Determination of High Frequency Package Currents from Near-Field Scan Data

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Abstract—Integrated circuits (ICs) are often a significant source of radiated energy from electronic systems. Near-field magnetic scanning is an effective tool for measuring the current distribution in IC packages and investigating chip-level EMI problems. This paper discusses analysis of near-magnetic field scan data using tangential and normal field measurements. Results show that combining near-field scan results from probes with multiple orientations is an effective way to identify the current paths in IC packages.

Keywords-- Near-field Magnetic Scanning; IC; VLSI; EMI

I. INTRODUCTION

Integrated circuits (ICs) are often a significant source of radiated energy from electronic systems. Although the IC devices and packages are electrically small and do not radiate efficiently by themselves in general, the RF currents generated by the ICs can drive unintentional radiating structures on the printed circuit board resulting in radiated emissions that are difficult or expensive to control [2]. Well-designed ICs maintain better control of the currents that they generate than poorly designed ICs, and therefore cause less radiation problems for the system that uses them. If one knows the current distribution inside the IC packages for different ICs with the same functionality, the quieter chip can be selected, resulting in fewer potential electromagnetic emission problems.

It has been shown in [1] that near field magnetic scanning is an effective tool for investigating chip-level EMI problems. Near magnetic field scans provide information about the current distributions within IC packages. Information about the current distribution can help EMC engineers track down problems with an IC design that contribute to system-level EMC problems. Estimation of high frequency currents using a near field scan technique may be especially important where currents are difficult to measure, for example for a ball grid array package.

This paper discusses the use of probes with different orientations to measure horizontal and vertical components of the near magnetic fields over the IC packages. Experimental results are shown to demonstrate how the magnetic scan results can be used to infer the current path inside the IC packages.

II. BACKGROUND

The magnetic field (H-field) near a current is proportional to the magnitude of the current. The current direction and magnitude can often be determined from an H-field measurement. The H-field can be measured using a small loop probe and an appropriate instrument, such as an oscilloscope or spectrum analyzer [1][3][4][5].

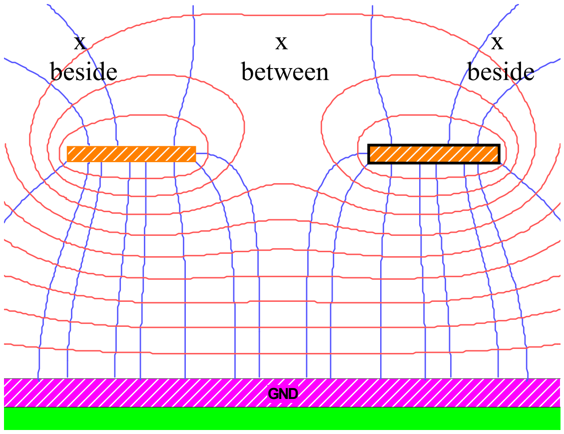
IC packages consist of multiple leads, often including bond wires that carry currents with different magnitudes and phases. The horizontal (tangential) and vertical (normal) components of the magnetic field provide different information about the current distributions inside the package. Using all of this information, the current distribution inside the IC package can be better understood. The horizontal and vertical components of the magnetic field can be measured using small loop probes with the appropriate orientation.

Fig. 1 illustrates the field distributions generated by two traces over a ground plane. Fig. 1(a) shows the field distribution when the two traces have even-mode currents and Fig 1(b) shows the field distribution when the two traces have odd-mode currents. In both cases, the lines starting/ending on traces represent the electric flux and the lines wrapping the traces represent the magnetic flux. The magnetic fields from the two traces either add constructively or destructively to the magnetic field depending on position and current direction, as summarized in Table I.

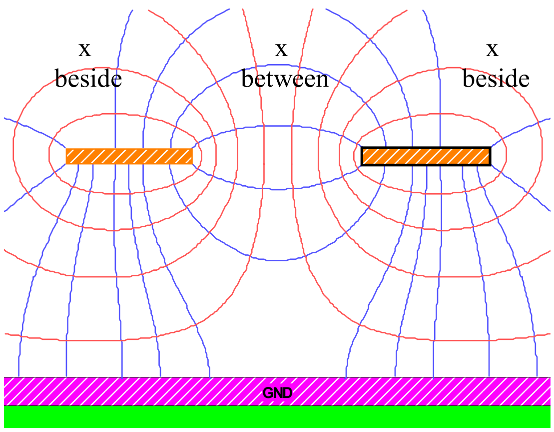
TABLE I. CORRELATION OF THE MAGNETIC FIELD AND CURRENTS ON TWO TRACES

	Horizontal component of H		**Vertical component of H**	
	Between two traces	***Beside the traces***	***Between two traces***	***Beside the traces***
Even-mode current	+	+	-	+
Odd-mode current	-	-	+	-

"+" means additive and "-" means subtractive.



(a) Even-mode



(b) Odd-mode

Fig. 1. Fields generated by two traces with even-mode and odd-mode current.

The magnitude and relative direction of the currents can be estimated from the horizontal magnetic field close to the traces. For example, when the two traces have currents with the same magnitude and are out of phase (odd mode), the horizontal component of the magnetic field has a relatively large magnitude right above the traces and a relatively small magnitude between the two traces (ideally, the horizontal magnetic field will be zero between the traces, assuming the spatial resolution is sufficient to measure it, i.e. the two traces are far apart, the loop is small, and the probe is very close to the traces). The vertical component of the magnetic field, on the other hand, has a relatively large magnitude between two traces and a relatively small magnitude right above the traces. When the two traces carry even-mode currents, the horizontal magnetic field will be large between the traces and the vertical magnetic field will be small between the traces. These concepts are illustrated in Fig. 2.

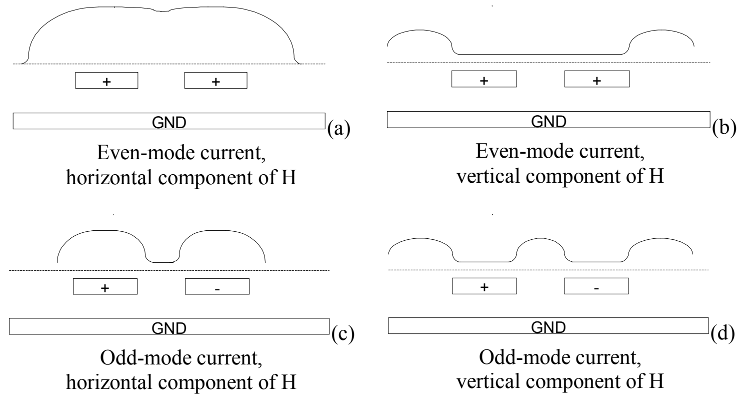


Fig. 2. Conceptual illustration of magnitude of magnetic field generated by two traces.

It should be noted here that analysis becomes much more complicated in real applications since there may be several traces carrying currents that have different magnitudes and phases. However, the simple analysis above still works in the general sense. Research has shown that currents flowing on the lead frame inside IC packages can be successfully extracted from near magnetic field scan data [6].

III. Measurement Setup

Fig. 3 shows a photo of a typical measurement setup. An automated field scanner is connected to an HP 8563E spectrum analyzer and used to measure the near-magnetic field over various ICs in the frequency domain. The height of the probe over the chip is kept constant while the probe is scanned in a horizontal plane parallel to the chip package surface. The height is typically less than 1 mm. For the results presented here, the magnetic field components were measured with a loop oriented in the x and y, (horizontal) and z, (vertical) directions.

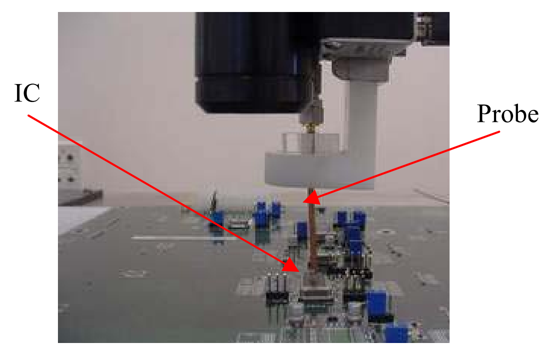
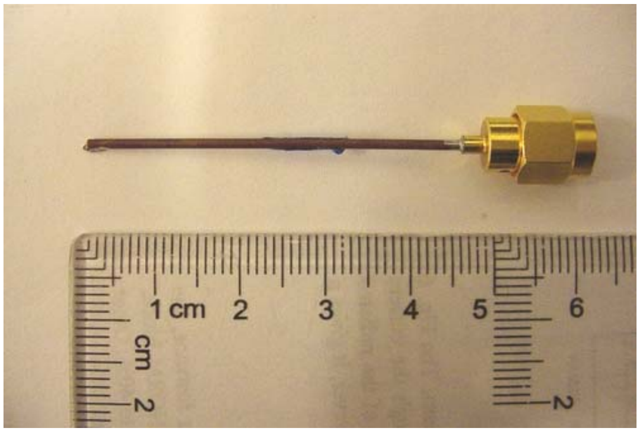
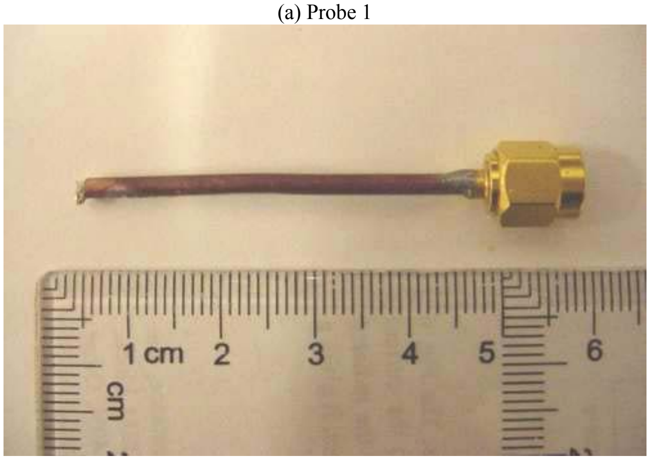


Fig. 3. Measurement setup.

Fig. 4 shows the small loop probes used for these measurements. Probe 1 was used to measure the horizontal components of the magnetic field over the IC packages. Its loop-plane was normal to the surface of the package. The orientation of the probe 1 was rotated by 90^0 during the scan to measure the two orthogonal horizontal components of the magnetic field. Probe 2 was used to measure the vertical component of the magnetic field. Its loop-plane was parallel to the surface of the package. The loop diameter of probe 1 is about 0.5 mm. The loop diameter of probe 2 is about 1 mm. The probes were placed about 1 mm above the package. The resolution of these probes at this height is sufficient, considering the size of the package, that probe outputs may be used without compensation.



(a) Probe 1



(b) Probe 2

Fig. 4. Probes used for near field scanning.

IV. Experimental results

Near magnetic field scans were performed for several samples including a short-circuited 84-pin PLCC package and an FPGA chip with and without a design implemented. The measurement results are summarized below.

A. A short-circuited 84-pin PLCC package

The first sample evaluated was an 84-pin PLCC package with a size of about 3 cm by 3 cm. A Xilinx Spartan XCS10 FPGA package was opened by removing the plastic covering the chip and the package leads were shorted using a copper patch placed over the leads in the center of the package as shown in Fig. 5. The package was mounted on a 4-layer PCB with solid power planes. A 24-MHz clock signal was fed into the right bottom corner of the package through a semi-rigid coaxial cable.

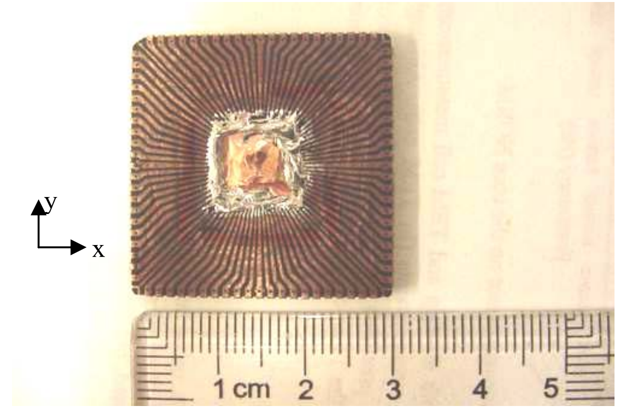
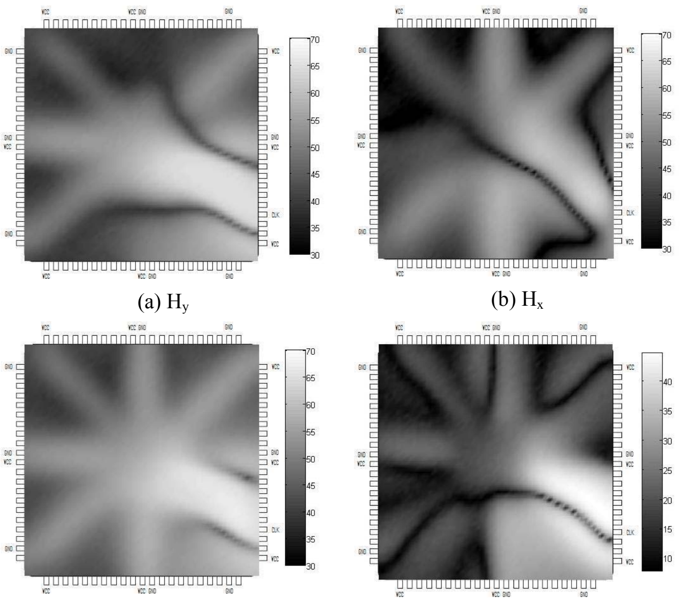


Fig. 5. A short-circuited 84-pin PLCC package

Fig. 6 shows a grayscale plot of the near magnetic field scan at 24 MHz, where (a) shows the y component of the magnetic field, (b) shows the x component of the magnetic field, (c) shows the total horizontal component of the magnetic field which was calculated as $H_h = \sqrt{H_x^2 + H_y^2}$, and (d) shows the z component of the magnetic field. As expected, the horizontal component (H_h) of the magnetic field has a relatively strong value above the traces carrying current and the vertical component (H_z) has a relatively small value above the traces carrying current. In Fig. 6(d), the strongest magnetic field appears in the area close to the CLK trace and the two nearest VCC traces (VCC and GND were shorted at 24 MHz through decoupling capacitors on the PCB) suggesting the majority of the current travels on these traces. Looking at the tangential magnetic field, H_h, one sees the field is strongest over the trace connected to CLK and comes to a minimum between the CLK and VCC traces, suggesting odd-mode currents. That is, that current traveling in through CLK returns through the two VCC traces. This supposition is supported by the measured vertical magnetic field, H_z, which shows a minimum over the CLK trace and a maximum between the CLK and VCC traces. This agrees with our expectations, since these traces are likely to represent the lowest impedance (or inductance) return paths. Note that the minimum in H_h or the maximum in H_z did not occur directly in between the CLK and VCC traces, since each VCC trace carries only a portion of the current on CLK. The slight shift of the magnetic field locations (e.g. the minimum in H_z is shifted slightly downward from the CLK pin) are most likely due to a small error in position registration in this case.



(a) H_y (b) H_x

(c) H_h (d) H_z

Fig. 6. Magnetic field scan over a PLCC 84 package

The vertical component of the magnetic field scan can be processed and presented in a different form than in Fig. 6(d) to better show the current paths. Fig. 7 shows the magnitude of the gradient of H_z, calculated by:

$$\left|H_{z,g}\right| = \sqrt{\left(\frac{\partial H_z}{\partial x}\right)^2 + \left(\frac{\partial H_z}{\partial y}\right)^2} \; . \tag{1}$$

It should be noted here that Fig. 7 was normalized to its maximum value. Fig. 7 shows a pattern similar to Fig. 6(d) that shows the total vertical component of the magnetic field. The pattern shown in Fig. 7 is not as smooth as Fig. (d), because the influence of noise becomes more severe when we differentiate the original signal. However, it still provides additional information. In particular, it shows the approximate locations of both the minimum and maximum of the vertical magnetic field as black lines, better indicating the complete current loop. The current path inside the IC package can be better understood if the original data and the processed data are combined.

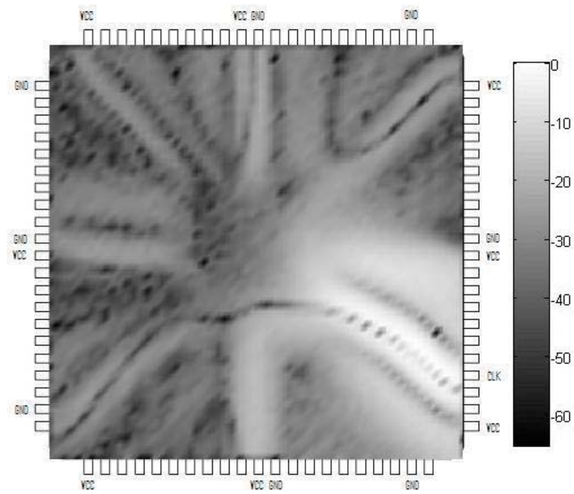


Fig. 7. Magnitude of the gradient of H_z

B. An FPGA without design impemented

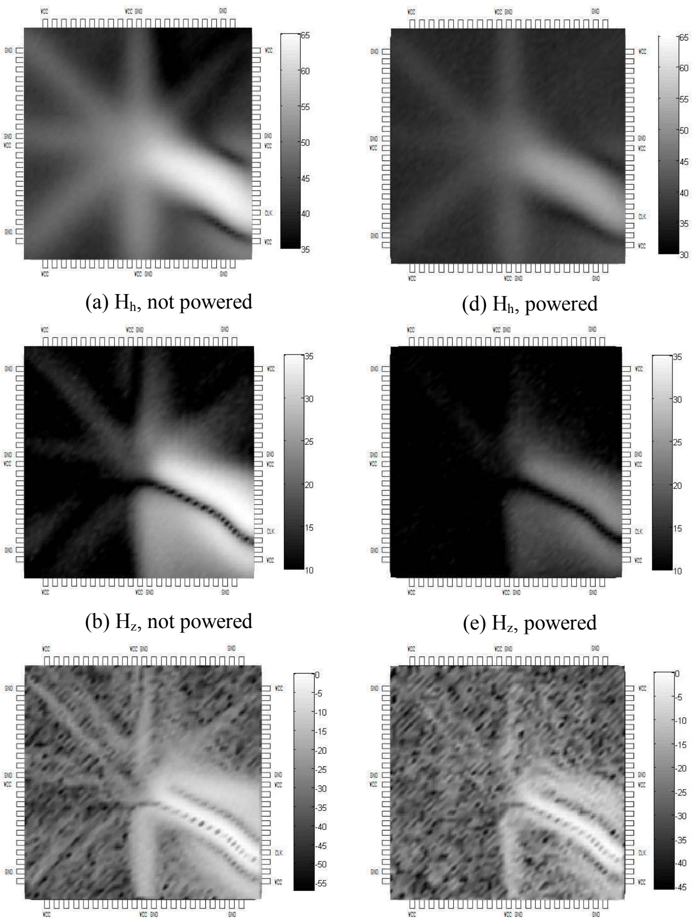
The second sample evaluated was a Xilinx Spartan XCS10 FPGA chip. The same PCB was used as in the previous experiment. A 24-MHz clock signal was fed into the FPGA at the right bottom corner through a semi-rigid coaxial cable to the same pin as in the previous experiment. There was no logic design implemented inside the FPGA. Fig. 8 (a) – (c) shows the scan results when the FPGA was not powered up. Fig. 8 (d) – (f) shows the scan results when the FPGA was powered up. The figures indicate that the IC drew less current when the FPGA was powered up. Further investigations are needed to explain this result.

It is interesting to note that while the scan results for the FPGA are similar to the results for the short-circuited PLCC package, they are not the same. This result is surprising since one would expect the current paths to be determined primarily by the package inductance, yet clearly the chip itself also influences results.

C. An FPGA with design implemented

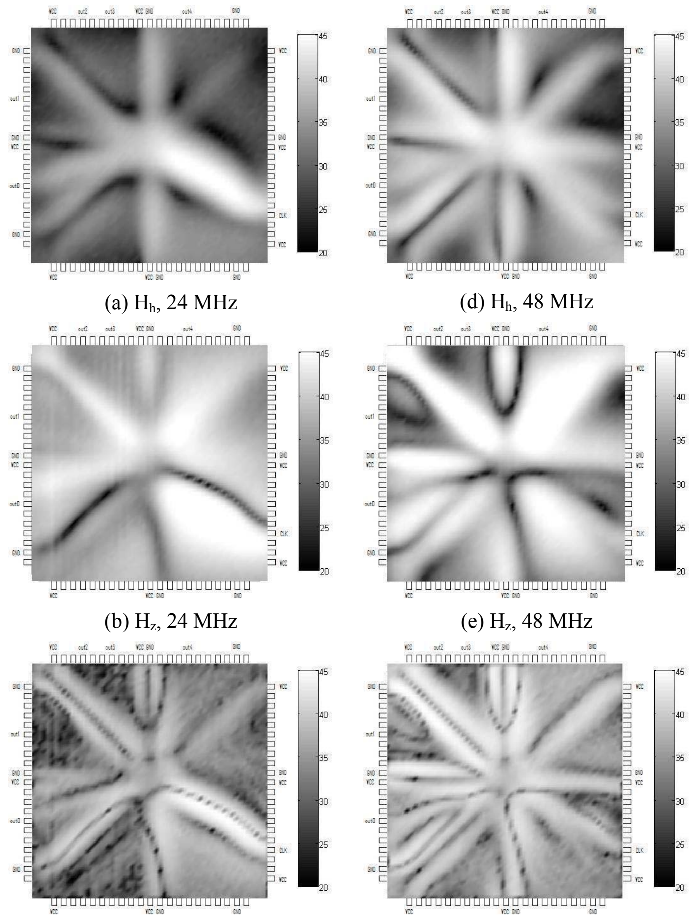
The third sample evaluated was a Xilinx Spartan XCS10 FPGA with a four-bit counter implemented inside. The FPGA was clocked at 24 MHz. Measurements were made at 24 and 48 MHz, the fundamental and second harmonic of the clock frequency. Fig. 9 (a) – (c) shows the scan results at 24 MHz and (d) – (f) show the scan results at 48 MHz.

Fig. 9 shows that the most significant current flowed in the CLK signal trace at 24 MHz, and the most significant currents were drawn from the VCC/GND traces at 48 MHz. This result is not surprising, as the clock trace is driven at 24 MHz, resulting in significant current at that frequency. Power bus noise should have significant components at twice the clock frequency, resulting in appreciable currents on VCC/GND pins at 48 MHz.



(a) H_h, not powered
(d) H_h, powered
(b) H_z, not powered
(e) H_z, powered
(c) $H_{z,g}$, not powered
(f) $H_{z,g}$, powered

Fig. 8. Magnetic field scan over an FPGA without design implemented



(a) H_h, 24 MHz
(d) H_h, 48 MHz
(b) H_z, 24 MHz
(e) H_z, 48 MHz
(c) $H_{z,g}$, 24 MHz
(f) $H_{z,g}$, 48 MHz

Fig. 9. Magnetic field scan over an FPGA implementing a four-bit counter.

V. CONCLUSIONS

ICs are often the primary source of radiated emissions from the electronic products that use them. The current distribution inside the package can be estimated from near magnetic field scans above the package surface. Information about the current distribution can help EMC engineers to track down problems with an IC design that contribute to system-level EMC problems.

The horizontal and vertical components of the magnetic field can be measured using probes with different orientations. The magnitude and relative direction of the high-frequency currents flowing on the lead frame inside the IC packages can be estimated by combining both the horizontal and vertical components of the magnetic field, providing useful information for the identification of current paths and potential EMI problems associated with the IC.

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