The Practical Measurement Setup of DPI Method above 1 GHz for ICs

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***Abstract*—A reliable DPI measurement is proposed to investigate the IC immunity above 1GHz. The direct RF power injection (DPI) method is reviewed, and the concern for extending frequency range is discussed. Details of the measurement setup are reported in this work. The critical part, on-board injection network, in the power injection path is realized with a 3dB bandwidth of 14.5GHz. A low dropout regulator is used to demonstrate the test and setup. The proposed DPI measurement above 1GHz is validated by the experimental results.**

I. INTRODUCTION

Moore's law increases the significance of the research of the electromagnetic compatibility (EMC) of integrated circuits (IC) because of the continuous miniaturization of the feature size in IC technology. Scaling down the size of the devices as well as the increasing transistors amount allows IC high-speed operation driven by lower power. The consequently desired high performances in the opposite side not only produce noise but also make the IC itself vulnerable to interference. It leads the demand of characterizing their behaviours of emission and immunity. Therefore, several measurement methods have been developed as the standards.

The technology subcommittee 47A of International Electrotechnical Commission (IEC) published a series of chip-level test methods for EMI (61967 series) [1] and EMS (62132 series) [2]. They are widely adopted as the comparative evaluation for choosing the best candidate of product from different designs. Among them, a method to measure the immunity of ICs called direct RF power injection (DPI) [3] is popular as shown in Fig. 1. The straightforward test setup helps to investigate the conducted emission behaviour of the certain IC pin/pins. Relying on the help of measurement, most EMC performance can be classified. [4] utilized the DPI to differentiate the improved susceptibility levels of an IC with several embedded on-chip EMI protection. Similarly, the ESD protection strategy uses DPI as the EMI aggression to demonstrate the impact on EMC performance [5]. Furthermore, DPI was applied to help build the model of a high-voltage p-channel metal-oxide-semiconductor (HV-PMOS) which can predict accurately the susceptibility in transistor level [6]. These reveal the fact that DPI is recommended when the experimental results were desired to be reproducible, repeatable, and confident. Furthermore, the models of DPI test setup were built for simulation which agrees well with measured results [7-8]. Based on the mature modeling, the differences between DPI and BCI (bulk current injection) [9] tests are analysed and the high conformity is observed [10]. These valuable literatures provide informative issues for DPI and polish it. The rest part of DPI to be looked for is its applicable frequency bandwidth.

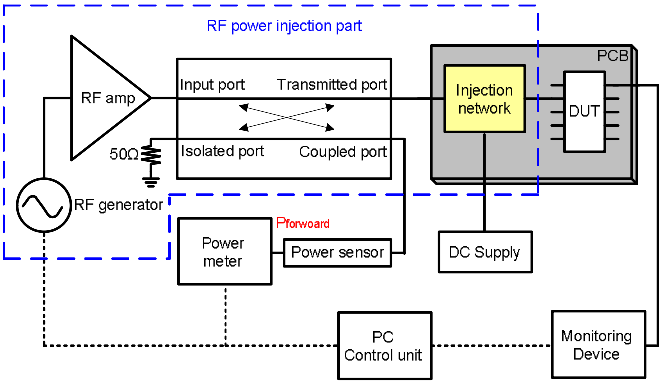


Fig. 1 The test setup of DPI method for ICs.

Most released standards like IEC series have the frequency range below 1 GHz. And sometimes it is insufficient to evaluate the EMC behaviours while the modern circuits operate higher than 1 GHz. Therefore, some measurement methods like GHz transverse electromagnetic (GTEM) cell [11] was proposed which has the frequency range up to 18GHz. As the trend, the DPI is also expected to having the capability of a wider bandwidth. [12] proposed a new methodology by using the edge coupled transmission line as a part of the injection network. The result shows requirement above 1GHz can be achieve, but the frequency bandwidth was limited by the narrow band nature of coupler.

This paper is organized as follows. At first, the DPI method is revisited and some principles are emphasised. In section III, the feature of DPI test above 1GHz is proposed. The measurement setup and discrete components used in the injection path with the test board are discussed in details. Finally, a LDO used widely in communication module is tested as the DUT. The result of immunity level from the conducted RF disturbances is measured, and the measurement setup is validated.

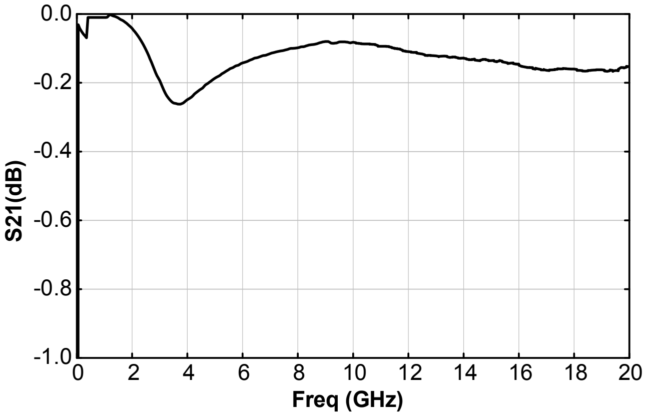


Fig. 2 The insertion loss of the chosen capacitor.

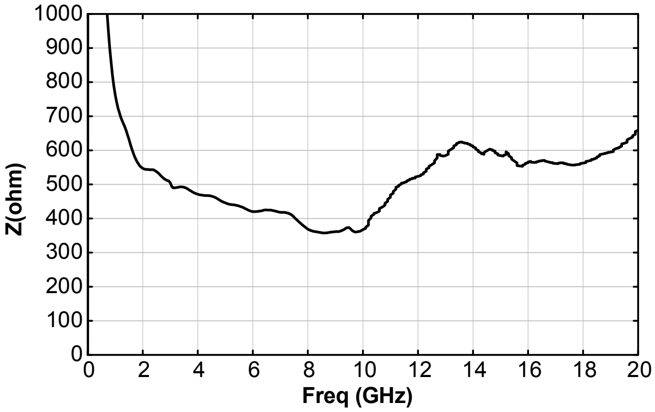


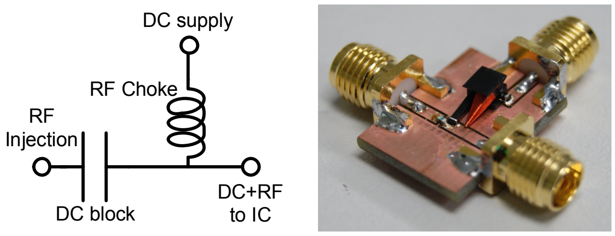
Fig. 3 The impedance of the chosen inductor .

II. CONSIDERATIONS OF THE DPI TEST SETUP ABOVE 1GHZ

The DPI method is defined to measure the immunity of IC in the presence of conducted RF disturbances. This conducted forward power which delivers to a circuit by the cable harness or the traces on a PCB can be measured. To characterize the immunity of an IC, the forward power that causes malfunction is measured. The general test setup accordance with the IEC 62132-4 standard is shown in Fig. 1. It contains the DC power supply, RF power injection part, test PCB with injection network links to DUT, monitoring device, and a control unit.

Several elements in the power injection part become critical while the measurement frequency extending above 1GHz. In order to deliver enough power into DUT pin, the 50Ω characteristic impedance (Z0) system has to be implemented for effective power level and less path loss. The power level from signal generator is often insufficient at high frequency. Therefore a power amplifier is driven for providing enough disturbance level into the pin under test which often presents high degree of mismatch. Because of the requirement of varied frequency, sometimes several amplifiers are needed to cover a wideband measurement. Besides, the level of harmonics has to be 20dB lower than interference according to the standard.

The directional coupler is employed to monitor the power ($P_{forward}$) injected to the port of test PCB from power amplifier. Only the $P_{forward}$ is concerned, though another port of directional coupler can obtain the reflected power. That is because different DUTs have different impedances, matching situations at their pin under test. To differentiate the immunity levels of ICs, the $P_{forward}$ is more meaningful. The $P_{forward}$ is measured by a power meter with a power sensor. The dynamic range and frequency range of power sensor should be taken care. Also the VSWR is desired to be smaller than 1.15. Notice that the $P_{forward}$ measured by power meter has to be corrected by adding the coupling factor of the directional coupler. Accompanying with applications in high frequency, most power injection parts can be found with expected performance. Dislike the discrete components in the on-board section of power injection part which will be discussed in the next section.



(a) (b)

Fig. 4 (a) The configuration and (b) photograph of on-board injection network

An oscilloscope, test receiver or other monitoring device is used to monitor the malfunction of the DUT during the experiment. The injected power when DUT becomes susceptible has to be recorded. A control unit or program can be used to control these equipments which will save time.

III. ON-BOARD INJECTION NETWORK

The RF power is injected to the pin of DUT on the PCB. The traces on PCB have to be design as short as possible with a characteristic impedance of 50Ω. A DC block capacitor is inserted to prevent DC going to the amplifier that may destroy it. A 6.8nF is mentioned in the standard which give the lower frequency limit around 150 kHz. The larger capacitance can achieve lower 3dB bandwidth and present a high pass response. The problem is the parasitic effect makes the resonance happen and make the capacitor become inductive and the upper 3dB roll-off occur. Therefore, a capacitor with wide bandwidth, flat frequency response, and low insertion loss is preferred. In this work, a 100nF capacitor (ATC 545L) is chosen with its S-parameters can be obtained for estimation in advance. Fig. 2 shows it has a low insertion loss over 20GHz.

If the pin under test is also supplied by a DC source, a decoupling component is necessary to avoid the injected RF power heading to the DC source where presents a low impedance AC path. Generally, a RF choke like inductor is a good candidate. It is recommended to have the AC impedance over 400Ω in the test frequency range and not cause too much DC voltage drop on the path. Again, the parasitic has to be minimized that can guarantee higher operating frequency without resonance. A 2uH inductor (ATC 506WLS) is selected, and the impedance as a function of frequency is shown in Fig. 3. The AC impendence is greater than 360Ω

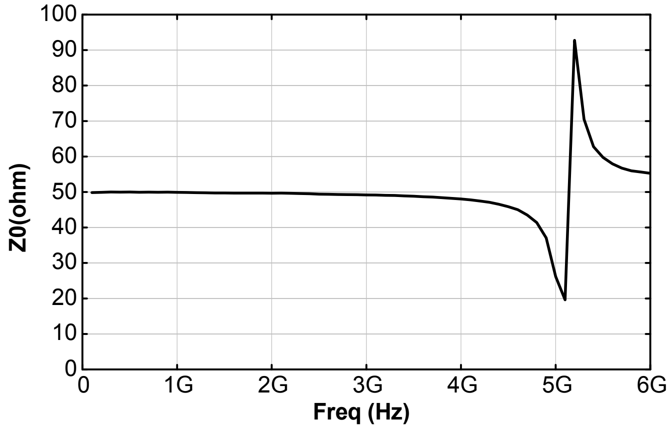


Fig. 5 Verification of Z0 for 1cm trace on PCB.

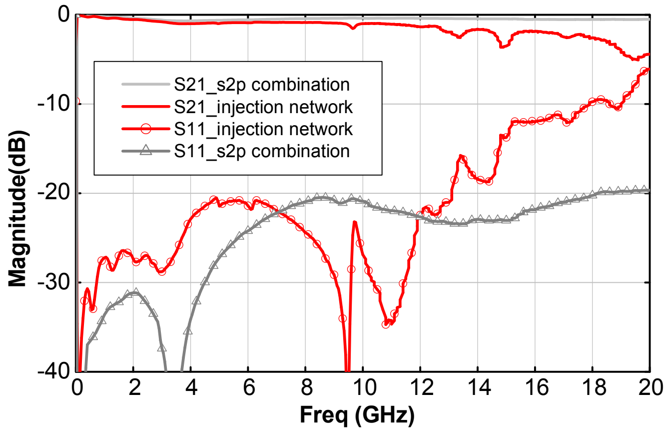


Fig. 6 The S-parameters of on-board injection network.

within 20GHz bandwidth. Both Fig. 2 and 3 are the ideal response while the component stands alone, the response will get worse when in conjunction with other components.

The capacitor and inductor are formed a bias tee as an injection network as shown in Fig. 4(a). They are mounted on a 1.6mm FR4 double side PCB as shown in Fig. 4(b). The vector network analyzer used in this work to measure the S-parameters is Agilent PNA N5230A with the measurement capability of 300 KHz to 20 GHz. The standard four-port short-open-load-thru (SOLT) calibration was performed before testing. A 1cm coplanar waveguide transmission line as the trace on PCB is designed to verify the Z0 of 50Ω as shown in Fig. 5, which can reduce the mismatch. The resonance causes the Z0 leave 50Ω at the quarter wavelength corresponding to the frequency around 4-5GHz is observed. This notices that the trace for connection on PCB has to be as short as possible. In the standard, a 3dB insertion loss of the on-board injection network is permitted to perform the DPI test. Fig. 6 shows the measured S-parameters of the implemented injection network. The stand alone S-parameters of capacitor and inductor are combined and simulated to make comparison with the implemented case. The discrepancy exists in S21 is mainly contributed by the extra SMA connectors and the parasitic effect at high frequency. The measured 3dB bandwidth reveals the DPI measurement frequency range can be expended up to 14.5GHz. And the return loss larger than -10dB confirms that the injected power can be delivered into DUT effectively. The following section will apply this injection network to achieve a DPI testing.

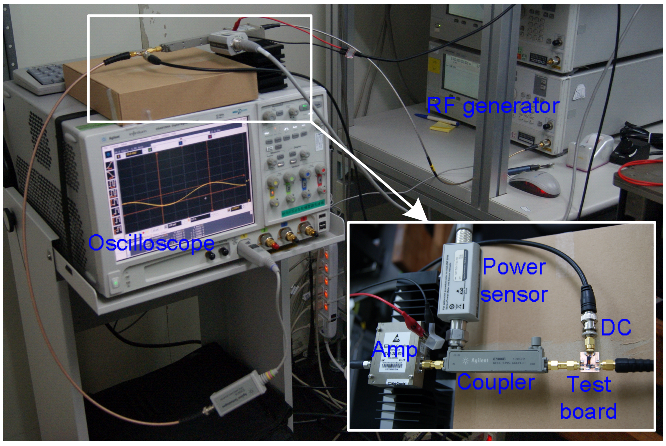
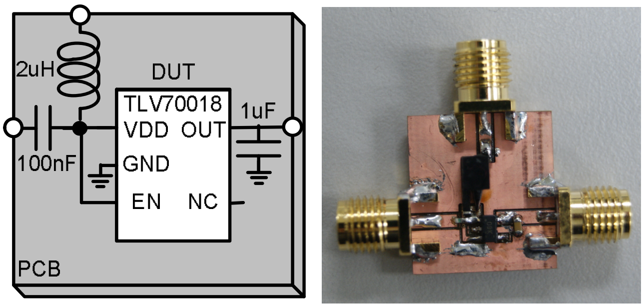


Fig. 7 The photograph of DPI test setup above 1GHz.



(a) (b)

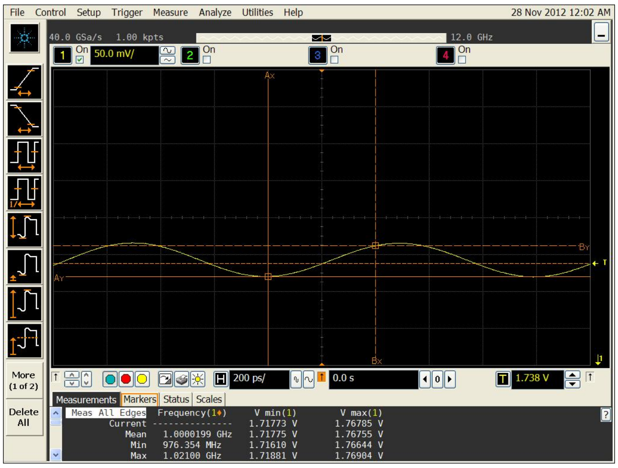
Fig.8 (a) The configuration and (b) photograph of test board.

IV. EXPERIMENT OF DPI METHOD ABOVE 1GHZ

The test setup for DPI measurement follows Fig. 1, it contains the DC power supply, power meter, RF power injection part (RF generator, RF amplifier, directional coupler, on-board injection network), test PCB with DUT, and the oscilloscope as monitoring device, but lack of the control unit. Fig. 7 shows the photo of the test setup.

A low dropout regulator (LDO) TLV70018 for portable devices is chosen as the IC under test. The function of LDO is to provide an accurate and stable DC voltage to the system. This device is widely used in the modern communication modules which operate at the frequency range from hundred MHz to several GHz. So it is a good candidate to perform DPI test. Fig. 8 shows the test board with injection network and the typical configuration of IC for general application. The injection point is set at the VDD to emulate once the interference injects into it and cause malfunction, the whole system will fail too.

To observe the DUT fails, the output pin is connected to an oscilloscope (Agilent DSA91204A 12GHz real time oscilloscope) through a 1MΩ probe. The immunity criterion has to be defined to tell if the DUT fail or not when subject to the interference. A failure is defined when the output voltage reach ±4% tolerance by referring to the data sheet (2% accuracy at 1.8V). In other words, once the output voltage lower than 1.728V or higher than 1.872V, it fails. No matter



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Meas All Edges  Frequency(1♦)    V min(1)     V max(1)
       Current  ---------------  1.71773 V    1.76785 V
          Mean    1.0000199 GHz  1.71775 V    1.76755 V
           Min    976.354 MHz    1.71610 V    1.76644 V
           Max    1.02100 GHz    1.71881 V    1.76904 V
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Fig.9 The measured waveform when DUT reach the immunity criterion.

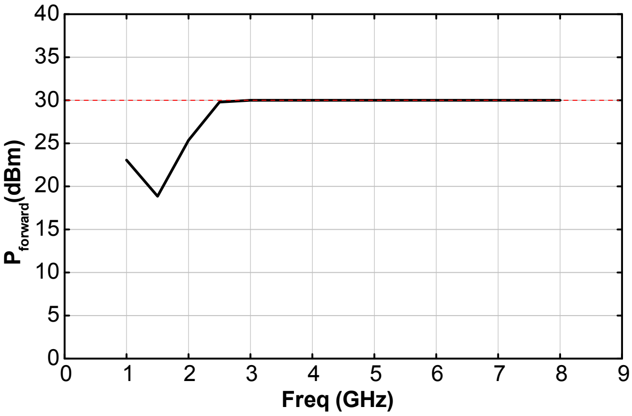

Fig.10 The immunity of LDO by applying DPI measurement above 1GHz

the average value or the AC ripple touch this limit, the $P_{forward}$ is recorded and represents the immunity level at that frequency. Fig. 9 displays an example waveform while failure occurs at 1GHz. Besides, the upper injected power level has to be set based on the performance of facilities. In this work, a maximum $P_{forward}$ of 30dBm is defined because of the restriction of instrumentation. The DPI test was demonstrated from 1 GHz to 8 GHz with a frequency step of 500 MHz. Fig. 10 illustrates the result of a DPI measurement. The immunity remains at 30 dBm limit after 3GHz indicates the pin under test is susceptible to the electromagnetic aggression because of its robustness. All the details of used instruments and components are listed in Table. 1.

TABLE I

INSTRUMENTS AND COMPONENTS USED IN DPI SETUP ABOVE 1GHZ

Component/Instrument	Vendor / part	Feature
RF generator	Agilent/E8247C	250k~20GHz
RF amp	Mini-Circuits ZVE-3W	2G~8GHz
Directional Coupler	Agilent 87300B	1G~20GHz
Power sensor	Agilent E4413A	50M~26.5GHz
Power meter	Agilent E4416A	20M Sa/sec
Oscilloscope	Agilent DSA91204A	12GHz, 40G Sa/sec
DC supply	Agilent E3615A	0~20V, 0-3A
Capacitor	ATC 545L	100nF, 16kHz~40GHz
Inductor	ATC 506WLS	2uH, 400kHz~40GHz
LDO	TLV70018	1.8V output

V. CONCLUSION

In this paper, the setup of establishing DPI measurement above 1GHz ICs is proposed. The on-board injection network, in the power injection path is designed and verified. To achieve such a wide bandwidth measurement, all the components, instruments, and Z0 of the PCB traces are carefully considered. By employing a LDO as the DUT, this proposed DPI measurement above 1GHz is validated. The experimental result shows the capability of investigating the immunity of ICs up to 8GHz.

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REFERENCES

[1] *Integrated Circuits, Measurement of Electromagnetic Emission, 150 KHz to 1 GHz: General Conditions and Definitions—Part 1*, International Electrotechnical Commission Standard IEC61967-1, Mar. 2002.

[2] *Integrated Circuits, Measurement of Electromagnetic Immunity, 150 KHz to 1 GHz: General Conditions and Definitions—Part 1*, International Electrotechnical Commission Standard IEC62132-1, 2007.

[3] *Integrated Circuits, Measurements of Electromagnetic Immunity 150 kHz to 1 GHz—Part 4: Direct RF Power Injection Method*, Standard IEC 62132-4, 2006.

[4] A. Alaeldine, N. Lacrampe, J. L. Levant, R. Perdriau, M. Ramdani, and F. Caignet, "Efficiency of embedded on-chip EMI protections to continuous harmonic and fast transient pulses with respect to substrate injection," in *Proc. IEEE Symp. EMC 2007*, Jul. 9–13, pp. 1–5.

[5] K. Abouda, P. Besse, and E. Rolland "Impact of ESD strategy on EMC performances," in *Proc. International Workshop on Electromagnetic Compatibility of Integrated Circuits EMC Compo*, Nov. 2011, pp. 224-229.

[6] O. Jovic, C. Maier, A. Baric, "High-voltage PMOS transistor model for prediction of susceptibility to conducted interference" *IEEE Transactions on Electromagnetic Compatibility.*, Vol. 53, Feb. 2011, pp. 53–62.

[7] Loeckx J., Georges G. "Assessment of the DPI standard for immunity simulation of integrated circuits," *IEEE Symp. on EMC*: Workshop and Tutorial Notes, Honolulu, HI, USA, 2007, vol. 1–3, pp. 813–817.

[8] A. Alaeldine, R. Perdriau, M. Ramdani, J. Levant, and M. Drissi, "A direct power injection model for immunity prediction in integrated circuits," *IEEE Trans. Electromagn. Compat.*, vol. 50, no. 1, pp. 52–62, Feb. 2008.

[9] *Integrated Circuits, Measurements of Electromagnetic Immunity 150 kHz to 1 GHz—Part 3: Bulk current injection (BCI) method*, Standard IEC 62132-3, 2007.

[10] S. Miropolsky, S. Frei "Comparability of RF Immunity Test Methods for IC Design Purposes," in *Proc. International Workshop on Electromagnetic Compatibility of Integrated Circuits EMC Compo*, Nov. 2011, pp. 59-64.

[11] D. Konigstein and D. Hansen, "A new family of TEM-cells with enlarged bandwidth and optimized working volume," *Proc.7th Int. Zurich Symp. and Tech. Exh. on EMC*, pp. 127 – 132, March 1987.

[12] J. Catrysse, D. Pissoort, and F. Vanhee, "Expanding the frequency range for DPI testing of IC's above 1 GHz: an alternative proposal," in *Proc. Int. Symp. Electromagn. Compat. (EMC Europe)*, Sep. 2011, pp. 400–404.