COMPARISON OF EMC IMMUNITY TEST METHODS FOR AUTOMOTIVE ELECTRONICS AT IC AND SYSTEM LEVEL

SERGEY MIROPOLSKY, STEPHAN FREI
Technische Universität Dortmund, Dortmund, Germany,
e-mail: sergey.miropolsky@tu-dortmund.de

Abstract The paper gives a comparison of selected standard EMC immunity test methods of automotive industry. Three methods are investigated: Direct Power Injection (DPI), Bulk Current Injection (BCI) and Stripline testing. A simplified circuit model of a test setup (PCB with DUT) was developed. Existing models of standard BCI probe and standard Stripline setup were used for simulation of power injection path. The correlation of the three methods is analyzed by simulation using circuit simulation software in the range from 200 kHz to 200 MHz.

Introduction

Nowadays in automotive industry, with the growing number of electronic components and rapidly increasing complexity of each electronic system, the question of electronic system reliability has high priority. In an automotive environment the electromagnetic fields can be high, and can be a reason for an IC or system failure. In order to characterize the behavior of the ICs under electromagnetic interference, several measurement methods are standardized.

Widely used are the Direct Power Injection (DPI) method [1] for ICs and Bulk Current Injection method for systems [2]. Less widely used, but not less important is the Stripline susceptibility test method [3]. The standards on the methods describe the measurement stage, i.e. real hardware based EMC immunity test of an IC or system and measurement procedure. To make it possible to predict the EMC immunity of an IC (i.e., its ability to withstand electromagnetic interference without failure) during the IC design stage, several models for simulation were introduced [4,5,6].

A major problem here is the comparability of the methods. ICs are qualified using the DPI method, later they are integrated into systems and tested again using other methods. Correlation between the test methods is sometimes low, e.g. an IC might pass the DPI test but fails when tested with BCI method later in a system. Systematic comparisons of the methods are required to predict and prevent failures on system level.

The paper gives the comparative analysis of the methods in range from 200 kHz to 200 MHz.

Immunity test methods

The immunity test methods inject RF power into an IC which is considered in this document as Device Under Test (DUT) in a wide frequency range with different physical mechanisms. In DPI method the RF power is injected through capacitive coupling. In BCI method, the RF current is injected into the line through magnetic coupling. In Stripline method the power is injected into the wire using the transversal electromagnetic field in stripline structure.

The common IC failure criteria suggested by standards state, that the IC is considered to be disturbed, if

- either the AC ripple of the output signal exceeds the specified boundary at established DC level [4,5],
- or (in case of digital modules) a jitter of output data signal edge exceeds a specified range relative to original signal form [4,5],
- or (in case of analogue modules, e.g. power supplies) the DC shift of the output signal under RF disturbance exceeds a specified value.

The methods propose to increase the input RF power for each frequency in the measurement range until either the input disturbance exceeds the specified limit (test success) or the failure criteria of DUT is achieved. Depending on the method, the disturbance is measured in different physical units (forward power in DPI, injected current in BCI and electromagnetic field in stripline method). The test is considered to be successful, if the DUT endures the specified input disturbance within the tested frequency range without failure.

The current work doesn't intend to simulate the immunity of the specific circuit. The criteria of the DUT failure are not exactly specified. Instead, the transfer characteristics of the RF power from the injection point to the DUT input are studied to obtain the voltage level and forward power at the IC input for specified test success criteria.

Test setups simulation models

The three separate test setups are modeled for three analyzed methods. The models of the test setups include power injection model, transmission lines, PCB and DUT models. The models of three test setups are kept as close as possible to each other. The differences are mainly in mechanisms of RF power injection.

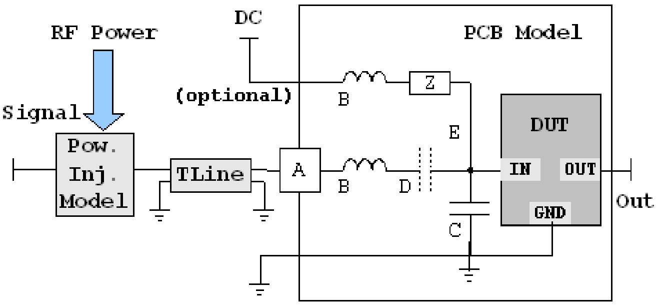

Fig. 1. The block-diagram of the test setups model, contains Power Injection Model (BCI probe or Strip-line), Transmission Line and model of PCB with DUT.

PCB model: The injected RF power is transferred into the DUT through the PCB. The model of the PCB includes the following main components:

- RF Injection Connector (A)
- PCB Tracks to DUT (B)
- Decoupling capacitor at DUT input (C)
- RF Injection Capacitor (DPI setup only) (D)
- DC supply path (optional) (E)

The accurate modeling of the PCB could be the most critical point in the simulation of test setup. Currently, the analysis is done for the frequency range of 200 kHz to 200 MHz. Thus, only the inductive effects of tracks and element pins are included. At higher frequencies, the model should assume other RF couplings and losses more thoroughly.

In DPI test setup the power is injected directly from the RF power source into the PCB through the transmission line. Two other methods require the models of the power injection stage.

BCI Injection Probe: In BCI method the RF power is injected with a special probe. The spice circuit models of BCI injection probes with calibration fixture were developed in [5,6].

The BCI injection probe behavior is described with two mutual inductors with frequency-dependent permittivity of the magnetic core. The parasitic couplings within the probe and the radiation effects are modeled with passive elements in the circuit. The model gives good correlation to the measurement data for frequencies up to 400 MHz [5].

Stripline. In stripline method the RF power is injected into the wire by the transversal EM field in the stripline structure.

The stripline model was obtained with 3D modeling in the EMCoS EMC Studio software. A common geometry of the stripline was used with stripline height of 150 mm and length of cable under stripline of 1.5 m (see fig. 3). The equivalent electrical circuit of the structure was extracted from the 3D model and introduced as a circuit subblock into the model of the test setup.

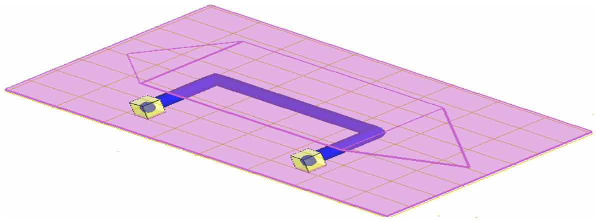

Fig. 3. 3D model of the stripline

The electrical field E_{SL} was estimated as

$$E_{SL} = V_{SL} / 150 \text{ mm} \qquad (1)$$

where V_{SL} is the voltage of the stripline obtained from a Spice simulation of the test setup.

DUT model: To compare the methods, a sample DUT model is necessary. In current work the DUT is a voltage regulator circuit, i.e. an IC that converts battery voltage to stable supply voltage. The RF immunity of this circuit is important, since such circuits are used in almost any larger system chip. The unstable voltage supply can easily be a cause of a system failure.

Based on a full IC circuit model, that is rather large and complex, a simplified model of the IC input was created. The full circuit was simulated in Mentor Graphics simulator program ELDO and the input impedance was calculated as

$$Z_{IN}(\omega) = V_{IN}(\omega) / I_{IN}(\omega) \qquad (2)$$

The input impedance was approximated with an RC model. The resulting passive circuit was used in the test setup as the model of DUT core.

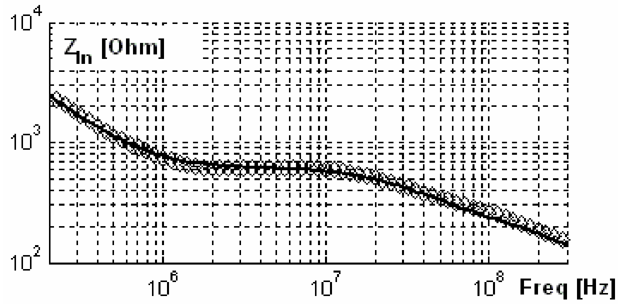

Fig. 2. Impedance profile (abs(Z_{IN})) of the DUT. Dots show the simulation results from ELDO. Solid curve shows the RC model approximation.

The full DUT model also includes the model of IC package [4]. The values of pin inductances and capacitances were estimated for a typical package type.

Results and Discussion

Comparison criteria: The investigated methods use different physical mechanisms of power injection, and hence, have different physical values as the input signal criteria (forward power, injected current and electrical field). Thus, to compare the methods, some common points of all three methods should be defined, such as, e.g. the resulting disturbance of the DUT (load voltage, injected current and injected forward power).

Calibration setups: First, the simulation models of the three compared methods are simulated in a calibration setup with 50 Ohm load instead of DUT.

For Stripline setup the input power is calibrated in frequency range to provide constant electrical field (E_{SL} = 200 V/m). Fig. 4 shows the forward power injected into the load by this field.

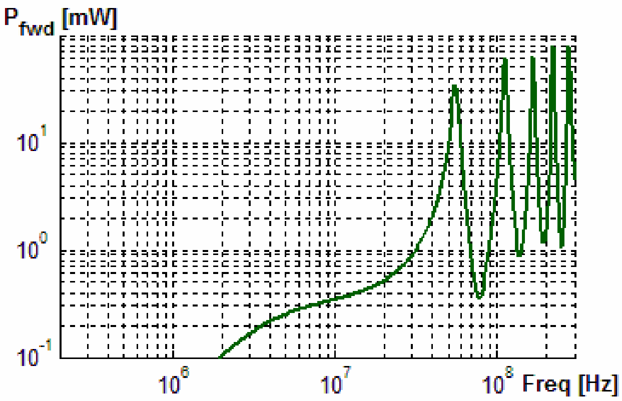

Fig. 4. Forward power injected into 50 Ohm load in Stripline setup by E_{SL} = 200 V/m

Fig. 4 shows, that starting with 50 MHz stripline model has plenty of internal resonances, which introduce peaks in injected power plot.

The calibration of BCI method is defined as measurement of input forward power necessary to inject the specified current into a 50 Ohm load. Later during the testing of the DUT the input forward power should be limited with this calibration curve. The current value of 50 mA (125 mW into the load) is selected. The same calibration is done for two other setups (see fig. 5) to see the possible correlation.

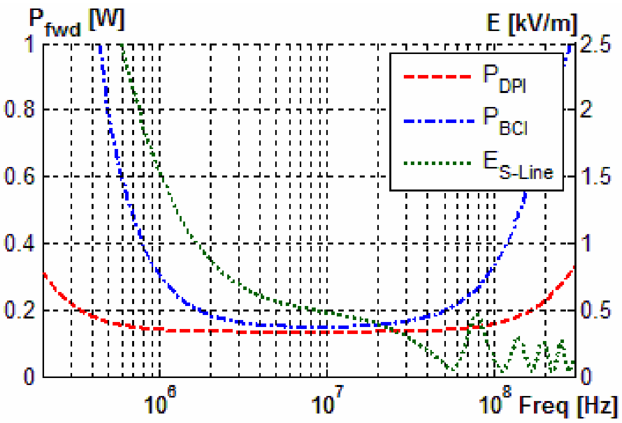

Fig. 5. Input forward power (BCI and DPI, left scale) and electrical field (Stripline, right scale) required to inject I = 50 mA into the 50 Ohm load

Fig. 5 shows, that DPI setup has the most flat power transfer function with small deviations (3 dB) at the edges of the measurement range. BCI setup shows significantly lower power transfer at high and low frequencies, but good correlation to DPI in middle-frequency range. The stripline setup transfer function has complex frequency dependence.

Test Setups with DUT: At the second step, the test setups are simulated with real DUT load. The comparison criterion here is the forward power, injected into the DUT. The differences between methods are determined both by mechanisms of power injection and differences in testing procedure definition.

In the first approach of comparing the methods we assume, that the DUT has constant failure threshold in terms of input forward power. The selected value is 1 mW. The input powers and electrical field (for Stripline setup) necessary to inject the specified power in each method are compared.

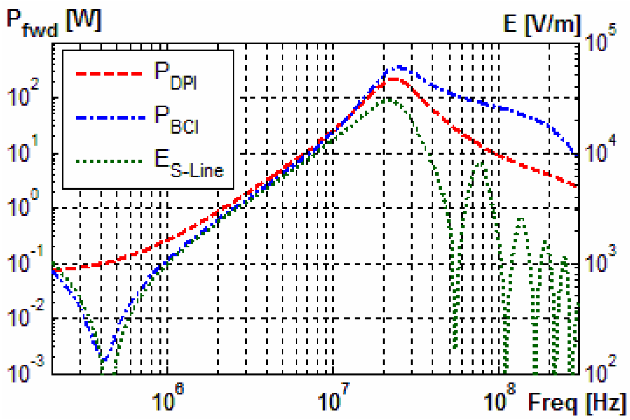

Fig. 6. Input forward powers (left axis) and EM Field in Stripline (right axis), required to inject the forward power of 1 mW of into the DUT

The values shown in fig. 6. are very high. The largest part of the input power is shorted by the decoupling capacitor. This means that within the real test the value of 1 mW into the DUT will not be reached. However, the correlation of the power transfer functions for three methods can be estimated.

Fig. 6 shows, that in terms of input forward power, in the range of 1 – 20 MHz the correlation of the methods could be good, when levels would be adjusted. At higher frequencies, the BCI setup power transfer function decreases comparing to DPI setup.

Here BCI and DPI methods show no correlation at lower frequencies due the resonance of BCI probe with decoupling capacitance at 400 kHz. With different DUT, which doesn't require the decoupling capacitor, the resonance may occur at other frequency.

In the second approach, we assume that the DUT endures any disturbance at input node. The goal is to estimate the resulting DUT input disturbance, when the limiting factors (test success criteria) for each method are reached, thus giving more respect to the measurement process definition.

The DPI method limiting factor is constant forward power in the entire frequency range. The value of

30 mW is selected to be in the same power range with BCI setup.

The BCI method limiting factor is injected current (50 mA is selected). The input power is increased, until the specified value of injected current is reached. By definition, the input power shouldn't exceed the calibrated forward power for selected current value.

The Stripline method limiting factor is the electrical field. The value of 300 V/m is selected.

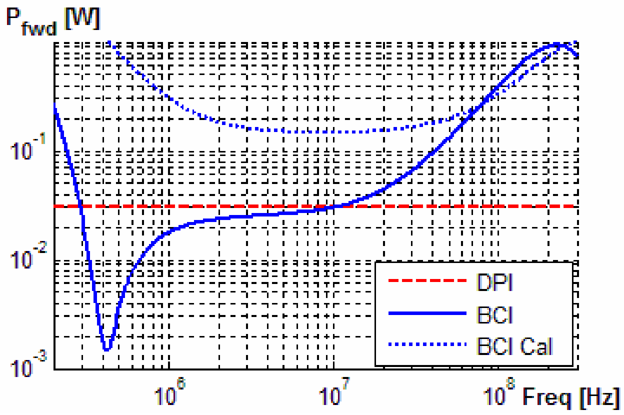

Fig. 7. Input forward power necessary to reach the test success criteria for BCI and DPI test setups. Dotted curve shows the limitation of BCI forward power, obtained from calibration setup.

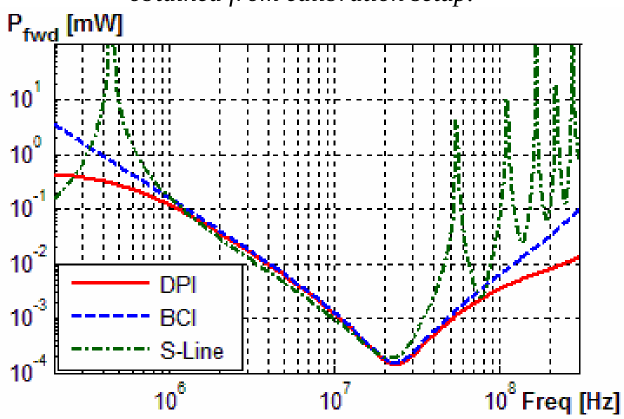

Fig. 8. Forward power injected into the DUT when the specified test maximum levels are applied

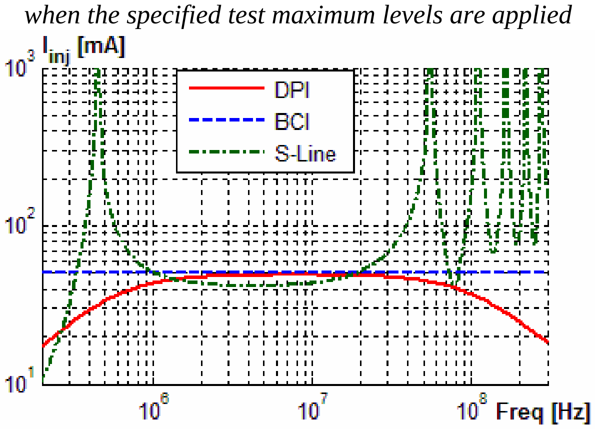

Fig. 9. Current injected into the test setup when the specified test maximum levels are applied

Fig. 8 shows, that in this frequency range the injected forward power profile shape is mostly determined by the decoupling capacitor at the DUT input.

BCI setup forward power transfer function has significant peak at 400 kHz comparing to DPI setup due to resonance of probe and decoupling capacitor. Near this resonance the input forward power in BCI method is limited by injected current value (see fig. 7), so the resulting power injected into the DUT remains comparable to DPI method (see fig. 8).

At higher frequencies (close to 100 MHz), the ratio of impedances changes, the power transfer decreases. In BCI method the input power is increased to inject the same 50 mA current into the setup, while in DPI method input power remains the same, providing lower injected disturbance.

Conclusions

In the current paper three different IC RF immunity test methods (DPI, BCI and Stripline) were analysed for possible correlation of the results. The correlation of BCI and DPI methods in terms of injected forward power is acceptable up to approx. 100 MHz. The Stripline method has shown lots of internal resonances in the power injection stage at frequencies higher than 50 MHz, The results of this method could correlate with first two only up to 30 MHz.

The BCI method aims for constant value of injected current in the measured frequency range. Due to this, the method becomes independent of the power transfer function of the injection probe and effects, caused by interaction of the probe with PCB. The results of the DPI instead depend directly on the power transfer function of the setup. Thus BCI is able to provide higher disturbance level to the DUT at higher frequencies (100 - 300 MHz).

Literature

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