Magnetic Near-Field Mapping of Printed Circuit Board in Microwave Frequency Band

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***Abstract*-A near-field mapping system has been setup to scan the magnetic field above PCB circuits. A loop-type magnetic probe is used to measure the magnetic field up to 9 GHz. The probe is easily fabricated by printing technology. A set of quasi-periodic notches, which functions as a microstrip filter, is embedded between the feeding port and the sensor to introduce self-resonance suppression characteristics. In order to verify the performance of our new system, EM surface field measurements were conducted for a shorted-microstrip line and an open-microstrip. The comparison between the measured results and the reference data validate the good performance of our system.**

I. INTRODUCTION

With increasing complexity of high speed digital circuit board and rapid development of wireless devices built-in cell phone or wireless LAN, there are numerous design and fabrication issues. Especially, these circuitry modules sometimes cause electromagnetic interference in self equipment [1] or excessive electromagnetic radiation to generate electromagnetic interference (EMI) problems. With a map of electromagnetic field intensity on the circuit board [2-3], one can find the whole field distribution around device and find out the corresponding noise source.

In order to locate noise or to predict far-field emission level, a near-field measurement by magnetic field probe is a promising method. In ref. [4], an integrated RF magnetic field probe micro-fabricated using CMOS–silicon-on-insulator (SOI) technology obtains a further-miniature and high spatial-resolution function; A stripline magnetic near-field probe for high frequency band up to 10 GHz achieved an improved spatial resolution [5]; a set of orthogonal loops was proposed for a rapid E-, Hx- Hy- and circular H-fields measurement [6]; In ref. [7], a bond wired rectangular magnetic field probe, which effectively suppresses resonance behavior between probe and ground plane, was proposed to gauge much higher frequency region than conventional magnetic probe. According to requirement of electromagnetic sensor, broad bandwidth, high spatial resolution, and large isolation in sensed electrical and magnetic field are respect. On the other hand, by adding modified periodic loads to a microstrip line [8], the proposed integrated microstrip antennas not only retained good performance, but also eliminated harmonic resonances and spurious emission. Here, the geometric dimension and structure should be suitably chose to achieve desired performance.

In this study, firstly, we will present a description of field-mapping principle as well as the probe design and automatic measurement system. Secondly, a microstrip line with a short end and an open were characterized by our new system to verify its performance. The comparison between the measured results and the reference data from commercial microwave simulation software are presented to validate the performance of our system.

II. MAGNETIC NEAR-FIELD MAPPING SYSTEM

A. PRINTED MAGNETIC FIELD PROBE WITH ENHANCED PERFORMANCES

In this study, our previous design [9], a broadband magnetic field probe, is tested over the band 1~9 GHz. Figure 1 shows the computer-aided design (CAD) layout of the proposed probe. The planar circular loop with radius R = 4 mm and 1 mm width was printed on a fiberglass microwave substrate, which is with permittivity ε_r = 4.4 and thickness h = 0.8 mm. For real applications, the circular loop was connected to spectrum analyzer or receiver through a pair of microstrip line with 8.5 mm length and 1 mm width. Note that three pairs of notch were quasi-periodically embedded into the connecting portion. Two pairs of notch near to the feeding edge have the same dimension while the last is different from and larger than the former. It is well known that the microstrip with periodic loads acts as the band-reject filter at some frequency bands [8]. In this design, the embedded notches also introduce a filterable feature to suppress the self-resonance of the circular loop, moreover, improve the probe performances at much higher frequency. The geometry structure associated with the connector should be suitably chosen to achieve desired performance. After several simulations, we choose the notch width as 0.5, 0.5, and 1 mm and with the same length of 0.5 mm for the optimum characteristics. In addition to the loop radius, the location of the embedded notches is an important to the resonance suppression. Here, the space between the larger notch and the edge of the connecting portion was noted as d = 3.5 mm and used to represent the corresponding position of the notches.

The reflection coefficient S_{11} of the proposed probe and the reference were presented. As shown in Figure 2, the first resonance is at about 3.5 GHz with 6 dB reflection for the reference probe. This self-resonance possibly interferes with the magnetic field penetrated through the circular loop. However, by the adding of the quasi-periodic notches, the S_{11} of the proposed probe has improved on the reference about 4 dB. Moreover, the operation bandwidth determined by S_{11} less than 3 dB is up to 9 GHz.

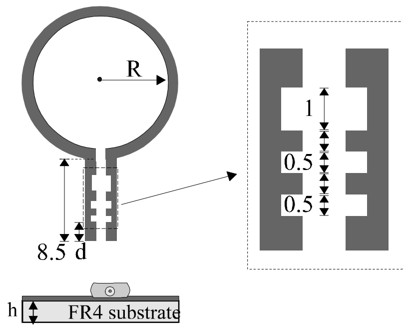


Figure 1 Configuration of the proposed magnetic probe. R = 4 mm, d = 3.5 mm, h = 0.8 mm.

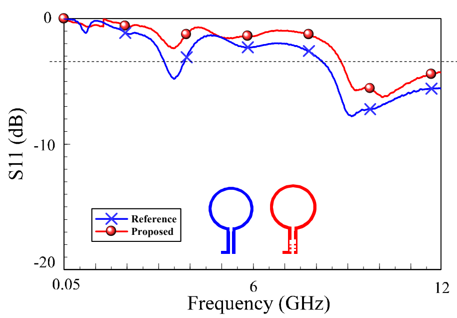
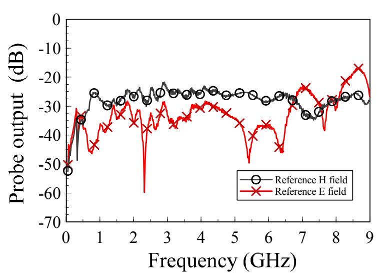
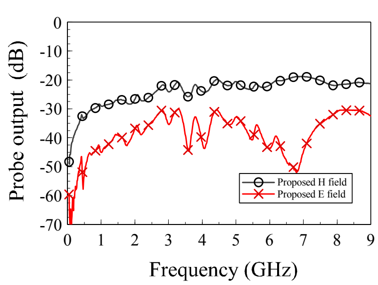


Figure 2 Measured S_{11} against frequency in embedded notches.

In addition, the new probes we developed could provide advanced isolation between the desired V_{emf} （caused by near magnetic field） and undesired V_{emf}（caused by near electric field）. Figure 3 shows that the proposed probe has 10 dB isolation at least.



(a)



(b)

Figure 3 Measured probe output against frequency of (a) conventional magnetic probe, and (b) proposed magnetic probe.

B. Automatic UWB Field Mapping System

According to the Faraday's law：

$$V_{emf} = -\int_s \frac{d\phi}{dt} = -\int_s \frac{d\vec{B}}{dt} \bullet d\vec{s};$$

The electromotive force V_{emf} at the ends of loop probe is in proportion to the magnetic flux $\vec{B} \bullet \vec{S}$, which passes through the small loop above the device under test (DUT). In our study, the near field measurement system has been setup as shown in Figure 3. The loop-type probe functions as a magnetic field sensor, while a spectrum analyzer (SA) as a signal-detector. A fixture is designed to hold the sensor above the test planar circuit. The movement of fixture can be precisely adjusted to 0.1mm/step by a 3-D movable controller system. Moreover, a LabVIEW-based program is designed to automatically control the procedures of both mechanical movement and data collection from SA via a GPIB interface. With this measurement system, the broadband magnetic fields ($H_x(x,y)$ and $H_y(x,y)$) at a certain z-position could be automatically detected. Furthermore, the proposed probe is with more than 10 dB isolation between the desired and undesired V_{emf}, which is induced by the spurious emission. The accurate predictions of near magnetic field are promising.

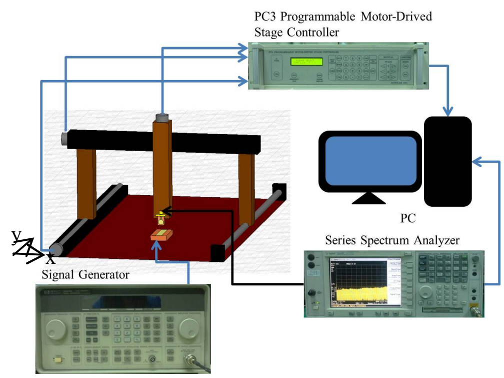


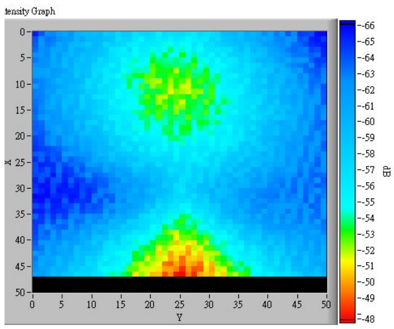
Figure 4 Configuration of measurement system

III. Experimental Results and Discussions

In order to validate the effectiveness of the proposed near-field mapping system, a directive fed 50-Ωmicrosctrip line (MSL) with an open end and a short end were measured. The measurement results will be compared with simulation from the commercial microwave software Ansys HFSS.

The 2D magnetic field distribution with the proposed probe is studied. The probe examined an printed 50-ΩMSL with 50 mm length on a 50×50 mm^2 FR4 substrate. Both open-end MSL and short-end MSL were tested. Also, the simulative study from the commercial microwave software Ansys HFSS was performed. The printed circuit is scanned with 1m/step along with both x and y direction (shown in Figure 4). The probe directs at x- and y-axis to detect $H_x(x,y)$ and $H_y(x,y)$, respectively. Here, the MSL was 1 mm below the magnetic field sensor, and the signal fed to the MSL is 1800 MHz with the power of 0 dBm.

The 2D near magnetic fields of open-end MSL is studied in Figure 5. Also, the shot-end MSL is in Figure 6. Near the loading end and feeding end, the magnetic fields were distorted because of the non-ideal short/open/impedance matching condition. However, the experimental results still show that all the measurement results agree with the simulation results, which validated the magnetic field characterization ability of the new loop probe. In Figure 5(a), the measured results of H_x show the characteristics of an open-circuited 50-Ω MSL. Whole field distribution is similar to half-wavelength, while the magnetic field was relative null near the open end ($Z_L=\infty$). In (b), the measured H_y associates with a half-wavelength-distribution. Besides, to compare H_x with H_y (shown in (b)), the former has larger magnetic field and more concentrate on MSL.



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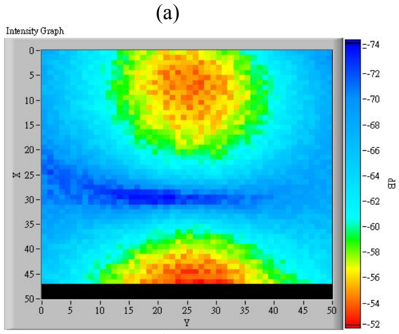

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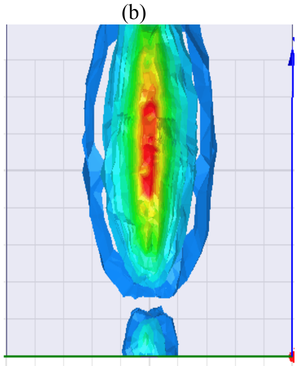
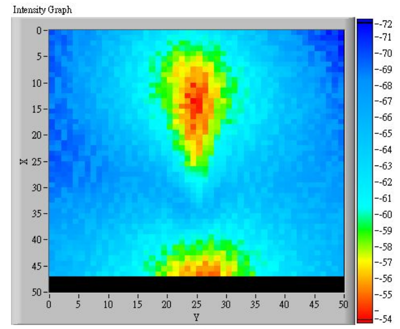


(c)

Figure 5 2D magnetic field distribution map of open-end MSL drawn with the proposed circular probe. (a) H_x, (b) H_y, and (c) simulated surface magnetic field from Ansys HFSS.

Figure 6 presents the 2D near magnetic fields of short-end MSL. In (a), the measured results of H_x show the characteristics of an short-circuited 50-Ω MSL. Whole field distribution is similar to half-wavelength, while the magnetic field was relative large near the short end ($Z_L=0$). In (b), the measured H_y associates with a half-wavelength-distribution. Besides, to compare H_x with H_y (shown in (b)), the former has larger magnetic field and more concentrate on MSL.



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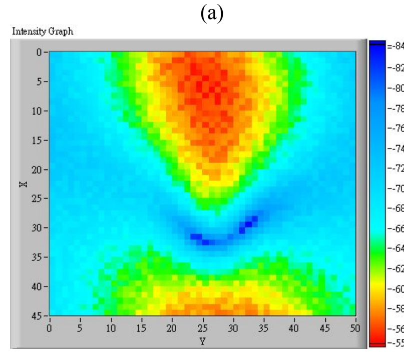

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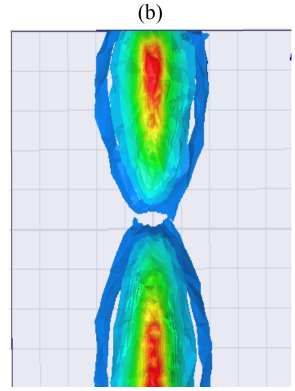

(c)

Figure 6 2D magnetic field distribution map of short-end MSL drawn with the proposed circular probe. (a) H_x, (b) H_y, and (c) simulated surface magnetic field from Ansys HFSS.

IV. CONCLUSIONS

A measurement system is proposed for scanning the surface magnetic field of PCB circuits within wide frequency band up to 9 GHz. Compared with the conventional one, the novel magnetic probe embeds a set of periodic notches into the connection port. As a result, it not only suppresses the self-resonance but also spurious emissions. In this primary study, the proposed probe was applied to a 2D magnetic field mapping system. It scans the surface magnetic field of an open-end microstrip line and a short-end microstrip line. The agreement between the measurement and simulation validate the good characteristics of the probe and the mapping system. In the future, an advanced mapping system with fast detection will be developed for larger PCB circuits to solve the electromagnetic coupling problems for EMI/EMC etc.

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