

# EFFECT OF LAMINATE PROPERTIES ON PASSIVE INTERMODULATION GENERATION

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

*The Institute of Electronics, Communications and Information Technology (ECIT),  
Queen's University Belfast, Northern Ireland Science Park, Queen's Road, Queen's Island,  
Belfast, BT3 9DT, UK*

*E-mail: d.zelenchuk@queens-belfast.ac.uk*

## Abstract

The results of experimental study of Passive Intermodulation (PIM) on Printed Circuit Board (PCB) laminates are reported. Comparison of PIM performance of different materials has shown correlation between the PIM level and the laminate physical properties. The effect of the line length on PIM level has been experimentally observed. A simple model has been devised to describe the relation between the line length, attenuation and PIM performance of the lengths of straight microstrip lines.

## Introduction

PIM has been known as a detrimental phenomenon in telecommunications devices for several decades [1]. It manifests itself in parasitic signals in adjacent channels of the base station receivers, and has been observed in military, space and mobile telecommunications. In the past, unawareness of PIM problem led to delay or even cancellation of some satellite projects [2]. PIM generation occurs in such passive devices as antennas, cables, connectors, circulators, delay lines, filters and many others. Therefore, the conventional means of eliminating the unwanted signals by filtering them out or by introducing pre-distortions cannot help here because the components used for their implementation can themselves cause PIM. Obviously, the most adequate way to suppress PIM is to identify and eliminate its source. In particular, it is well known now that loose and corroded joints ("rusty bolt" effect), ferrites and ferrous metals should be avoided to decrease PIM level in the passive devices [1], [3].

New challenges of telecommunication industry require more compact devices, including printed antennas and feeders integrated on PCB. However, in order to enable for wide use of PCB in high power applications, the issue of PIM in PCB should be thoroughly addressed. In several studies [4]-[9] it has been shown that apart from connectors and soldered contacts PCB itself can be the source of PIM. These papers demonstrated that copper type (electrodeposited or rolled annealed), copper roughness, etching quality and finishing have strong impact on PIM performance of the devices. All these factors undoubtedly contribute to the overall PIM level. But, to the best authors' knowledge, there has not been reported a clear evidence of effect of dielectric material used in PCB laminates on PIM level.

In this paper, effect of the laminate dielectric on the PIM performance has been examined for a set of materials. The measurements were performed on the straight microstrip lines of 917mm long. The idea underlying the design of test samples was to minimise uncertainty of PIM measurements. In order to reduce unpredictable effect of the line discontinuities on PIM response, the straight 50 $\Omega$  microstrip lines have been fabricated across the full length of the laminate standard sheet. It was anticipated that the longer lines would facilitate differentiation of the laminates in terms of their PIM performance. Since device manufacturers do not use so long lines in practice, a simple approach to correlate PIM for the lines of different length has been proposed. To verify the approximation, PIM dependence on the line length has also been investigated.

## Experiment design

In order to study a laminate itself, all other possible factors causing PIM generation should be excluded. To meet these requirements, the PCB materials with the same copper foils were chosen and the samples were manufactured in the same batch using the same etching and finishing processes. The basic properties of the laminates are specified in Table 1.

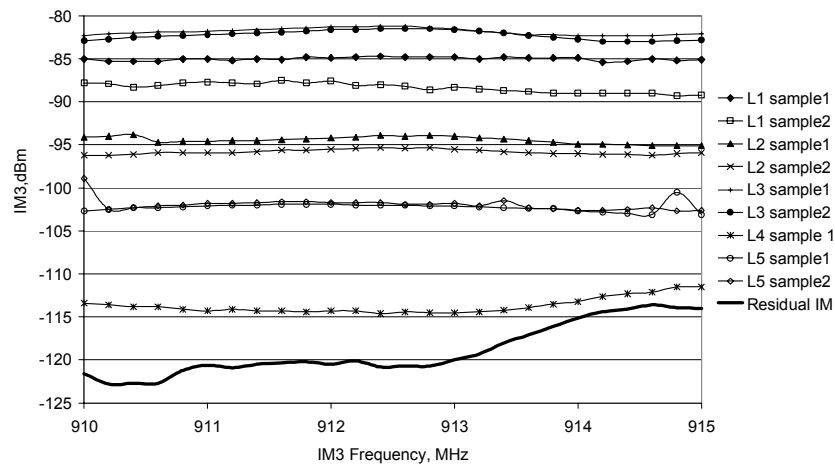
The measurements were carried out with Summitek SI-900B PIM Analyzer. The device can measure both PIM at input port called Reverse and at output port called Forward. The specified maximum sensitivity of the IM receiver is -140dBm and dynamic range is 75dB. The actual minimum measurable value of PIM for a sample is determined by the noise floor and residual PIM of the measuring setup. The latter was measured at 2 $\times$ 43dBm carriers to be below -126dBm in Reverse measurements and below -120dBm from 910MHz to 913MHz with the further growth up to -114dBm at 915MHz in Forward PIM measurements. The specification for GSM band is -112dBm as the maximum acceptable level of IM3 products at 2 $\times$ 43dBm input carriers. Note

that this PIM level is specified for the whole system, and it is difficult to predict contribution of individual components. Nevertheless, keeping PIM of every component below the specified threshold is of great importance for the system performance.

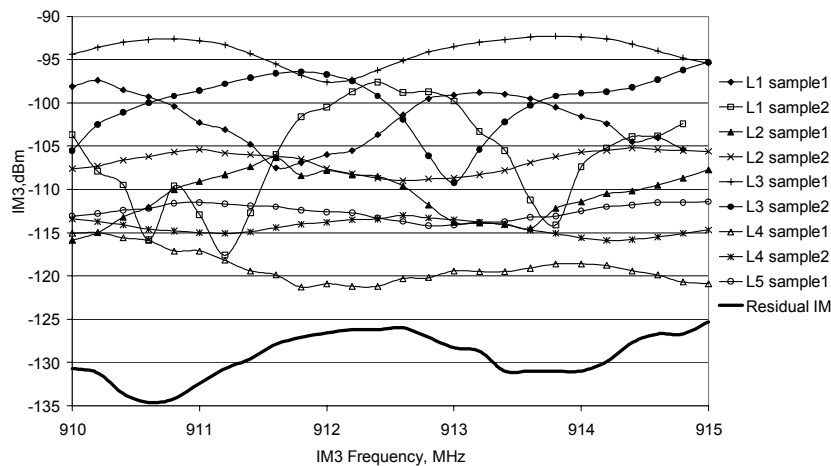
Each board in the study contained three samples of 50Ω microstrip lines. All the lines were visually inspected and no cracks, scratches and traces of finishing defects had been found. Two different techniques were used for launching signals to the lines: direct cable launch using specially designed coaxial-to-microstrip transitions and edge-mount DIN 7/16 connectors. The cable assemblies were certified at 2×43dBm carriers to have the residual IM3 below -122dBm in GSM band. Three lines per board with different launches have been used to assess the effects of assembly and launchers.

**Table 1. Properties of the examined materials, (a) – value at 10GHz, (b) – value at 1.9GHz, (\*) – Supplier 1, (\*\*) – Supplier 2.**

Part #	Composition	DK	DF	Moisture Absorption%	Substrate thickness, mm
L1*	Cured resin-impregnated woven fibreglass	3.00 (a)	0.0034 (a)	0.8	0.76
L2**	PTFE Woven Glass	3.00 (a)	0.0030 (a)	<0.02	0.76
L3**	PTFE Woven Glass	3.00 (a)	0.0026 (a)	<0.16	0.76
L4**	PTFE Ceramic Woven Glass	3.00 (b)	0.0014 (b)	<0.02	0.76
L5**	PTFE Woven Glass	2.17 (a)	0.0009 (a)	<0.02	0.76
L6**	PTFE Woven Glass	2.50 (a)	0.0019 (a)	<0.02	1.58



**Fig. 1. Forward PIM characteristics.**



**Fig. 2. Reverse PIM characteristics.**

## Material study results

The results of Forward PIM measurements are presented in Fig.1. The laminate L3 exhibits the poorest performance closely followed by L1. The PIM characteristics of L2 and L5 are much better, and L4 shows the best performance and meets the specification of -112dBm. The tests have shown variations in PIM performance of the lines fabricated on the same board. This can be attributed to workmanship factor and also allows us to assess the measurement uncertainties.

Large variations of Reverse PIM level with frequency can be observed in Fig.2, although the sequence of the materials in respect to their PIM performance remains qualitatively the same. For some samples of L1 and L3 materials, PIM level changes for about 20dB. Such variations can be attributed to the increased return loss. Indeed, Reverse PIM can be affected by the standing wave pattern in the line and therefore exhibits such strong frequency dependence. It is noteworthy that the Reverse PIM is lower than the Forward PIM for all the materials, and for L4 and L5 it is below -112dBm.

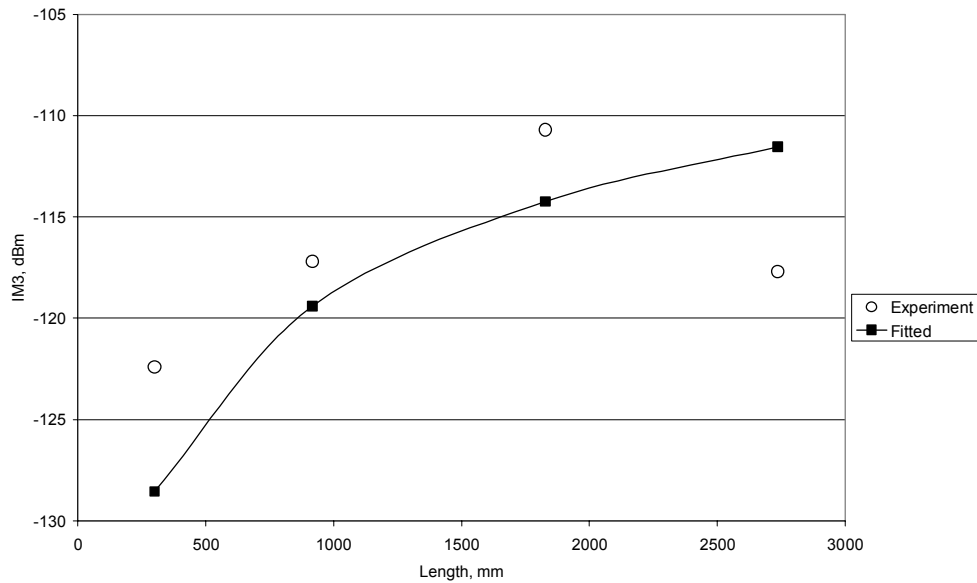
The fact that all the samples retain similar relation between Forward and Reverse PIM suggests certain common PIM related properties of the materials. The data sheets for the materials have been carefully analysed and two parameters have come to the front. Table 1 shows that the two best materials have significantly lower losses than others, albeit the material L5 with lower loss than L4 had worse PIM performance. Another interesting observation is that the moisture absorption for L2, L5 and L4 is much less than for L1 and L3. In the study L1 and L3 materials have exhibited worse PIM than the other materials. It is noteworthy that L1 and L3 laminates come from different suppliers and have dissimilar structure, which emphasise the correlation between moisture absorption and PIM. This suggests the necessity of further investigation of the moisture effect that can facilitate copper oxide formation in course of lamination process and potentially cause PIM generation.

## PIM dependence on the line length

Four meander-like 50Ω lines of different length were fabricated on the L6 laminate so as to experimentally assess PIM dependence on the line length and to devise a simple formula for calculating the PIM level in dependence on the line length. In [11] it was found for the line with distributed nonlinear resistance that Forward IM3 current distribution along infinite transmission line could be expressed as follows:

$$P_{PIM}(x), dBm = 20 \log[\exp(-\alpha x) - \exp(-3\alpha x)] + C,$$

where  $\alpha$  is attenuation constant, which can be easily estimated from the specified material parameters [10].  $C$  is a fitting parameter obtained by an optimization technique.



**Fig. 3. PIM dependence on the length of the 50Ω microstrip line.**

Fig.3 shows the results of the measurements at 914.2MHz in comparison with the fitting procedure. The optimization process converged to  $C = -98.18\text{dBm}$  and theoretically predicted attenuation is  $0.052\text{m}^{-1}$ . Maximum deviation of the experimental data from the theoretical curve is 6.17dBm. The value is commensurable with

uncertainties of measurements observed in these experiments. Using the approximate formula, Forward PIM for all laminates used in the material tests was recalculated for the lines of length 300mm (see Table 2). These estimates have shown that even for the short 300mm line L4 and L6 laminates only meet the PIM specifications.

Measurements on the laminate L6 is used to verify the recalculation procedure. Indeed, IM3 product for the 300mm microstrip line measured at 914.2MHz (Fig.3) was -122.4dBm that is reasonably close to the recalculated value in Table 2.

**Table 2. Forward PIM at 914.2 MHz recalculated from 917mm line to 300mm line.**

Part#	$\alpha$ , m <sup>-1</sup>	Averaged over the samples Forward PIM 917mm, dBm	PIM reduction, dB	Recalculated PIM for 300mm line, dBm
L1	0.106	-87.2	8.6	-95.8
L2	0.101	-95.5	8.6	-104.1
L3	0.095	-82.5	8.7	-91.2
L4	0.08	-112.6	8.9	-121.5
L5	0.064	-102.8	9.0	-111.8
L6	0.052	-117.2	9.2	-126.4

## Conclusion

Effect of the PCB laminate material properties on PIM performance has been discussed. Experimental measurements of Forward and Reverse PIM on several laminates have been performed. It has been shown that loss factor and moisture absorption correlate with PIM level of the laminates. The dependence of PIM on the length of the microstrip line has been investigated. Based on the measurement results, a simple approximation for estimation of PIM level on the microstrip lines of various lengths has been suggested and validated.

## Acknowledgements

The work is supported by the EPSRC grant EP/C00065X/1. The authors appreciate the generous help of Taconic ADD and assistance of Trackwise Ltd., Rosenberger Hochfrequenztechnik GmbH & Co. KG, Castle Microwaves and Racal Antennas Ltd. The authors are grateful to Prof. V. Fusco, Dr. O. Malyuskin and Dr. D. Linton for stimulating discussions.

## References

- [1] A.P. Foord and A.D. Rawlins, "A study of passive intermodulation interference in space RF hardware," (ESTEC contract 111036 final report), University of Kent at Canterbury, May 1992
- [2] C. F. Hoerber, D. L. Pollard, and R. R. Nicholas, "Passive intermodulation product generation in high Power communication satellites," Communication Satellite Systems Conf., San Diego, CA, Mar. 1986, pp. 361-374.
- [3] Y.-S. Wu, W. H. Ku, and J. E. Erickson, "A study of nonlinearities and intermodulation characteristics of 3-port distributed circulators," IEEE Transactions on Microwave Theory and Techniques, vol.24, no.2, Feb.1976, pp. 69-77
- [4] 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, Report S267, Helsinki University of Technology, March 2005
- [5] B. El Banna, T. Olsson, J. Uddin, "Sources of Passive Intermodulation in Base Station Antenna Systems," Proceedings of LAPC 2006, pp. 139-144, Loughborough, UK, 11<sup>th</sup>-12<sup>th</sup> April 2006
- [6] A.G. Schuchinsky, J. Francey, and V.F. Fusco, "Distributed sources of passive intermodulation on printed lines," 2005 IEEE AP-S/URSI Symposium, USA
- [7] N. Kuga and T. Takao, "Passive intermodulation evaluation of printed circuit board by using 50Ω microstrip line," Asia Pacific Microwave Conference APMC 2004, New Delhi, India
- [8] "Passive intermodulation study," Taconic ADD, April 2002, [www.taconic-add.com](http://www.taconic-add.com)
- [9] J.V.S. Perez, F.G. Romero, D. Ronnow, A. Soderbarg, and T. Olsson, "A microstrip passive intermodulation test set-up; comparison of leaded and lead-free solders and conductor finishing," 5th International Workshop on Multipactor, Corona and Passive Intermodulation In Space RF Hardware MULCOPIIM 2005, ESTEC, Noordwijk, The Netherlands.
- [10] R. E. Collin, Foundation for Microwave Engineering, 2nd Ed., McGraw-Hill (1992).
- [11] A. P. Shitvov, D. E. Zelenchuk and A. G. Schuchinsky, "Distributed Model Of Passive Intermodulation Phenomena In Printed Transmission Lines", Proceedings of International Student Seminar On Microwave Applications Of Novel Physical Phenomena, pp.61-63, Rovaniemi, Finland, August 24-25, 2006