The Direct RF Power Injection Method up to 18 GHz for Investigating IC's Susceptibility

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***Abstract*—The direct RF power injection (DPI) measurement up to 18 GHz is proposed to investigate the IC immunity. The DPI method is reviewed and the consideration of extending frequency range is discussed. Furthermore, the details of the measurement setup are depicted in this work. The critical part, on-board injection network in the power injection path with a 3 dB bandwidth of 18.7 GHz is realized. A low dropout regulator (LDO) is used to demonstrate the test setup. The proposed DPI test with the experimental results shows the significance up to 18 GHz.**

***Keywords*—integrated circuit; EMC; immunity; DPI**

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 their 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 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 popular method to characterize the immunity of IC is called DPI [3] as shown in Fig. 1. The straightforward test setup in this method is helpful to observe the conducted emission behavior of a certain IC pin/pins. The DPI was utilized to differentiate the improved susceptibility levels of an IC with several embedded on-chip EMI protection [4]. Similarly, the electrostatic discharge (ESD) protection strategy also used the DPI as the EMI aggression to demonstrate the impact of interference on EMC performance [5]. These important findings reveal the fact that DPI is recommended when the experimental results were desired to be reproducible, repeatable, and confident. In addition, the models of DPI test setup were built for simulations which agree well with the measured results [6-7]. Based on the

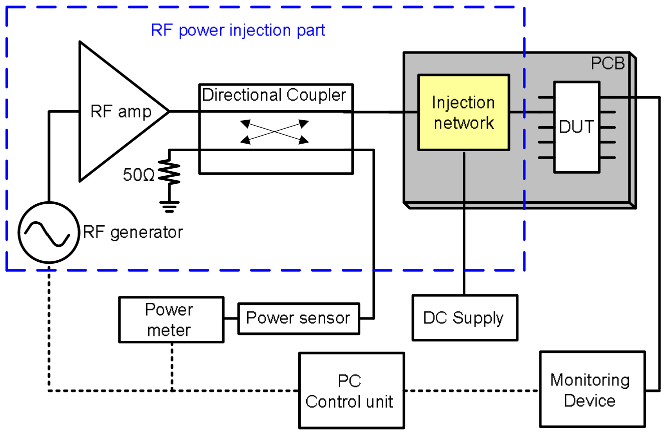


Fig. 1. The test setup of DPI method for ICs.

mature modeling, the differences between DPI and BCI (bulk current injection) [8] tests are analyzed with high conformity [9]. These previous studies provide valuable information regarding DPI. However, its applicable frequency bandwidth remains an issue which needs further investigation.

Most released standards such as IEC series have the frequency range below 1 GHz. Sometimes it is insufficient to evaluate the EMC behaviors while the modern circuits operate higher than 1 GHz. Therefore, some measurement method like GHz transverse electromagnetic (GTEM) cell [10] was proposed which has the frequency range up to 18 GHz. As a trend, the DPI is also expected to having the capability of a wider bandwidth. A new methodology was proposed by using the edge coupled transmission line as a part of the injection network [11]. The result showed the requirement above 1 GHz can be achieve, but the frequency bandwidth was limited by the narrow band nature of coupler. A significant study [12] was proposed to perform the DPI up to 20 GHz which focused on the PCB fixture design for a SOIC8-packaged IC, while the injection network is off-board.

This paper integrates the injection network into the test board with the bandwidth up to 18 GHz and is organized as follows. At first, the DPI method is revisited and some principles are emphasized. In section III, the feature of DPI test up to 18 GHz is proposed. The measurement setup and 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.

II. REQUIREMENTS OF WIDEBAND DPI TEST SETUP

The DPI method is defined to characterize the immunity of IC in the presence of conducted RF disturbances. This delivered conducted forward power ($P_{forward}$) injects into a IC through the cable harness or the traces on a PCB. To characterize the immunity of an IC, the $P_{forward}$ which causes malfunction of IC is recorded. The general test setup according to 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 and DUT, monitoring device, and a control unit.

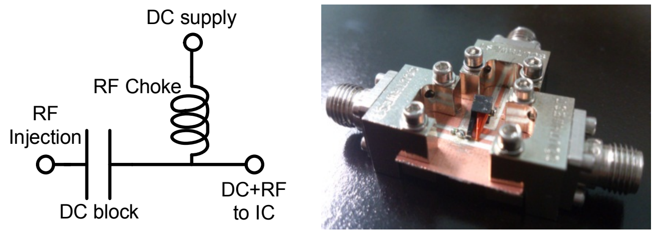
Several elements in the power injection part become critical while the measurement frequency extends above 1 GHz. In order to deliver enough power into DUT, a 50Ω characteristic impedance (Z0) system has to be implemented for effective power injection with less path loss. Besides, the power level from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

The directional coupler is employed to monitor the $P_{forward}$ injected to the port of test PCB from power amplifier. The $P_{forward}$ can be measured by a power meter with a power sensor. Therefore, 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 various applications at high frequencies, most devices in power injection parts can be found with expected performance. But the components in the on-board section which will be discussed in the next section are not common.

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

III. ON-BOARD INJECTION NETWORK DESIGN

The RF power from amplifier is expected to transmit onto the pin of DUT for a wide bandwidth of 18 GHz. Therefore, all the elements which form this injection network on PCB have to be designed carefully and supposed to have excellent performance. So the traces on PCB have to be design as short as possible with a characteristic impedance of 50Ω. And a DC block capacitor is inserted to prevent DC current destroying the amplifier. 6.8nF capacitors as an example mentioned in the standard gives the lower frequency limit around 150 kHz. The larger capacitance can achieve lower 3dB bandwidth and



(a) (b)

Fig. 2. (a) The configuration and (b) photograph of on-board injection network.

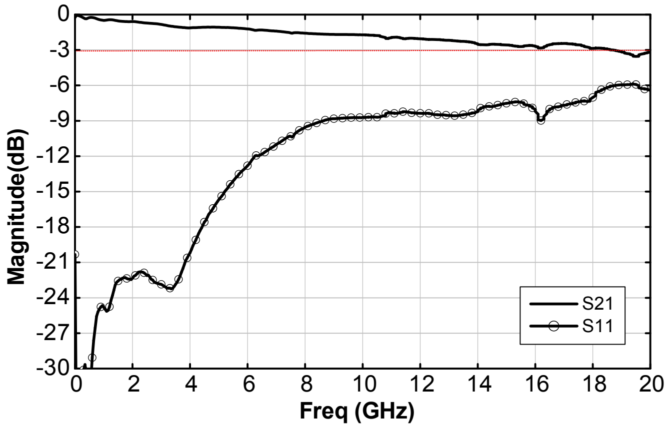


Fig. 3. The S-parameters of on-board injection network.

present a high pass response. The problem is the parasitic effect makes the resonance happen and transforms the capacitor become inductive which limits the upper 3dB roll-off bandwidth. 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.

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 AC impedance path. Generally, a RF choke like the inductor is a good candidate to have the AC impedance over 400Ω in the test frequency range without causing too much DC voltage drop on the path. Again, the parasitic has to be minimized to guarantee higher operating frequency without resonance. A 2uH inductor (ATC 506WLS) is chosen in this work. The capacitor and inductor are formed as an injection network as shown in Fig. 2.

Except for the selection of lump components with wide bandwidth, the performance of PCB and connectors should also be concerned. The capacitor and inductor are mounted on a 0.254mm double side high frequency PCB (RO4350B) with SMA end launch connectors (Southwest Microwave 292-04A-5) as shown in Fig. 2(b). 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 four-port short-open-load-thru (SOLT) calibration was performed before testing.

In the standard, a 3dB insertion loss of the on-board injection network is permitted to perform the DPI test. The measured 3dB bandwidth reveals the DPI measurement

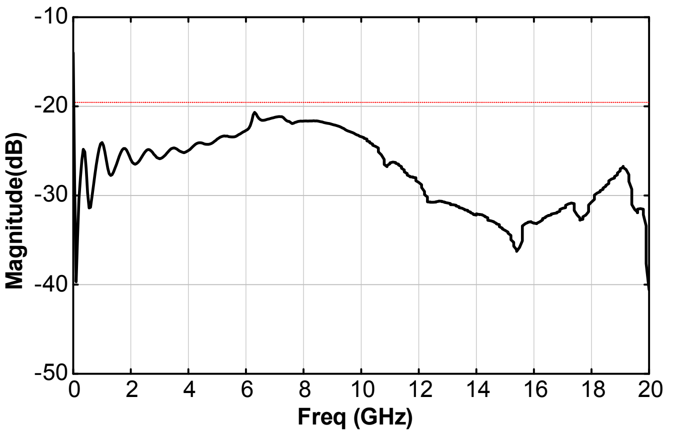


Fig. 4. The attenuation contributed by the decoupling inductor on the DC path.

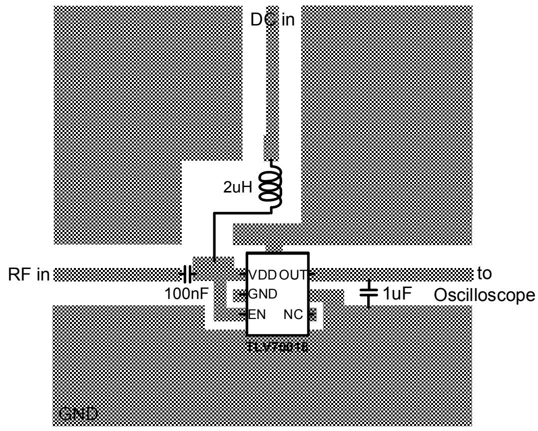


Fig. 6. The test board composed of on-board injection network and DUT.

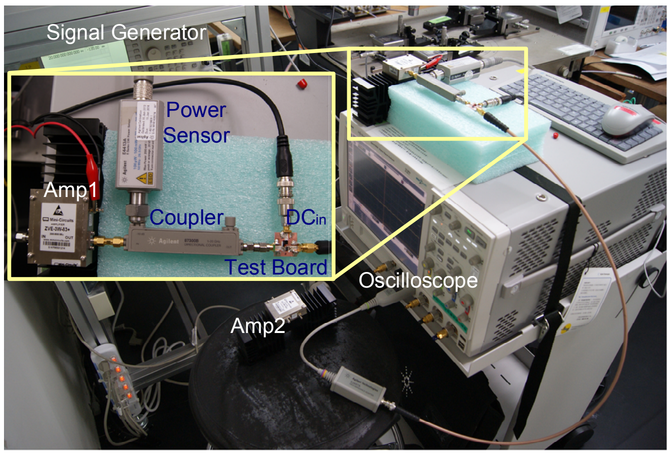


Fig. 5. The photograph of 18 GHz DPI test setup.

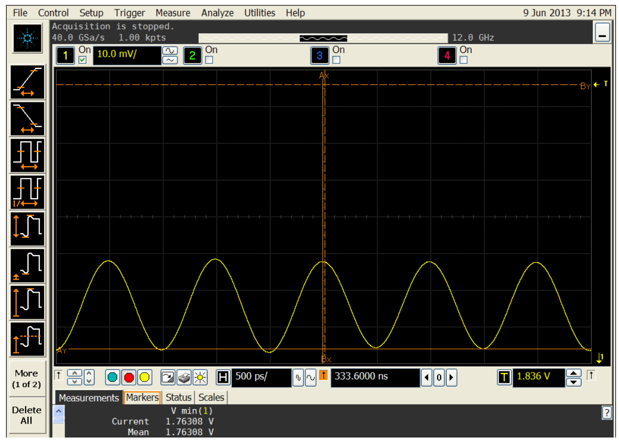


Fig. 7. The measured waveform when DUT reach the immunity criterion.

frequency range can be extended to 18.7 GHz as shown in Fig. 3. Regarding to the AC impedance over 400Ω recommended in the standard, the corresponding insertion loss of DC path is 19.6 dB. Fig. 4 shows the validated results with the insertion loss greater than 19.6 dB over the whole frequency range. The following section will apply this injection network to achieve a DPI testing.

IV. Experiment of DPI up to 18 GHz

The test setup in this work for DPI measurement similar to Fig. 1 is shown in Fig. 5. It contains DC power suppliers, power meter, RF power injection part (RF generator, RF amplifier, directional coupler, and on-board injection network), test board with DUT, and the oscilloscope as monitoring device, but lack of the control unit.

A LDO (Texas Instruments 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 whole system. This component is used widely 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. 6 shows the test board design with on-board injection network and the typical configuration of IC operation. The injection point is set at the VDD pin to emulate the interference injection which may cause malfunction of IC and lead the failure of the whole system.

To observe the failure of DUT, 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 an interference. A failure is determined when the output voltage reach ±2% tolerance by referring to the data sheet. In other words, once the output voltage lower than 1.764V or higher than 1.836V, it fails. Neither the average voltage nor the AC ripple reaches limits; the $P_{forward}$ is recorded and represents the immunity level at that frequency. Fig. 7 shows a failure occurs at 1 GHz while the ripple of waveform hits the lower boundary. Besides, the highest 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 18 GHz with a frequency step of 500 MHz as shown in Fig. 8. The immunity remains at 30 dBm limit in the frequency range between 4 GHz to 11.5 GHz which indicates the pin under test is immune to the electromagnetic aggression. And the immunity degrades again at higher frequency band. It demonstrates the interference at the band which is out of operating frequency of IC may cause malfunction. This finding shows the significance that the DPI method with

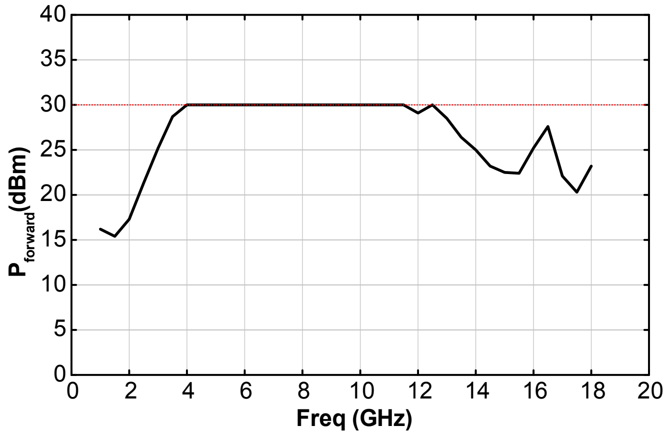


Fig. 8. The immunity of LDO by applying DPI measurement up to 18 GHz

extended bandwidth is needed. All the details of used instruments and components are listed in Table. I.

TABLE I. INSTRUMENTS AND DEVICES USED IN DPI SETUP UP TO 18 GHZ

Instrument/Device	Vendor / part	Feature
RF generator	Agilent/E8247C	250k~20GHz
RF amp1	Mini-Circuits ZVE-3W-83	2G~8GHz
RF amp2	Mini-Circuits ZVE-3W-183	5.9~18GHz
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 up to 18 GHz for ICs is proposed. To achieve such a wide bandwidth measurement, all the components, instruments, and Z0 of the PCB traces are carefully considered. The on-board injection network in the power injection path is designed and verified. By employing a LDO as the DUT, this proposed DPI measurement is demonstrated. The experimental result shows the capability of investigating the immunity of ICs up to 18 GHz. A significant finding that IC could be affected by the interference at such high frequency is observed.

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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] 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.

[7] 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.

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

[9] 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.

[10] 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.

[11] 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.

[12] Sjoerd Op 't Land et al., "Design of a 20 GHz DPI Method for SOIC8," in *Proc. Int. Symp. Electromagn. Compat. (EMC Europe)*, Sep. 2012, pp. 1–6.