Mapping of Passive Intermodulation Products on Microstrip Lines

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***Abstract* - A new approach to the direct observation of third-order passive intermodulation (PIM3) products on the microstrip transmission lines is proposed. Mapping of PIM3 product distributions along printed microstrip traces and nearby localised sources has been realised with the aid of the near field probing and a standard PIM analyser. The results of PIM3 measurements are presented and discussed in comparison with simulations based on a nonlinear transmission line model (NTL) as well as earlier experimental studies.**

***Index Terms* - Microstrip lines, near field probing, nonlinearities, passive intermodulation**

I. Introduction

Passive intermodulation (PIM) phenomenon in printed lines has recently attracted considerable attention due to the increasing use of printed circuit boards (PCB) in mainstream telecommunications equipment. However, the mechanisms of PIM generation in PCBs are scantly addressed in the literature, and trial-and-error still remains the main methodology for reducing PIM levels in PCB-based devices.

Earlier experimental studies of PIM performance of printed lines, cf. [1] and [2], were based on comparative tests of a series of representative PCB specimens. Those tests involved two-port measurement of the output forward (signals at the line output travelling in the same direction as the carriers) and input reverse (signal at the line input flowing in the direction opposite to the carriers) PIM products generated by the reference length of a microstrip line under two-tone excitation. While these tests revealed certain general trends in PIM generation, even minor dissimilarities of the individual samples, made on different boards with their own launches, considerably increased measurement uncertainty.

An alternative approach based on the near field probing enables direct observations of the PIM product distribution on printed microstrip lines. This technique has been earlier used for identification of the localised PIM sources on patch antennas, [3], and high-temperature superconducting transmission lines, [4]. However, its implementations required specially designed ad-hoc setups which made the measurements rather cumbersome and incompatible with the standard industrial PIM measurement equipment.

In this paper we propose a new test setup for near field probing of PIM products. It is based on a conventional PIM analyser employed for the two-port forward/reverse PIM measurements. The developed approach extends the application range of the standard instrument and enables for the first time effective mapping of PIM products generated on PCB traces by distributed nonlinearity of substrate materials as well as the localised PIM sources.

Details of the test arrangement and verification of the technique are outlined in Section II. Section III reports the representative results of mapping PIM product distributions on uniform printed lines and nearby the localised sources. Main findings are summarised in the Conclusion.

II. Test Arrangement

The test arrangement shown in Fig. 1a is based upon a Summitek Instruments SI-900B PIM analyser [5] operated in the two-port measurement mode. The transmitter port of the PIM analyser is connected to the input of the test line terminated in a PIM certified cable load, and an E-field probe is connected to the receiver port. The probe is made of 6.35 mm diameter semi-rigid coaxial cable with a 6 mm long tip formed by the inner conductor protruding from the shield. To ensure the constant elevation of the probe above the test line, 6.7 mm long polyethylene sleeve cut from an insulating spacer of RG58/U coaxial cable was slipped onto the tip. When placed normally to the board surface, the probe picks up predominately vertical component of electric field. To assess effect of the probe on PIM measurements in this arrangement, the probe was characterised in both linear (Fig. 1b) and nonlinear (Fig. 2) regimes using a reference microstrip line (Sample 1).

The reference 50 Ohm uniform straight microstrip line of width 1.87 mm and length 915 mm was fabricated on a 0.76 mm thick substrate with dielectric constant DK=3.0 and dissipation factor Df=0.0026. The strip and ground plane were coated by 1 um immersion tin plating. Board launchers were made of 125 mm long 0.25″ semi-rigid coaxial cable with a DIN 7/16 flange mount connector at one end and specially designed coaxial-to-microstrip transition unit at the other. The whole assembly provided return loss (RL) below -25 dB at 910 MHz. It is necessary to note that as shown in [6] a good matching is essential for adequate PIM characterisation. The standard two-port PIM test of the reference line at frequency 910MHz corresponding to the 3^{rd} order PIM (PIM3) product (carrier frequencies: 935 MHz and 960 MHz) showed forward PIM3 level -80.1 dBm and reverse PIM3 -113.3 dBm at 2×44 dBm carrier power. Residual forward/reverse PIM3 levels of the instrument were measured below -125 dBm. In the linear regime, the probe was characterised by the S-parameters measured in test arrangement of Fig. 1a where a vector network analyser (VNA) was used instead of PIM analyser. Low RL (|S11|), linear phase variation and almost constant low magnitude of S21 at all positions of the probe along the reference line as shown in Fig. 1b suggested that the probe produced only minor perturbation of the line near field. The probe-to-line coupling estimated as a mean value of S21 measured along the line at 910 MHz was -33.2 dB (Fig. 1b).

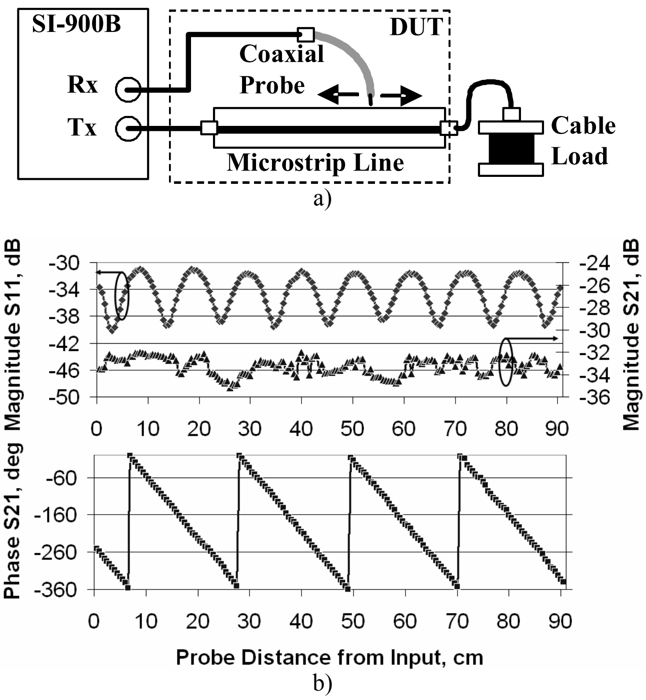

Fig. 1. Test arrangement for near field probing (a) and linear S-parameters measured on the reference line with the probe vs. the probe position (b).

In the nonlinear regime, the probe impact on PIM level was evaluated by comparison of PIM3 product distributions along the reference line measured with different tip caps and probe orientations which provided different probe coupling:

1) Vertical probe with Cap 1 made of the 6.7 mm long sleeve of the cable insulating spacer as described above.

2) Vertical probe with Cap 2 made of 6.7 mm long thin polyethylene tube (pen refill) providing the same elevation (0.7 mm) of the probe tip as the Cap 1.

3) Horizontally oriented probe without cap: a tip side wall was elevated for 2.5 mm above the substrate surface.

Comparison of the PIM3 product distributions measured with these 3 probe arrangements (Fig. 2) shows no qualitative differences and thus illustrates weak effect of the probe on PIM3 generation. The trend of PIM3 level growth along the line is consistent with the earlier observed intensification of forward PIM3 products on the longer lines, cf. [7], and with the predictions of the nonlinear transmission line (NTL) model based upon the concept of distributed nonlinearity in printed lines [8]. It is necessary to note here that ripples on the curves in Fig. 2 are associated with the input/output mismatch of the reference line. This effect has been confirmed by the simulation results for the 50 Ohm reference line (Sample 1) terminated in 48 Ohm input/output loads which are in good agreement with the measurement data in Fig. 2.

Thus, the presented results demonstrate that the proposed technique for near field probing enables fairly accurate mapping of PIM3 product distributions on printed lines and favourably complements the conventional two-port forward/ reverse PIM testing. In the next section, application of the developed techniques to PIM3 product mapping is discussed for the samples with distributed and localised PIM sources.

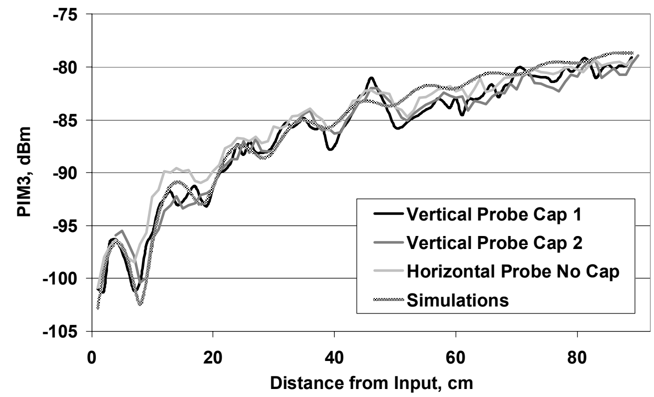

Fig. 2. PIM3 product distribution obtained by near field probing of the reference line with different probe arrangements (PIM3 frequency 910 MHz and carrier power 2×44 dBm) and simulations based on the NTL model [8].

III. Measurement Results and PIM3 Maps

A. Distributed PIM3 Generation

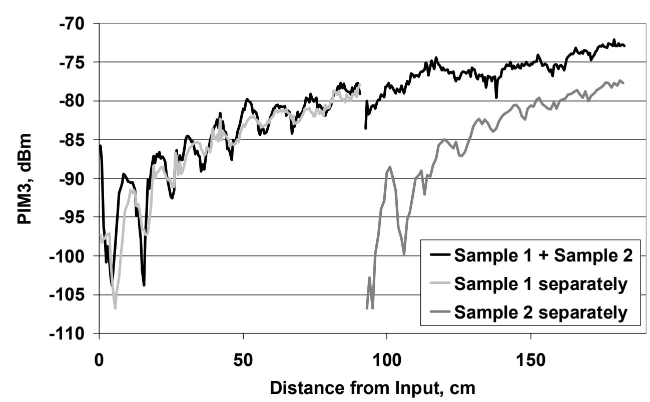

Fig. 3. PIM3 product distributions along a pair of identical microstrip lines (Sample 1 and Sample 2) and their tandem assembly at 910 MHz; carrier power: 2×44 dBm.

In order to explore further distributed generation of PIM3 products on long lines, two identical microstrip lines were connected in tandem. The reference line (Sample 1) referred to in Fig. 2 and its replica made on the same board (Sample 2) were cascaded through a 1 m long PIM-certified coaxial cable. The distributions of PIM3 products on each line and on their tandem assembly shown in Fig. 3 explicitly demonstrate cumulative growth of PIM3 products along the lines.

It is noteworthy that the connecting cable, launchers and Sample 2 in the cascaded arrangement affect PIM3 product distribution on Sample 1. Namely, additional attenuation and reflection of the carriers at the assembly joints incur a discontinuity of the PIM3 distribution plot for the tandem at 91 cm from the input (Fig. 3). Indeed, since an input impedance of the terminated Sample 2 is not exactly 50 Ohm, this gives rise to additional mismatch which causes larger ripples in PIM3 products distribution on Sample 1, especially near its input.

B. *Localised PIM3 Generation*

In order to examine applicability of our near field probing setup to mapping of PIM3 products generated by the localised sources on printed lines, a test sample was fabricated on the low PIM laminate of thickness 1.58mm with DK=2.5, Df=0.0019. The straight microstrip line (Sample 3) comprised a 522 mm central section of width 13.46 mm between two tapered sections providing matching to 50 Ohm input/output launchers. Forward and reverse PIM3 products measured on Sample 3 at frequency 910 MHz and carrier power 2×43 dBm were at the residual level of the test instrument (-125 dBm).

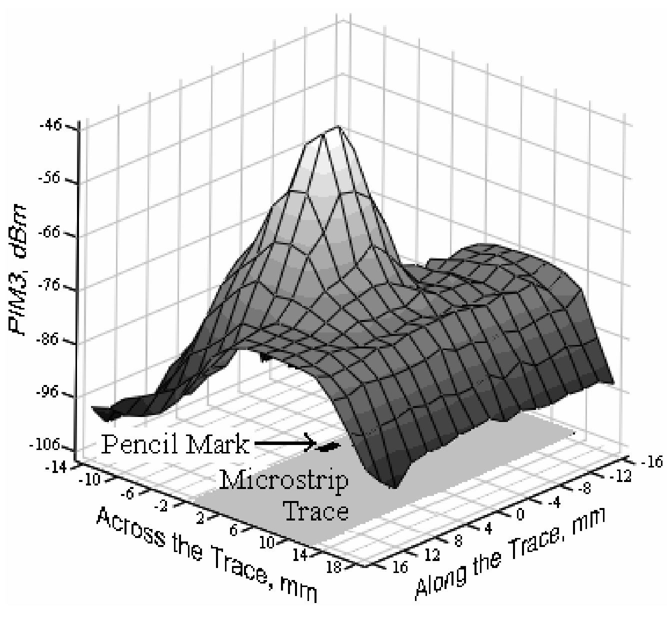

Fig. 4. Near field mapping of PIM3 products at PIM3 frequency 910 MHz generated by a pencil mark (dark spot at the origin of the bottom plane) at the strip edge; carrier power: 2×43 dBm.

The localised nonlinearity was then introduced by 3.5×1 mm pencil mark† drawn at the strip edge in the middle of the central section of Sample 3. The mark did not produce any discernable disturbance of the linear S-parameters measured with the VNA, but generated PIM3 products at the level of -77.8 dBm (forward) and -78 dBm (reverse) in two-port PIM measurements at carrier power 2×43 dBm. Moreover we found that even a tiny pencil mark stimulated noticeable PIM3 response in forward/reverse PIM3 measurements on microstrip lines. In contrast to distributed PIM3 generation, the reverse PIM3 products from the localised source could be equal to or exceed forward PIM3 level, depending on the mark position.

A surface plot in Fig. 4 displays PIM3 product distribution near the microstrip trace (grey rectangle in the bottom plane) with a localised nonlinearity at the strip edge (dark spot). It illustrates the following features of PIM3 generation:

1) A sharp nearly conical spike in the source vicinity, cf. [9].
2) PIM3 products generated by a small pencil mark are guided by the strip conductor in both forward and reverse directions, towards input and output ports with almost equal magnitudes. These PIM3 products from the pencil mark have increased the measured background PIM3 level on the line for about 40 dB.

IV. Conclusion

The new experimental setup solely based on the standard PIM analyser has been developed for mapping of PIM3 products generated by distributed and localised sources on printed lines. It combines near field probing with two-port measurements of PIM products, and offers a versatile means for identification of different mechanisms of PIM generation, discrimination of intrinsic and extraneous PIM sources (localised and distributed) and artifacts, and their location on printed lines. The presented measurement results are in full quantitative agreement with the predictions of the NTL model and earlier experimental studies. Sensitivity of near field probing may, however, pose limitations on mapping distributed generation of PIM3 products in low-PIM laminates, and the conventional two-port forward/reverse PIM testing will be necessary for complete characterisation of such materials.

Acknowledgment

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† Graphite and carbon composites are known to exhibit strong nonlinearity generating PIM products in high-power transmission [10].

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