2010 IEEE AP-S International Symposium/URSI Meeting, Toronto, Canada, 533.3, doi:10.1109/APS.2010.5561733

Self-Induced Instability of Passive Intermodulation in Microwave Laminates

Torbjörn Olsson(1), Alexey Shitvov*(2) and Alexander Schuchinsky(2)
(1) Powerwave Technologies Sweden AB, Kista, Sweden
(2) The Queen's University of Belfast, Belfast, Northern Ireland, UK
E-mail: a.shitvov@qub.ac.uk

Introduction

Passive intermodulation (PIM) generation in microwave laminates presents one of the major challenges to the manufacturers of printed antennas and beamforming networks. Whenever the PIM products, interspersed into the transmitting signals, appear at the receiver input, they degrade the system performance and might even block the channel completely. This is a common problem for GSM base stations, where the third-order PIM products of the transmitted multi-carrier signals appear as spurious signal in the receiver band. This detrimental effect is further aggravated by the inter-band interference in multi-band communications systems. The low PIM performance of the printed circuit board (PCB) materials is a key issue for ultra-wide-band communications, co-located antennas, antennas in a complex changing environment and densely-packed electronic front-ends.

The PIM response currently is a subject of stringent specification for every component, ranging from individual printed antennas to the packaged systems. However, despite the extensive research in the PIM production in PCB, the complexity of the phenomena and difficulties of low-PIM measurements have long been hindering the understanding of the origins and mechanisms of the distributed PIM generation. Apparently, this still hampers the development of the low-PIM microwave laminate materials and printed devices.

This paper presents the new aspects of the PIM characterization of PCB materials revealed by the recent experiments carried out over extended period of time on the commercial laminates with different finishing of printed lines. A significant self-induced reduction of the PIM level has been discovered and the main mechanisms involved in this effect are identified. These properties of the microwave laminates are of particular importance for PCB industry and the microwave equipment manufacturers.

Phenomenology of Passive Intermodulation Generation in Printed Lines

PIM generation in PCBs stems from the distributed weak nonlinearity of the conductor tracks and dielectric substrate [1]. In particular, it had been demonstrated experimentally that the low-profile copper foils provide lower PIM response, which subsequently led to adoption of low-profile reverse-treated copper foils in microwave laminates [2]. In a wider context, the quality of the conductor-to-substrate interface is perceived as the primary factor affecting the PIM performance of PCBs. It has also been noted that the PCB processing may cause slight delamination of the etched strip edges which can trap the chemical residues [3], thus leading to a higher PIM level. The strip finishing also has significant impact on the PIM performance of the printed tracks [4], and immersion-tin coating proved to be the best option for the low-PIM circuits.

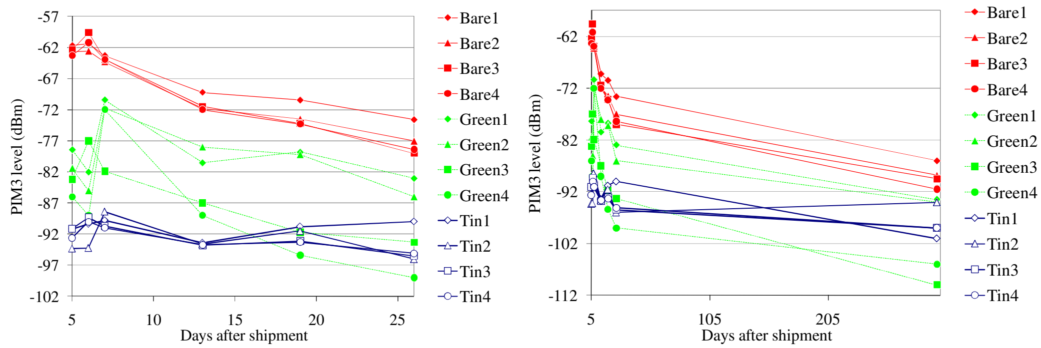
Whatever were the mechanisms involved in the distributed PIM production, it has been normally observed that the PIM performance of PTFE-based laminates does not significantly degrade with time. In the meantime, experimental data indicate that the water absorption, formation of intermetallic composites between the copper cladding and finishing, chemical residues trapped at the delaminated strip edges and environmental oxidation of the bare copper strips might cause detectable variations of the PIM response. The dependence of the measured PIM on the duration of the power exposure due to heating or 'burn-in' effects [5] has also been of concern. Next section presents new experimental observation of PIM instability in PCBs and its physical interpretation.

Stability of Passive Intermodulation Performance of Printed Lines

To investigate the stability of the PIM performance, a series of experiments with commercial laminates has been conducted using the test setup with the contactless broadside strip launchers (CSL) [6]. The forward third-order PIM (PIM3) level has been monitored on the microstrip lines with different finishing. The microstrip layout was comprised of 1234-mm-long uniform strip section terminated into two end couplers. Four replicas of the layout were fabricated in the same batch for several types of the finishing on the commercial Taconic RF-30-0300-CL1/CL1 laminate. The reference samples had bare copper tracks, while the conventional coatings of 1 μm immersion tin or solder mask over bare copper ("green-mask") were applied to the other samples. The forward PIM3 measurements were performed at the single intermodulation frequency of 915 MHz (corresponding carriers 930 and 945 MHz) at 2×43 dBm carrier power. The specimens were tested several times during the 297-day period starting from the shipping date. Between the test sessions, the panels were stored on a flat surface in office environment.

The measurement results in Fig. 1 demonstrate a considerable improvement of the PIM3 performance of the bare-copper and green-masked boards over the test period. Notably, the bare copper tracks initially produced significantly higher PIM3 level, which faster decreased with time as compared with the coated boards. On the contrary, the tin-plated boards have exhibited much less variations of the PIM3 level. Remarkably, in the first two rounds of the measurements, slight bow of the green-masked boards was observed and attributed to the contraction of the coating film. In the third round of the measurements on the 7th day after shipping the panels were bent over a cylindrical post in order to straighten them. This resulted in significant increase of the PIM level measured on the two of the four boards, see Fig. 1a.

The observed reduction of the PIM level could be attributed to the stress relaxation in the commercial woven glass/ PTFE composite substrates. The CSL test fixture employed in the testing required the copper cladding to be completely removed from the bottom (ground) side of the panel and most cladding was also etched out from the top side to form the signal tracks. Indeed, so extensive exposure of the laminate surface inevitably causes dimensional instability of the substrate due to relaxation of the stress imposed during the glass fabric coating and panel lamination [7]-[8]. In particular, the manufacturer specification of the RF-30 laminate [9] gives 200-400 ppm lengthwise (machine direction) expansion and up to 1000 ppm crosswise (cross direction) shrinkage as the typical estimates for the processed laminates. Similarly, the forced board bending is thought to have caused a considerable elastic stretching strain and its subsequent relaxation after the stress release. The dimensional changes due to the viscous response of the amorphous phase of semi-crystalline PTFE can take days in ambient conditions, which is consistent with the timescale of the variations observed in Fig. 1.



a) b)

Fig. 1 Variations of the PIM3 response measured on the processed printed lines with different strip finishing: a) short-term observations; b) extended observation period.

It is noteworthy that the stress relaxation can be facilitated by elevated temperatures. This phenomenon has apparently entailed the weaker PIM3 response of the green-masked and tin-plated boards, because deposition of these coatings involves high-temperature processes. Furthermore, the strain variations of the green-mask coating could also cause additional dimensional instability of the finished boards. This property is indicated by the larger spread of the PIM3 responses of the green-masked boards in Fig. 1.

To further corroborate the former conjecture a series of the tests has been carried out with a heat-treatment of the printed boards involved. The tests were performed on the printed boards fabricated on the same commercial laminate in three different production batches. In each batch, six replicas of the printed lines in two sets of different finish coating, viz. bare copper and ‘green mask’, were fabricated. The objective of this experiment was to assess the effect of heat treatment in course of fabrication on the PIM generation.

In the first round of measurements, the forward PIM3 level was recorded for all boards shortly after arrival. The carrier power level and frequencies, and the test setup were the same as in the previous experiment. After that, three lines from each set of the bare-copper boards were subjected to heating at 125°C for 80 min. Three other lines from each set were held at room temperature. The green-masked lines were not heated either, because application of the green-mask coating during the fabrication had already involved the heat treatment. These boards have been used as the reference samples.

The second round of measurements was performed in four days after the first. Fig. 2 displays the changes of the forward PIM3 level of the heat-treated bare copper boards against the reference bare copper boards and green-masked boards. The green-masked boards show a minor increase of the PIM level which is within the measurement uncertainty. The most important result in Fig. 2 is that the heat-treated bare-copper boards demonstrate considerably greater PIM decrease over the test period as compared to the reference bare-copper and green-masked boards. Moreover, the final PIM level of the heat-treated boards approaches the initial PIM level of the green-masked boards, which corroborate the conjecture of the heat-treatment effect on the PIM generation.

It is noteworthy that the presented measurement results bear no clear indication of the actual physical phenomena underlying the effect of elastic stress relaxation in the processed PTFE-based substrates on PIM performance of the printed lines. This issue still requires further investigation.

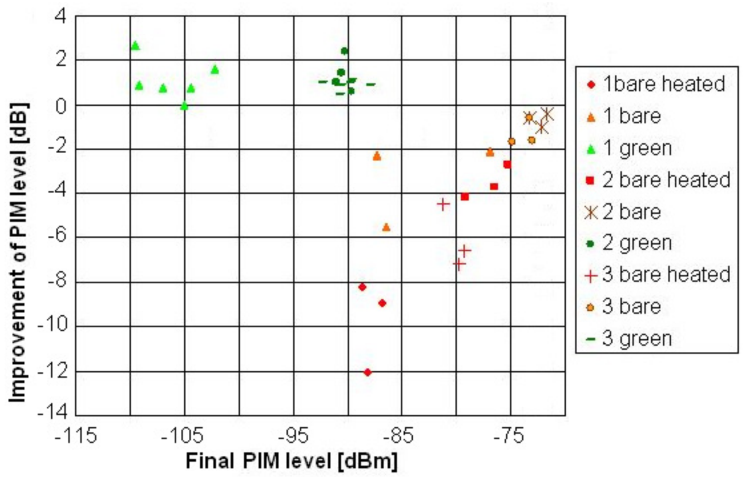


Fig. 2 Four-day improvement of the forward PIM3 in the bare-copper and green-masked microstrip lines. The boards are from 3 different production batches of 6 boards for the respective finishing each with 3 of 6 bare-copper boards subjected to the heat treatment.

Conclusion

The experimental results presented above provide the strong evidence of the significant instability of the PIM performance of commercial PCB laminates. The observed phenomenon is attributed to the viscoelastic stress relaxation in the processed boards. Although the presented data show improvement of the PIM performance with time, the associated physical mechanisms indicate the necessity of tighter manufacturing control over the electromagnetic properties of the high-performance laminate materials.

References

[1] Schuchinsky, A.G., Francey, J., Fusco, V.F., “Distributed sources of passive intermodulation on printed lines,” in *Proc. IEEE Antennas and Propagation Society International Symposium*, 2005, vol. 4B, pp. 447-450

[2] Francey, J., “PIM – passive intermodulation,” Taconic ADD, 2007. [Online] http://www.taconic-add.com/en--technicaltopics--pim-passive-intermodulation.php

[3] Shitvov, A.P., “Passive intermodulation in printed transmission lines,” Ph.D. dissertation, Queen’s University of Belfast, Belfast, United Kingdom, 2009

[4] Pérez, J.V.S., Romero, F.G., Rönnow, D., Söderbärg, A., and Olsson, T., "A microstrip passive intermodulation test set-up; comparison of leaded and lead-free solders and conductor finishing," in *Proc. MULCOPIM’05,* 2005, pp. 215-222

[5] Gohdes, H., “Impact of power variation on 3rd order passive intermodulation of coaxial RF-cables and their connectors,” in *Proc. IWCS’97*, 1997, pp. 1-7

[6] Shitvov, A.P., Zelenchuk, D.E., Olsson, T., Schuchinsky, A.G., and Fusco, V.F., “Transmission/reflection measurement and near-field mapping techniques for PIM characterisation of printed lines,” in *Proc. MULCOPIM’08,* 2008, paper PIM-6, p.1-6

[7] *Taconic fastRise27 Multilayers: General Processing Guidelines*, Taconic ADD. [Online] http://www.taconic-add.com/pdf/taconic-fastRise27-processing.pdf

[8] *After Etch Stress Relief in RT/duroid® High Frequency Laminates*, Rogers Corporation, 2003. [Online] http://www.rogerscorp.com/documents/636/acm/After-Etch-Stress-Relief-in-RT-duroid-Microwave-Laminates.aspx

[9] *ORCER RF-30*, Taconic ADD, Technical Datasheet, 2007. [Online] http://www.taconic-add.com/pdf/rf30.pdf