Investigation on Realizing 1 Ω Current Probe Complied with IEC 61967-4 Direct Coupling Method

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***Abstract*—The practical approach to implement a 1 Ω current probe with verification for measuring the IC conducted emission is proposed. The 1 Ω/150 Ω direct coupling method is reviewed and the considerations on improving the applicable bandwidth of 1 Ω method are discussed. The critical component, 1 Ω resistor which dominates the frequency response, is designed. The realized 1 Ω probe was fully certified with the specification in the IEC 61967-4 standard. The experimental results show the applicable bandwidth of the 1 Ω could cover 1 GHz with accuracy and confidence.**

Keywords—integrated circuit; EMC; conducted emission; 1 Ω current probe

I. INTRODUCTION

The continuous miniature of the feature size in integrated circuit (IC) technology, as known as Moore's law, increases the significance of the electromagnetic compatibility (EMC) of IC. Scaling down the size of the devices as well as the increasing transistors amount allow IC to be operated at high-speed with low power consumption. The consequently desired high performances not only produce noise but also make the IC itself sensitive to interference. This situation leads the demand of characterizing ICs' behaviors of emission and immunity. To investigate these problems, several measurement methods have been developed as the standards.

The technology subcommittee 47A of International Electrotechnical Commission (IEC) published a series of IC level test methods on electromagnetic interference (61967 series) [1] and electromagnetic susceptibility (62132 series) [2]. Depend on the transfer types of electromagnetic wave, the test methods can be further classified into radiated or conducted ones. A concise method to characterize the conducted emission of IC is standardized as IEC 61967-4 [3], as known as the 1 Ω/150 Ω direct coupling method. It guarantees the electromagnetic emission (EME) measurement of IC with high repeatability and correlation. Since EME is caused by fast changes of currents/voltages inside the IC. The resulted radio frequency (RF) currents/voltages distribute and form emitting loop antennas via on-chip passive distribution network (PDN), interconnect of package (solder bump, bond wire, and IC pins), and the off-chip PDN (traces on PCB, cable harness). In order to analyze the RF currents/voltages, two acquisitions named 1 Ω current measurement and 150 Ω voltage measurement are specified in IEC 61967-4. Using the probes composed of few lump components makes the observation on EME behaviors on certain IC pins become easy. Though the accuracy problem of 150 Ω method were reported with some comparative experiments [4]-[5] in the early period, the issue was improved and the 150 Ω method is used widely. The emission masks were used to help generate the design constraints of a microcontroller [6]. Similarly, with the ease of implementation and accuracy, the behavioral model of memory IC was built by utilizing the 1 Ω method [7]. However, the details of 1 Ω method is depicted in the standard, seldom work [8] was reported and met the specifications of current probe. The practical problem on implementing the current probe is raised from the imperfection of the critical component, 1 Ω resistor, at high frequency. Therefore, the literature of adopting 1 Ω method to measure conducted emission are relatively less than that of using 150 Ω voltage probe. And the specification of 1 Ω current probe in these paper are not described with verification, which may lead to the measurement error when the comparative experiments are proceeded.

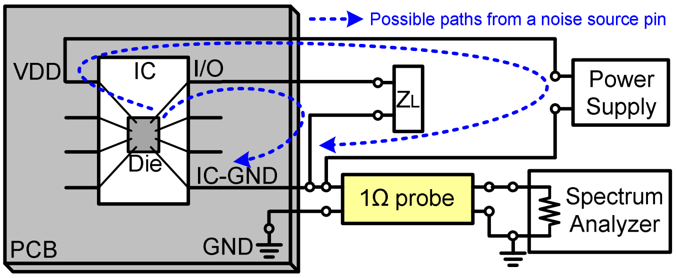


Fig. 1. 1 Ω method test setup: 1Ω probe is inserted between IC-GND & GND.

This paper depicts the consideration and approach to implement a 1 Ω current probe with certification. The IEC 61967-4 direct coupling method is revisited and the improvement on the probe is proposed in section II. In section III, the realized 1 Ω probe is tested and verified to comply with specification set down in the standard. The measured results prove the current probe was validated and could be used to perform the conducted emission test for IC.

II. 1 Ω DIRECT COUPLING METHOD

All RF currents have their selves' loop that flow out and back to the IC. The return paths are mostly via the ground or

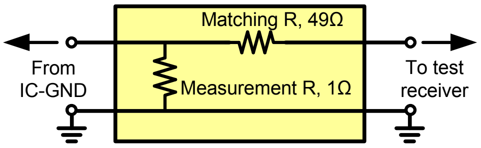


Fig. 2. The configuration of the 1 Ω current probe.

power plane. Therefore, the ground pin of IC is a great position for measuring the RF return current. A 1 Ω probe is inserted between the ground pin (IC-GND) of the IC and the ground (GND) as shown in Fig. 1 to measure the RF voltage across the 1 Ω resistance of probe. The RF voltage measured by a test receiver is resulting from all of RF currents returning to the IC. The two ports 1 Ω probe as shown in Fig. 2 is composed of a 1 Ω resistor and a 49 Ω resistor. One end of the 1 Ω resistor is linked to the ground pin (IC-GND) of IC and the other end is connected to ground (GND). The 49 Ω resistor is placed between the ground pin (IC-GND) of IC and the test receiver with 50 Ω input impedance. As the result, this configuration achieves the 50 Ω (49 Ω plus about 1 Ω) impedance matching which satisfies maximum power transmission by looking from test receiver side. From the ground pin (IC-GND) side, the 1 Ω provides a low impedance current path for IC operation. Finally, the RF current/voltage are divided and be measured by the test receiver.

A. The Concern of Realizing 1 Ω Resistor

As the miniature trend of every electronic device, the surface mounted device (SMD) becomes the best candidate to realize a printed circuit board (PCB) level design. The leadless property reduces the unwanted parasitic than the axial leaded device for high frequency or high speed applications. But the parasitic never disappears, a typical high frequency model of SMD resistor is shown in Fig. 3. The resistance represents the intrinsic resistor and the inductance is formed by the finite length of the resistor and contacting pads, while the capacitance is the coupling of the pads. These parasitic values could be measured or provided by the manufacturer. Unfortunately, unlike the inductors and capacitors which are used frequently in the RF and microwave applications, most resistor data sheets do not provide the detailed model or frequency response as the reference of performance. Sometimes only limited information such as low band results can be obtained, or some other insufficient results were released for estimation. The normalized impedance-to-resistance (Z/R) plot could show the behavior of a resistor is inductive or capacitive. It is easy to make comparison of the parasitic elements of different resistances or different types, but it may lead to a misunderstanding of the actual applicable bandwidth. For instance, a Z/R curve maintains one until 5 GHz that does not mean the imaginary part impedance of this component equals to zero up to 5 GHz. Because the resistance may also increase as well as the reactance while the frequency increases. As a result, even a component with a flat Z/R curve over a wide frequency range, the overall impedance indeed has changed to an undesired value. Besides, only certain resistor values not for radical ones are tested and shown in the datasheets. Especially for a low value resistor, the inductance dramatically dominates the impedance out of low frequency band. Therefore, the estimation of choosing component relies on the basic network analysis. By measuring the S-parameters of the resistor, the real part and imaginary part can be distinguished. Then user can choose the appropriate component from different vendors into design.

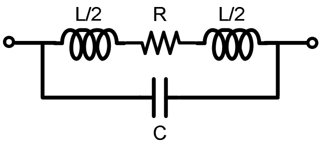


Fig. 3. The high fryqency equivalent circuit of a SMD resistor.

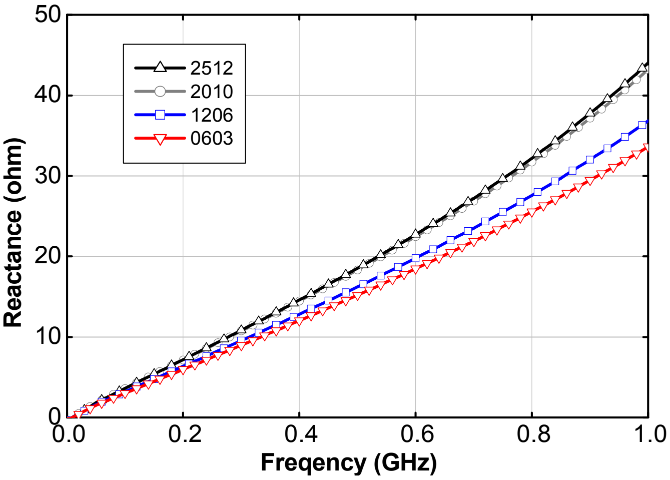
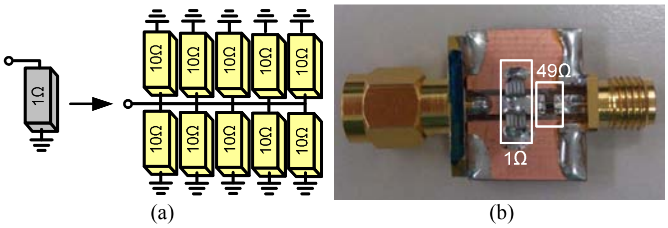


Fig. 4. The reactance caused by the parasitic within different SMD packages.

Except for the performance which dominated by the supplier ability, the package type plays an important role for implementation. To investigate the influence of the package, several 1 Ω SMDs of different package sizes ranging from the imperial code 2512 to 0603 were examined. The equivalent parasitic inductance and capacitance for each package type were obtained from the measured S-parameters. The resistor under test is shunt to ground, with the contact pads, transmission lines, and SMA adapters are took into account in a simplified model as same as shown in Fig. 3. Therefore, the out coming results could be estimated directly for constructing the 1 Ω probe. In this work, the vector network analyzer used to measure the S-parameters is Agilent PNA N5230A with the measurement capability of 300 KHz to 20 GHz. The standard short-open-load-thru (SOLT) calibration was performed before testing. Fig. 4 shows the measured results of 1 Ω SMD resistor of different package sizes on a PCB with two SMA adapters. As can be seen, the impedance increases as well as the increasing frequency. The extracted coupling capacitances are about 0.6 pF to 0.8 pF, while the inductances range from 4.75 nH to 5.7 nH. As a conclusion, the smaller package size contributes less parasitic effect which is determined to be the candidate for implementing the 1 Ω probe. However, to reduce the parasitic inductance relies on using the small package size is not enough from the experimental results. Solutions via layout and placement have to be considered. A brilliant technique used to reduce the parasitic inductance contributed from wraparound terminations is to flip the resistor side down to the PCB; it shortens the signal path that minimizes the



(a) (b)

Fig. 5. The improvement on imperfect 1 Ω resistance: (a) multiple shunt resistors for reduction of parasitic inductance, (b) photograph of the relized 1 Ω probe.

inductance.

One more concern has to be addressed that the surface mounted resistors are almost film resistors which composed of a thin coating material like metal or carbon on a substrate. These resistors are very accurate and stable because of the well-developed technologies such as deposition and trimming. This advantage makes these components meet the 1% variation in the 1 Ω probe specification. But a drawback of the film resistor is the power handling ability that also is a specification item of the 1 Ω probe. The typical power rating of a 0603 SMD is about 0.1 W which is easy to be damaged. As a result, the power rating and package size become a design tradeoff.

B. Proposed Improvement on 1 Ω Resistor

In this work, a practical solution is utilized to satisfy both aforementioned demands. Based on the property of shunting several components, the overall resistance and inductance will divided by the amount of components. Therefore, ten 0603 package resistors with resistance of 10 Ω were connected in parallel to form the 1 Ω resistor as shown in Fig. 5. Except for using shunted components, the layout and placement were also carefully designed. The coplanar-waveguide (CPW) transmission line is utilized to maintain the 50 Ω characteristic impedance for eliminating unwanted parasitic at high frequency. The CPW structure with ground planes located at two sides of signal path makes the shunt connection in ease. Furthermore, it shortens the return path compared to the microstrip-line type transmission line that may contribute inductance from the through substrate via to the backside ground. Five resistors were mounted on each side of ground planes which saves the total dimension. As a result, the measured corresponding parasitic shunt capacitance across the resistor element is 0.6 pF. And the parasitic series inductance was further reduced to 4.25 nH. In addition, the shunt connection brings another advantage of enhancing the power rating ten times than a stand-alone 1 Ω resistor theoretically. With such an impressive improvement, this solution was then used to implement the 1 Ω current probe. The following section will discuss the verification and prove the 1 Ω probe in this work could meet the specification in IEC 61967-4.

III. VERIFICATION OF THE CURRENT PROBE

The specification of current probe in direct coupling method is listed in table I. The most critical item is the insertion loss with a calibration circuit board. This calibration could bring out the isolation and insertion loss provided by the current probe. Though the standard depicts a design sample of the calibration board for reference, the board with N-type connector is not suitable for the test setup in this work. All the adaptor of the test setup in this work use SMA adaptor because of its small size feature and stability. Therefore, the layout design is modified for SMA adaptors but obeys the same schematic proposed in the standard.

TABLE I. SPECIFICATION OF THE 1 Ω CURRENT PROBE

Frequency range	DC-1 GHz
Measurement resistor	1 Ω (1%)
Matching resistor	49 Ω (1%)
Maximum current	<0.5 A
Output impedance Zo	40 Ω -60 Ω
Insertion loss in calibration circuit	34 dB±2 dB
Decoupling	Larger than the limit line as shown in Fig. 8

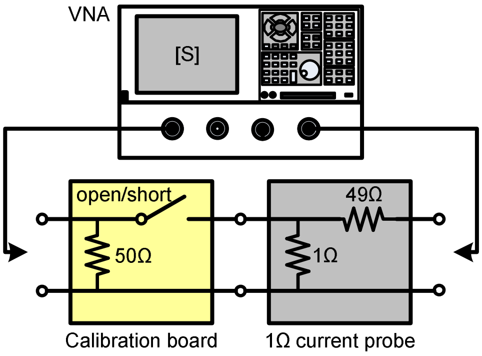


Fig. 6. The configuration for performing sensitivity and decoupling by connecting the 1 Ω probe to the calibration board.

For proceeding this measurement, the detailed procedure and test setup is reviewed. A calibration board with an input port is linked to the signal source. The current probe input port is connected to the output of the calibration board, and the output port of current probe is connected to a test receiver. A vector network analyzer can be used to perform this testing as shown in Fig. 6. With the clamp on the calibration board at short or open status, two measurements have to be performed. The measured insertion loss when the clamp is at short status is referred to the sensitivity of the probe. The sensitivity is desired to exhibit a flat frequency response over the test bandwidth of 1 GHz. A variation of ±2 dB from -34 dB is allowable in the given specification. Practically, this is difficult to fulfill because the poor 1 Ω characteristic presents a much higher impedance on the shunt path which leads in the insertion loss decreasing sharply at higher frequency and fails to serve as a current probe. The solution proposed in the previous section was adopted to overcome this problem. Fig. 7 shows the measured result which meets the specification in the standard. The black curve shows the insertion loss of the current probe connected to the calibration board. An interesting experiment was done to point out the importance of the calibration board design. Before connecting to the calibration board, the S-parameters of current probe can be

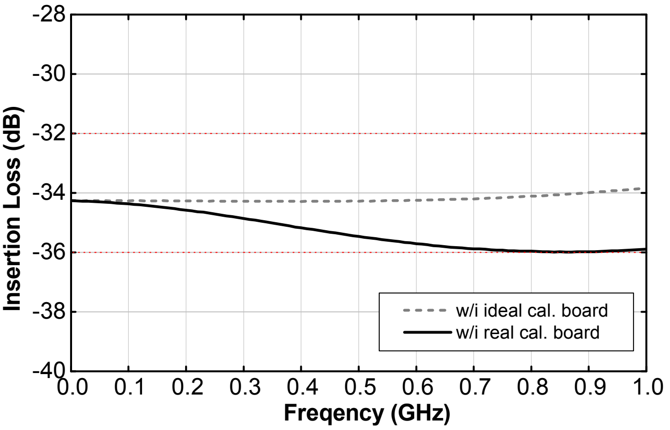


Fig. 7. The insertion loss of the 1 Ω probe connected to the calibration board.

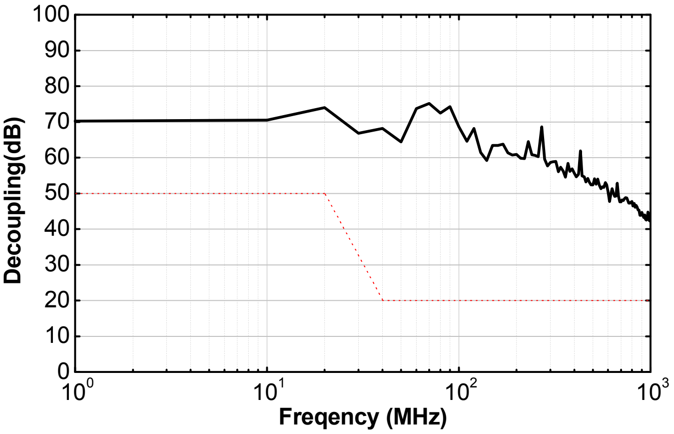


Fig. 8. The decoupling performance of the 1 Ω probe.

measured solely. The measured data was then imported into the simulator and be connected to a virtual calibration network composed of an ideal 50 Ω resistor. The grey dashed curve shows the result of sensitivity which improves the flatness of frequency response and expands the applicable bandwidth wider than 1 GHz. Therefore, the calibration board does affect the calibration and should be design carefully.

Another insertion loss measurement is performed when the clamp is at open status. By subtracting this data from the sensitivity measured previously, the difference is called decoupling which correlates to the quality characteristic related to the signal source and also represents the shielding of probe. The decoupling performance is shown in Fig. 8 with a limit curve (red dotted line) versus frequency reported in the standard. The last check item is the output impedance as show in Fig. 9, it describes the impedance looking from the test receiver side should be near 50 Ω to maintain the matching condition for receiving disturbance. The result shows the output impedance complies with limited range from 40 Ω to 60 Ω within 1 GHz. As a result, all the items in the speciation table are reviewed and verified as a certified current probe used in the IEC 61967-4 direct coupling method.

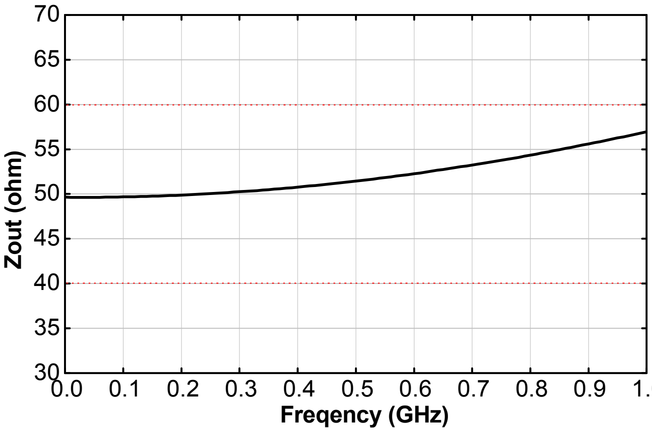


Fig. 9. The output inpedance of the 1 Ω probe.

IV. CONCLUSION

The consideration on implementing the 1 Ω current probe for measuring the IC conducted emission is proposed. The detailed design techniques are discussed. The performance of applicable frequency range, output impedance, sensitivity, and decoupling performance are fully complied with the specification of IEC 61967-4. The experimental results prove the current probe could be used to perform the conducted emission test for IC with accuracy.

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REFERENCES

[1] *Integrated Circuits, Measurement of Electromagnetic Emission, 150 KHz to 1 GHz*, International Electrotechnical Commission Standard IEC61967, 2002.

[2] *Integrated Circuits, Measurement of Electromagnetic Immunity, 150 KHz to 1 GHz*, International Electrotechnical Commission Standard IEC62132, 2006.

[3] *Integrated Circuits, Measurements of Electromagnetic Emission, 150 kHz to 1 GHz—Part 4: Measurement of Conducted emission- 1Ω/150Ω direct coupling method*, Standard IEC 1967-4, 2006.

[4] F. Fiori and S. Pignari, "Analysis of a test setup for the characterization of integrated circuits electromagnetic emissions," in *Proc. IEEE Int. Symp. on Electromagn. Compat.*, Aug. 2000, pp. 375–378.

[5] B. Deutschmann, G. Winkler, and R. Jungreithmair, "Measuring the electromagnetic emissions of integrated circuits with IEC 61967-4 (The measuring method and its weakness)," in *Proc. IEEE Int. Symp. Electromagn.* Aug. 2002, pp. 407–412

[6] F. Musolino, Y. Villavicencio, and F. Fiori, "Chip-level design constraints to comply with conducted electromagnetic emission specifications," *IEEE Trans. Electromagn. Compat.*, vol. 54, no. 5, pp. 1137–1146, Oct. 2012.

[7] S. Stievano et al., "Behavioral modeling of IC memories from measured data," *IEEE Trans. Instrum. Meas.*, vol. 60, no. 10, pp. 3471–3479, Oct. 2011.

[8] F. Fiori and F. Musolino, "Comparison of IC conducted emission measurement methods," *IEEE Trans. Instrum. Meas.*, vol. 52, no. 3, pp. 839–845, Jun. 2003.