# THE COMPUTATIONAL SIMULATION OF FICBE TEST BENCH USING TRANSIENT ANALYSIS TECHNIQUE

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**Abstract** - This works reports the computational simulation of the FICBE test bench the transient analysis technique. The discharge probe and its stray impedance had been simulated using RLC circuit analyzed in transient mode. The simulation revealed that the stray impedance could distort FICBE discharge current, which is very high peak current, fast rise time waveform, and lead the non-compliant in test bench qualification. In addition, the adding of ferrite bead could shape the discharge current to meet the standard waveform requirement. These findings is beneficial to the FICBE test bench design guideline to meet the waveform qualification accurately.

**Keywords** - Field-Induced, Charged Board Model, Charged Board Event, Circuit Simulation

## I. INTRODUCTION

In the year 2020, electrostatic discharge sensitive (ESDS) devices will be tinier than 10 nm. Electrostatic charges of 0.1 nC; and electrostatic fields of 10 V/cm is enough to damage them permanently [1]. As a result, it is necessary for ESD engineers and device engineers who handle ESDS device require a critical value of ESD sensitivity levels for each classifications. Several ESD models have been used for classifying ESD sensitivity such as human body model (HBM), machine model (MM) and charged device model (CDM) [2]. ESDS devices assembled in the print circuit board (PCB) can accumulate more charges than standard CDM because the PCB consists of the insulator and conductive traces connected to such devices. These accumulated charges are induced by either directly charging or inducing by the external field. Finally, these charges are rapidly discharged when an exposed conductor on PCB is contacted to an external ground path. This event is defined as charged board model (CBM) which normally occurs in the field-induced charged board event (FICBE) [3]. Also, the CDM and CBM events are resembled, however the major difference is the larger energy of capacitance in CBM [4]. Currently, the test model of FICBE has not been confirmed. Mostly ESD engineers applied the AEC-Q100-11 [5] and ANSI/ESDA/JEDEC JS-002-2014 [6] for classifying, evaluating, and simulating of devices with FICBE under the conceptual framework of CDM standard. The computational simulation could emulate the FICBE test bench with the stray impedance. This simulation can enhance the understanding of electrostatic potential (ESP) level and discharge current waveform for validating the measurement results. This method can estimate the high frequency and high amplitude waveform where measurement system frequency or current are limited by stray impedance. For an accuracy of FICBE waveform measurement, the computational simulation also can be, used to approximate the discharge current waveform, and verifying the correctness of the measured values in technical report [7]. Thus, it is a necessity to consider the stray impedance in FICBE test bench. Especially, the stray impedance in discharge probe which could create a large impact to discharge current waveform because that discharge current has a high peak current and fast rise time [8]. Therefore, the computational simulation is required for understanding the effects of stray impedance in the FICBE test bench for verifying discharge waveform compliance. In addition, the results also could be rather useful guideline for designing or troubleshooting the FICBE test bench for non-compliant in waveform verification.

This work aims to simulate the stray impedance in the discharge probe, which could affect the FICBE discharge current waveforms. The transient analysis of RLC circuit is used for simulating the FICBE and discharge probe that consists of stray impedance of POGO pin, resistive current sensor, ferrite bead, voltage probe and oscilloscope. The simulation result will be used for validating and troubleshooting the FICBE test bench to meet the CDM waveform verification requirement.

## II. RLC STRAY IMPEDANCES OF FICBE SIMULATION MODEL

The discharge probe and FICBE test bench has been built based on the standard test method (STM) [5, 6]. This discharge probe consists of the grounded POGO

pin, resistive current sensor, ground wire, ferrite bead, and voltage probe which is connected to oscilloscope. The FICBE test bench requires the waveform verification with both 4 pF and 30 pF modules to measure the 1st peak current and the rise time. The 30 pF verification module is used for simulating as device under test (DUT). This work applied 500 volts high voltage DC as a power supply ($V_S$). This verification module was selected in this experiment because of it is the largest capacitance module that could be referenced by STM.

The equivalent circuits of FICBE were represented two scenarios as shown in figure 1 and figure 2. The 1st scenario is the FICBE test bench, consists of RLC with stray impedance excluding the measurement component, is shown in figure 1 called as "Setup A". The 2nd scenario is the equivalent circuit of FICBE test bench including the measurement tools (resistive current sensor [9], voltage probe and oscilloscope) as shown in figure 2, called as "Setup B". In figure 1, VS is high voltage supply, $C_{DUT}$ is the capacitance between field-plate to DUT, $C_{CH}$ is the capacitance between field-plate to ground, $C_G$ is the capacitance between DUT to ground plane, $R_S$ is the series resistance of pogo pin include spark resistance, $L_S$ is the series inductance of pogo pin, $R_R$ is the one-ohm resistance. In figure 2, the RLC modeling of test bench is included the stay impedance of resistive current sensor, the voltage probe with the common mode noise filter using ferrite bead. $R_{R1}$ and $R_{R2}$ are the resistance of two ohms parallel resistor, $C_{R1}$ and $C_{R2}$ are the stray capacitance of resistor, $L_{R1}$ and $L_{R2}$ are stray inductance of the two ohms parallel resistors. The equivalent resistor $R_S$ is the resistance of ground wire, the $L_{F1}$ and $L_{F2}$ are self-inductance of ferrite bead and M is their mutual inductance. The equivalent resistor $R_{os}$ is the input resistance of oscilloscope, $C_{os}$ is the stray capacitance of oscilloscope, Rprobe is the resistance of probe attenuator, and $C_{probe}$ is stray capacitance of probe attenuator. In general, the ration of $R_{probe}$/ $R_{os}$ typically is 9 [10]. The value of these parameters shows as table 1.

| Parameters | Setup A | Setup B |
|---|---|---|
| $V_S$ | 500 V | 500 V |
| $C_{CH}$ | 35 pF | 35 pF |
| $C_{DUT}$ | 28 pF | 28 pF |
| $C_G$ | 0.12 pF | 0.12 pF |
| $C_{R1}$ | - | 50 pF |
| $C_{R2}$ | - | 50 pF |
| $C_{probe}$ | - | 0.067 pF |
| $C_{os}$ | - | 0.6 pF |
| $L_P$ | 4.2 nH | 4.2 nH |
| $L_{R1} = L_{R2}$ | 0.1 nH | 0.1 nH |
| $R_{R1} = R_{R2}$ | 2 Ohms | 2 Ohms |
| $R_R$ | 1 Ohm | - |
| $R_P$ | 15 Ohms | 15 Ohms |
| $R_G$ | - | 0.5 Ohms |
| $R_{probe}$ | - | 450 Ohms |
| $R_{os}$ | - | 50 Ohms |

**Table 1 - The FICBE simulation parameters**

The FICBE discharge current *i(t)* by has been described in work [8] is shown in (1). Where $V_S$ represents charging voltage, $L_T$ represents total inductance of discharge path,

$$i(t) = \frac{V_s}{\omega_d(L_T)} \cdot e^{-\alpha t} \cdot \sin \omega_d t \quad (1)$$

When the damping attenuation $\alpha$ of FICBE current discharge show as,

$$\alpha = \frac{R_T}{2L_T}. \quad (2)$$

And, the resonance frequency $\omega_d$ of FICBE current discharge show as,

$$\omega_d = \sqrt{\left(\frac{1}{\sqrt{(L_T)(C_T)}}\right)^2 - \left(\frac{R_T}{2L_T}\right)^2}. \quad (3)$$

For the voltage probe and oscilloscope section, the voltage $V_R$ represents the voltage across a one-ohm current sensing resistor and $V_O$ represents the voltage across an input impedance of oscilloscope. The relationship between $V_O$ and $V_R$ can be describes as,

$$V_o = \frac{\frac{R_{OS}}{1+j\omega R_{OS}C_{OS}}}{R_g + i_R[j\omega L_1 + j\omega L_2 - j\omega M] + \frac{R_{probe}}{1+j\omega R_{probe}C_{probe}}} V_R. \quad (4)$$

Therefore, the equivalent circuit in Setup B provides higher accuracy than Setup A when compare these computed results with the measurement result, because it includes the measurement tools and their stray impedance.

## III. FICBE DISCHARGE CURRENT WAVEFORM COMPARISON BETWEEN SIMULATION AND MEASUREMENT RESULTS

The computational simulations in Setup A and B were done, their results were compared to the measurement result, which is evaluated using the 30pF verification module with 500V voltage source. The capacitance of test bench was calculated by equation,

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \quad (6)$$

Where $C$ is capacitance of test bench, $\varepsilon_0$ represents dielectric constant of free space, $\varepsilon_r$ is the relative dielectric constant of material (air = 1 used in this work). A is conductive exposed area of DUT and d is distance between conductor. The equation can be calculating $C_{CH}$, $C_{DUT}$ and $C_G$. In addition, the initial condition of $C_{CH}$ and $C_G$ are 500 volt. The stray impedance of $C_{R1}$, $C_{R2}$, $L_{R1}$, $L_{R2}$, $L_P$, $R_G$ and $R_R$ are

measured. The resistance of pogo pin ($R_P$) included spark resistance this is described in [11]. For oscilloscope, $R_{os}$ = 50 ohms and $C_{os}$ = 0.6 pF of input impedance (from manual) and resistance of probe $R_{probe}$ = 450 ohms. This can be calculated $C_{probe}$ = 0.067 pF by using equation [10]

$$C_{os}R_{os} = C_{probe}R_{probe} \quad (7)$$

In addition, the discharge switch as figure 1 and 2 are setting the close switch time = 1 nanosecond and transient time = 3 nanosecond.

The measurement discharge waveform was recorded by the 1 GHz digital storage oscilloscope with 10GS/s sampling rate, using the 20 dB attenuator connecting to one-ohm current sensing resistor, recorded the measurement waveform. The computational simulated and measurement waveform are illustrated as shown in figure 3.

The stray impedance of POGO pin and the resistive current sensor were minimized by using the parallelized structure. The discharge current flowed through lower inductance the POGO pin and two ohms paralleled resistors for reducing of stray impedance purpose. In addition, ferrite bead consists of the ferrite material with high permeability. The resulting high inductance and core loss at high frequencies used for common mode noise reduction due to their inductive properties as equations (4) and (5).

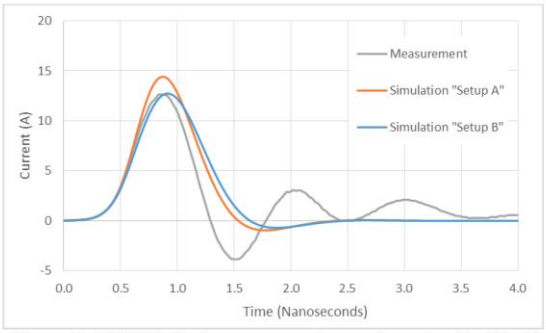



**Figure 3: FICBE discharge current waveform by the 30 pF verification disk at 500 V.**

Figure 3 consists of measured discharge current waveform (1st peak = 12.60 A, rise time= 310 ps.), computational simulated discharge current waveform of Setup A (1st pea k = 14.41 A, rise time= 541 ps.), and computational simulated discharge current waveform of Setup B (1st peak = 12.73 A, rise time= 308 ps.). The discharge current waveforms from measurement and Setup B are complied with the STM [5] requirement (14 A ±20% 1st Peak, rise time < 400 ps.). In other hand, the computational simulated in Setup A does not complied with the STM, especially the rise time. Therefore, the stray impedance of measurement tools described in Setup B provides the better accuracy when compare to Setup A, and comparable to the measurement result.

## IV. CONCLUSION

The computational simulation result validates that the stray impedance in measurement system affects the FICBE discharge waveform. The transient analysis results also prove that the stray impedance could distort the discharge current waveform and lead non-compliant in the waveform verification process, which is required by STM. Especially the stray impedance in discharge probe including the common mode noise reduction using ferrite bead. Finally, this analysis technique could benefit the guidance of FICBE test bench designing and troubleshooting to apply the adding of physically inductor or eliminating the stray inductance or capacitance FICBE test bench including measurement tools for complying in the waveform verification.

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