International Journal of Scientific Research in Science and Technology
Print ISSN: 2395-6011 | Online ISSN: 2395-602X (www.ijsrst.com)
doi : https://doi.org/10.32628/IJSRST

Experimental Analysis and Circuit Modeling of Pulsed Current Injection in a pair of Wires

J. S. S. Divya[1], Prof. P. Rajesh Kumar[2], Mr. P. Siva Kumar[3]
M Tech (R&M)-Student[1], Head of the ECE Department[2], Scientist-C[3]
ECE Department, Andhra University College, Visakhapatnam, Andhra Pradesh, India

Article Info
Volume 9, Issue 5
Page Number : 370-371

Publication Issue
September-October-2022

Article History
Accepted : 01 Oct 2022
Published : 13 Oct 2022

ABSTRACT

A pulse current injection (PCI) setup involving a pulse generator with adjustable parameters is designed and modeled in SPICE. In order to allow causal and accurate time-domain simulation, the circuit model makes use of an augmented network to approximate the non-rational frequency response of the injection probe. The obtained SPICE model is preliminary validated by measurement for different sets of values of the pulse-generator parameters. Afterward, an explicative example of radiated test setup is considered. The stress waveform induced at the points of entry of the equipment under test by radiation (evaluated either by theoretical prediction or by measurement in a low-level radiation environment) is taken as reference to prove the effectiveness of the proposed PCI-setup model in identifying the values of the generator parameters required to reproduce the same disturbance by PCI.

Keywords: Pulse Current Injection, Pulse Generator, SPICE, Stress Waveform, Parameters, and Radiation Environment.

I. INTRODUCTION

Pulsed current injection (PCI) allows testing the immunity of electric/electronics devices against fast and intense transient electromagnetic disturbances. The technique resorts to inductive couplers to inject intense transient electromagnetic (EM) disturbances directly into the cable harnesses entering the device under test (DUT). The noise entering the DUT input ports may exhibit significant differences due to the frequency response of the injection device. To investigate these influence factors, a PCI test setup involving a wire-pair is setup and modelled in the SPICE environment. Measurements and simulations are exploited to put in evidence the effects that the presence of other wires in the bundle play on the voltage waveform induced at the terminations of a specific wire.

A formulation for obliquely incident electromagnetic wave has been presented [1] for an analysis of high-power electromagnetic pulse penetration into multilayered dispersive media. Based on generalized models of measured dielectric constants and propagation channels reflecting the Earth's general features, the propagation phenomenon of the obliquely incident early-time (E1) high altitude electromagnetic pulse (HEMP) is analyzed. In addition, the polarization and critical angle are also considered. It is found that the total reflection occurs at an incident angle of about 38 degrees at the soil-rock interface, and that the parallel-polarized E1 HEMP penetrates better than the perpendicular-polarized one. The peak level of the penetrating electric field is found to be 5.6 kV/m at normal incidence, regardless of the type of polarization, and E1 HEMP is greatly reduced near the critical angle. Moreover, the penetrating E1 HEMP is analyzed as a variation of moisture content and depth of materials, resulting E1 HEMP could be useful in determining the levels of shielding required for buried facilities.

II. PULSE CURRENT INJECTION

Pulse Current Injection (PCI) acceptance testing is used to demonstrate that electrical Point of Entry (POE) protective devices perform in accordance with the transient suppression / attenuation requirements. The PCI tests require high energy generators for delivering current pulses either directly or through coupling devices in the cables. The short pulse test is covered with two generators, PPG-E1-1200 for current pulses up to 1.2 kA and EMP300K-5-500 for 1.5 kA up to 5 kA pulses. Additionally, montena proposes a lower-level pulse generator (EMP10K-5-500) for tests on electronic components. The intermediate pulse test requires a generator delivering up to 260 A.RF antenna line POE must be tested up to 400 A. Montena proposes two "charge line" generators for testing the susceptibility of those antenna ports. A set of charge line plugs of different lengths are supplied in order to generate frequencies in the specified range. Each generator is fully configurable, with current adjustable output, manual or remote control.

Montena has developed a full range of pulse generators according to MIL-STD -188-125-1 & 2. This standard describes the pulsed current injection (PCI) tests, simulating the currents induced in cables exposed to NEMP pulses. The systems provided cover the short pulse (E1) and the intermediate pulse (E2) tests. A charge line pulser is also available for antenna line testing. Accessories such as current injection and measuring probes, coupling and decoupling networks, fiber optic links, etc. are delivered with the equipment. A PC software application drives all the instruments for a simple and effective operation.

The advantages of the PCI are mentioned below:

- Unique fully compliant test solution to cover the entire standard requirements.
- Transportable for on-site verification tests.
- Control and pulse management software package to simplify the test procedure.

A typical test setup comprises following elements as shown in the following fig. 1.

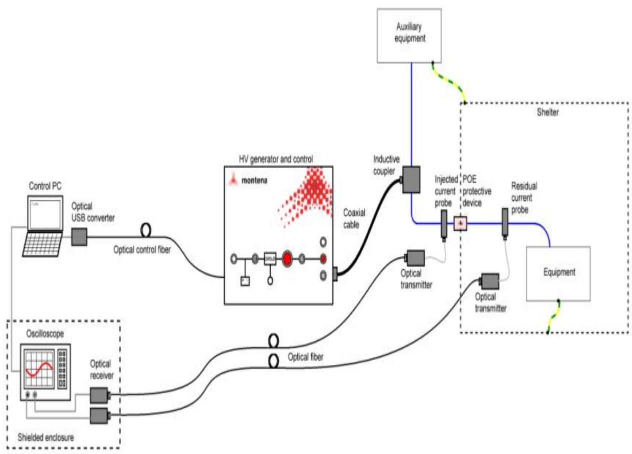

Figure 1: Schematic of a typical PCI test setup installation

The high voltage pulse generator delivers the specified high current pulses either directly or through coupling devices into the wire attached to the protective device under test. The major part of the injected energy shall be shortcut to the grounded shielding. Only a small residual part of the pulse may enter the facility through the point of entry protective device. An oscilloscope measures the injected and residual pulse with current probes for display and eventually storage in the control PC. In order to ensure correct measurement, the current probes are connected using fiber optic links and the measurement equipment shall be installed in a shielded enclosure. Montena Pulse Lab software application takes care of the configuration of the measurement oscilloscope. It directly provides the injected and residual current pulse shapes and parameters, what reduces to almost zero the risk of measurement errors.

Montena's PCI test system is able to perform pulsed current injection tests according to MIL-STD 188-125-1 & -2, short pulse (E1), intermediate pulse (E2) and charge line pulse tests. This is shown in the below table I.

TABLE I

PULSE SHAPES

	E1 - Short pulse	E2 - Intermediate pulse	Charge line pulse
Max. short circuit current (Isc)	≥ 5'000 Amp	≥ 250 Amp	≥ 400 Amp
Adjustable range of Isc	≤ 100 to ≥ 5'000 Amp	≤ 25 to ≥ 250 Amp	≤ 10 to ≥400 Amp
Waveform	Double exponential	Double exponential	Variable pulse width
Rise time (10%~90%)	≤ 20 ns	≤ 1.5 µs	≤ 5 ns
FWHM (50%~50%)	500 .. 550 ns	3 .. 5 ms	variable
Source impedance	≥ 60 Ω	≥ 10 Ω	≥ 50 Ω

The PCI test setup can be established in three different manners based on the pulse. They are:

- Portable Low Level Short Pulse Test Setup
- High Level Short Pulse Test Setup
- Intermediate Pulse Test Setup

Portable Low Level Short Pulse Test Setup

This test setup shown in fig. 2 shall be used for the injection of the short pulse (E1) with a peak current intensity of up to 1200 A. It has been designed to ease the onsite tests, especially for the periodic reverification campaigns

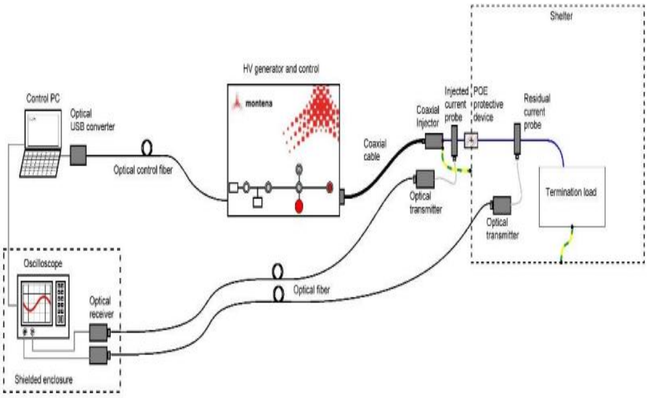

Figure 2: Typical acceptance test setup with the PG-E1-1200 generator

1200 AMP SHORT PULSE GENERATOR

The portable generator PPG-E1-1200 generates output current pulse according to MIL STD 188-125, E1. It has an internal impedance of >60 ohm and its charging between may be set between may be set between 5-80 kv It delivers short circuit current pulses in the range of 50-1200 A.

The generator is compact, battery powered for easy deployment at customer site, where power is not always available. The power autonomy is up to one day and it can be charged from a 110V – 240V power plug directly.

The generator is remote controlled from a web-based software application through an USB optic link. The operator is thus totally electrically insulated from the high voltage elements. The generator is delivered with ruggedized transportation box on wheels for easy deployment on site.

TABLE II

1200 APM SHORT PULSE GENERATOR SPECIFICATIONS

SPECIFICATIONS	
Type	PPG-E1-1200
Standard	MIL-STD-188-125-1 and -2 / short pulse (E1)
Peak short circuit current	≤ 50 A to 1.2 kA
Peak voltage (open circuit)	≤ 5 kV to 80 kV
Output waveform	double exponential
Source impedance	≥ 60 ohms
Pulse rise-time (short circuit)	< 20 ns
Pulse length (FWHM, short circuit)	500 - 550 ns
Output interface	8 meters HV coaxial cable with a special coaxial termination
Insulation	oil
Interfaces	USB / optic fiber
Power rating	85 – 132 / 187 – 264 Vac, 47 - 63 Hz
Autonomy (on internal battery)	about 8 hours
Generator dimensions	55 x 50 x 25 cm (L x W x H)
Weight	31 kg (with external HV cable), 50 kg (total with transportation box)

High Level Short Pulse Test Setup

This test setup shall be used for the injection of the short pulse (E1) with a peak intensity between 1500 A and 5000 A.

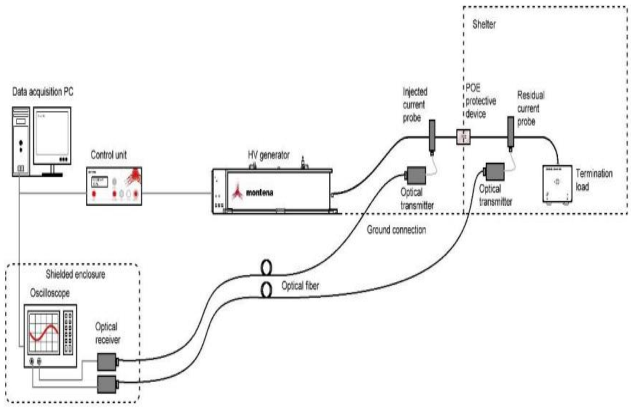

Figure 3: Typical acceptance test setup with the EMP300K-5-500 generator

5000 AMP SHORT PULSE GENERATOR

To fulfil the MIL-STD test specifications up to more than 5000 A peak current with a 60 Ohm internal impedance, this short pulse generator must be charged at more than 300 kV. The generator is based on a Marx technology. The generator is remote controlled from a control unit with USB and RS232 control interfaces. A dedicated control software application is also available to automate the test setup.

TABLE III

5000 AMP SHORT PULSE GENERATOR SPECIFICATIONS

SPECIFICATIONS	
Type	EMP300K-5-500
Standard	MIL-STD-188-125-1 and -2 / short pulse (E1)
Peak current (short circuit)	≤ 1.5 kA to 5 kA
Peak voltage (open circuit)	100 kV to 350 kV
Output waveform	double exponential
Source impedance	≥ 60 ohms
Pulse rise-time (short circuit)	< 20 ns
Pulse length (FWHM, short circuit)	500 - 550 ns
Output interface	Bar with screws
Insulation	SF6
Interfaces	USB / optic fiber
Power rating	210 – 250 Vac, 50 - 60 Hz, 600 VA
Generator dimensions	188 x 60 x 42 cm (L x W x H)
Weight	about 175 kg

Intermediate Pulse Test Setup

This test setup shall be used for the injection of the intermediate pulse (E2) with a peak intensity up to 260 A.

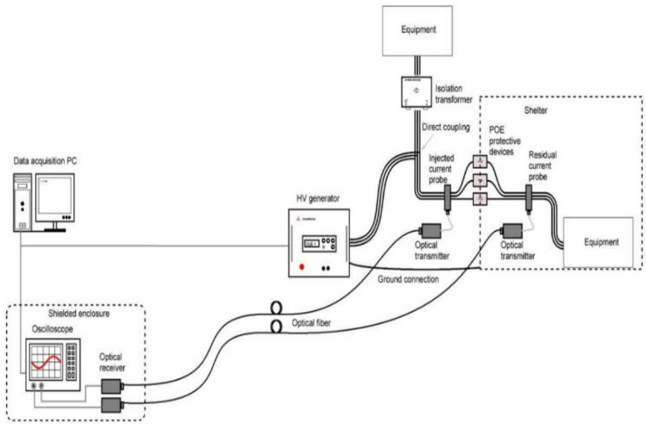

Figure 4: Typical verification test setup with the IPP3K-4MS generator

INTERMEDIATE PULSE GENERATOR

This generator is built using a direct discharge of high voltage capacitors.

TABLE IV

INTERMEDIATE PULSE GENERATOR SPECIFICATIONS

SPECIFICATIONS	
Type	IPP3K-4MS
Standard	MIL-STD-188-125-1 and -2 / intermediate pulse (E2)
Technology	direct discharge
Peak short circuit current	25 A to 260 A
Peak voltage (open circuit)	3 kV max, positive only
Output waveform	double exponential
Source impedance	≥ 10 ohms (typ.11 ohms)
Pulse rise-time (short circuit)	0.6 µs
Pulse length (FWHM, short circuit)	3.4 ms
Output interface	4 outputs, safety connectors
Interfaces	RS 232 / USB
Power rating	200 – 264 Vac, 50 - 60 Hz, 1.6 kVA peak
Generator dimensions	55 x 51 x 40 cm (L x W x H)
Weight	42 kg

III. PCI TEST SET UP AND CIRCUIT MODELLING IN SPICE

Overview of the used Test Set up

PCI is a non-interfering and cost-effective technique, to test the robustness of electric/electronic devices to high-altitude electromagnetic pulses (HEMPs).The technique resorts to inductive couplers to inject intense transient electromagnetic (EM) disturbances directly into the cable harnesses entering the device under test (DUT).For bulk current injection (BCI), the PCI test the input of the equipment under test a transient disturbance with expected characteristics (i.e., amplitude, rise time, and pulse width).

When the probe is then mounted on the real cable harness, significant differences between the waveform actually injected in the DUT and the theoretical waveform set through calibration can be expected. Measurement on controlled test setup and circuit (SPICE) simulation are used with the objective to accurately predict and compare the stress waveforms theoretically injected across the 50-fi terminations of a single-wire cable. With respect to other testing techniques, PCI does not require large and expensive test facilities. Moreover, since the disturbance can be injected into a cable or even into a single wire at a time. Pulsed current injection (PCI) is widely used for immunity testing of electronic equipment to intense transient electromagnetic disturbance, caused by lightning, switching operations in substations, high-altitude nuclear explosion, etc. Pulse current injection (PCI) is a convenient and effective technique to test the vulnerability of electric/electronic equipment to high-altitude electromagnetic pulses (HEMPs).

Circuit Modelling

In this Section, circuit modelling of the key components in the PCI test setup in Fig. 5 (i.e., the pulse generator and D-coupler, the wiring fixture and coupling device) is addressed, with the objective to implement and simulate the PCI test setup.

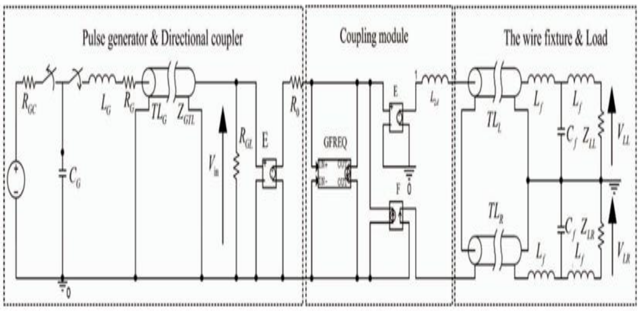

Figure 5: Depiction of Circuit Modelling

The test consists in injecting an electromagnetic (EM) threat-retable transient onto the cables of the equipment under test (EUT) by an injecting probe, and monitoring EUT robustness against such a stress waveform. Compared with radiated tests, where the system is completely immersed in the EM environment, PCI allows more accurate screening and detection of critical cables (and points of entry), by resorting both to common mode and single wire-to-ground noise injection [1]. Moreover, since the test is run on the tabletop, PCI is attractive in terms of required time and costs. The standards in provide several regulations for the injected current waveform, in terms of amplitude, rise time, and pulse width. However, most of them focus just on the calibration setup.Hence, though interference at the EUT input represents the key-quantity to qualify EUT vulnerability, it is hard to control and set the actual standards in provide a number of regulations for the injected current waveform, in terms of amplitude, rise time, and pulse width. However, most of them focus just on the calibration setup. Hence, though interference at the EUT input represents the key-quantity to qualify EUT vulnerability, it is hard to control and set the actual waveform induced at the EUT input pins. On the other hand, though several recent works investigated the correlation between field-to-wire coupling and bulk current injection (BCI) under continuous-wave (CW) conditions little has been done so far concerning the injection of transient EM disturbances. In this framework indeed, stressing the EUT with a pulsed waveform with the same characteristics of the current induced at the EUT input in a radiation environment would be highly desirable. In this letter, a PCI test setup assuring accurate reproduction at the EUT input of a stress waveform with assigned characteristics is presented. The setup comprises a BCI probe clamped on a single-ended wiring interconnection and fed by a pulse generator with adjustable parameters.

Figure 6: Test setups deployed to experimentally investigate PCI on the case of single- wire harness

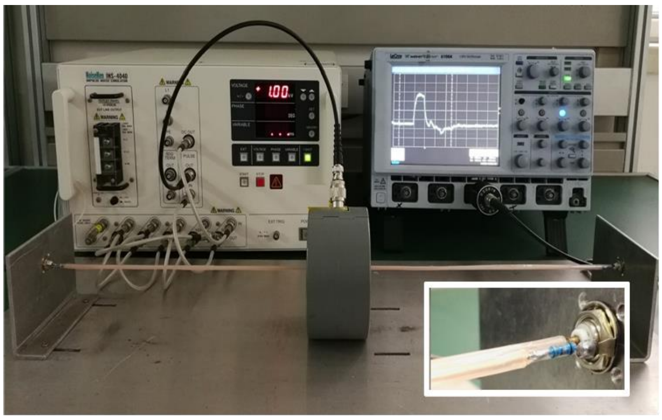

Figure 7: Test setups deployed to experimentally investigate PCI on the case of a straight wire-pair cable

Test setups exploited for experimental investigation of PCI

It is shown that accurate modeling of the test setup in SPICE can be profitably exploited to set the adjustable parameters of the pulse generator so that a specified stress waveform, preliminarily evaluated either by calculations or by measurements in a low-level radiated test, can be subsequently injected in the input pins of the EUT. The obtained PCI setup model (exploiting an augmented RLC model of the BCI probe to avoid convergence issues in the time domain) is first assessed versus measurement data. Then, by a specific example of radiated immunity test setup, it is exploited to identify the pulse-generator parameters required to reproduce the stress waveform injected in the EUT.The actual stress waveform injected at the DUT input often exhibits significant differences with respect to the theoretical one. If on the one hand this weakens test significance, on the other hand it makes hard the correlation with the stress waveform, that would be induced by direct illumination of the system in a radiation environment.

IV. RESULTS AND DISCUSSION

Assessment investigation of acceptance and validation assessment data of PCI is needed for sorting out every instrumentation and probe entity reply attributes. These assessment investigations are also needed for transforming measured outcomes into measurables in terms of engineering units. Another outcome desirable was to support in devising a conclusive hardness of subsystem and system statement. These assessments are possible only from the support imparted from a few sponsoring agencies. The assessments could generally include the following:

- CW immersion-oriented threat replies.

- Test data of PCI.
- Illumination of threat-level.
- Investigations of Validation assessment necessity.
- Conclusions drawing based on hardness.
- Suggestions for remedial course of actions.

With the final objective to assure equivalence between radiated and conducted immunity testing to intense electromagnetic pulses, in this work a circuit model of a typical. Pulsed current injection (PCI) test setup is derived, implemented in SPICE, and validated by measurement. By virtue of such a model, the parameters of the discharge circuit of the pulse generator can be adjusted to compensate the waveform distortion introduced by the injection probe. Results of preliminary PCI tests are presented with the twofold objective to validate the models proposed in the previous sections, and to show the effects of different values of the PCI setup parameters.

A. *Probe Circuit analysis*

In this sub-section, we will analyse the probe circuit with its schematic in the below fig. 8. We will make this comprehensive analysis by making use of Microcap in order to indicate the various attributes.

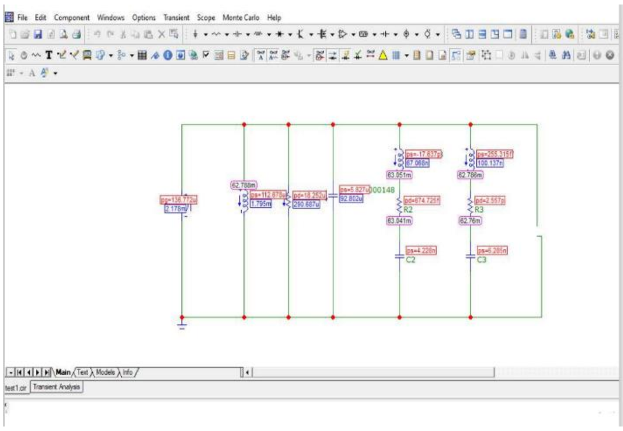

Figure 8: Probe Circuit analysis in Microcap

Now that, we have known the attributes, we will see the result of AC Analysis and Frequency of it in the following fig. 9 and fig. 10, respectively.

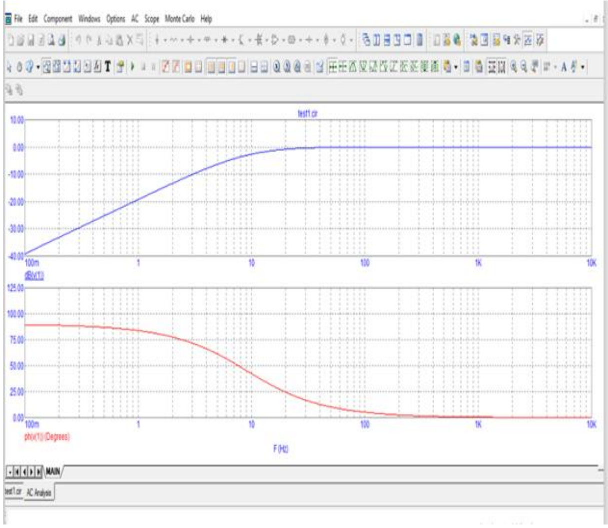

Figure 9: AC analysis result

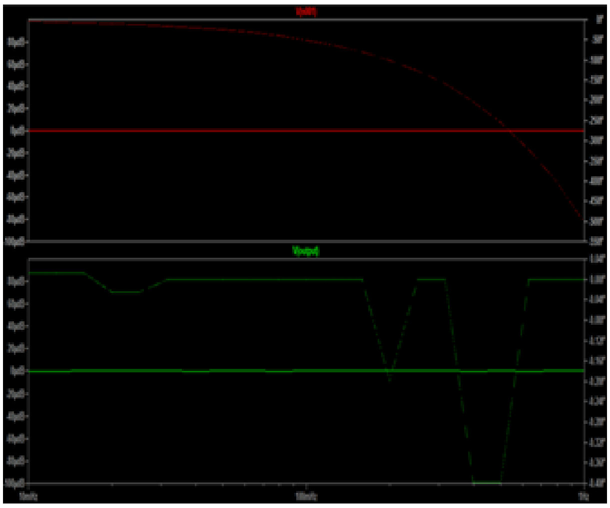

Figure 10: Frequency response

Pulse generator

In this sub-section, we will look into the simulation aspect of the pulse generator with its schematic in the below fig. 11.

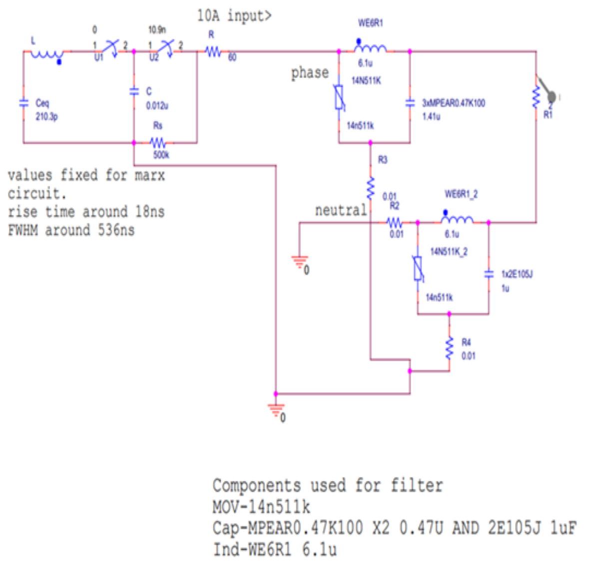

Figure 11: Simulation-based schematic for Pulse Generator

This schematic will be having several information including but not limited to: Values utilized for circuitry, components utilized for filter, etc. Then, the output from this generated will next be analyzed. In the below fig. 12, the time output has been shown and in the next fig. 13, - I output has been shown in appropriate manner.

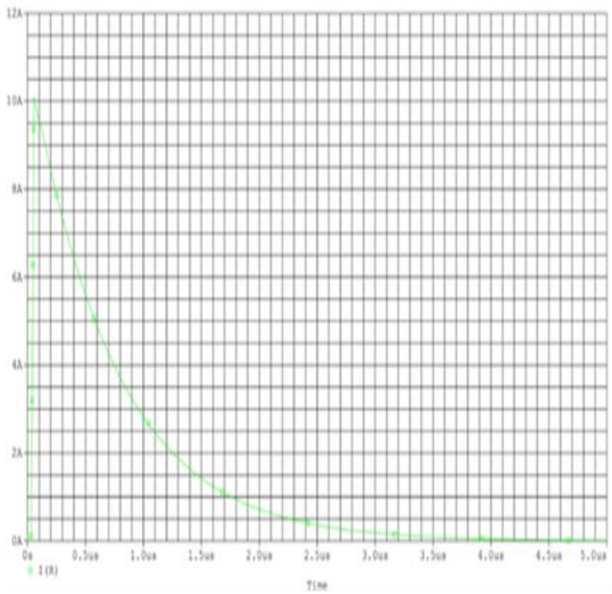

Figure 12: Time output from Pulse Generator

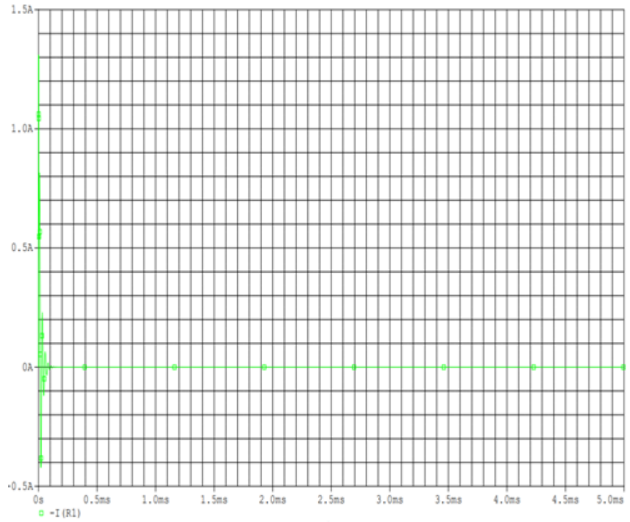

Figure 13: - I output from Pulse Generator

Circuit on microcap

Having already analysed about the probe circuitry, we will now analyse about the main circuit in this sub-section. In the following fig. 14, the analysis of our circuitry on Microcap has been depicted.

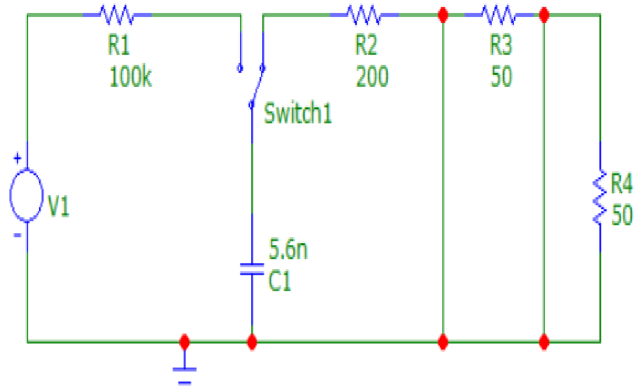

Figure 14: Circuit Analysis on Microcap

Switch 1 on left side

In this sub-section, we will first discuss the case of considering the switch 1 in the left side with its corresponding schematic in the following fig. 15 and then its outcomes:

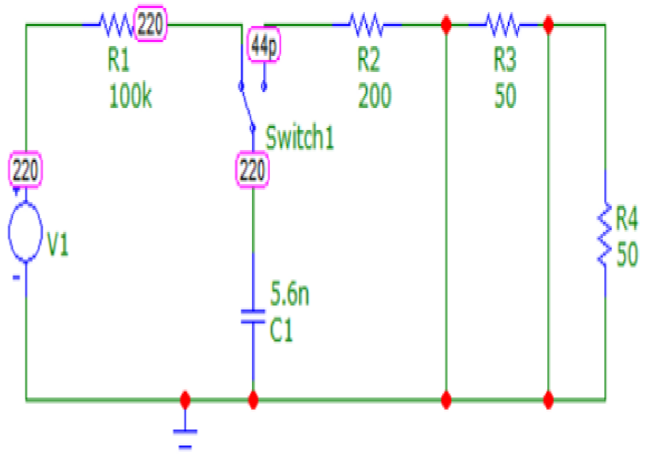

Figure 15: Depiction of Switch 1 on Left Side

Now, we depict the observed transient result in the below fig. 16. Followed by it, the observed AC result has been given in the next fig. 17. In the same way, the DC results were observed and depicted in the next fig. 18. Finally, fig. 19 is depicted to show the Observations from the Dynamic DC Result.

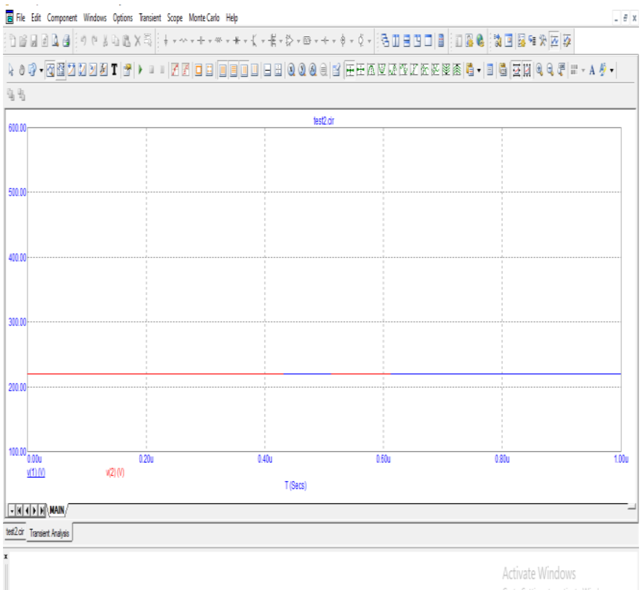

Figure 16: Transient Result Observations

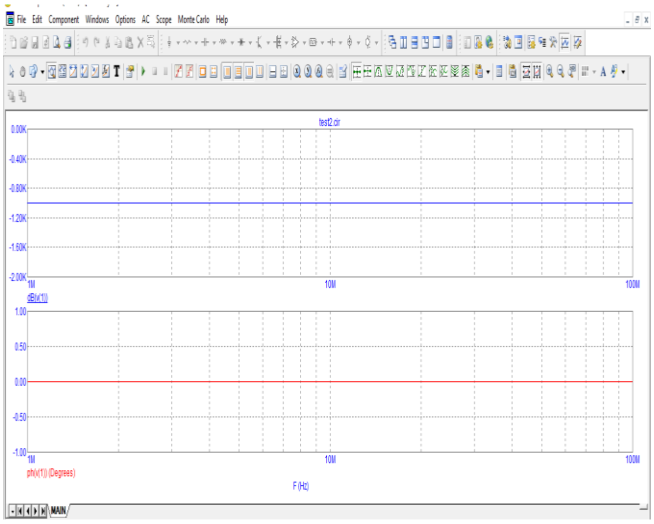

Figure 17: AC Result Observations

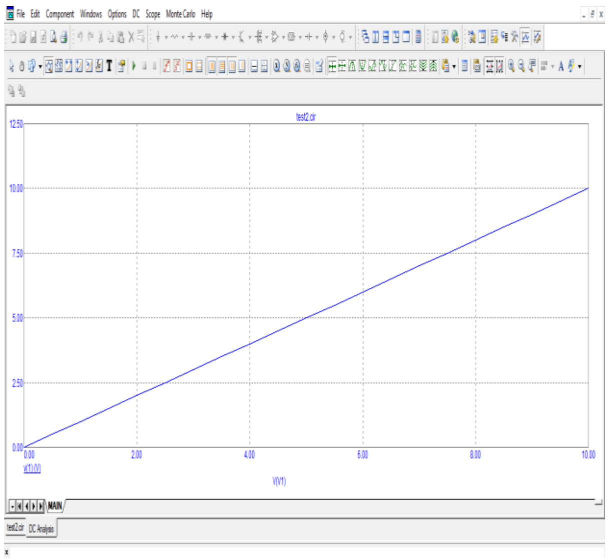

Figure 18: DC Result Observations

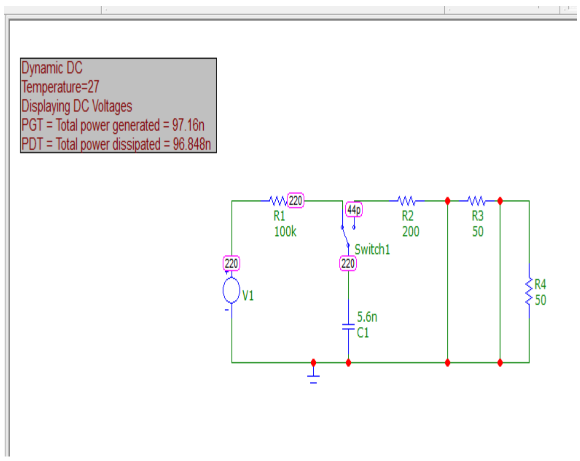

Figure 19: Dynamic DC Result Observations

Switch 1 on right side

In this sub-section, we will first discuss the case of considering the switch 1 in the right side with its corresponding schematic in the following fig. 20 and then its outcomes:

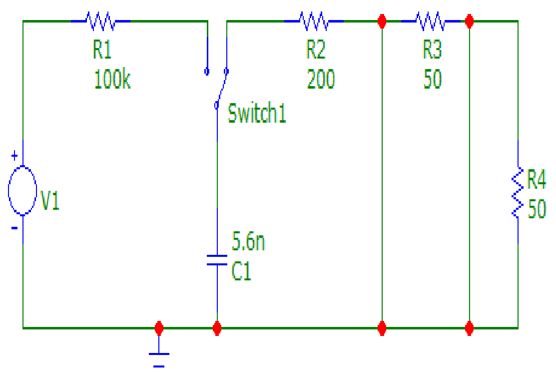

Figure 20: Depiction of Switch 1 on Right Side

Now, we exhibit the observed transient result in the below fig. 21. Next to it, the observed AC result has been shown in the succeeding fig. 22. Likewise, the DC results are depicted in the next fig. 23 and finally by fig. 24, which has been indicated to show the Observations from the Dynamic DC Result.

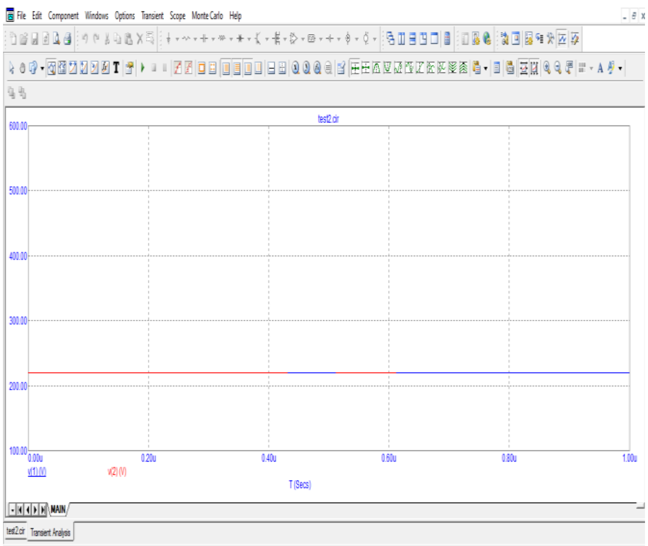

Figure 21: Transient Result Observations

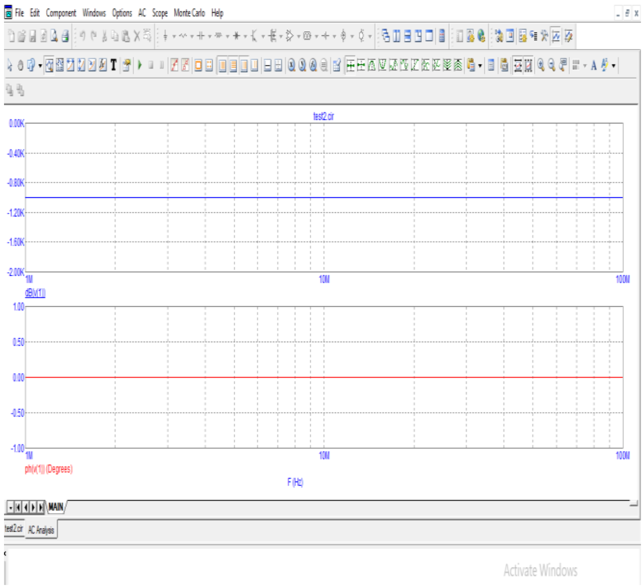

Figure 22: AC Result Observations

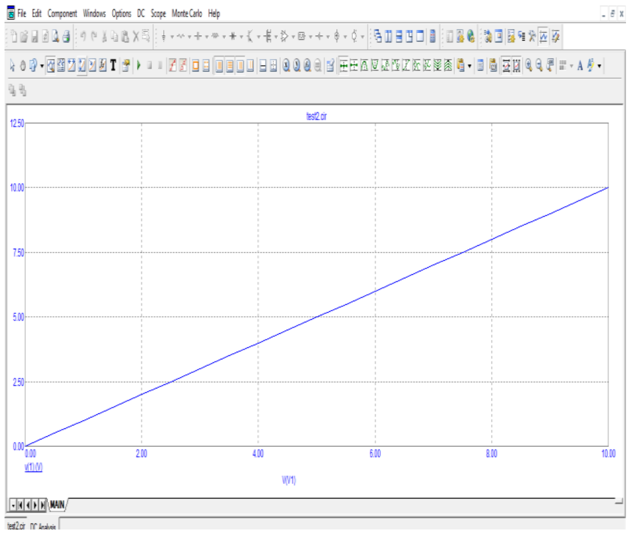

Figure 23: DC Result Observations

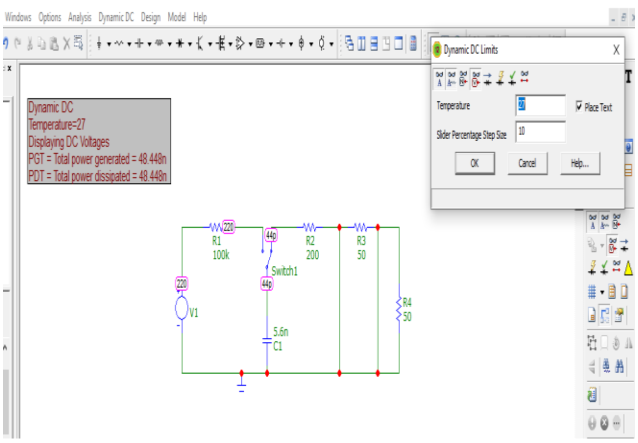

Figure 24: Dynamic DC Result Observations

V. CONCLUSION

This finding suggests to further investigate the role that different loads connected at the terminations of the wiring harness plays on the amplitude and shape of the induced voltage waveform. Test setup for PCI injection has been realized and modelled in the SPICE environment. Measurements and simulations have been used to investigate the influence of the presence of additional wires in the bundle, as well as their terminations, on the stress waveforms induced at the input pins of the device under test.

VI. REFERENCES

[1]. Kang, H.-D., et al., Analysis of Penetration Phenomenon of High Altitude Electromagnetic Pulse into Buried Facilities with Various Moisture Content and Depth. 2013. 24(6): p. 644-653.

[2]. MIL-STD-188-125-1, High-altitude electromagnetic pulse (HEMP) protection for ground-based C4I facilities performing critical time- urgent missions, 2005.

[3]. MIL-STD-461E, Requirement for the control of electromagnetic interference characteristics of subsystems and equipment, 1999.

[4]. Testing and measurement techniques-HEMP immunity test methods for equipment and systems, IEC 61000-4-25, 2001.

[5]. Z. Cui, F. Grassi, S. A. Pignari, B. Wei, “A Pulsed Current Injection setup and procedure to reproduce intense transient electromagnetic disturbances,” IEEE Trans. Electromagn. Compat., vol. 60, no. 6, 2018.

[6]. NOSIKEN Impulse Noise Simulator INS-4020/4040. Online at: http://www.noiseken.com/modules/products/index.php?content_id=191

[7]. F. Grassi, S. A. Pignari, “Bulk current injection in twisted wire pairs with not perfectly balanced terminations,” IEEE Trans. Electromagn. Compat., vol. 55, no. 6, pp. 1293-1301, Dec. 2013.

[8]. C. R. Paul, Introduction to Electromagnetic Compatibility, New York: Wiley-Interscience, 1992.

[9]. N. Toscani, F. Grassi, G. Spadacini, S. A. Pignari, “Modeling bulk current injection test setups involving complex wiring harnesses,” IEEE Trans. Electromagn. Compat., vol. 60, no. 6, 2018.

Cite this article as :

J. S. S. Divya, Prof. P. Rajesh Kumar, Mr. P. Siva Kumar, "Experimental Analysis and Circuit Modeling of Pulsed Current Injection in a pair of Wires", International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN : 2395-602X, Print ISSN : 2395-6011, Volume 9 Issue 5, pp. 370-380, September-October 2022.

Journal URL : https://ijsrst.com/IJSRST229571