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Orthogonal Loops Probe Design and Characterization for Near-Field Measurement

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***Abstract*—Near-field probes are often used to measure the electric and magnetic fields above a printed circuit board in order to identify the sources and coupling paths of an electromagnetic interference (EMI) problem. It is the objective of this paper to propose a rapid E-, Hx- Hy- and circular H-fields measurement using an orthogonal loops probe design. The effects of this probe are analyzed using full-wave simulations and measurements.**

***Keywords*—Orthogonal loops, phase shifting**

I. INTRODUCTION

Near-Field scanning measurements are increasingly being used to provide information about the electric and magnetic fields in the vicinity of an integrated circuit (IC) and printed circuit boards (PCB).

In general, all 6 field components are of interest. However, in many cases only three components are measured as the others can be reconstructed from having three components. If a loop is connected to two coax cables one can measure the E and the H-field. The H-field, given by the induced loop voltage is the difference between the signals while the E-field is the sum of the signals. It is possible to obtain a circular (magnitude the same in all directions) pattern by adding two orthogonal loop outputs but at 90 deg phase difference [1]. This system enables us to do an overall scanning by taking the circular pattern of H-field, to detect the coupled H-field in all directions without changing the orientation of the probe. Upon identifying the area of interest, the users can then carry out the detail scanning by measuring specific Hx, Hy and E-fields. This test procedure would save a lot of time.

An orthogonal loops probe attached to a wideband (10 MHz to 3.8 GHz) universal field analyzer is built to measure circularly and linearly polarized magnetic fields and total electric field. The complete universal field analyzer would consist of the probe and the electronics system. This paper focuses on the probe design. It starts with an overall description of the probe analyzer system, followed by the characterization of the probe using detailed full-wave simulation and measurements.

II. PROBE ANALYZER SYSTEM

The electric coupling between the device under test (DUT) and the loop probe induces a common mode current. By adding the output signals of the probe the E field can be obtained. The E coupling could also be represented as a mutual capacitance. The magnetic coupling between the DUT and the loop induces a differential current [2]. By adding the output signals of the probe by a 180 degree phase difference the H field can be obtained. The magnetic coupling could also be represented as a mutual inductance.

For a given spherical coordinates shown in Figure 1, the H-field components can be expressed with the following equations:

$$H_x = A\sin(\theta)$$
$$H_y = A\cos(\theta)$$

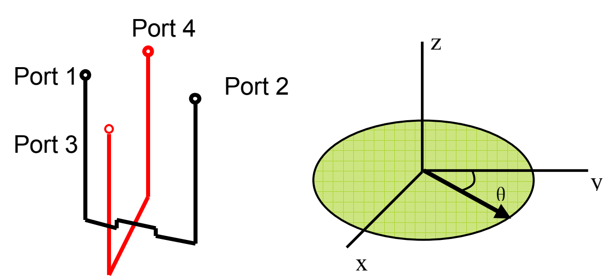

Figure 1. Orthogonal loops and spherical coordinates

The amplitude of the H-field and the sensitivity of the loop had been accounted in factor A. If Hx and Hy are 90° out-of-phase and then added, the resulting signal can be expressed using complex numbers as:

$$H_{circular} = \left| H_x + jH_y \right| = A$$

The amplitude of Hcircular is now no longer a function of θ. Hx and Hy can be measured with a single probe system with orthogonal loops. A circular H-field current distribution pattern can then be obtained by adding Hx and a 90° phase-shifted Hy together.

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Figure 2 shows the measurement concept for the orthogonal probe design. Combination of signals can be obtained by changing the phase differences and RF switch positions. The sum of the two in-phase voltages from the coaxial terminals of a single loop is proportional to the electric-field coupling. The addition of two out-of-phase signals from the coaxial terminals of a single loop produces a voltage which is proportional to the magnetic-field coupling. By adding Hx and Hy with a 90° phase difference, the probe detects the magnetic field in all directions with a circular H-field current distribution pattern.

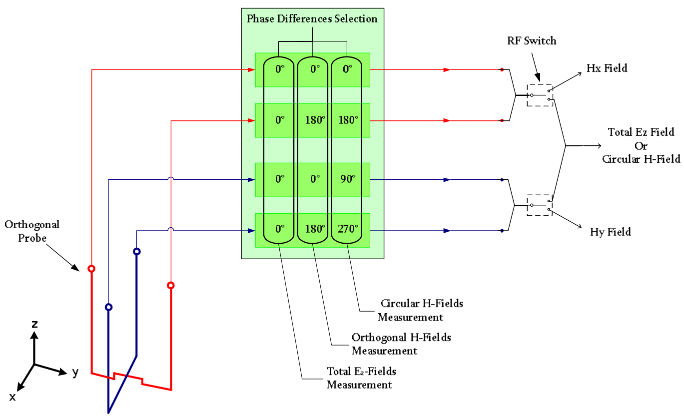

Figure 2. Measurement concept

III. FULL-WAVE SIMULATION

A full wave model is built in Microwave Studio. The objective of the simulation is to understand the coupling of different field components to a trace. As shown in Figure 3, the probe can be placed above a 7 mils wide, 50 Ω trace.

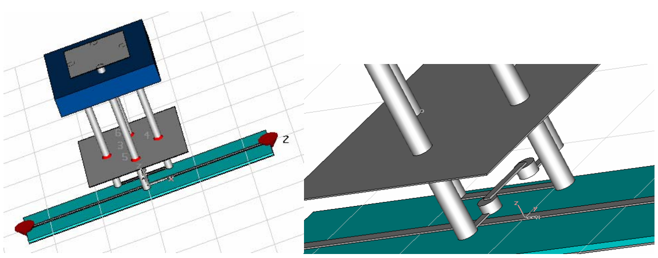

Figure 3: Full wave model of the orthogonal loops probe

When the probe is moved away form middle of the trace to one side (shown in Figure 4) then both H field and E field coupling of the loop which is parallel to the trace will decrease. For the other loop that is perpendicular to the trace, when the probe is moved to the side, the common mode current caused by capacitive coupling is no longer balanced ($I_{c1} \neq I_{c2}$, shown in Figure 4). Consequencely, the 'H field' coupling consists of both real H field coupling and the unbalanced E field coupling. In addition, due to the trace design of this loop, the distance between the loop and the micro strip changes when the probe is moved sideway, so the mutual capacitance also changes.

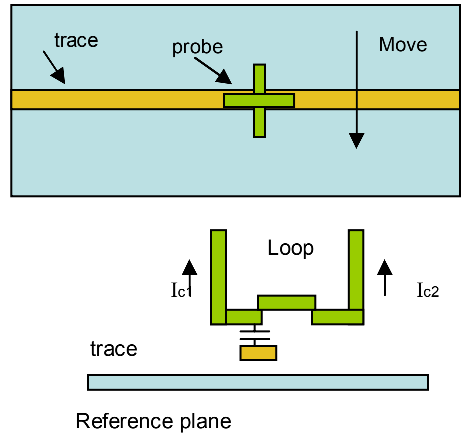

Figure 4: Unbalanced common mode current caused by capacitive coupling when probe is not sitting in the middle of the trace

At low frequency, for example, less than 50 MHz, the wavelength is larger than 6 m, the unbalanced common mode current would not cause a strong effect on the H field. The frequency response follows a 20 dB/dec line, which indicates that it is purely due to the magnetic coupling. At high frequency, the 'H field' follows a combination of magnetic coupling and unbalanced electric coupling, the frequency response is a 40 dB/dec line (as shown in Figure 5).

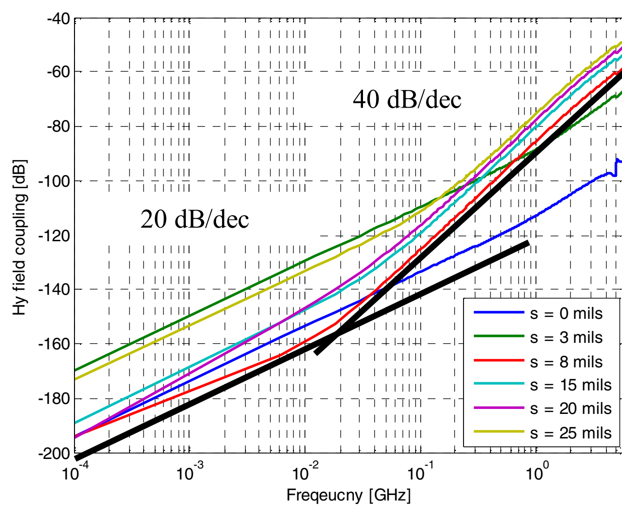

Figure5: E field and E field coupling of the loop perpendicular to the trace

When the probe is rotated with a phase θ which changes from 0o to 360o, the magnetic coupling in loop 1 (as shown in Figure 4) is a sine function of the phase θ, and it starts at |H1| = 0. The magnetic coupling in loop 2 is also a sine function of phase θ, starting at |H2| = max(H). The circular pattern of the H field would be same during the rotation. The magnitude of E field depends on the mutual capacitance between the loop and the trace.

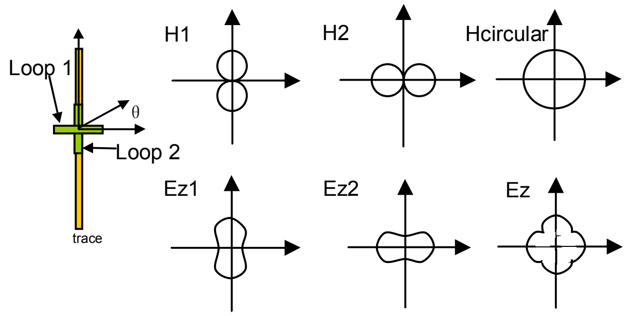

Figure 6: Approximate field variation expected while rotating the probe

Simulation results are shown in the next figures. Figure 7 shows the H field and E field coupling on both of the loops during the 180 degrees rotation, at 3 GHz. It can be observed that Hx is the strongest and Hy is the weakest at θ = 0° or 180°, and Hy is the strongest and Hx is the weakest at θ = 90° or 270°. There is a little change in the circular pattern of H field during rotation, because the probe is too close to the trace.

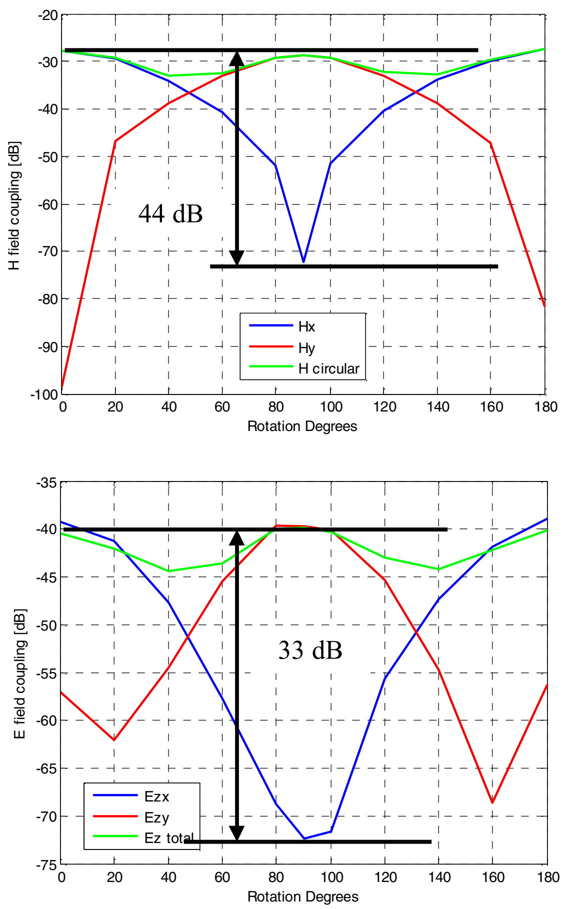

Figure 7: H field and E field changes by rotation (freq = 3 GHz)

When the distance between the loop and the probe increase from 20 mils to 40 mils, the amplitude of filed coupling decreases, the circular pattern of H field is improved. On the other hand, the difference between the minimum and maximum value of H field increases, the difference between the minimum and maximum value of E field decreases. It indicated that the E field coupling is less sensitive to the probe orientation than H field coupling. Figure 8 shows how the coupling looks like at 3 GHz.

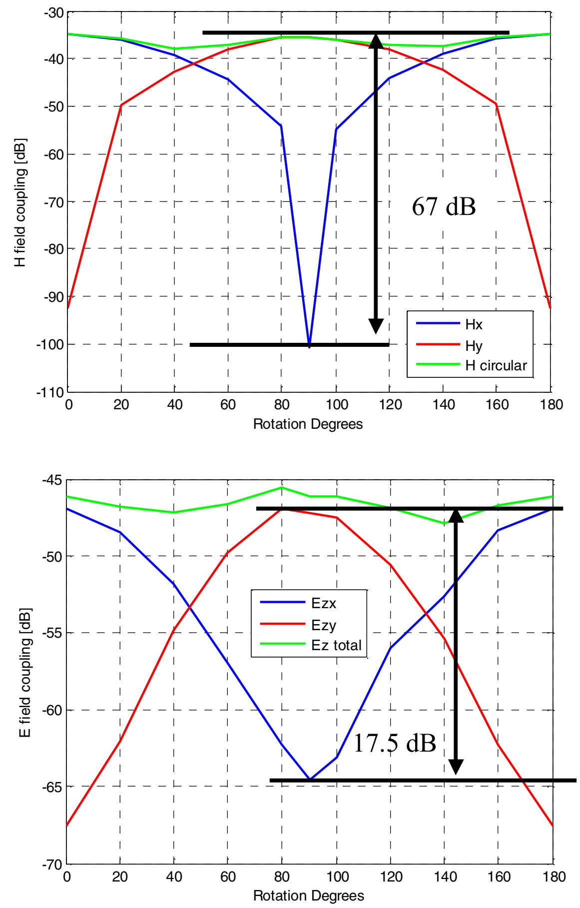

Figure 8: H field and E field coupling at a specified frequency (3 GHz) during rotation

IV. MEASUREMENTS

The probe is measured on a printed circuit board with a single trace and is mounted on a precision rotating platform. One end of this trace is connected to the port 2 of network analyzer; the other end of the trace is matched by a 50 Ω termination. An orthogonal probe is connected to two 180° hybrids and one 90° phase shifter in order to detect the E and H-fields coupling from the trace. The output from the phase shifter is connected to port 1 of network analyzer. The output signals from the probe would be phase-shifted and added accordingly by the subsequent stages in order to obtain the desired field measurement. The relative placement of the probe, DUT and the configuration of phase difference for a circular pattern is shown in Figure 9.

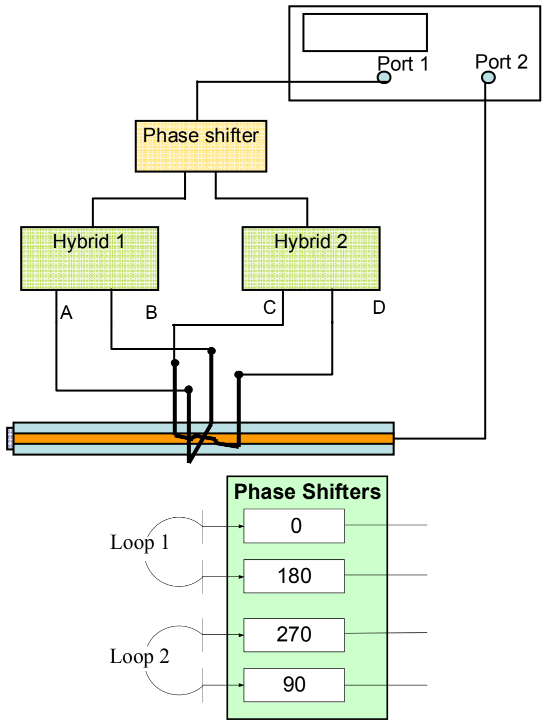

Figure 9: Test setup

In near-field scanning, in order to detect the field coupling on pins of the IC, the spatial resolution of the probe should be very good. By scanning across the traces, the spatial resolution of the orthogonal loops probe can be investigated. The measured singal is shown in Figure 10. The electrical coupling of the probe has a 3 dB spatial resolution of 21.5 mils. The magnetic coupling of the probe has a 3 dB spatial resolution of 13 mils. This result demonstrates a good spatial resolution of the orthogonal loops probe.

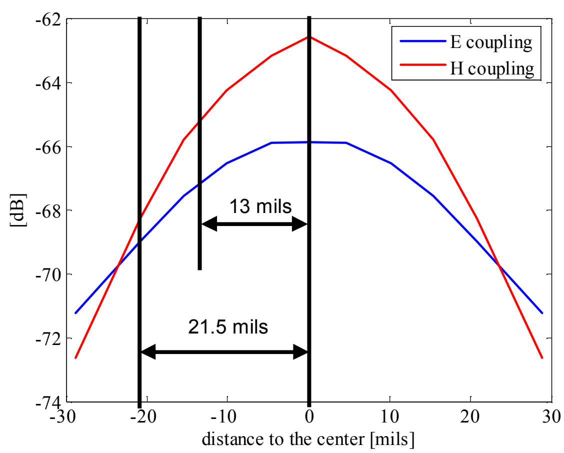

Figure 10: Spatial resolution of the probe

Figure 11 shows the H field and E field coupling on both of the loops during the 180 degrees rotation, at 61 MHz. At the reference angle of 0°, Hx field coupling is expected to be maximal, while Hy field coupling should be minimal. This relationship between Hx and Hy would be alternated for every 90° angular intervals. The field variation matches with the expectation and the results of full-wave simulation very well.

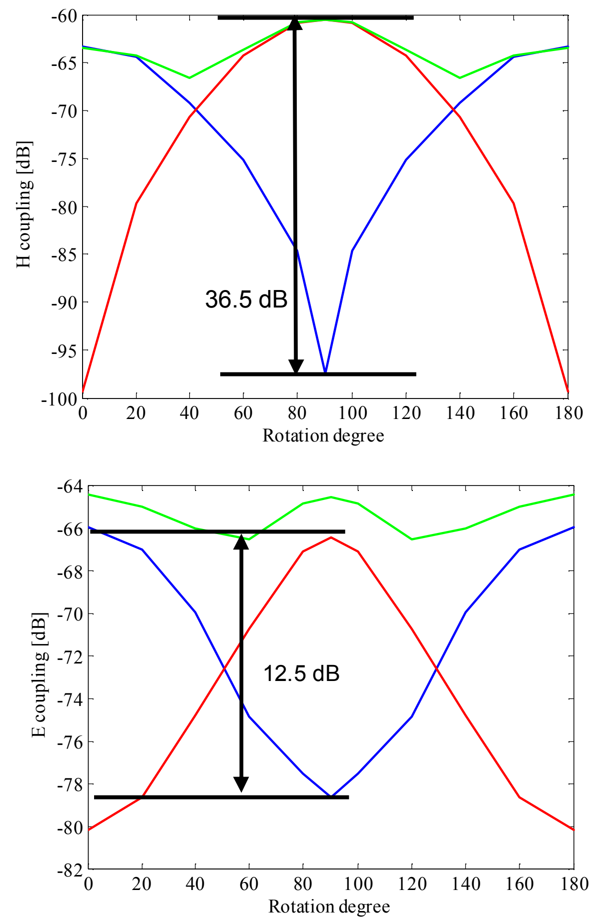

Figure 11: H field and E field coupling at a specified frequency (61 MHz) during rotation

V. CONCLUSIONS

An orthogonal loops probe attached to a wideband universal probe analyzer was designed and built. Simulation and measurement for characterizing the probe are presented in this paper. The final results proved that probe performances as intended for measuring Hx, Hy, HCircular, and Ez field. After attaching the probe to the probe analyzer system, all of the field coupling of interest could be obtained in a rapid sequence, without changing probe and changing the orientation of the probe.

The probe has a limitation when measuring a trace which width is comparable to the width of the loops. The unbalanced E field will be considered as H field coupling. However, this can be circumvented through using approximately sized loop probe fro the trace size of interest.

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