High Frequency conducted Power Injection, an alternative Measurement Methodology to IEC 62132-4(DPI-Method) to test Robustness of VLSIs

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Abstract — **This paper describes an alternative measurement methodology to IEC 62132-4 (DPI). The DPI measurement method is based on RF-power measurement, whereas the alternative measurement methodology uses injected RF-current and –voltage on the pin of the device under test (DUT) to describe EMC robustness against injected sinusoidal RF-signals.**

In accordance to the frequency-dependent behavior of the various VLSI input structures, the measured current and the voltage at the pin of the DUT provide more in-depth information concerning the EMS behaviour of the tested device.

1. INTRODUCTION

Most remarkable difference to above mentioned international IEC 62132 – 4 [1] specification is based on the fact that HFPI (High Frequency Power Injection) method measures the injected current flowing into the pin of the DUT. At the same time the RF voltage which developes at the injected pin gets also measured. Whereas IEC 62132 – 4 (DPI Direct Power Injection) measures the absorbed power injected into the pin of the DUT by means of an RF direction coupler and power meter, the alternative HFPI uses a dedicated RF current and voltage measurement strategy to describe the EMS behavior of the violated pin. The injected RF current can be measured in time domain. At the same time the established RF voltage at the injected pin of the DUT gets also measured. The existing phase shift between current Ipin(t) and the associated voltage Upin(t) gives additional information about the unknown impedance of the measured pin. The observer can detect how this pin (pin impedance) behaves in a certain frequency range. Does impedance (Pin of DUT towards Vss ground) behave inductive, capacitive or does there exist a series resonance (very low impedance Zpin(w)) or any parallel resonance (high impedance Zpin(w))?

These measured parameters Ipin, Upin with their amplitude and timing relation to each other provide a lot more valuable information compared to the DPI measurement method. The DPI method only provides the observer with the figure of power the pin of the DUT absorbed in a certain frequency range. You do not know anything about the pin impedance behavior in the selected frequency range. You measure scalar energy (power) which gets absorbed at the violated pin. The investment of the broadband directional coupler and the RF power meters, necessary to calculate the amount of RF power the pin absorbs, combined with the test setup is higher than with the HFPI method. Further limitations of the IEC 62132 – 4 methode is the proposed coupling mechanism (4,7nF) which doesn't allow to inject RF power to every pin of the victim (VLSI DUT) during its operation.

Another very important advantage against the DPI method is that the RF signal coupling path is not influenced by the DUT pcb layout like RF SMA/B connectors, trace running from the connector to the pin of the DUT where the signal has to be injected.

HFPI method uses a dedicated RF injection fixture which is capable to inject the RF power into the pin of the DUT without the necessity to use additional connectors and traces to feed the RF signal to the desired pin. Additionally the measurement unit for measuring Ipin and Upin is implemented in the RF injection tool.

2. MEASUREMENT SETUP's

2.1 Measurement setup IEC62132-4

Principal measurement setup of DPI method in accordance to IEC 62132-4 is shown in fig. 1

The RF generator drives the RF power amplifier with its inherent 50 Ohm Output impedance. In order to measure the transmitted and reflected RF power a broadband directional coupler with its associated RF power meters is connected at the output of the 50 Ohm power amplifier. Alternative to the broadband coupler there can also be used selective RF couplers which have to be used in their applicable frequency ranges (lower- and upper-Frequency range). The full frequency span covers 150kHz up to 1000MHz. There exists one additional important point which is not mentioned in the block diagram (fig. 1) on the DPI measurement setup. In order to minimize the measurement error it is recommended to include a damping resistor with minimum -3dB or even better -6dB in the RF power transmission chain. The damping element isolates the unknown load impedance from the 50 ohm based measurement system (direction coupler, RF power meter, RF power amplifier output). There exists a tremendous impedance mismatch at the physical interface between measurement system and the point of RF injection to the pin of the DUT. The pin where the RF signal is intended to get injected represents a frequency dependent impedance of unknown characteristic (see also Fig. xx). In reality the impedance mismatch between the 50 Ohm based measurement system and the unknown DUT pin impedance (impedance of the pin measured toward Vss of DUT) is high. VSWR figure is much beyond a desirable level.

Of course this additional damping element forces to provide more RF power as usually would be necessary to analyse the DUT. As example with a damping element of -6dB we have to provide four times the RF power at the output of the RF amplifier. Our measurement experiments on the DUT (embedded controller) have shown that the RF power amplifier with aro 20(30)Watt is adequate.

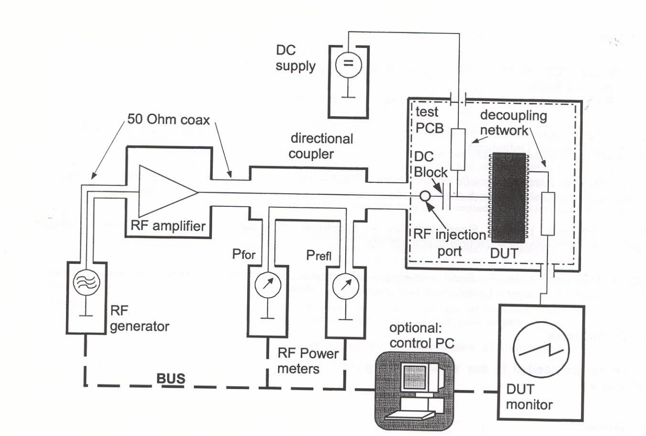

Fig. 1 Measurement setup according to IEC 62132-4 method. Block diagram of components to test EMS of the DUT.

During practical measurements and evaluations applying DPI method on embedded controllers (DUT) we exercised one main drawback when applying the RF signal to the pin of the DUT.

There exists a variety of different QFP packages (QFP64, QFP80, QFP112, TQFP48,…TQFP144). Physical dimensions of the plastic package size vary from 5mm x 5mm up to 20mm x 20mm, pitch sizes vary from 0,8mm, 0,65mm to 0,5mm(TQFP packages). In practical live it is not mandatory to test every pin of the DUT. Embedded controllers usually provide high amount of bidirectional I/O ports (arranged as 8-bit or 16-bit clusters) which are build up in regular and identical manner. Evaluation results on EMS measurements show in such cases that the behaviour of such bidirectional I/O pins on the same I/O port is nearly identical. As consequence not every pin of the port has to be tested.

On the other side a 112 or even 144 pin QFP(TQFP) controller offers a lot of pins which will have to be tested in order to get a picture of the overall EMS performance of the DUT. According to the recommendation given in IEC 62132-4 paper it will occupy a lot of space on the dedicated EMS test board to adapt the RF signal in order to inject it into the pin of the DUT. The SMA/SMB connector in conjunction with the dc block capacitor and the necessary signal trace to the device’s pin limit the measurement flexibility you want to have. Fig. 2 shows a picture of the RF signal injection path IEC 62132-4 recommends to apply on the EMS test board. This proposal might be fine if you only have to test a couple of dedicated pins on the DUT (as examples you might take receiver- transceiver IC’s for CAN, LIN or other similar serial data transmission tasks). Based on these recommendations you will detect in practical measurement exercises this will limit your RF injection flexibility. As result, from a practical point of view another approach for RF signal injection has to be used to cover the requirements of an embedded controller (DUT).

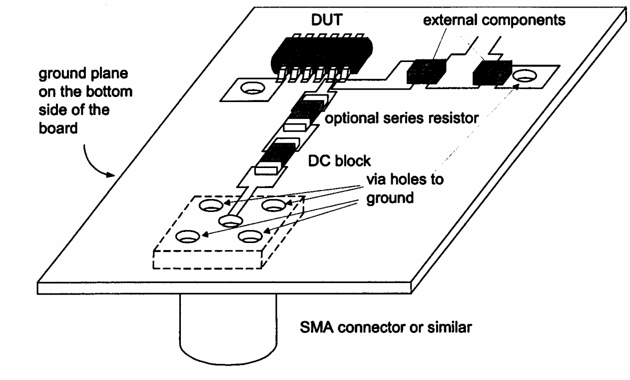

Fig. 2 Recommendation how to design the RF signal injection path to the dedicated pin of the DUT (IEC 62132-4).

Another question arises on cost. Beside physical/technical aspects the main objective in EMC measurement on IC level should also be minimum cost. If there exists the possibility to design a test board for the DUT (IC) where you can evaluate EME as well as EMS your benefit is twofold. To align with this target we used the EME test board and slightly modified it in order to fit for the following extensive EMS evaluation on embedded controllers.

Fig. 3 and fig. 4 represents our approach to utilize the EME test board to do DPI EMS measurements with only minor hardware changes on the original EME test board. The test software to run the EMS evaluations has completely be changed in order to allow EMS testing of the DUT. The necessary test software changes can be done very easily because of the on-chip integrated “background debug interface” which allows “flashing”, erasing" and "debugging" the DUT burned software on the fly. Provisions in hardware are implemented on the test board where the 1-wire serial communication between host PC and the DUT (embedded controller) can be done.

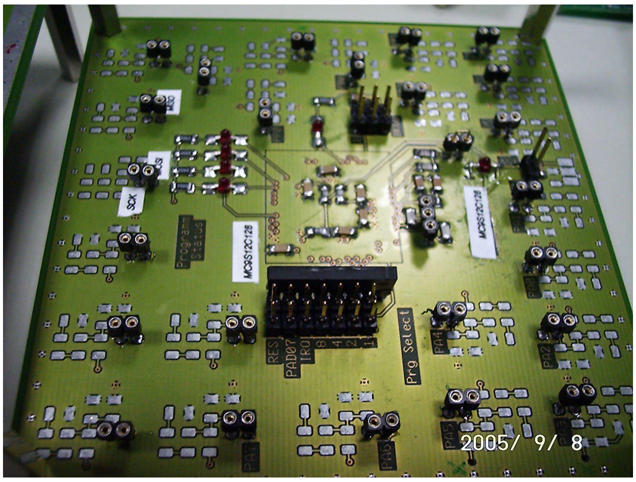

Fig. 3 Original designed EME test board, top side assembled glue components to run application test software.

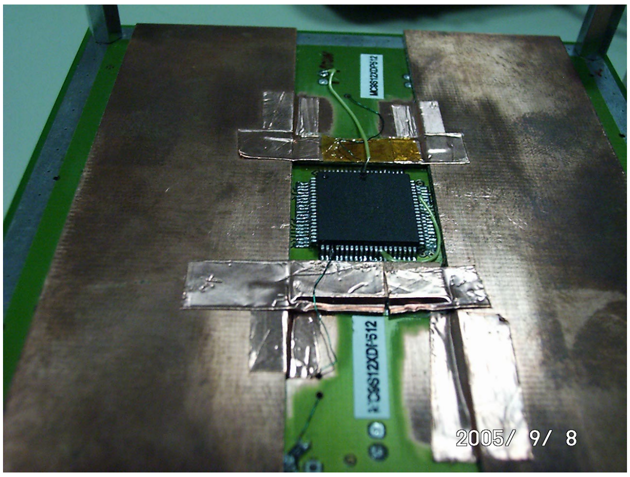

Fig. 4 EME test board bottom side, assembled with DUT (embedded µC QFP 80 pin) and solid reference ground Vss.

Equipped with above described hardware test board and test firmware EMS behaviour evaluation was started.
RF signals (CW as well as 80% modulated AM signals) have been injected into various pins of the DUT by means of a special designed probe tip (Fig. 5)

Fig. 6 identifies the pin assignment for the evaluated µC (DUT). Measurement results have shown various different malfunctions of the embedded controller depending on applied frequency, power level and location on the package of the DUT, where the RF signal has been injected.

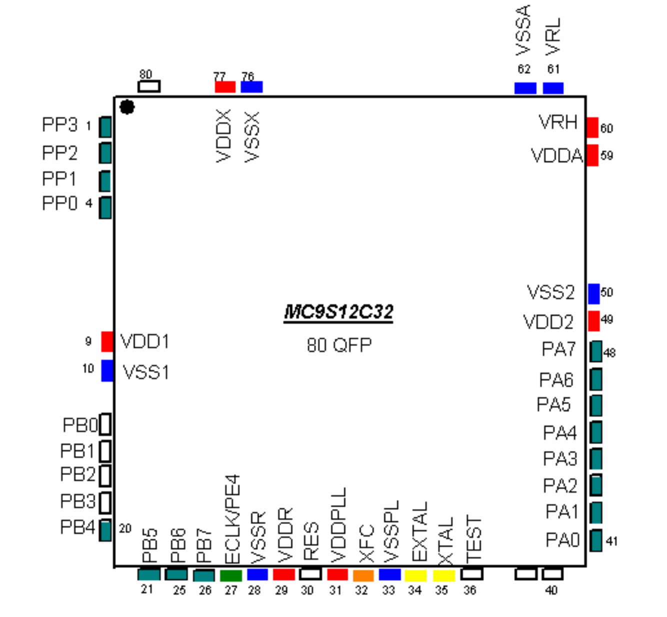

Fig. 6 Coloured pins on the 80 pin QFP package of the DUT show where the RF-signal has been injected.

EMS measurement set up was equipped with the "Integrated Measurement System" (IMS) provided by Rhode & Schwarz. This smart EMC one box solution operates from 150kHz up to 3GHz.
The IMS offers all necessary components like signal generator, integrated power amplifier, direction couplers (Forward -coupler and Reverse -coupler) with RF power meter head and associated switching units, all integrated in one enclosure. The IMS station is also provided with the capability to control one or more additional external power amplifiers. The external power amplifier used was the 30 Watt remote controlled ……-series manufactured by Bonn Elektronik.
The IMS system offered a powerful control-, monitoring-, data reporting- and visualisation- software package to be controlled via USP and a PC resident EMC 32 software package (Fig. 7).

Fig. 5 Test fixture with optimal flexibility to inject EMS RF signal on a dedicated pin of the DUT.

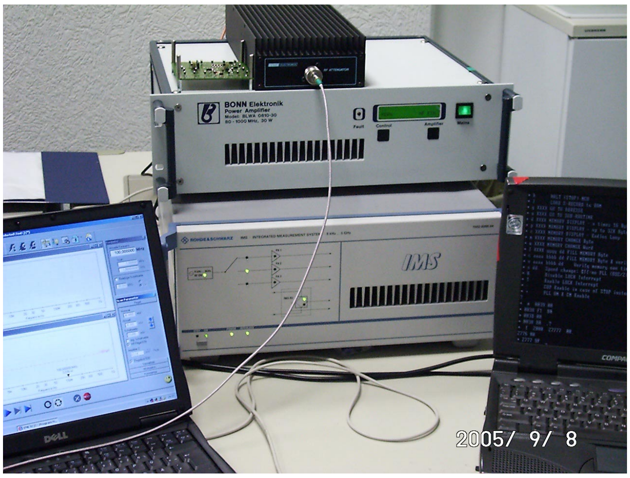

Fig. 7 IMS station (R&S, Germany) equipped with additional external 30Watt power amplifier (Bonn Elektronik, Germany) represent the EMS measurement components. Screen on the lower left side shows control panel of IMS station. Screen on the lower right corner monitors results from the DUT under RF signal violation.

2.2 Measurement setup using HFPI as an alternative method to IEC 62132-4 (DPI method).

As mentioned before the most obvious drawback applying the DPI method is based on the fact that you measure injected or absorbed RF power as criteria of functional fail of the DUT. This might not be any disadvantage if you only make measurements for comparison purposes where you differentiate which product fails first under the same environmental conditions. For a first general decision which device among different vendors to use in a systems application the EMS results derived from the DPI measurement provide enough information to decide which product to use. If in addition to the power measurement you would measure VSWR ratio you only could decide the relative degree of mismatch between 50 Ohm reference Impedance and the real physically measured pin of the DUT. From a chip-designer’s point of view you miss some important information which are hidden in the DPI method EMS results. The injected RF power is measured as scalar figure and doesn’t tell you details about the EMS behaviour of the tested pin of the DUT.

In order to adjust the DUT pin behaviour or to improve it in the next redesign cycle the chip designer needs in-depth information about the frequency related impedance of the tested pin. Measuring the real voltage which develops at the pin and the current flowing into or out of this pin allows to collect much more information about the physical behaviour of this pin.

The complex impedance determines current and voltage at the measured pin at a given frequency. The HFPI (High Frequency conducted Power Injection) method gives insight to the behaviour of the tested pin. Is injected RF current low and RF voltage high or vice versa?. Phase shift between RF voltage and RF current at a certain frequency distinguish between resistive, inductive or capacitive behavior of the internal pin circuitry.

Reproducable and reliable measurement of voltage and current in a broad frequency range is a real challenge and inherent parasitics in the measurement equipment cannot be neglected. As result in order to obtain real EMS measurements it will be necessary to apply frequency dependent corrections on the RF voltage and RF current measured at the pin of the DUT (Fig. 10, 11, 12).

Fig. 8 shows an example of a realized high frequency signal injection probe as used in the experiment.

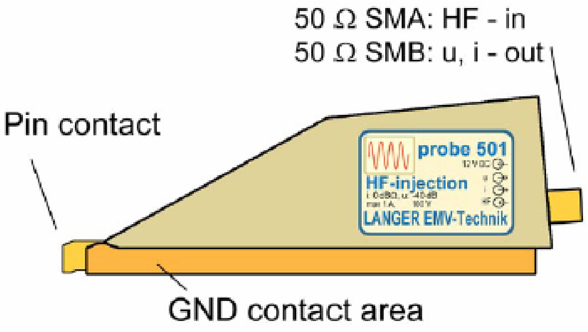

Fig. 8 Probe includes RF voltmeter & RF current-meter
Voltmeter: -40 dB; max range 100V
Current-meter: with intl. Amplifier (sensitivity 1V/1A)
Bandwidth: 20kHz – 3 GHz
Correction : depending on frequency range (see graphs)

A simple equivalent circuitry of the RF signal injection probe and the violated pin of the DUT is shown in fig. 9.

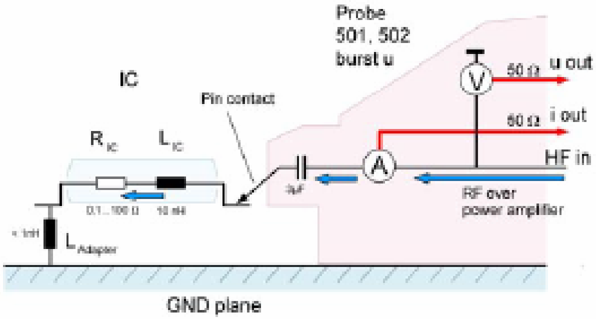

Fig. 9 RF injection probe and DUT pin equivalent circuitry.
Internal dc blocking capacitor 3µF
Maximum power transmission aro 15 Watt on HF in SMA
Voltage and current signals adjusted to 50 Ohm reference
Auxiliary power supply 12V

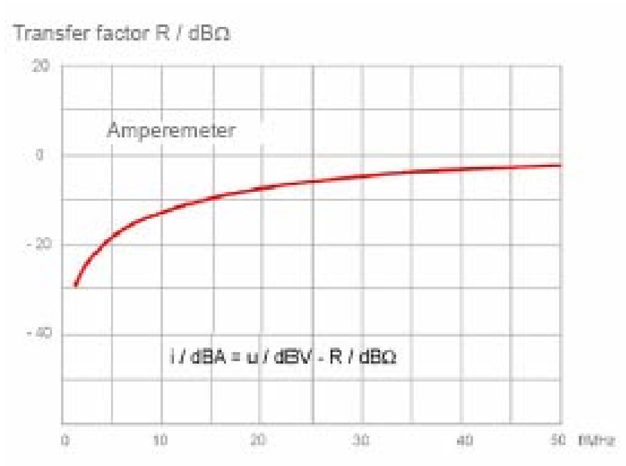

Fig. 10 Correction graph for current transfer ratio in the lower frequency range.

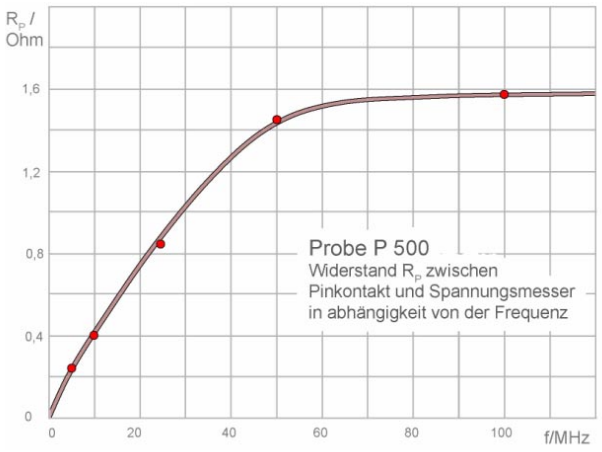

Fig. 11 Influence of resistance in the path between current injection tip and node of RF voltage measurement.

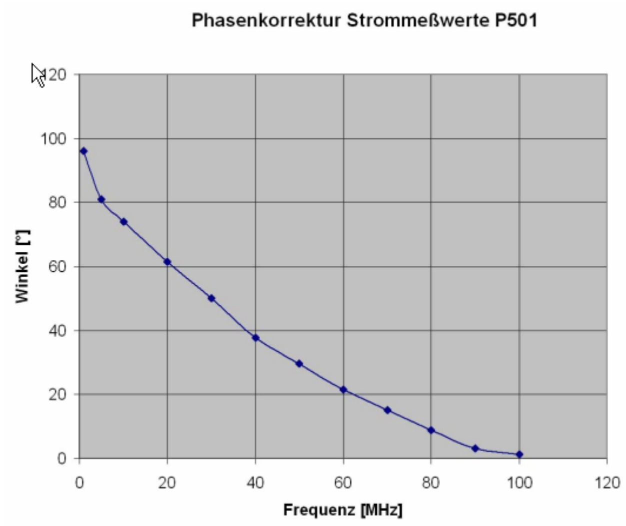

Fig. 12 Phase correction figure of RF current measurements.

Practical handling is shown in figures 13, 14, 15.

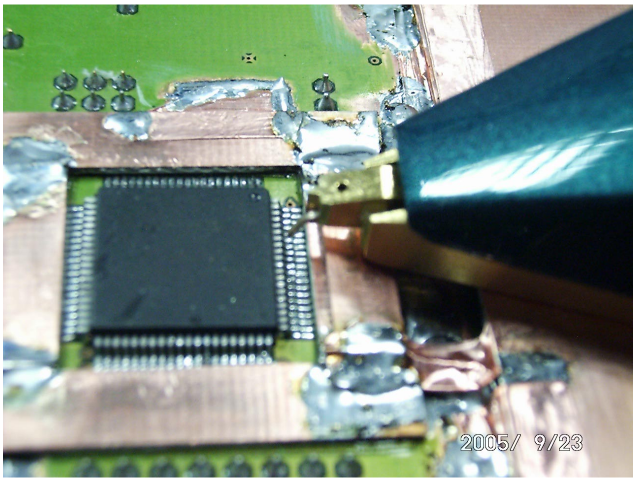

Fig. 13 DUT (80QFP µC) and RF injection probe.

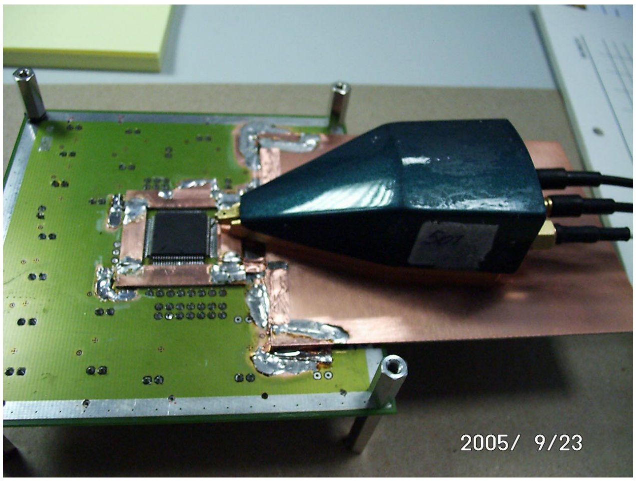

Fig. 14 EMS measurement setup with EMS test-board and injection probe.

Fig. 15 Rear panel of RF injection probe with connectors for RF power, RF current and RF voltage measurement.

To evaluate the impedance behavior over a desired frequency range, measurements have been applied to a couple of pins of the DUT. Derived impedance characteristics demonstrate the mismatch to the 50 Ohm reference impedance. Three pin configurations have been selected to analyse their impedance over the frequency range from 10MHz up to 1000MHz. Impedance analysis have been exercised with a VNA where the derived data have been visualized in Smith-Diagram. The SD draws the complex impedance of the measured pin of the DUT (embedded µC) in relation to the frequency. Visualized data of the measured impedance in the SD contains all the necessary information about the characteristic of the pin (magnitude- and phase- information).

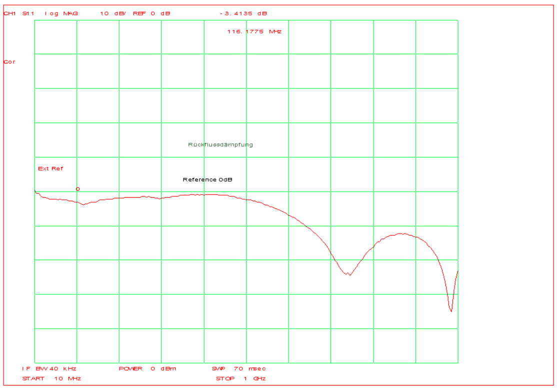

Fig. 16 Pin XTAL(µC), Rückfussdämpfung, log mag (s11) dB
Frequency span 10MHz..1000MHz, (horizontal axis)
Reference line 0dB, scale 10dB/div. (vertical axis)

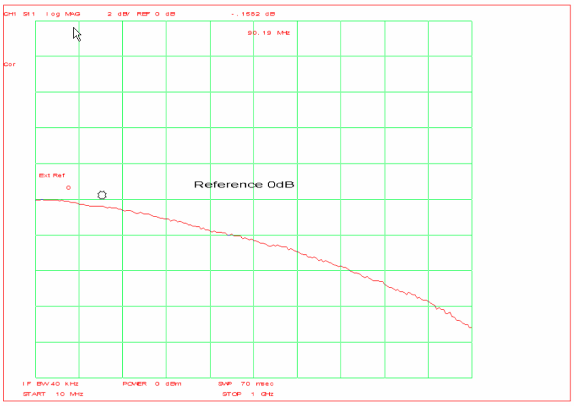

Fig. 17 Pin PP3(µC) Rückflussdämpfung, log mag(s11) dB
Frequency span 10MHz, 1000MHz, (horizontal axis)
Reference line 0dB, scale 10dB/div. (vertical axis)
Measured pin is configured as Input pin.

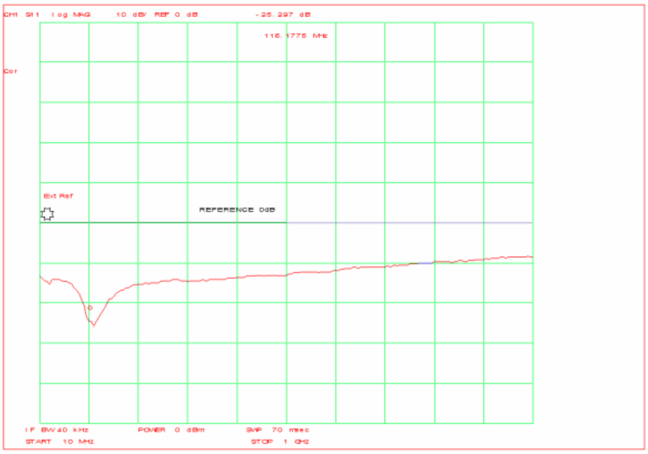

Fig. 18 Pin PB5 (µC) Rückflussdämpfung, log mag(s11)
Frequency span 10MHz..1000MHz, (horizontal axis)
Reference line 0dB, scale 10dB/div. (vertical axis)
Measured pin is configured as output “H” level.

3. CONCLUSION

Paper analysis standardized IEC 62132-4 measurement method. It reflects experiences made during practical measurement exercises applied on QFP package 80 pin embedded controller. Pro’s and con’s according this measurement methodology are discussed.

Alternatively a very similar RF signal injection method with a dedicated injection probe is introduced. Based on the fact that measured voltage and current at the pin of DUT can be analysed also at a certain frequency in time domain it provides the observer with much more additional information about the EMS behaviour compared to the DPI method. Major focus is put on variable utilisation of test hardware. The EME test-board can also be used to run EMS tests with only minor modifications which finally increases cost efficiency.

4. ACKNOWLEDGMENT

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5. REFERENCES

[1] IEC 62132-4, "Measurement of Electromagnetic Immunity 150 kHz to 1 GHz. Part 4: Direct Power Injection Method”