EXPERIMENTAL CHARACTERIZATION OF MINIATURE NEAR-FIELD PROBES

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ABSTRACT

This paper presents an experimental characterization of miniature near-field probes. Different probe geometries are shown and their ability to measure only the desired component of the electric field are investigated. By using an absorbing material and proper shielding, it is possible to eliminate the undesired common-mode contributions. Experimental results are compared to a theoretical response obtained by simulating a near-field measurement with an equivalent magnetic current model.

INTRODUCTION

A possible outcome of in-situ near-field measurement techniques is the possibility to extract the equivalent current distribution on the device under test (DUT) [1,2]. In the case of a printed circuit, we can calculate the magnetic equivalent current distribution directly from the tangential component of the electric field $\left(E_x \hat{x} + E_y \hat{y}\right)$ measured in the close vicinity of the DUT. However, the probe geometry must enable a high level of accuracy for such measurements. Also, its size must be small enough to allow a high spatial resolution and it must reject the undesired perpendicular component of the electric field E_z.

This work started with an investigation on different techniques used for the design of miniature probes. It appeared that the kind of miniature dipole probe described in [3] cannot lead to the equivalent current distribution. Since the dipole is connected to a coplanar waveguide (CPW) via a twin-lead transmission line, the measurements contain the contributions of the tangential components of the electric field but may as well include the undesired perpendicular component. The elimination of this contribution becomes critical in the design of such probes.

This paper presents an experimental study of different probe topologies. We will compare the ability of a few probe prototypes to reject the vertical component of the electric field. We shall first study a balanced structure represented by a shielded wire loop made of semi-rigid coaxial cable. Then, we will extend the research to some structures represented by dipoles connected to unbalanced transmission line through a balun. All measurements reported here were done at 5 GHz (λ= 0.06 m).

The measured results will be compared to the theoretical response obtained by a Magnetic EQuivalent current extractor program **MEQ** [4]. This code can be used to simulate near-field measurements over a DUT represented by an equivalent model of magnetic dipoles. The probe is modeled by a simple symmetric dipole terminated by a lumped load, without transmission line.

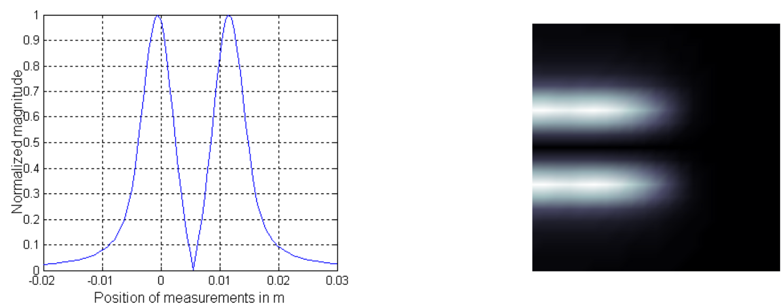
THEORETICAL RESPONSE

In order to validate the probes experimentally, a simple circuit with a predictable behavior was used. It consists of a short-circuit-ended CPW transmission line (see Fig.1). The advantage of using this structure is that we can easily excite an odd symmetry mode over the two slots. Thus, the rejection ratio of the vertical component of the electric field is easily verified.

Let us assume an x-directed dipole probe moved along the x axis over a CPW line aligned on the y axis. As seen in Fig.1a, when the probe is shifted at $x \neq 0$, there is a different excitation on each arm of the dipole. Consequently, common mode current will be excited in the twin-wire transmission line. Since both the probe and the CPW line are symmetrical with respect to $x = 0$, we expect the tangential component of the electric field, measured by this dipole, to present a maximum at the same level over each slot and a minimum value (null) at $x = 0$. Fig.2 shows the theoretical response of a near-field measurement provided by **MEQ** for a slot separation of 11 mm.

(a) (b)

Fig.1. (a) Equivalent filamentary magnetic current for CPW line; (b) Short-circuited-ended CPW line.



(a) (b)

Fig. 2. Theoretical response of a near-field measurement over a short-circuited-ended CPW. (a) 1D measurement along *x* axis at a constant *y* value (b) 2D measurement.

The height of the probe was taken at h = 2mm (h=λ/30). We will compare these results to experimental ones obtained by different probes built in our laboratory. In the experiments, there are many reasons that could affect the symmetry of the response shown in fig.2: (i) unequal length of the dipole arms; (ii) common mode currents induced directly on the transmission line structure by the E_z component; (iii) poor common mode rejection ratio of the balun; etc…

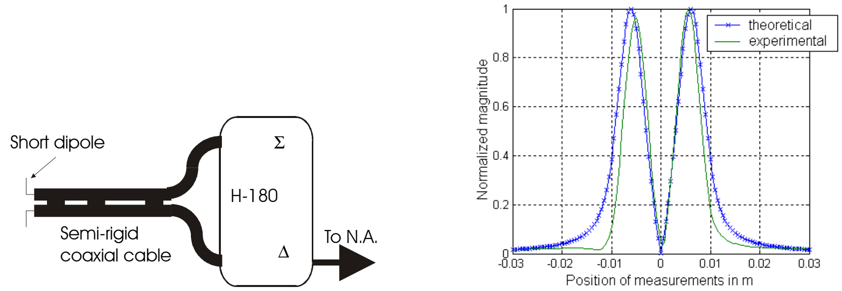
WIRE LOOP PROBE

A shielded loop made of coaxial cable can be made "self-balanced". Shielding of the transmission line eliminates the factor (ii) mentioned above. Therefore the only possible source of asymmetry resides in the accuracy in the construction of the probe. This probe is made of coaxial cable with a 1.07 mm outer diameter forming a square loop of 8x8 mm^2. A lot of effort was spent to build the smallest loop with this kind of cable. The probe is parallel to the y-z plane and directly connected to a network analyzer HP8753D. The measurements are made along the x axis over the DUT at a height of 2mm. As this probe is balanced and shielded, we obtained good results represented by a maximum over each slot and a minimum in the middle of the feed line. The vertical field rejection ratio (VFRR) can be defined as the ratio of the greatest maximum over the minimum measured in the valley between the two maximums. In this case, the VFRR is about 28 dB. Also, we can verify the symmetry of the probe by comparing the level of the two maximums. For the magnetic loop we have a difference of 0.2 dB.

BALANCED DIPOLES

Coaxial Cable Feed

From a practical point of view, coaxial cables do not allow 90^o bends with a small inner radius. For this reason, we investigated dipoles, which are more easily miniaturized. We built a dipole made by the inner conductors of two parallel coaxial cables (see Fig.3a.) [5].



(a) (b)

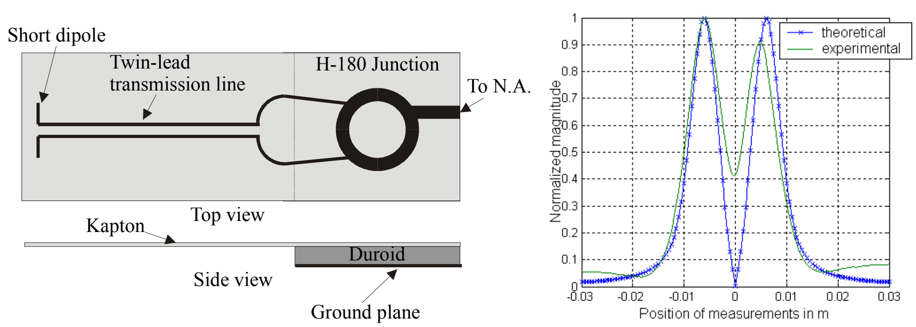
Fig.3. (a)-Balanced dipole used for near-field measurements; (b)- Comparative result between theoretical and experimental near-field measurements

The network analyzer measures the difference signal (Δ) at the output of the H-180 junction, which corresponds to the desired coupling to the probe's current distribution, while the sum (Σ) signal (not measured) contains parasitic couplings to the probe feed cable. The H-180 junction was designed for a center frequency of 5 GHz. The length of the dipole is about 7.8 mm. Again, the near-field measurements are made with the dipole oriented along the x axis at a height of approximately 2 mm over the circuit.

Fig.3-b compares the simulated and the experimental measurement. We found a VFRR of 28 dB. On the other hand, the asymmetry of the probe shows a difference between the two maximums of 0.35 dB. This asymmetry could be caused by limitations in the mechanical construction of the probe.

Twin-Lead Line Feed

In order to minimize asymmetry sources and to allow miniaturization of the probes, we built a printed circuit including a short dipole feed by a twin-lead transmission line and connected to a H-180 junction. Several attempts were done to find the best practical configuration. To minimize the possible disturbance of the current distribution on the DUT during the measurements, the dipole and the twin-lead line were printed on a thin Polyimide substrate (Kapton) with a thickness of 0.05 mm (2mil). The H-180 junction could not be designed on this substrate for practical reasons. Therefore, we designed the H-180 junction on a double layer substrate. The junction is printed on the Kapton layer, which is fixed on top of a 0.635mm thick PTFE/ceramic composite (Duroïd), from ROGERS, with a dielectric constant ε_r=10.2 (see fig.4-a N.B.: Termination on Σ port not shown). In that manner, we can have the dipole and the H-180 junction on the same layer and avoid error sources that could be created by soldering the twin-lead line with the arms of the junction.



(a) (b)

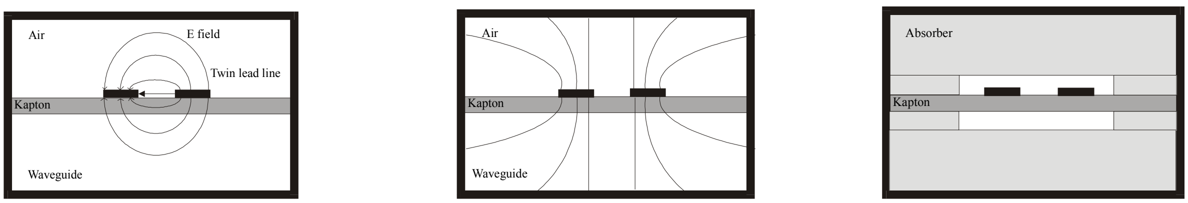
Fig.4. (a) Design of the printed short dipole probe. (b) Experimental and theoretical response of the printed probe.

Fig.4-b shows a comparison between theoretical and experimental near-field measurements. We can see that the VFRR is quite low. The experimental ratio is about 8 dB instead of 28 dB obtained with the previous probe. Consequently, this topology is not desirable in spite of the precision of the construction and the very small size of dipole that can be built.

We noticed that the main difference between this probe and the previous topology was the shielding provided by the coaxial cables. Consequently, we considered shielding the twin-wire line to improve performance. We simulated the twin-lead line in a rectangular waveguide shield to identify the mode properties.

Fig.5 (a) and (b), show the two modes of interest. This topology has the same electric field distribution as the suspended microstrip. In our experimental conditions, we would like to reproduce the "ideal" conditions that prevail when a

lumped load is connected at the terminals of the dipole. This is equivalent to say that we are only interested in the differential mode and that we should concentrate on eliminating the common mode in the shielded twin-wire line.
As the electric field for the common mode spreads from the twin-lead transmission line to the waveguide walls, and the field lines of the differential mode are concentrated near the two wires, it is possible to put an absorbing material inside the waveguide to attenuate the undesired mode and let the desired mode (differential) propagate. The absorber is inserted in manner to fill the waveguide but isolated symmetrically from the twin-lead line by an air gap. In that way we could achieve a minimum attenuation of 12 dB for the common mode and 0.9 dB attenuation for the differential mode.
To minimize all parasitic coupling in the vicinity of the DUT, we shielded the entire circuit including the H-180 junction. Fig.6 presents the result of the near-field measurements along the x axis versus the theoretical response.
We can see a very good agreement between the two curves. The achieved VFRR in this case is 38 dB. The symmetry of the probe presents a 0.1 dB difference between the two maximums. When the shield is not loaded with absorbing material, we obtain a VRFF of 28.5 dB but the difference between the maximums is 14 dB, which make it an unacceptable topology of probe.



(a) (b) (c)

Fig.5. (a) differential mode; (b) common mode; (c) the twin-lead line with absorber

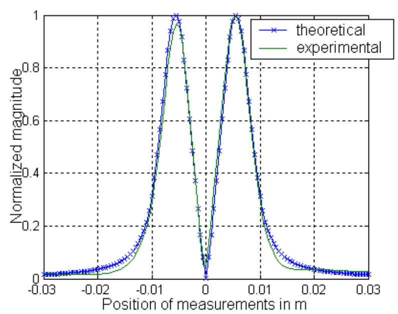


Fig.6. Theoretical response versus experimental near-field measurements using a dipole probe with shielded transmission line and channeled absorbing material.

CONCLUSION

In this paper, we have shown the results of experimental near-field measurements for different probe topologies. We have seen the importance of the shielding to avoid the common mode current to be propagated in the transmission line. The rejection of the common mode has been achieved by using an absorbing material in the case of a balanced twin-lead transmission line. Shielding of this transmission line and the entire H-180 junction reduces drastically the sources of common mode current induction. This method provided a very good agreement between the experimental results and the theoretical response. The remaining asymmetry can be caused by a difference in the length of the probe arms or the length of the twin-lead transmission line, a misalignment of the probe and DUT or a slight asymmetry in the CPW line dimensions.

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