EXPERIMENTAL OBSERVATIONS OF DISTRIBUTED NONLINEARITY IN PRINTED LINES

A.P. Shitvov, D.E. Zelenchuk, A.G. Schuchinsky

Queen's University of Belfast
Belfast, United Kingdom

Abstract

The paper reports direct experimental observations shedding a new light on nonlinear response of printed transmission lines implemented on PTFE woven glass reinforced substrates. Distributed mechanism of nonlinearity in printed boards is demonstrated by near-field probing of passive intermodulation products generated by two CW carriers along the transmission line. Nonlinear transmission line phenomenology has been successfully applied to analysis and interpretation of the experimental data.

1 Introduction

Effects of weak nonlinearity of printed circuit boards (PCB), perceived as negligible in the past, have become increasingly important for modern mobile telecommunications. Shared antennas, sensitive receivers, modulated signals are just only a few areas affected by PCB nonlinearity at higher power levels. Depending on the signal properties and circuit layout, intrinsic PCB nonlinearity manifests itself in various forms such as passive intermodulation (PIM), cross modulation, AM-to-PM conversion, etc. These processes cause spectral regrowth and distortion of the transmitted signal, which may result in spurious signals falling into the reception bands.

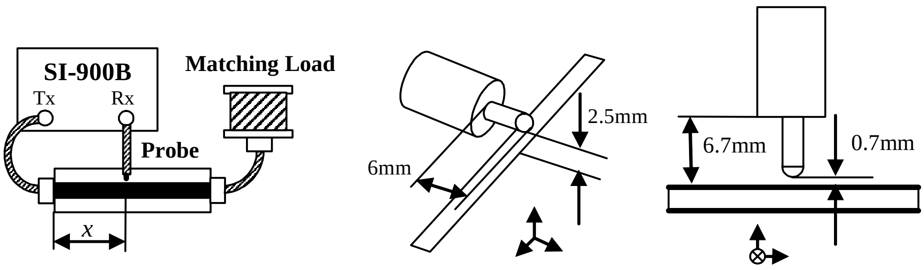
Mechanisms of PCB nonlinearity have been studied so far by mainly measuring the third-order PIM products on 50Ω microstrip lines at two-tone excitations, see e.g. [1]. Observed PIM intensification with the transmission line (TL) length was attributed to the distributed sources of PIM generation [2]. However, such PIM measurements on TL essentially represent only indirect evidences of the distributed nature of nonlinearity. Alternatively, near-field probing earlier used for detection of localised PIM sources on printed lines [3] could be employed for mapping PIM level on the conductor traces and provide necessary information about actual distribution of PIM sources on the printed TL.

In this paper, we present for the first time the results of a direct near-field probing of cumulative PIM effect on a straight 50Ω microstrip line. These results provide explicit evidences of the distributed nonlinearity existing in printed TL and well correlate with the phenomenology of the nonlinear transmission line (NTL) model. Characterization of PCB nonlinearity is also discussed on the basis of PIM measurements for a wide range of input power variation.

2 Experiment Methodology and Results

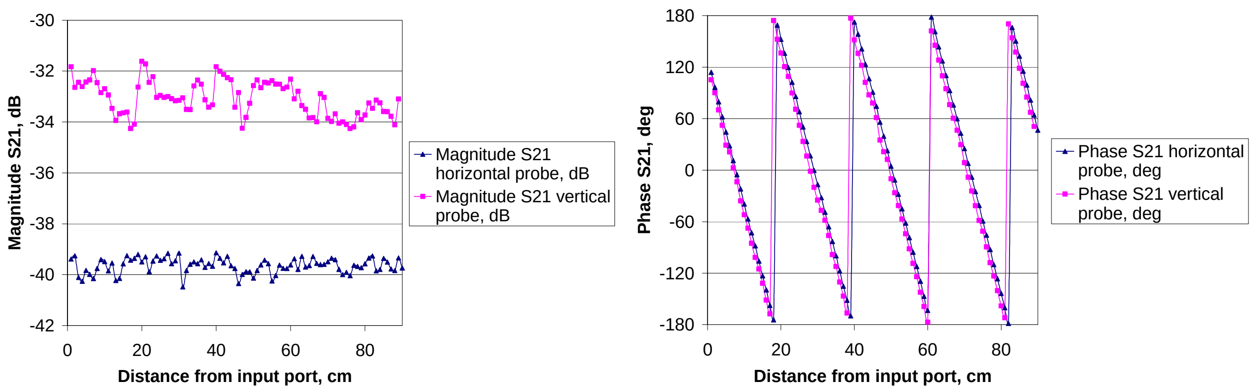
Basically, PIM frequencies are the by-products of nonlinear mixing of a multi-tone signal, which constitute various linear combinations of the fundamental tones. Third-order PIM (PIM3) products are subject of major concern because the third-order intermodulation products of the transmitted multi-carrier signal may fall in the reception band, particularly for GSM networks. We employed PIM3 measurements to characterise intrinsic nonlinearity of printed boards.

The test setup for near field probing of PIM3 products was based on the standard Summitek SI-900B PIM analyzer used in transmission mode (Fig. 1). However, in contrast to the conventional arrangement, the receiving port of the analyzer was employed to measure PIM3 on the probe as two tones were injected at the input of the terminated microstrip transmission line. The capacitive near-field probe made of 0.25″ semi-rigid coaxial cable had six millimeter long pin with a rounded tip protruding from the enclosure; the probe was moved along a microstrip line at fixed height as shown in Fig. 1. Two orientations of the probe provided different coupling due to different distance to the trace surface: 2.5mm for the horizontal and 0.7mm for vertical probes. A straight 50Ω microstrip line of width 1.87mm and length 914mm was fabricated from 35 microns low profile copper cladding on 0.76mm thin PTFE based woven glass reinforced PCB laminate with DK=3.0, Df=0.0026. Immersion tin plating was used for trace coating.

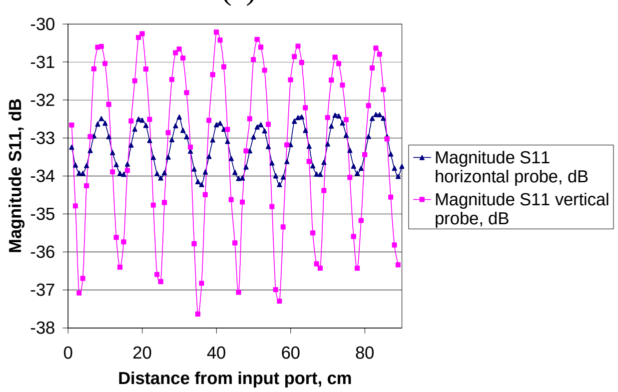


(a) (b) (c)

Fig. 1: Measurement set-up (a) and probe arrangements: horizontal (b) and vertical (c)



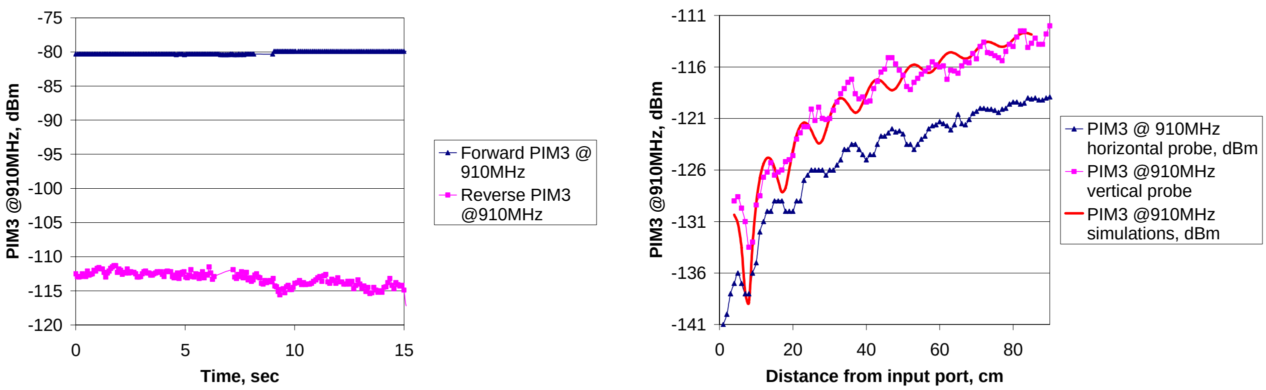
(a) (b)



(c)

Fig. 2: S-parameters for the vertical and horizontal orientations of the probe (Fig. 1) at PIM3 frequency 910MHz. Average coupling was -40.2 dB for the horizontal and -33.1 dB for vertical orientations.

To assess the probe effect on the measurements, the probe was characterised by its S-parameters. Linear dependences of the phase of S21 versus the probe position and fairly stable magnitudes (within measurement uncertainty): -33.1 dB at vertical and -40.2 dB at horizontal orientations, shown in Fig. 2, indicate that the probe caused very weak near-field perturbation. S11 also showed regular behaviour as the probe was moved along the line with stronger disturbance caused by the vertical probe. The results of PIM3 measurements at 2×44 dBm carrier power are shown in Fig. 3a for input ('Reverse') and output ('Forward') ports of the test line without probe. Fig. 3b displays the results of the near-field probing at 910MHz with 935MHz and 960MHz fundamental tones on the line terminated into a hundred meter long low-PIM semi-rigid 50Ω coaxial cable.



a) b)

Fig. 3: PIM3 testing: a) PIM3 at the input ('Reverse') and output ('Forward') ports; b) Near-field probing results and NTL-simulations.

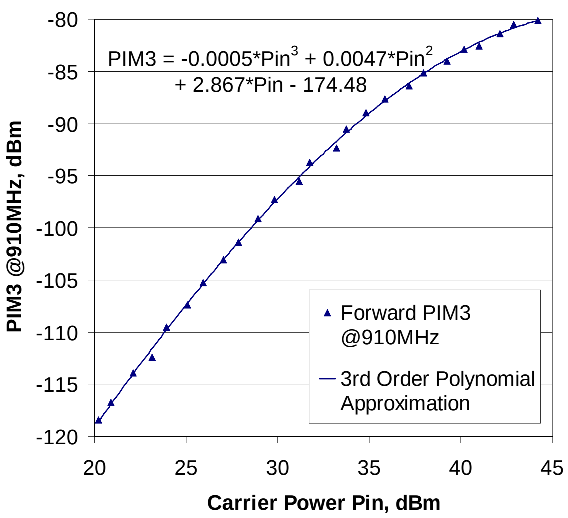


Fig. 4: Measured Forward PIM3 (dBm) as a function of the carrier power (P_{in}, dBm) @910MHz

The results in Fig. 3b clearly demonstrate the cumulative intensification of PIM3 as the probe moved away from the input port. The magnitude of ripples on the curves in Fig. 3b depends on the probe coupling: tighter coupling causes larger variations. In addition, it demonstrates a tendency of PIM3 saturation with the distance from input port. The observed cumulative growth of PIM3 level and long distance saturation are consistent with the nonlinear transmission line (NTL) model and appear as the manifestations of distributed nonlinearity and attenuation [4]. Details of the model and analysis will be presented elsewhere, and now we only illustrate very good correlation between the model of the TL with distributed nonlinearity and the results of near-field probing (Fig. 3b).

To gain a deeper insight into nature of PCB nonlinearity, we performed PIM3 measurements in a wide range of variation of the carrier power (Fig. 4). The power curve shows saturating behaviour at higher power levels. The measured slop of the PIM3 curve versus the carrier power differs from the theoretical value of 3 predicted by the simple PIM3 models [4]. Analysis of the model limitations has revealed that the basic third-order model, despite good agreement with the near-field results, is rather incomplete for thorough description of nonlinearity in printed lines and needs to be refined by taking into account the higher order nonlinear terms.

3 Conclusions

Experimental study of PCB nonlinearity was carried out by means of near-field probing of the 50Ω microstrip line with aid of the standard test instruments. Direct observation of cumulative growth of PIM3 along the length of microstrip line has been performed for the first time. It has been demonstrated that the measurement results are consistent with the PIM3 analysis based on the model of transmission line with distributed weak nonlinearity. It has been shown that PCB nonlinearity has complex nature, and its model requires accounting for the higher-order nonlinear terms for correct evaluation of PIM3 dependency over the carrier power.

Acknowledgements

The work is supported by the EPSRC grant EP/C00065X/1. Authors wish to acknowledge Taconic Advanced Dielectric Division, Trackwise Designs Ltd, PCTEL Inc and Castle Microwave Ltd for their generous help with preparation of the samples and providing measurement facilities.

References

[1] B. El Bana, Passive intermodulation from printed circuit boards, *Technical Report No D1200002735*, *Powerwave Technologies*, June 2006

[2] Schuchinsky A.G., Francey J., Fusco V F., Distributed Sources of Passive Intermodulation on Printed Lines, *2005 IEEE AP-S Int. Symp./URSI Meeting, Washington, DC,* 3-8 July 2005.

[3] S. Hienonen, Studies on microwave antennas: passive intermodulation distortion in antenna structures and design of microstrip antenna elements, *Dissertation for the degree of Doctor of Science in Technology*, Helsinki University of Technology, 2005

[4] A.P. Shitvov, D.E. Zelenchuk, A.G. Schuchinsky, Distributed model of passive intermodulation phenomena in printed transmission lines, *Proc. of 2006 International Student Seminar on Microwave Applications of Novel Physical Phenomena*, Rovaniemi, Finland, pp.61-63, 2006