Design, Modeling & Simulation of Analysis of coupling to Cables due to Electromagnetic Pulse (EMP)

Priti Mandal, B. Venkata Ramana, P.V.Y Jayasree

Abstract*: This paper is to analyze the EMP coupling to cables using 3D EM Modeling and Simulation Analysis. Bounded wave transmission line structure as per MIL-STD 461, RS105 EMP requirement in terms of peak electric field of 50KV/m with rise time-2.3ns and pulse width-25ns was developed. Single conductor cable, RF Coaxial cable were modeled. EMP Coupling to cables was carried out by placing the cable under generated EMP field in terms of induced voltage and currents due to EMP fields. EMP coupling to active line with matched termination also analyzed.

Index Terms*: Electromagnetic pulse (EMP), Bounded wave Transmission line, cables.

I. INTRODUCTION

ELECTROMAGNETIC PULSE-

An electromagnetic pulse is a short burst of electromagnetic energy. EMP arises from two principal sources, the first of which is the gamma rays emitted by the nuclear detonation. The second significant type of EMP from high altitude bursts is a low frequency, low amplitude field caused by explosion plasma motion in the upper atmosphere. This environment is commonly referred to as magneto-hydrodynamic EMP or MHD EMP. EMP have devastating effect on the unprotected electronics systems.

Gamma rays represent about 1/1000th of the total bomb energy and are emitted within ten billionths of a second. The amount of gamma emitted by a one- megaton detonation is about 4 X 1012 Joules. The gamma rays, by a process known as the "Compton Effect," strip electrons from air molecules to create a large-scale electron current in the upper atmosphere. This electron current is deflected by the earth's magnetic field and thereby radiates an intense electromagnetic pulse (EMP) over extensive portions of the earth's surface. Effects extend to ground areas within the line-of-sight of the burst as shown in fig.

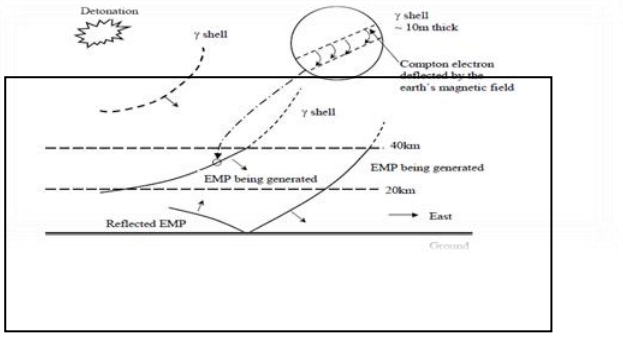

Fig. **1** Mechanism of gamma-induced EMP from a high-altitude burst

The second significant type of EMP from high altitude bursts is a low frequency, low amplitude field caused by explosion plasma motion in the upper atmosphere. This environment is commonly referred to as Magneto hydrodynamic EMP or MHD EMP. The plasma created by the explosion perturbs the earth's magnetic field which, in turn, generates electric fields on the Earth's surface and the upper layers of the ground.

COAXIAL CABLE-

Coaxial cable is a two conductor electrical cable consisting of core as the inner conductor, shield as outer conductor and with dielectric as an insulating space between inner conductor and outer conductor. For the transmission of Radio Frequency energy coaxial cables are used. Cables can be a main source of transfer for EMI/EMP, both as a source and receiver. As a source, the cable can either act as an antenna radiating noise or conduct noise to other equipment. As a receiver, the cable can pick up EMI/EMP radiated from other sources. Any current-carrying conductor radiates electromagnetic field, including a cable.

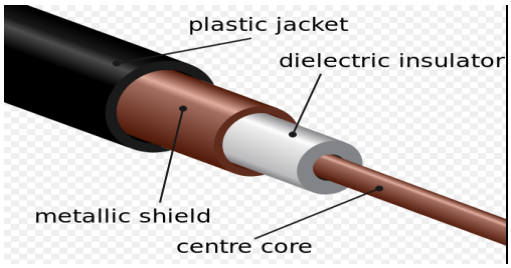

Fig.2 Coaxial cable

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Any conductor including cable will pick up energy from any existing electromagnetic field around it. These effects are often undesirable. Due to unwanted transmission of energy it may adversely affect nearby equipment and even other parts of the same piece of equipment and in the second case, unwanted pickup of noise which may mask the desired signal being carried by the cable, or, if the cable is carrying power supply, distort them to such an extent as to cause equipment malfunction.

II. BOUNDED WAVE TRANSMISSION LINE STRUCTURE

Transverse electromagnetic (TEM) cell type of triangular transmission line with a matching termination resister bank will be best structure for generating EMP pulse with minimum distortions. Generally radiating lines will be made with multiple metal wires terminated with distributed load resistors. Bottom ground plane resistors will of metallic mesh for simulation the TEM cell type structure.

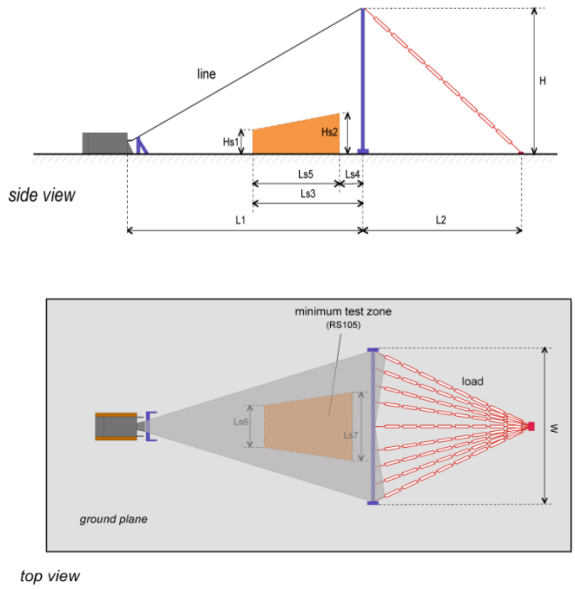

Fig.3 Radiation Line (Triangular)

In the triangular radiation line, the pulse produced by the HV generator is transformed into a TEM electromagnetic field travelling in the direction of the load. Because there is no discontinuity along the line, no other electromagnetic modes than TEM are exited. Some reflections are induced due to the construction of load.

In the parallel plate, between the slope (triangular part) and the flat part the wave is travelling up to the transition placed. In this region other modes than TEM are produced that induce reflections and field distortions. At the end of the flat part process is repeated and finally the reflections are influenced by terminated load.

Hence we are going to consider the triangular plate structure for the EMP test set up to perform RS105 tests according MIL-STD 461-E/F.

MODELING OF BOUNDED WAVE TRANSMISSION LINE STRUCTURE

Modeled bounded wave transmission line structure with matched terminated resistors for generating standardized EMP field. As an input, Double Exponential voltage pulse is given and it is measured at equipment zone area.

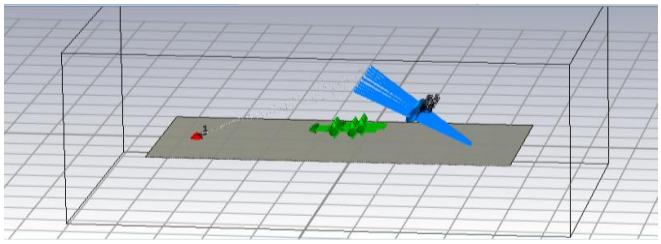

Fig.4 CAD model of Bounded Wave Transmission Line structure

We placed probes at the place of EUT to measure the E.F at every probe. As shown in figure below-

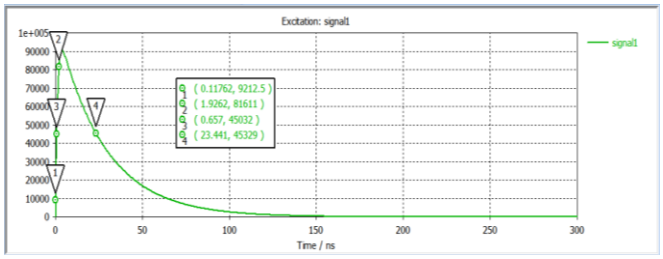

Fig.5 Double Exponential Pulse

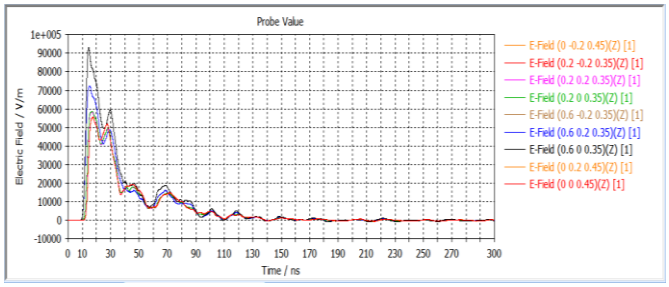

Fig.6 Electric field obtained at different probes

Input here given is 90KV, as the upper plate is kept at height 1.8 m. E.F obtained at EUT zone is more than 50 KV/m as per MIL-STD 461, RS105 EMP requirement.

III. EMP COUPLING ANALYSIS

A.SINGLE CONDUCTOR

(a) SINGLE CONDUCTOR CABLE PLACED LENGTH WISE INSIDE THE UNIFORM FIELD AREA UNDER BOUNDED WAVE TRANSMISSION STRUCTURE

Modeled bounded wave transmission line structure with matched terminated resistors by maintaining the impedance 110 ohms according to the width by height ratio for generating standardized EMP field. As an input, Double Exponential voltage pulse is given and it is measured at equipment zone area.

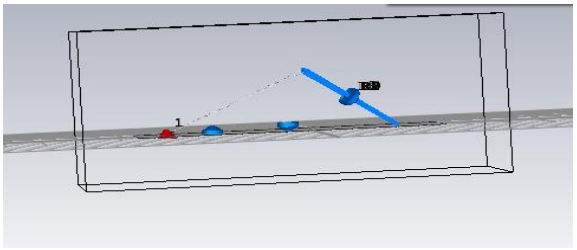

Fig. 7 CAD Model of Single conductor placed inside Bounded Wave Transmission line Structure

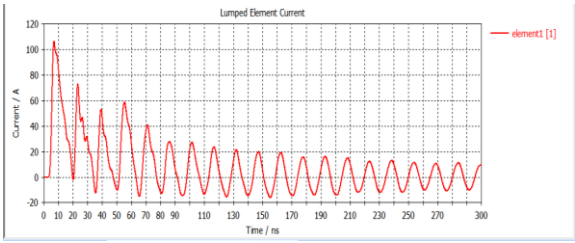

Fig. 8 Current across near end element

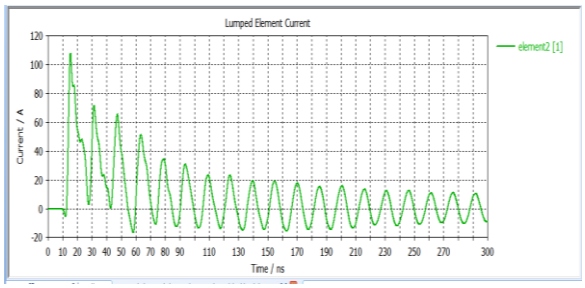

Fig. 9 Current across far end element

(b) SINGLE CONDUCTOR CABLE PLACED ALOND THE WIDTH INSIDE THE UNIFORM FIELD AREA UNDER BOUNDED WAVE TRANSMISSION STRUCTURE

Single conductor cable is placed inside the bounded wave structure which is shorted on both the sides. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns**.**

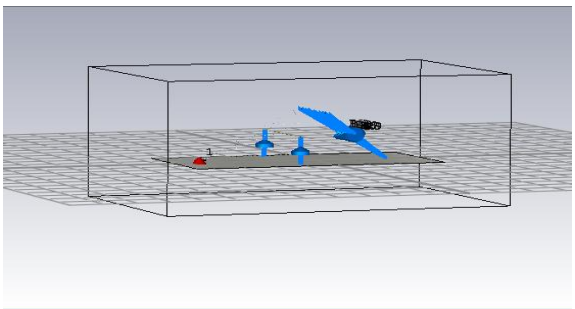

Fig. 10 CAD Model of single conductor placed inside Bounded Wave Transmission line Structure along the width

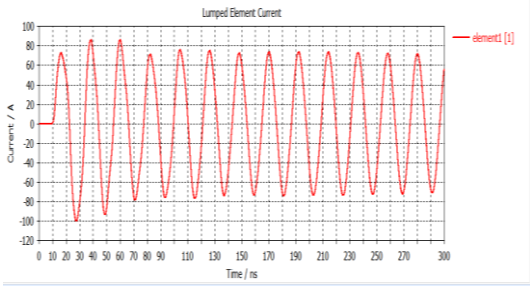

Fig. 11 Current across lumped element1

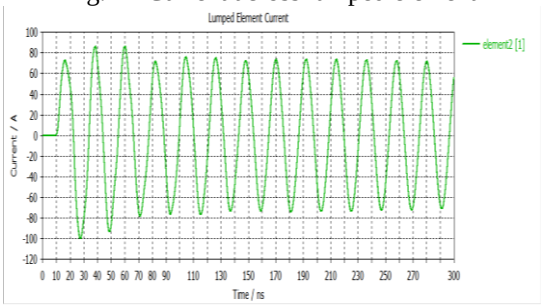

Fig. 12 Current across lumped element2

(c) SINGLE CONDUCTOR PLACED INSIDE THE BOUNDED WAVE TRANSMISSION STRUCTURE WITH INCLINATION OF 30 DEGREE ALONG THE LENGTH

Single conductor cable is placed with an inclination of 30 degree inside the bounded wave structure which is shorted on both the sides. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

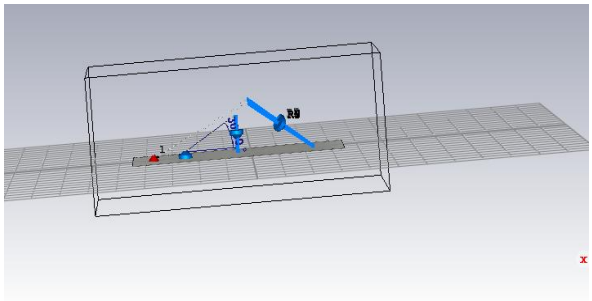

Fig. 13 CAD Model of single conductor placed inside Bounded Wave Transmission line Structure with inclination of 30 degree.

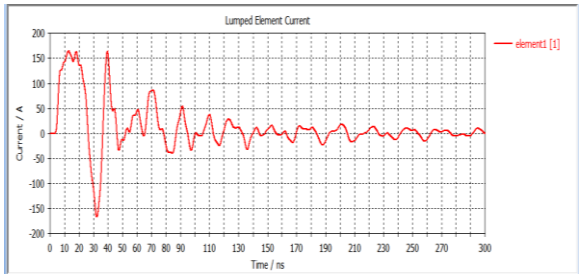

Fig. 14 Current across lumped near end

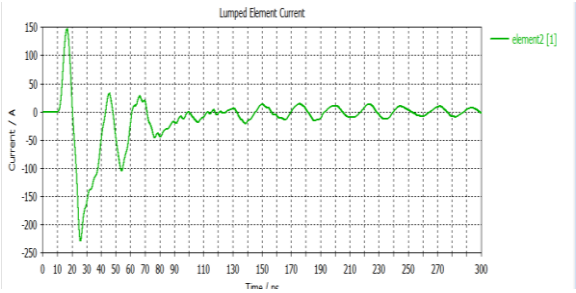

Fig. 15 Current across lumped far end

B. COAXIAL CABLE PLACED INSIDE THE BOUNDED WAVE TRANSMISSION STRUCTURE

Coaxial cable is placed inside the bounded wave structure which is terminated with 50 ohm resistors on both the sides. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

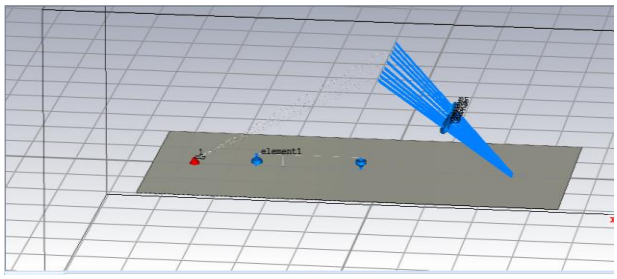

Fig. 16 CAD Model of Coaxial Cable placed inside Bounded Wave Transmission line Structure

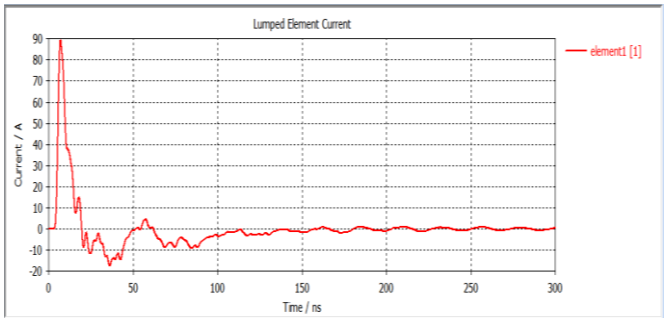

Fig.17 Current across near end lumped element

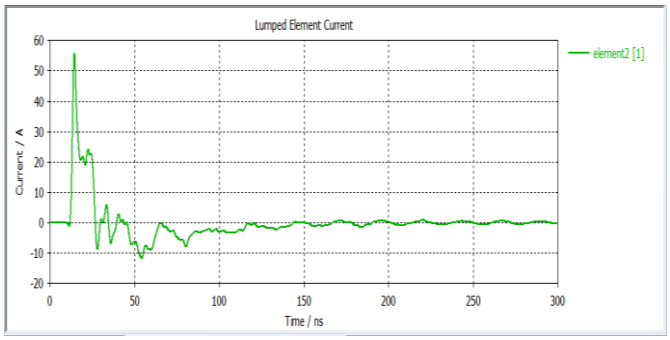

Fig.18 Current across far end lumped element

C. LIVE COAXIAL CABLE PLACED INSIDE THE BOUNDED WAVE TRANSMISSION LINE STRUCTURE

Coaxial cable is placed inside the bounded wave structure which is terminated with 50 ohm resistors on one side and source on other end. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

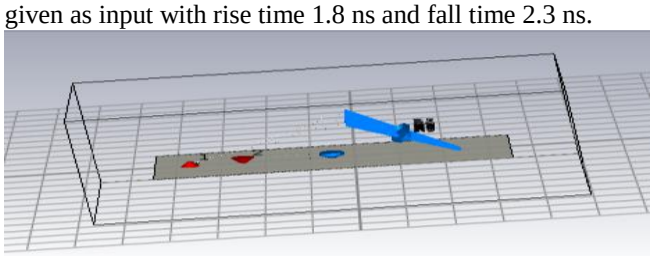

Fig.19 CAD Model of Coaxial Cable placed inside Bounded Wave Transmission line Structure

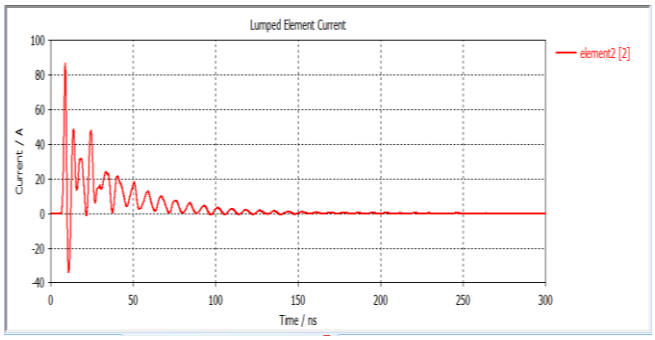

Fig.20 Current across lumped element

D. COUPLING ANALYSIS AT DIFFERENT LENGTH-

(a) 4m length

Coaxial cable was placed inside the bounded wave structure which was terminated with 50 ohm resistors on one side and source on other end. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

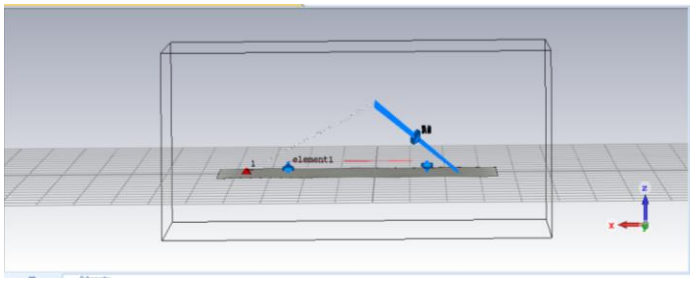

Fig. 21 CAD Model

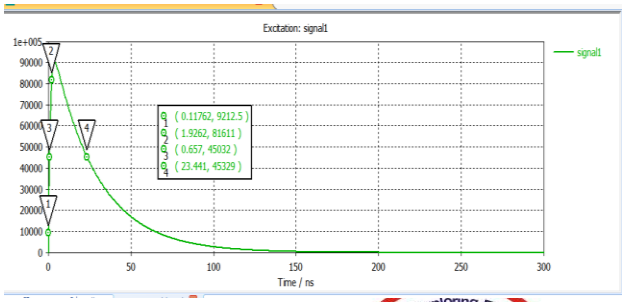

Fig. 22 Double Exponential Pulse

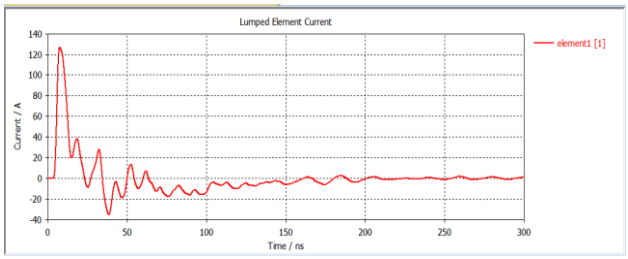

Fig. 23 Current across near end element

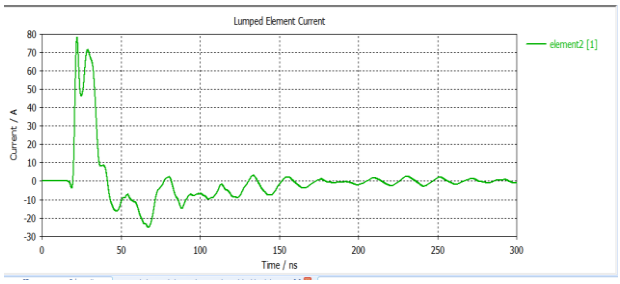

Fig .24 Current across far end element

(b) 3m Length

Coaxial cable was placed inside the bounded wave structure which was terminated with 50 ohm resistors on one side and source on other end. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

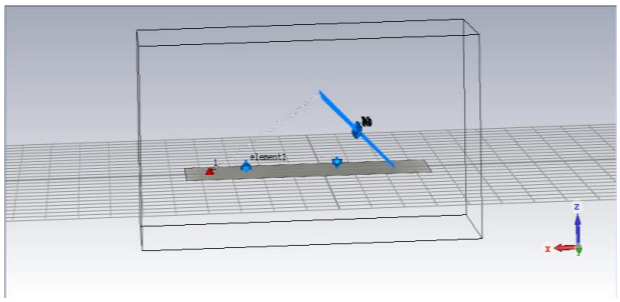

Fig. 25 CAD Model

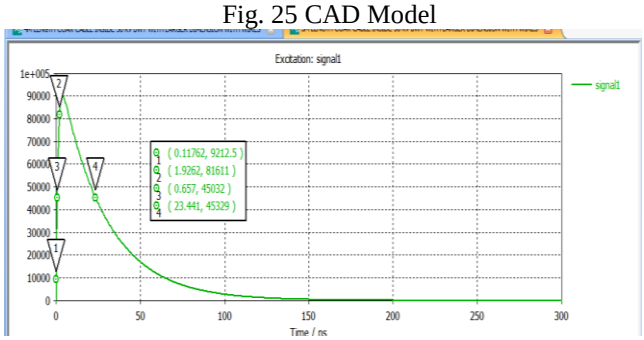

Fig. 26 Double Exponential Pulse

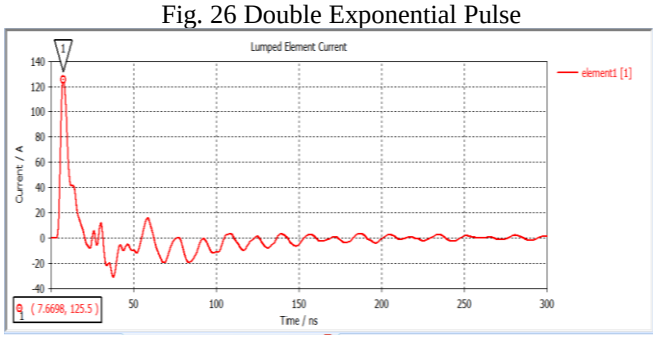

Fig. 27 Current across near end element

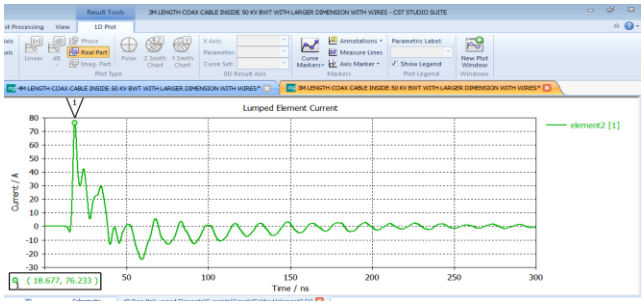

Fig.28 Current across far end element

(c) 2m

Coaxial cable was placed inside the bounded wave structure which was terminated with 50 ohm resistors on one side and source on other end. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

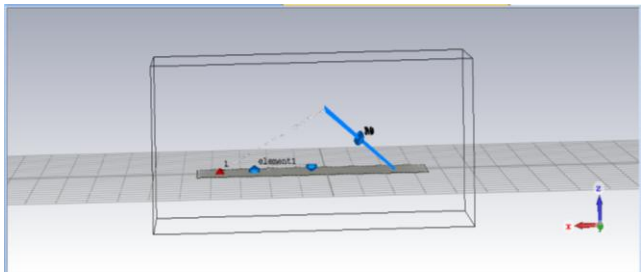

Fig.29 CAD Model

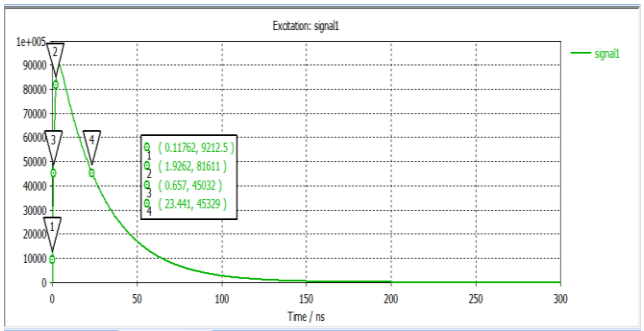

Fig.30 Double Exponential Pulse

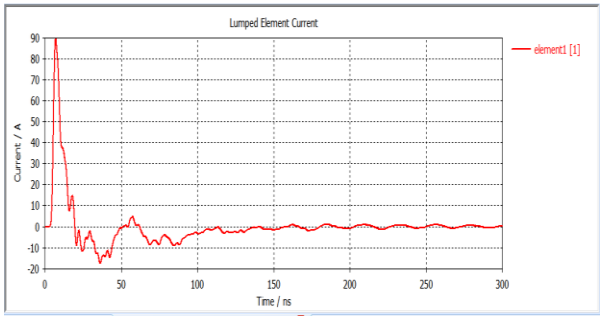

Fig.31 Current across near end element

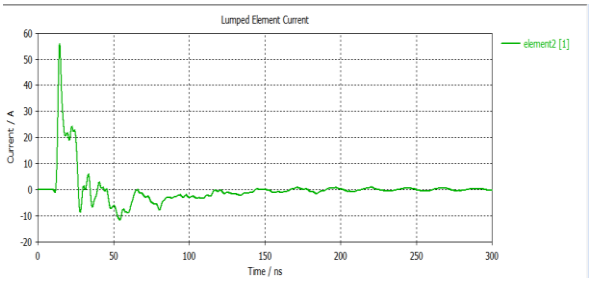

Fig.32 Current across far end element

E. COUPLING AT DIFFERENT HEIGHT-

(a)Coaxial cable placed **0.3m** above the ground plate-

Coaxial cable was placed at 0.3m above the ground inside the bounded wave structure which was terminated with 50 ohm resistors on both the side. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

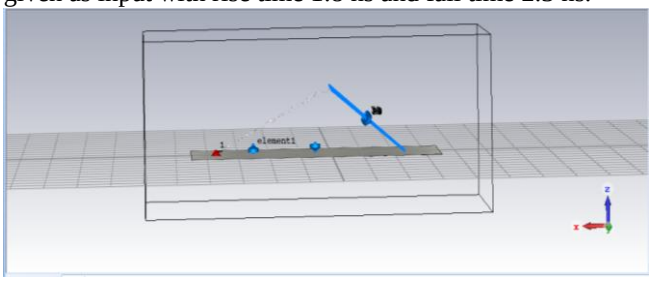

Fig.33 CAD Model

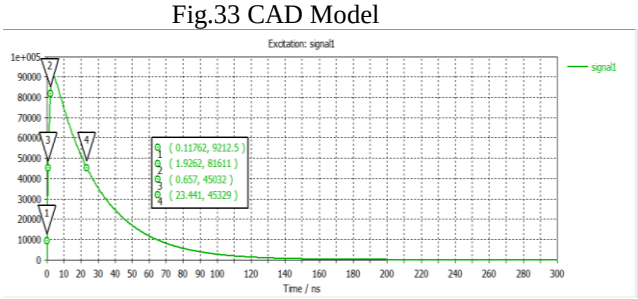

Fig.34 Double Exponential Pulse

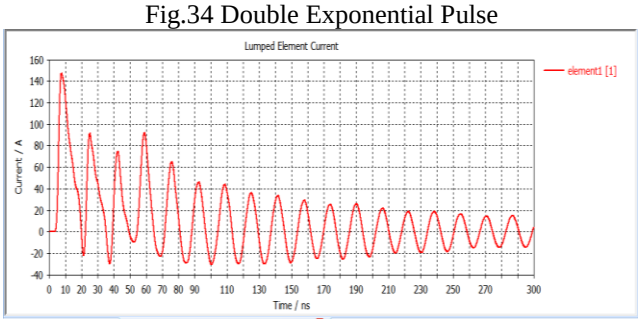

Fig.35 Current across near end element

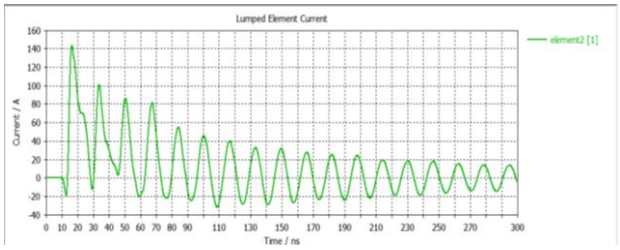

Fig.36 Current across far end element

(b)Coaxial cable placed **0.5m** above the ground plate-

Coaxial cable was placed at 0.5m above the ground inside the bounded wave structure which was terminated with 50 ohm resistors on both the side. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

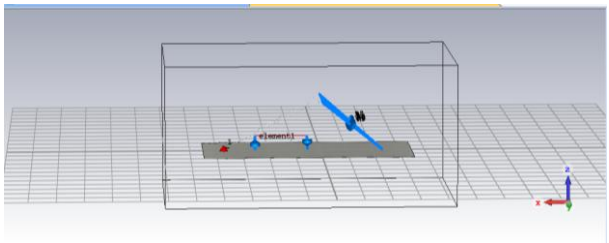

Fig.37 CAD Model

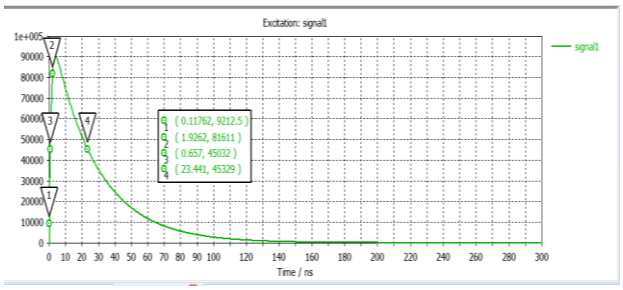

Fig.38 Double Exponential pulse

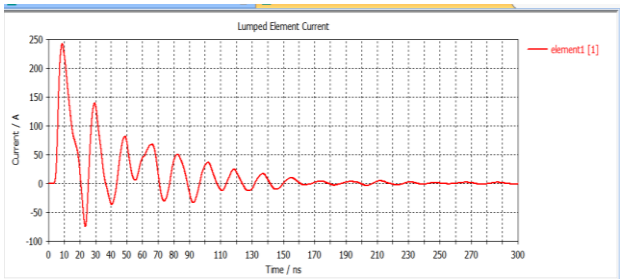

Fig.39Current across near end element

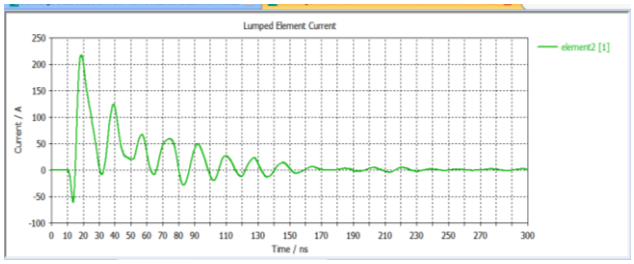

Fig.40 Current across far end element

(c)Coaxial cable placed **0.6m** above the ground plate-

Coaxial cable was placed at 0.6m above the ground inside the bounded wave structure which was terminated with 50 ohm resistors on both the side. Double exponential pulse is given as input with rise time 1.8 ns and fall time 2.3 ns.

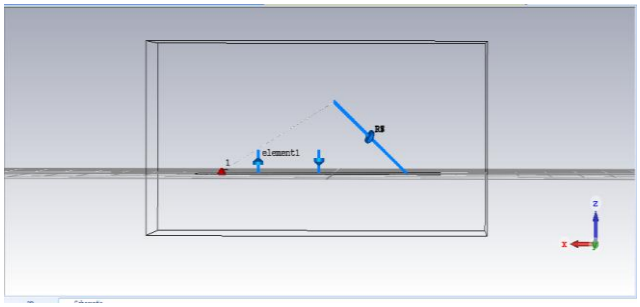

Fig.41 CAD Model

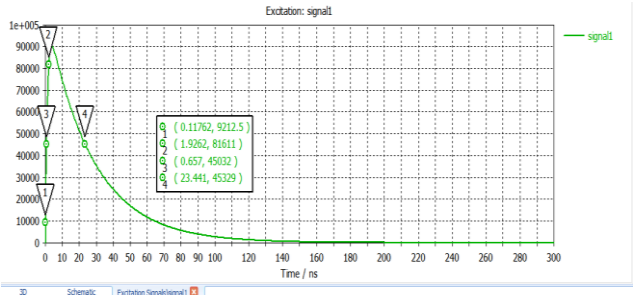

Fig.42 Double Exponential pulse

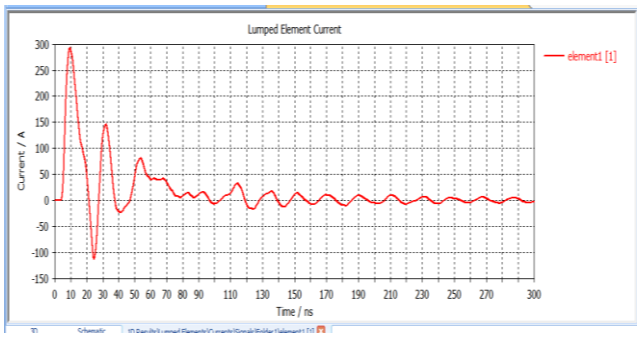

Fig.43 Current across near end element

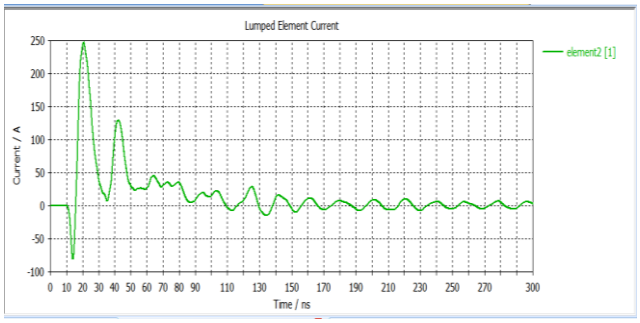

Fig.44 Current across far end element

IV. RESULT IN TABULAR FORM

Table.1 Comparision of current in cables across near end and far end

CABLES / CURRENT	SINGLE CONDUCTOR ALONG THE LENGTH	SINGLE CONDUCTOR WITH INCLINATION OF30 DEGREE	SINGLE CONDUCTOR ALONG THE WIDTH
NEAR END	107 A	160 A	70 A
FAR END	105 A	150 A	70 A

CABLES / CURRENT	COAXIAL CABLE	ACTIVE LINE CABLE
NEAR END	90A	-
FAR END	55A	85 A

Table .2 Comparisons of current in Coaxial Cable at different length.

LENGTH(in meters)	**CURRENT**	
	Near End	Far End
4m	127A	80A
3m	125.5A	76A
2m	90A	55A

Table .3 Comparisons of Current in Coaxial Cable at different height

CABLE PLACED AT DIFFERENT HEIGHT	**CURRENT**	
	Near End	Far End
0.3m	150A	140A
0.5m	250A	220A
0.6m	300A	250A

V. CONCLUSION

Bounded Wave Transmission Line Structure is modeled. The electric field at different positions (h/3, w/2) within EUT volume is measured using E-Field probe. Modeled different cables (single conductor cable and RF Coaxial cable). EMP Coupling to cables was carried out by placing the cables under generated EMP field in terms of induced voltage and currents due to EMP fields. EMP coupling to active line with matched termination also analyzed. EMP coupling is less in Coaxial Cable as compared to the Single conductor cable. Instead of placing the cable along the length, it is suitable along the width. Coupling to the cable increases as the height increases. So it is recommended to keep the cable along the ground to minimize the coupling effect. All this analysis can be used in different applications. One of the major applications is in the defense sector. Cable routing in Defense system (aircrafts, ships, missiles, etc) Defense routing consist of n number of modules which are connected through cables of different kinds. So by using this analysis orientation and routing of cable is possible.

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