Development and validation of a wide band Near Field Scan probe for the investigation of the radiated immunity of Printed Circuit Boards

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***Abstract*—The increasing complexity of electrical functions embedded in automotive and aeronautic applications increases the duration of the EMC qualification tests and the risk of non-conformity. The cost of certified means and skilled personnel for a normative test in radiated immunity are high and are often a bottleneck for the electronic suppliers. Any late-detected EMC non-compliance leads to an increased costs. To solve their problem, electronic suppliers need fast, economical and easy-to-use investigation tools. The Near Field Scan Immunity (NFSI) method developed for Integrated Circuits (IC) testing seems to be a good solution to perform quick investigation at Printed Circuit Board (PCB) level. This paper presents the desired characteristics of such an immunity probe based on normative requirements at equipment level and compares several probe design.**

Keywords—Near Field Scan Immunity; Radiated immunity; probe; near field calculation; calibration; IEC 62132-9

I. INTRODUCTION

Near-field scan technique to evaluate the susceptibility of IC appeared in the early 2000 [1] and [2]. This method allows the spatial localization of functional defects caused by electric and/or magnetic field generated by a probe placed above the Device Under Test (DUT). In [2], the method is applied to a 16-bit microcontroller to determine the level of susceptibility of the Phase Lock Loop (PLL). In [3] and [4], the method is compared to the IEC 62132-4 [5] Direct Power Injection (DPI) method and the IEC 62132-2 [6] TEM cell and Wideband TEM Cell method. The immunity level of an operational amplifier AD8622 has been investigated with these 3 different techniques and the NFSi measurement revealed sensitivities in frequencies not revealed by TEM cell and DPI methods. In [7], the immunity of a 8-input ARINC bus transceiver has been measured using NFSI method between 1 MHz and 1 GHz and compared to the immunity measured using a TEM cell method. These works stated the interest of NFSI method as it revealed some susceptibility areas whereas the TEM cell method revealed no defect.

Near Field scan immunity standard measurement method is described in IEC TS 62132-9 [8]. This measurement method provides a mapping of the susceptibility of an IC to an electric or a magnetic field with a spatial resolution depending of the performance of the probe and of the probe positioning system. The method is applicable from 150 KHz to 6 GHz. This standard specification does not impose the scanning system nor the probes to use which depends of the wished frequency band, spatial resolution and of the nature of the field.

One major advantage of this method is its direct use on applicative board. The main limitations of this method leads in the test duration and the choice or the design of the immunity field probe, the geometric and electrical parameters directly affecting the frequency band and the spatial localization of the defect. Compared to normative immunity test at equipment level, the advantages and drawbacks of this method are summarized in [10]. Among advantages, this method provides much more information on the problem source as precise localization and susceptibility level and may avoid the test at equipment level in case of the qualification of a component second source. Among drawbacks, the authors point out the hardly interpreting results and the fact this method may focus on susceptibilities not seen during the test at equipment level. But the main lock is the reliable extrapolation of a measure performed in near field for the evaluation of a level of susceptibility in far field. The goal of this study is to define the characteristics of a probe able to reproduce at PCB level the effects seen during normative test at equipment level, then to develop and validate probe's design according these criteria.

II. SUMMARY OF REQUIREMENTS FOR RADIATED IMMUNITY TEST AT EQUIPMENT LEVEL FOR AUTOMOTIVE AND AERONAUTIC SUPPLIERS

Concerning Radio Frequency (RF) immunity testing, electronic suppliers qualify their product mainly according the ISO 11452-2 [11] and ISO 11452-9 [12] for automotive or according the section 20 of the RTCA DO160 [13] for aeronautic. These test methods have different requirements in term of electric field level and frequency band covering.

In automotive industry, the most severe requirement for the Absorber-lined shielded enclosure (ALSE) method is an Electric field test level of 200 V/m in career wave (CW) calibrated at the DUT level within the frequency band of 200

MHz to 1.4 GHz and 150 V/m within 1.4 GHz to 6 GHz. In pulse modulation (PM), the requirement increase up to 600 V/m within 1.2 GHz to 1.4 GHz and within 2.7 GHz to 3.2 GHz frequency bands. For the same method, the most severe requirement of aeronautic manufacturers is an Electric field of 200 V/m in CW or square wave modulation within the frequency band of 100 MHz to 700 MHz and 6 GHz to 8 GHz, 240 V/m within 700 MHz to 1 GHz, 250 V/m within 1 to 2 GHz, 490 V/m within 2 to 4 GHz, 400 V/m within 4 GHz to 6 GHz and 330 V/m within 8 to 18 GHz. In case of PM, these requirements increases up to 7 200 V/m within 4 to 6 GHz.

The ISO 11452-9 is a test applied in automotive industry to determine the susceptibility of electronic equipment to portable transmitters. During the test, a simulated antenna is placed at 50 mm of the DUT placed on a low permittivity support 50 mm above a ground plane. The frequency band extends from 26 MHz to 5 850 MHz with net power varying from 0.5 W peak in Bluetooth/WLAN frequency band to 16 W peak in GSM900 band. Due to the specific test set-up, the value of the E-field during the DUT testing is not known. Annex B2 of the ISO 11452-9 provides, as example, calculated values of E-field at 50 mm for a miniature broadband antenna covering a large frequency range from 350 MHz to 2 700 MHz. As example, for the test in GSM900 band, the calculated E field is 230 V/m. The maximum calculated E field is 316 V/m for the test at 400 MHz.

As a conclusion, the maximum E field susceptible to be present at a PCB level during a normative test at equipment level varies from 200 to 490 V/m in career modulation according the frequency. But, to consider only the EM field present at PCB level ignoring the currents induced into the harness during the test may lead to an approximation of the EM field effect. We have also to consider the probe's coupling factor to be able to correctly compare the efficiency of the probes.

III. DEVELOPMENT OF A WIDE BAND IMMUNITY PROBE

Probes used in immunity testing are the same as probes used for emission measurement. But unlike the emission probes, they have to withstand power with minimal losses due to Joule effect. The most common field probes are based on coaxial cable as described in [8]. We may find in [14] and [15] the characterization of electrical and magnetic fields respectively produced by Electrical Z-axis probe (called Ezl probe) and Magnetic Z-axis probe (called Hzl probe) as well as their coupling factor on a micro strip line. If these probes are adapted to measure the susceptibility level of an integrated circuit with a submicron spatial resolution, they are not adapted to investigate the susceptibility level at PCB level. Some requirements must be predefined to design the probe according the specific need we have expressed.

A. Definition of probe's requirements

The first requirement (R#1.0) concerns the covering area. As the main objective is a quick investigation of the immunity at PCB level and not a precise defect localization, the probe must provide an E and/or H field covering a large area, larger than 1 cm². The requirement R#2.0 concerns the frequency band. As seen in clause III, to cover the requirements at equipment level, the frequency band must be larger than 100 MHz to 3 GHz. The R#3.0 concerns the requirement on the generated field. According to the hypothesis made in the previous clause, our need is at minima one of the field components (normal or tangential) must be > 1 000 V/m for E-field and > 2,5 A/m for H-field (RMS value measured at 1mm of the probe). To avoid spot effect, field uniformity must be < -6 dB (R#3.1). The field uniformity is defined by the standard deviation / median value ratio calculated on the required covering area positioned at 1 mm of the probe. The field uniformity must be calculated for E field and H field in probe's normal and tangential plans @1 GHz. Ideally, all the field components (normal or tangential) must be homogeneous but one homogenous component is acceptable if the maximal strength of non-homogeneous field components is 20 dB lower than median value of the homogenous field. H-field wire probe. Finally, the last requirement (R#4.0) concerns the probe's coupling factor. As the coupling factor is very dependent of the PCB, it will be determined on a 50 Ω microstrip line loaded by ideal 50 Ω. Using the results of [16] giving the trend curve of induced voltage on whatever the PCB load during the irradiation of a 5-wire harness by a 1 V/m E-field plane wave, the requirement for the probe coupling factor is given by the Table I.

TABLE I. REQUIREMENT ON PROBE COUPLING FACTOR

	Frequency	
	100 – 500 MHz	***500 – 3000 MHz***
S21	$- 2.5\ 10^{-4}$ F(MHz) + 0.225	$- 1.82\ 10^{-5}$ F(MHz) + 0.109

B. H-field wire probe

The first probe we consider is an H-field wire probe built from RG58 coaxial cable with a 10 x 10 mm square loop. The loop is surrounded by a polyimide substrate to avoid direct contact with the component. The Fig 1a (resp. 1b) illustrates the magnitude of Hz (resp. Ez) field calculated with CST Studio at 1 GHz 1 mm above a PCB plane.

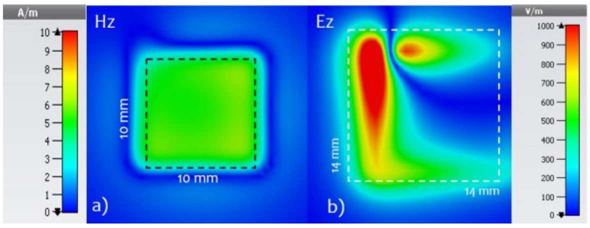

Fig. 1. a) Hz magnitude b) Ez magnitude field produced by a Hz wire probe

The normal Hz field is uniform on a 1 cm² square area with an uniformity factor of 0.18 (-14.9dB). The median value of Hz field is 7.38 A/m@1 GHz. The normal Ez field is not homogeneous showing a high magnitude spot in the vicinity of vertical inner conductor. The calculated uniformity factor calculated on a 14 x 14 mm area is 1.12 (0.97 dB) with a median field value of 380 V/m and a maximum value of 2 019 V/m. The wave impedance |Ez|/|Hz| is equal to 72 Ω. The R#3.1 requirement is not fulfilled because the maximum value of Ez field is only 2.78 dB lower than Hz median value. Consequently, this probe does not fit to our requirements.

C. Coplanar waveguide (CPW) E-field probe

The CPW E-field probe is derivate from an ultra-wideband PCB antenna designed for monitoring applications described in [17]. It consists of a 35 µm thick copper coplanar wave guide printed on a 23 x 5 mm polyimide substrate and attached to a RG58 coaxial cable. Fig 2 illustrates the geometry of the CPW E field antenna.

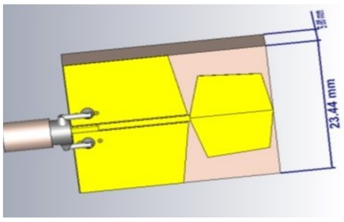

Fig. 2. CPW E-field probe

Fig 3a (resp. 3b) illustrates the magnitude of Ez (resp. Exy) field calculated with CST Studio at 1 GHz 1 mm above a PCB plane.

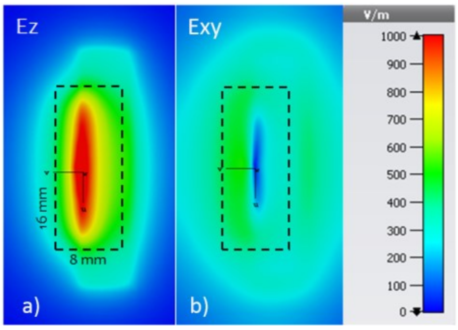

Fig. 3. a) Ez magnitude b) Exy magnitude field produced @1 GHz by a CPW E-field probe

The normal Ez field is uniform on a 16 x 8 mm area with a uniformity factor of 0.33 (-9.6dB). The median value of Ez field is 828 V/m @1 GHz. The tangential Exy field is homogeneous with a uniformity factor of 0.55 (-5.2 dB) and a median value of 321 V/m calculated at 1 GHz. The H field is negligible with a maximal value of 80 mA/m for the normal component and 194 mA/m for the tangential one. This probe fulfills all our requirements. Fig 4 illustrates the magnitude of the normal E field when 1 V is applied on the probe.

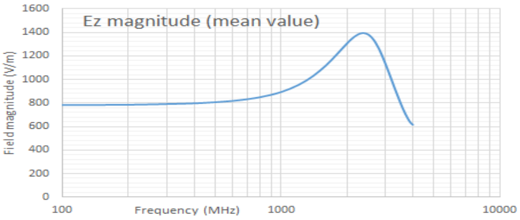

Fig. 4. Magnitude of the normal E field produced by the CPW E field probe

D. Conical E-field probe

A conical E-field probe is created from a coaxial cable based Ezl probe where a 8 mm height copper cone with a bottom radius of 6.38 mm and top radius of 0.5 mm is attached to a RG58 coaxial cable inner conductor. Fig 5a (resp. 5b) illustrates the magnitude of Ez (resp. Exy) field calculated at 1 GHz 1 mm above a PCB plane.

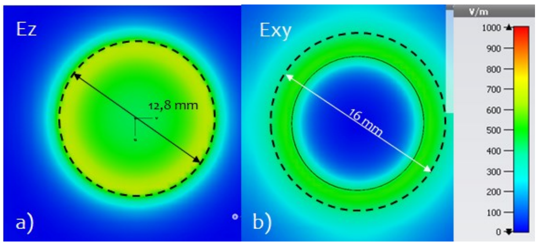

Fig. 5. a) Ez magnitude b) Exy magnitude field produced @1 GHz by a Conical E-field probe

The normal Ez field is uniform on a 1.28 cm² circular area with a uniformity factor of 0.12 (-18.2 dB). The median value of Ez field is 804 V/m@1 GHz. The tangential Exy field is not homogeneous when calculated on the same area but homogeneous with a uniformity factor of 0.44 (-7 dB) and a median value of 466 V/m when calculated on a ring with outer diameter of 16 mm and inner diameter of 12.8 mm. The H field is negligible with a mean value of 60 µA/m for the normal component and 54 mA/m for the tangential one. All the requirements are fulfilled by this probe. Fig 6 illustrates the magnitude of the normal and tangential E field when 1 V is applied on the probe.

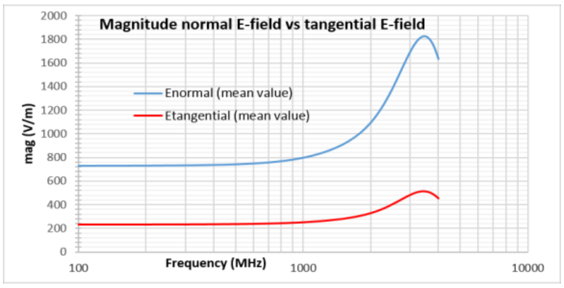

Fig. 6. Magnitude of the E field produced by the conical E field probe

E. Coplanar waveguide (CPW) H-field probe

The CPW H-field probe is derivate from a miniature ultra-wideband magnetic PCB antenna designed for magnetic near field measurement described in [18]. It consists of a 40 x 18 mm x 1.6 mm 4-layer PCB attached to a RG58 coaxial cable. Fig 7 illustrates the geometry of the CPW H field antenna.

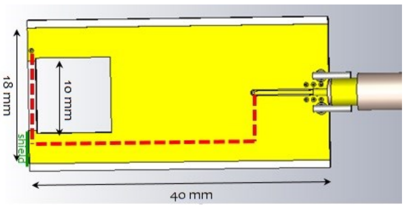

Fig. 7. CPW H-field probe

This probe shows the same advantages and drawbacks as the H field wire probe. Used perpendicularly to the PCB, Fig 8a (resp 8b) illustrates the magnitude of normal and tangential E field (resp H-field).

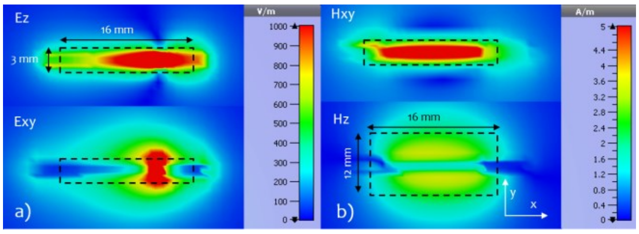

Fig. 8. a) Ez and Exy magnitude b) Hz and Hxy magnitude field produced @1 GHz by a CPW H-field probe

Despite some requirements are not achieved, this probe seems interesting because, as illustrated by Fig 9, it produces both high H field in frequencies below 1 GHz and high E field above when 1 V is applied on the probe.

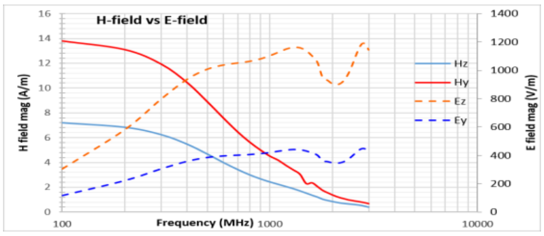

Fig. 9. H and E fields magnitude produced by CPW H- probe

The R#1.0 requirement could be achieved superposing several PCB to increase the probe thickness. The R#3.1 has still to be evaluated. The probes characteristics given at 1 GHz are summarized in TABLE II.

TABLE II. COMPARISON OF PROBES CHARACTERISTICS AT 1 GHZ

Probe name	**Probes characteristics at 1 GHz**		
	Area	***Median value***	***Field Uniformity Normal / Tangential***
Wire H field	1 cm²	7.38 A/m	no
CPW E-field	1.28 cm²	828 V/m	0,33 / 0,55
Conical E-field	1.28 cm²	804 V/m	0,12 / 0,44
CPW H-field	0.48 cm²	4.52 A/m 1100 V/m	To be evaluated

IV. CONCLUSION

Fig 10 shows a comparison of probes coupling factor on a 50 Ω microstrip line. The conical and the loop probes have been realized and measured. No probe fulfill the requirement on the coupling factor (R#4.0). As mentioned in [16], the requirement on coupling factor must be adjusted to take in account all parameters of the test at equipment level.

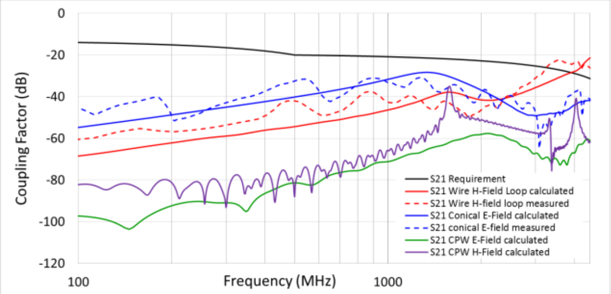

Fig. 10. Probes coupling factor comparison

We may conclude that the level of E or H field produced at PCB level is not a sufficient criteria to design and validate an immunity probe and consequently a probe's calibration method only based on E or H-field level measurement as preconized by [8] is not the right solution to calibrate the probe. Despite they produce high fields, CPW probes show a very bad coupling factor. The conical and the wire loop probes shows the best coupling factor but are still far from the target. Solutions must found to improve the coupling factor for frequencies < 1 GHz.

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