Two-Probe Method for Advanced EM Wave Propagation Analysis

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***Abstract*— The Poynting vector method is adapted to accommodate a non-zero phase shift between electric and magnetic field vectors in a technique used to gauge the direction of energy propagation at a point close to a tested device. With this method and the pifa antenna, evidence of cases where energy propagates back towards the device are set forth. The technique verifies the applicability of the Poynting vector theorem for near-field evaluation.**

I. Introduction

The Poynting vector method allows for the calculation of energy propagation as the cross product of the electric field vector, $\vec{E}$, and the magnetic field vector, $\vec{B}$. The current industry method, based as it is on impedance approximation from far-field measurements, is unreliable in near-field evaluations, as evidenced by [1]. Instead, the authors propose using a two-antenna probe measuring technique to take electric and magnetic field vector measurements, and to modify the Poynting vector theorem to calculate the energy propagation direction and magnitude at any point arbitrarily close to a studied electronic device.

II. A Comment on the Magnetic Field

The H-probe used measures the magnitude of the magnetic field strength, *H* (in *A/m*). In free space, as in a vacuum, the magnetic field density vector $\vec{B}$ is proportional to *H* by the familiar formula

$$\vec{B} = \mu_0 \vec{H}, \quad (1)$$

where *B* is magnetic flux density (*T*) and μ_0 is the magnetic constant (*H/m*). Unless specified otherwise, the terms *magnetic field* and *magnetic field vector* are used to refer to *H*.

III. A Comment on Theory

The current practice is to calculate energy propagation with the use of electric field measurements in the near-field and far-field zones. Close to the device, however, this method loses its accuracy; moreover, repeatability can be difficult to achieve for the same measurement conditions.

At the far-field area electric and magnetic waves are synchronised: the phase shift is zero, waves are orthogonal, and signal propagates in the direction perpendicular to each. In the near-field zone, however, the electric and magnetic fields have a phase shift θ'. As a result there is no EM wave propagation close to a device, and the field oscillations are unstable [2].

In the proposed method, the Poynting vector is employed with the use of electric and magnetic field directivity data to construct the energy propagation vector,

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}, \quad (2)$$

where $\vec{S}$ is power density vector (W/m^2), as shown in [3].

Should an angle θ occur (measured counterclockwise from $\vec{E}$) between the direction of the maximum electric field $\vec{E}$ and the direction of maximum magnetic field $\vec{B}$ vectors, the latter is projected perpendicular to the electric field vector as seen in Fig. 1. Thus, (2) is modified to become

$$\vec{S} = E_{max} B_{max} \cos(\theta')\, \hat{n}, \quad (3)$$

where E_{max} and B_{max} are maximum measured magnitudes of electric and magnetic fields respectively, $\hat{n}$ is the unit vector normal to both $\vec{E}$ and $\vec{H}$, and θ' is the phase shift.

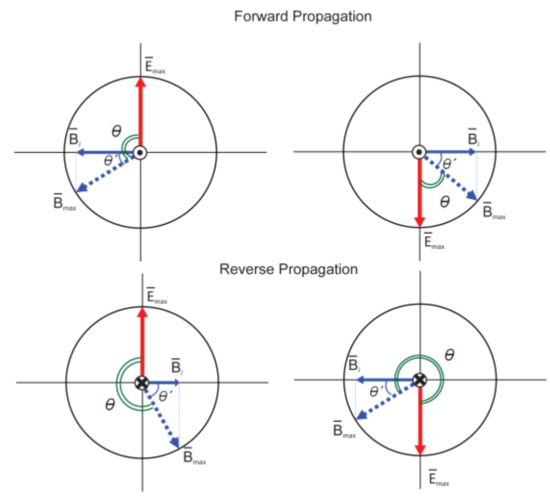

Fig. 1. The four possible arrangements of electric and magnetic field vectors resulting in energy propagation in freespace (top) moving out of the page, and (bottom) moving into the page, respectively. Note the projection of the measured magnetic field is perpendicular to $\vec{E}_{max}$.

In cases when angle θ is greater than 180 degrees the Pointing vector changes its direction. An angle of exactly 180 degrees represents the standing wave condition when the energy is not moving. Precisely this event was observed at the half-wavelength distance over a horn antenna.

IV. Method

EM-ISight automated scanning system was used to measure electric and magnetic fields on 5 spatial layers over three test cases and analyzed at distances of 0.5 mm, 5 mm, 10 mm, 15 mm, and 20 mm. The three test cases are: horn antenna, pifa antenna, and micro stripline. At every point of a grid both *E*- and *H*- probes were rotated 360 degrees with a step of 15 degrees. A spectrum analyser was set up to measure magnitude using maximum hold setting. The directions of the vector maxima $\vec{E}_{max}$ and $\vec{B}_{max}$ were detected. The graphical representation of the pifa antenna measurement data is shown in Fig. 2 below.

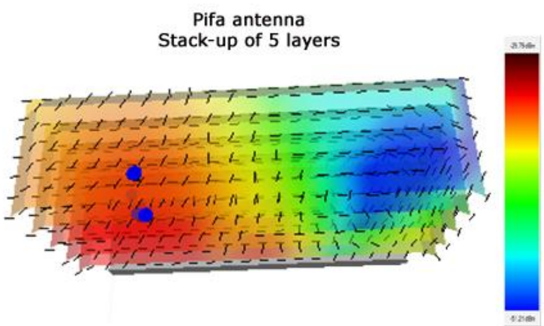

Fig. 2. $\vec{E}_{max}$ and electric field distribution. Energy propagation through five layers is shown for the pifa antenna.

V. Results

The near-field non-zero phase shift phenomenon was detected during the two-probe test over all three devices. In Fig. 3 the pifa antenna power density plot shows that a portion of the energy is propagating backwards.

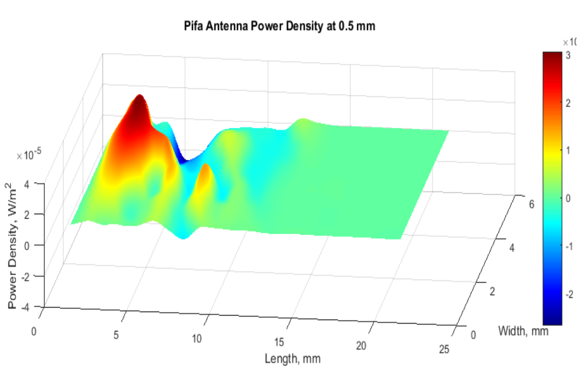

Fig. 3. Power Density distribution.

At a distance of 0.5 mm, almost half of the energy is returning back to the device. As shown in Fig. 4 the pifa antenna results prove the theoretical inference.

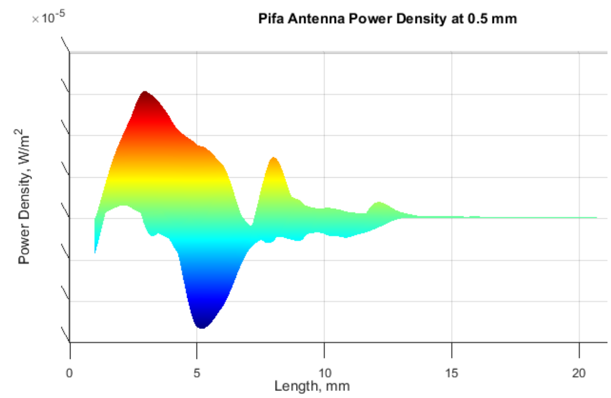

Fig. 4. Power density indicates positive and negative energy propagation orientation.

VI. Conclusion

The Poynting vector theorem, together with the probes capable of providing synchronised electric and magnetic field measurements in the near-field zone, offers reliable and detailed data about energy propagation near an electronic device (consult [4] for a robust analysis), where far-field calculation methods often break down due to the erratic nature of energy propagation in the near field. The data shows that, far from radiating orthogonally away from the device, in some sections energy instead radiates in the reverse direction. This effect should be studied further, as it affects PCB components and device performance as well as humans and animals in a close proximity zone to a wireless device.

References

[1] T. Lecklider, "The world of the near field," Evaluation Engineering, vol 44, p. 52, October 2005.

[2] I. Straus, "Near and far fields – from statics to radiation", Conformity, February 2001, www.conformity.com/0102reflections.html.

[3] D. J. Griffiths, "Introduction to Electrodynamics,"Prentice-Hall, Inc.,September 1999, pp. 347-405.

[4] D. Brooks, S. Nicol, J. Hones, J. Lee, "Near-Field Magnetic Probe Method Predicting Far-Field Measurements," Progress in Electromagnetics Research Symposium, March 2013.

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