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A Common-mode Current Measurement Technique for EMI Performance Evaluation of PCB Structures

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Abstract

An experimental technique that measures the common-mode current on a cable attached to a DUT for assessing EMI performance is introduced herein. The technique was applied to evaluate the EMI performance of a module-on-backplane configuration with different connectors and different connector pin-outs.

I. Introduction

A typical PCB structure produces two types of radiated emissions - differential-mode and common-mode emissions [1]. It has been shown that common-mode currents are typically the predominant source of radiation from a PCB [2]. Therefore, measuring the common-mode current (if applicable) can be helpful in evaluating the EMI performance of a PCB design.

An experimental technique that measures the common-mode current on a semi-rigid coaxial cable attached to the DUT for assessing the EMI performance is introduced in this paper. The experimental method is then applied to a module-on-backplane configuration to evaluate the EMI performance of different connectors and different connector pin-outs.

For the multi-PCB configuration, the signal return of the inter-board connection has appreciable impedance, and a potential difference between connecting PCB planes may develop. The planes are typically of appreciable electrical extent, and can function as EMI antennas at several hundred megahertz or higher, resulting in an EMI problem. This has been demonstrated previously [3], [4]. The potential difference induced at the inter-board connection acts as an "effective" noise source. The common-mode current on the cable attached to the PCBs is indicative of the EMI, as shown in Figure 1.

II. Experimental method

The setup of the experimental method is shown in Figure 2. It is basically a two-port $|S_{21}|$ measurement using an HP8753D network analyzer. A 60 *cm* × 60 *cm* aluminum plate is used to separate the DUT and the measuring instruments to enhance the repeatability and dynamic range of the measurement, and eliminate artifacts associated with the dressing of cables to the measuring instrument. Two SMA bulkhead through connectors are mounted on the aluminum plate to provide the signal paths through the plate. A semi-rigid coaxial cable is attached to the DUT. The cable also provides the feeding path from Port 1 of the network analyzer to the DUT. A Fischer 2000 clamp-on current probe is placed around the semi-rigid coaxial cable and connected to Port 2. The induced common-mode current on the outer-shield of the attached semi-rigid cable is then picked up by the current probe, and fed into Port 2 of the network analyzer. The measured $|S_{21}|$ is related to the common-

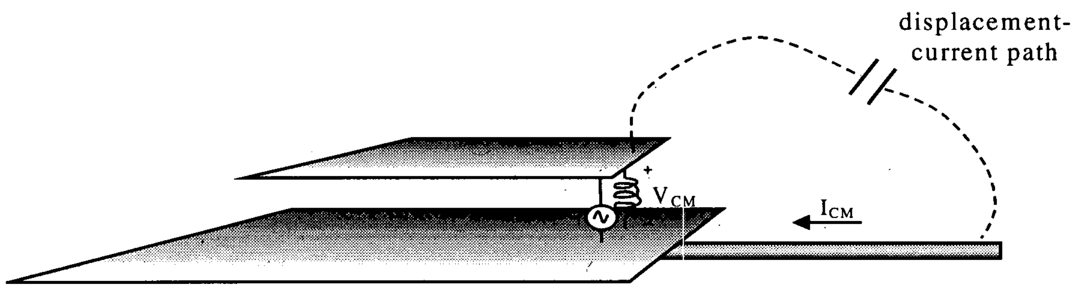


Figure 1. Schematic showing the mechanism of common-mode current being induced on the attached coaxial cable.

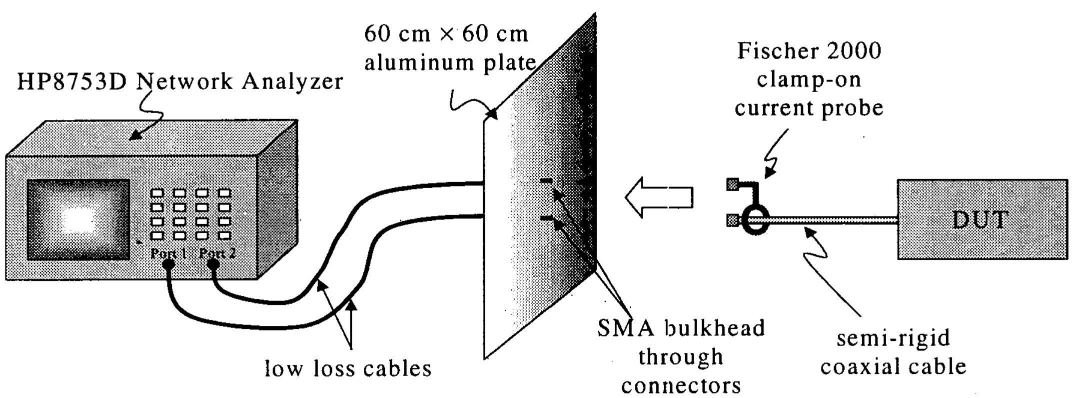


Figure 2. Schematic representation of the experimental setup for the common-mode current measurement.

mode current induced on the attached coaxial cable, which is indicative of the EMI. A specific calibration procedure is conducted to determine the relationship between $|S_{21}|$ and the magnitude of the induced common-mode current on the attached cable as:

$$\left|S_{21}^{measured}\right| = \left|\frac{I_{CM} \cdot 50\Omega}{V_s}\right|$$

The transfer impedance of the current probe is removed in the calibration procedure. Since the common-mode current can be readily calculated with numerical modeling, this equation makes possible an absolute comparison between the measured data and the modeled results. Other advantages of this experimental setup includes its low-cost; straightforward and easy implementation; repeatability; and it can be used for evaluation of prototype and production PCBs.

A simple test configuration as shown in Figure 3 was built to investigate the dynamic and frequency range of this measurement technique. Two conductors with a radius of 24 mils were used as the feeding and receiving monopole antennas. Both monopoles were 15 cm long, and separated by 5 cm. The induced current on the receiving monopole was measured. The measured result is shown in Figure 4, together with the FDTD modeled result. Discrepancies become prominent as frequency increases beyond 1.5 GHz. The discrepancies result possibly from the limitation of the calibration procedure, and parasitics of the current-probe (which was not included in the modeling).

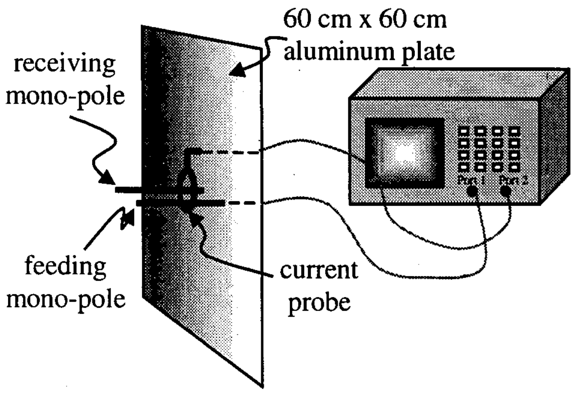


Figure 3. Schematic of the coupled monopole antennas measurement

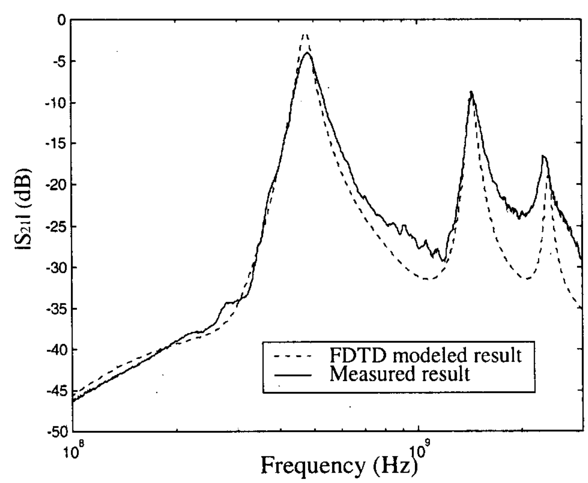


Figure 4. Modeled and measured results of the coupled monopoles.

III. EMI performance study of module-on-backplane connectors.

The common-mode measurement technique was then applied on a module-on-backplane configuration to investigate the effect on EMI of the inter-board connections. Module-on-backplane configurations are commonly used in high-speed digital designs to conserve real estate. A typical module-on-backplane structure can have an appreciable electrical size, and, when provided with suitable excitation, can function as an EMI antenna in the frequency range of several hundred MHz into the GHz range. An appreciable signal return impedance at the connector can then facilitate excitation of the structure as an EMI antenna [4], [5], [6]. Therefore, the inter-board connector may be of significant importance for the EMI performance of the multi-board configuration.

A specific test fixture was built for this study, with the schematic shown in Figure 5. The test fixture includes a 30 cm × 20 cm mother-board, a 12 × 10 cm daughter-board, an inter-board connector, and a 20 cm long 0.085" semi-rigid cable attached to the ground plane of the mother-board. The signal is fed through the attached cable and penetrates through the ground plane of the mother-board, and is then directed through the connector and terminated at the daughter-board. No traces are present on either board. The outer shield of the semi-rigid cable is soldered to the ground plane of the mother-board along the entire contacting length.

Two types of commercially available connectors were studied. Only one signal pin of either connector is used to provide the signal path, while the signal-return geometry differs. Figure 6 illustrates some possible connector signal and signal-return patterns in PCB designs. For Cases A1-A5, B1-B3, and C1-C3, the connector under test is an open-pin-field connector. The signal pin has different adjacent signal-return geometries, as detailed in the figure. For Case D1-D2, the connector is a stripline-type product connector, where each column of connector signal pins (except one column at the edge) is

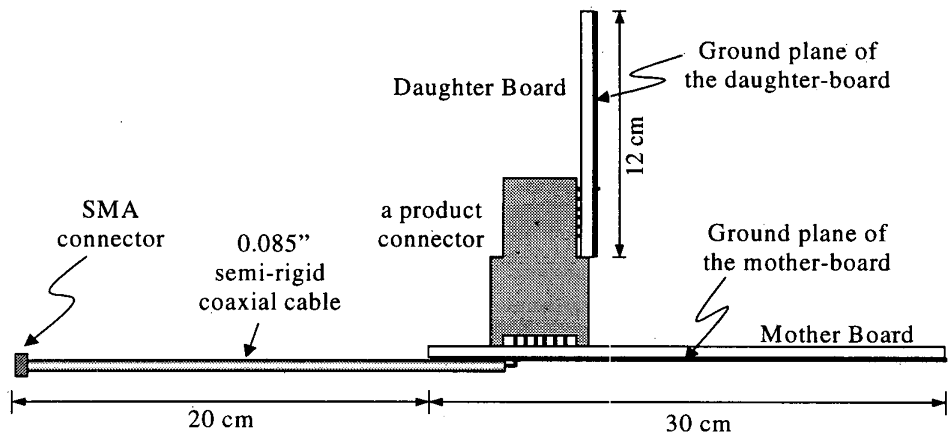


Figure 5. Schematic of the test fixture built for the common-mode current measurement on a module-on-backplane configuration.

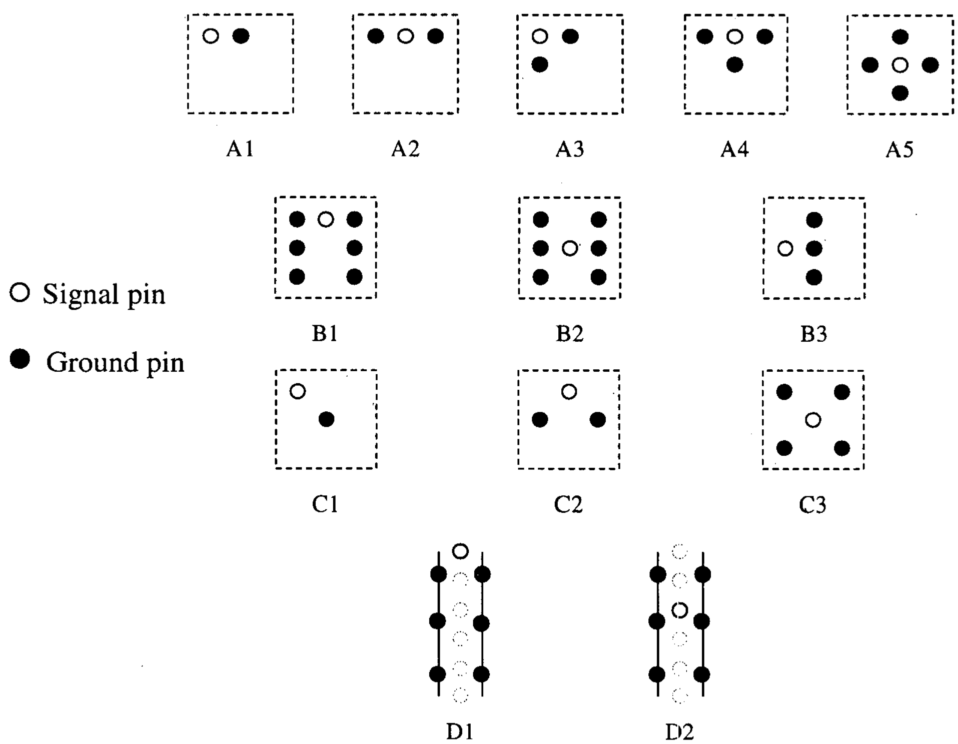
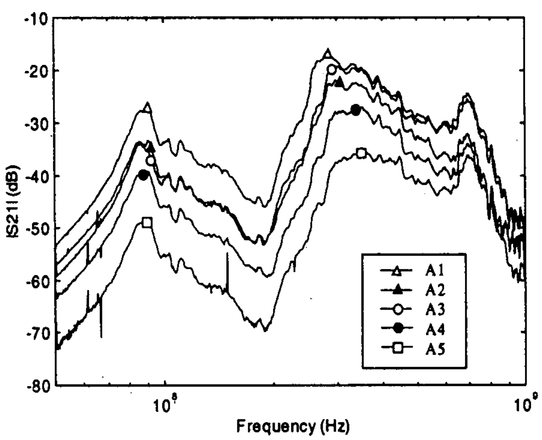


Figure 6. Possible connector signal and signal-return designations.

sandwiched by two ground blades. The ground blade has 3 short contacts, which are used for the electrical connection between the blade and the PCB ground plane or power plane. Cases D1 and D2 have different signal pin designations.

A series of experiments was then conducted using the experimental technique shown in Figure 2. The common-mode current on the attached semi-rigid cable for each case is shown in Figure 7. The results indicate that the EMI performance of the connector is very dependent on the signal-return geometry. A few conclusions may be drawn from the comparisons. First, the EMI performance can be enhanced by improving the field containment at the inter-board connection, including using multiple signal-return pins (see the improvement from Case A1 to Case A5), closer signal and signal-return spacing (comparing Case C1 with Case A1), or a stripline-type connection (comparing Case D2 with Case A5). Also, the signal pin designation is critical for EMI performance, i.e., routing the signal through the inner connector pin-rows is beneficial for EMI mitigation (comparing Case D1 with D2). FDTD modeling has also been done on several of these geometries, with good agreement to the measurements.



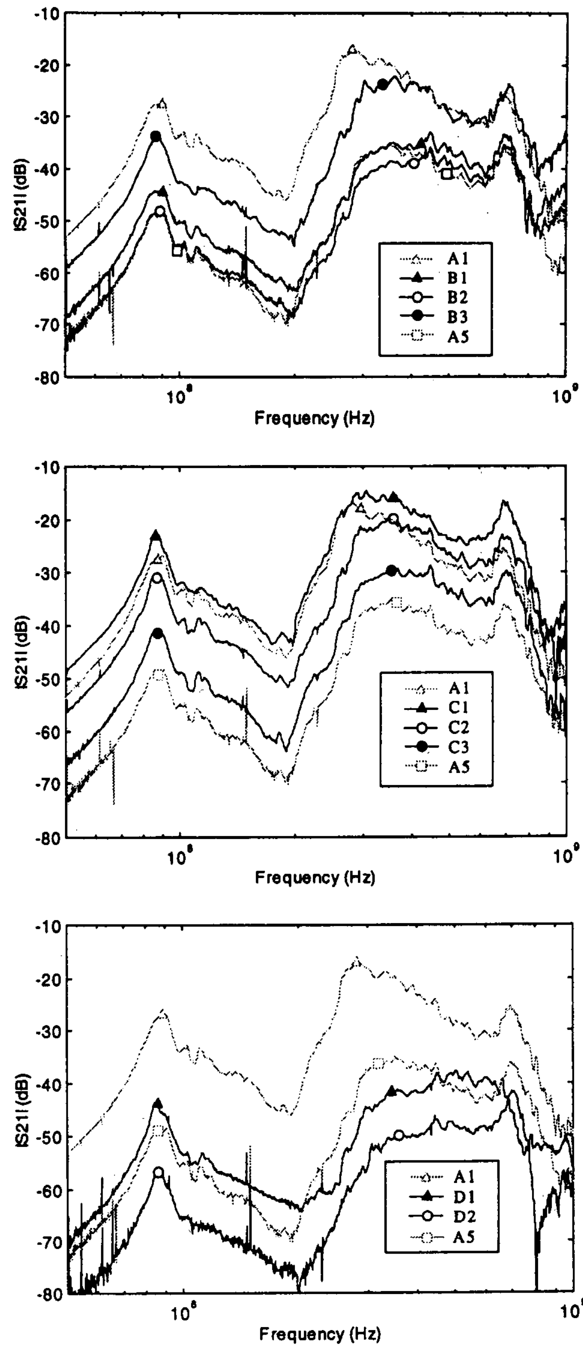


Figure 7. Measured common-mode current for the test fixture with connector signal and signal-return patterns shown in Figure 6.

VI. Summary and Conclusions

A common-mode current measurement technique is introduced in this study and applied to evaluate the EMI performance of two types of module-on-backplane connectors. It is found that the EMI performance of the connector is very dependent on the signal-return geometry. The EMI performance can be enhanced by improving the field containment at the inter-board connection, including using multiple signal-return pins, closer signal and signal-return spacing, or a stripline-type connection. It is also found that the signal pin designation is critical for EMI performance. Routing the signal through the inner connector pin-rows is beneficial for EMI mitigation.

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