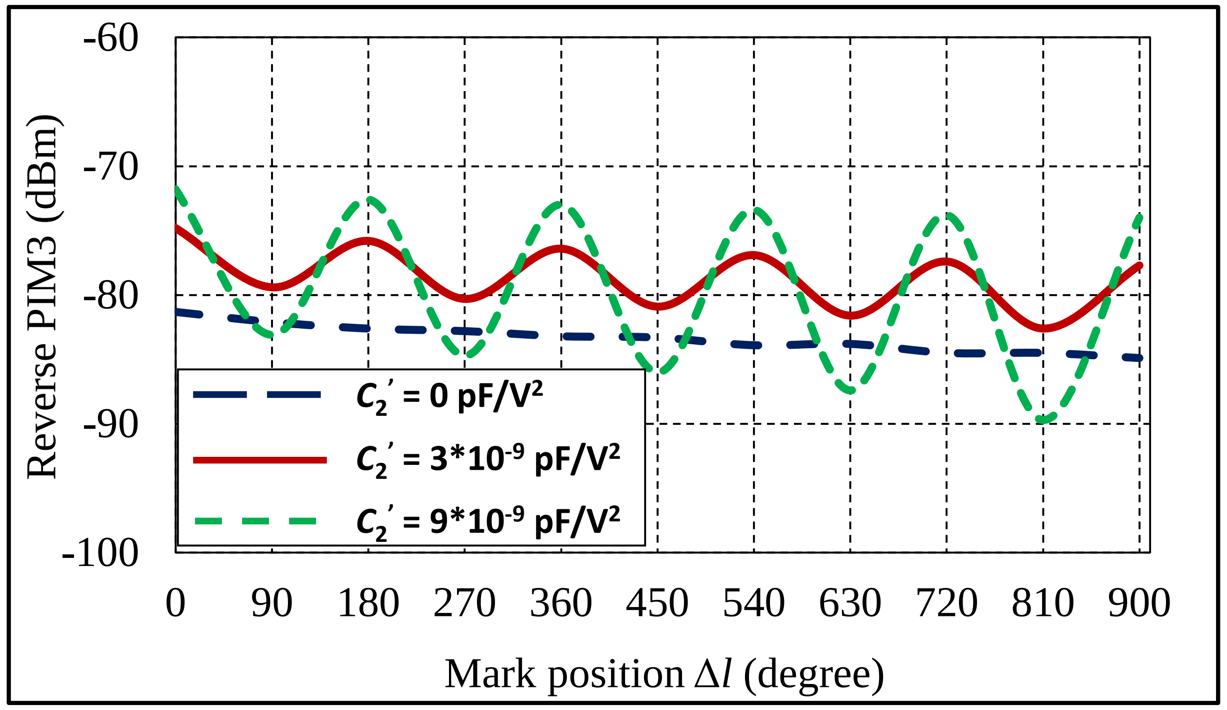
Launcher capacitive nonlinearity: **$C^L = C_0^L + C_2^L U^2$ where $C_0^L = 5.2\times10^{-3}$ pF**

Pencil mark is used as a probe to analyse a mechanism of PIM generation in the nonlinear TL

Magnitude of forward PIM3 products



Magnitude of reverse PIM3 products



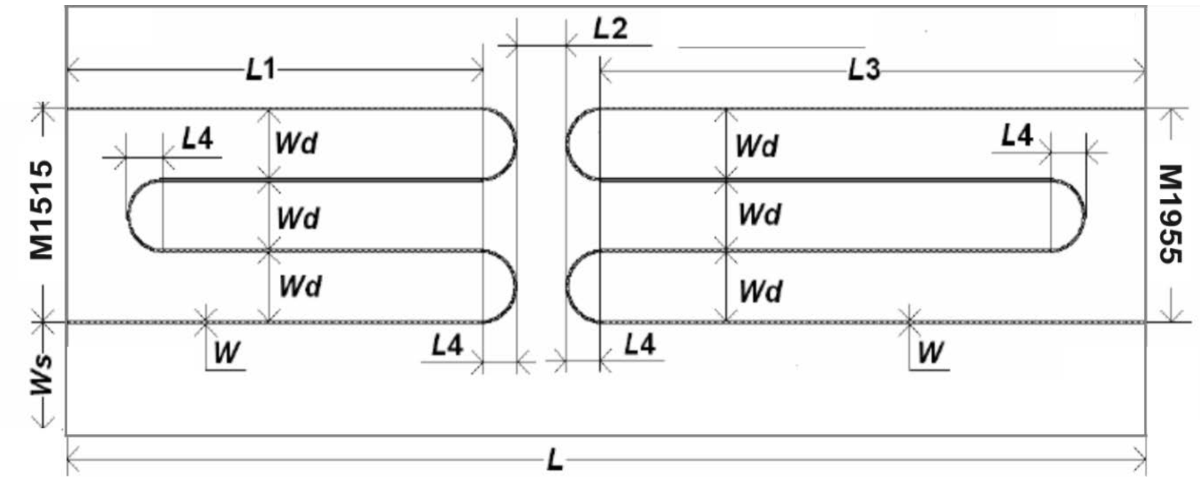
- **Undulations of reverse PIM3 level strongly depend on the launcher nonlinearity relative to the TL distributed nonlinearity**
- **Position of a lumped nonlinearity can be located with the aid of the nonlinear probe, provided that the nonlinearity is strong enough**

Dynamic characteristics of PIM3 products in TL

The effect of carrier input power on PIM3 performance of straight and meandered microstrip lines has been measured:

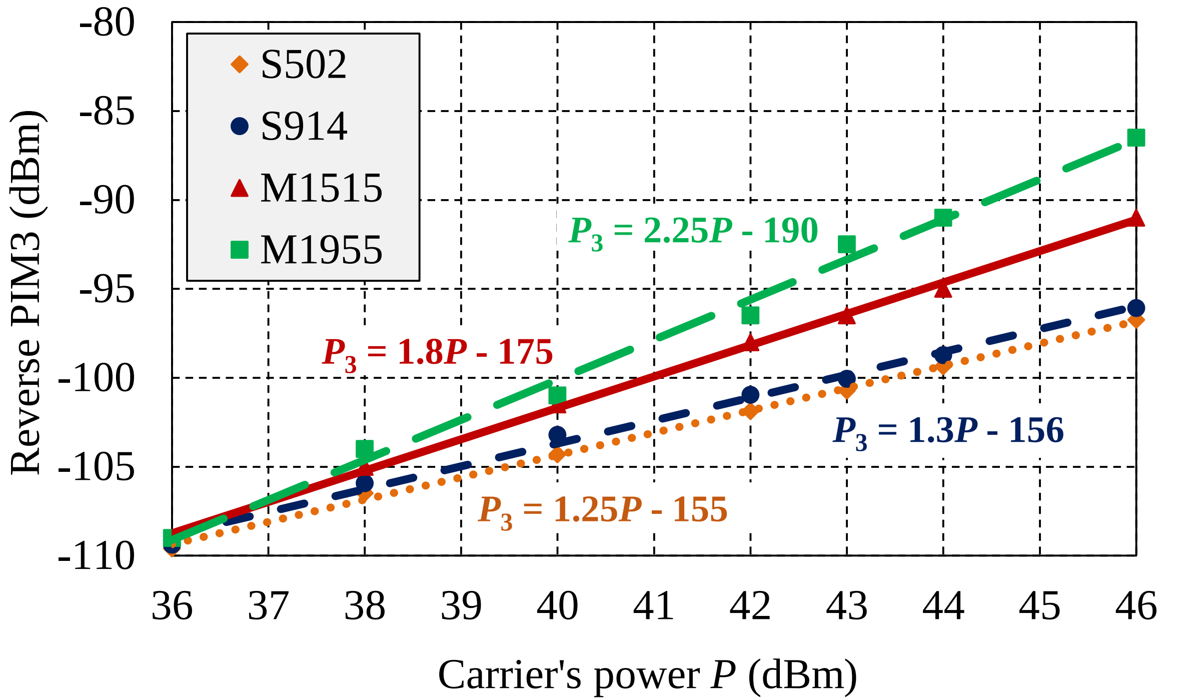
- ✓ **Straight uniform lines of lengths 502 mm (S502) and 914 mm (S914);**
- ✓ **Meandered uniform lines of total lengths 1515 mm (M1515) and 1955 mm (M1955)**

Printed layout of the meandered lines



L=914mm; *W*=1.9mm; *Ws*=87mm; *Wd*=85.1mm; *L*1=350mm; *L*2=42.6mm; *L*3=460mm; *L*4=29.9mm

Magnitude of reverse PIM3 products



PIM3 slopes for the two meandered TLs considerably deviate from those for the straight TLs. Such a behaviour cannot be explained by the effect of the line length only

Conclusions

- The interference patterns created by artificial localised PIM source are instrumental for detecting lumped nonlinearities in distributed circuits;
- The equivalent circuit models based upon the X-parameter formalism have been devised for the analysis of printed TL with distributed and cascaded lumped nonlinearities;
- Distributed PIM generation in printed circuits fundamentally depends on the phase coherence of carriers and PIM products;
- Distinctive difference in dynamics of PIM3 products in the meandered and straight TLs demonstrates significant effect of the conductor layout on the PIM3 generation and suggest multiple physical mechanisms affecting in the behaviour of meandered lines, particularly near the strip bends.