Impulse Electromagnetic Interference Generator

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Abstract

Electromagnetic Interference related malfunctioning of equipments containing electronic control devices has become serious problem these days, as it couples to wires and PCB's in the equipment, reflecting and resonating and then being amplified by IC finally resulting in mal-operation. In order to test and simulate the immunity of electronic circuits towards EMI environment, an Electrical Fast Transient/Burst generator has been developed which generates broadband interference spectrum in the range of 20MHz to 600MHz. Burst Generator mainly comprises of coaxial cables, pressurized spark gaps, HV Power Supply, terminating resistor and a TEM Horn which acts as load. For pulse sharpening, switching has been done at two stages. Depending upon the delay time of coaxial line, width of square wave pulse has been kept 50ns. The total energy of the portable system is 34 Joules and weighs less than 50kg. In the presented paper we describe the system design, results of measurements and areas of further improvements in energy transfer efficiency.

I. INTRODUCTION

Electronic components and subsystems are essential parts of modern civilian and military systems. Failure of these systems could cause major accident as well as economic disaster. Therefore, the susceptibility of modern electronic systems against fast transient fields like EMP and UWB pulses is of great interest. For investigating effect of short pulses on electronic systems, the generation of fast transient field with high magnitude is necessary. Applications of such high power RF generators outside the laboratory environment place extra challenging and demanding requirements on source design. Such device must be robust, compact and highly effective in total energy use due to limitations in primary power supplies. Following these guide lines, devices that generate RF power with direct switching technology has inherent advantage of less complexity involved over those that require high energy electron beams.

In this paper we describe a simple mobile and robust RF source system to investigate the undesired effects, when electronic components are exposed to high power electromagnetic radiation. The ultra fast spark gap based system mainly comprises of - TEM Horn antenna, driven by high voltage pulser, with rise time of better than 500ps and having output voltage higher than 100kV.

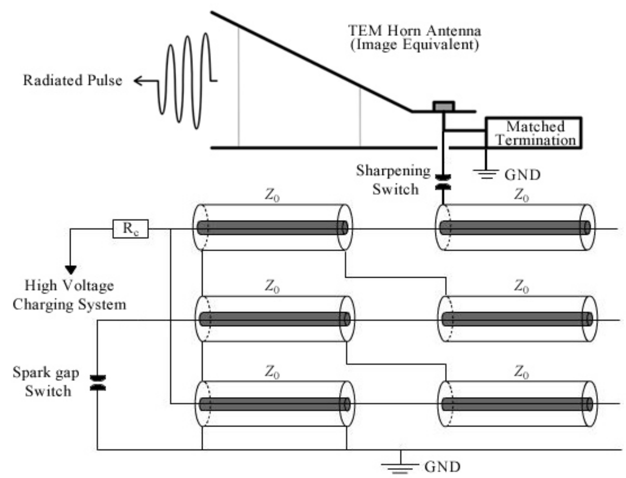

Figure 1. Schematic layout of EMI Generator

II. HIGH VOLTAGE GENERATOR SCHEMATIC

Figure 1 shows schematic diagram of RF Source System. As shown it mainly consists of cascaded Blumlein pulser, shorting spark gap, peaking spark gap, termination resistor and a TEM Horn Antenna. There are mainly three pulser approaches generally followed for the generation of nanosecond duration pulses. These are simple PFL, Blumlein pulser and Bipolar pulser. Blumlein is the chosen configuration because it has the advantage of producing load voltage equal to the charging voltage.

Our approach involves capacitive charging of 50 ohm coaxial cable in cascaded blumlein configuration and then discharging them synchronously in series in to the matched load by using a self breaking un-pressurized air spark gap. It produces rectangular flat top of 50ns with rise and fall time of less than 10ns and generates output voltage up to 300kV under open circuit conditions and 150kV/500A under matched load condition, delivering 75Mega Watts of peak power in 300Ω load at repetition rate of 33Hz. To ensure high breakdown voltage RG 218/50Ω coaxial cable has been chosen.

The double transit time for 5m length of cable implies pulse duration of 50ns. Each section of the cable contributes 50Ω to the total output impedance of the generator. Hence, for three stage cascade the net impedance of the pulser becomes 300Ω. To achieve, nominal output voltage of 150kV across matched load, it requires maximum charging voltage of 50kV.

As the distributed cable capacitance is of the order of 100pF/m, hence the total cascaded Blumlein capacitance is calculated as – 5m x 6 x 100pF/m = 3nF. At a charging voltage of 50kV, the total energy stored in the system is ~ 34 Joules. Charging of the cables is done using 100W DC to DC Converter powered by 24V DC Battery. It has average charging rate of 1.1kJ/s, hence maximum pulse repetition rate of the order of 33Hz is obtained.

An oscillogram of the output voltage pulse of the cascaded Blumlein pulser, when charged up to voltage of 20kV is shown in figure -2.

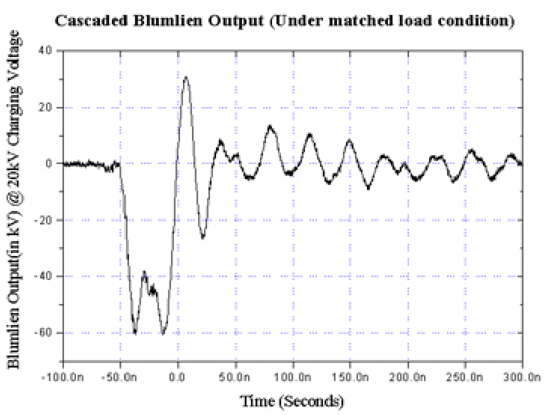

Figure 2. Oscillogram of Output Voltage before pulse sharpening, when pulser is charged up to 20kV

The voltage was measured to have value of 60kV across matched load of 300Ω using 1000X RC compensated high voltage probe (make – North Star, model – PVM1) having bandwidth of 90MHZ.

III. HIGH PRESSURE PEAKING SWITCH

Peaking spark gap switch used in second stage of switching is a "High Voltage, High Pressure Spark gap Switch" especially designed to achieve pulse rise time in the order of few hundred picoseconds. As shown in the schematics, it is connected in series with the load for pulse sharpening. Pulse sharpening in Ultra wideband radiation systems is critical because the fast pulse rise time contains high frequency components of the resulting spectrum. The crux of peaking gap is the establishment of very high electric fields in the inter-electrode spacing. The velocity of the propagation of electron avalanche is proportional to electric filed applied across the electrodes, and the gap closure time is dominated by applied electric field. Inter electrode spacing is also chosen as small as possible to minimize the intrinsic inductance of the spark channel, since it limits the achievable rise time of the resultant pulse. Because of short gap lengths even voltages of less than 100kV can produce inter electrode electric fields in MV/cm range.

Here, the peaking switch used has a high strength insulating shell to support the hemi-spherical brass electrodes at the spacing of 3mm and contains high pressure gas. The insulating shell of transparent Perspex material has been especially used for visual observation of the arc and for the possible use of photo diode detector. This spark gap is being designed to operate up to pressure of 10ATM, sustaining voltages up to 300kV. The switch chamber is tailored to reduce field stress and provide low inductance current path, with a very compact geometry.

To produce ultra fast switching, the spark gap is dramatically over-volted i.e. it is charged far in excess of its self break down voltage developing electric filed in the order of 0.5MV/cm. Full voltage appears across the peaking gap before it breaks down. When the gap breaks, total voltage applied appears across the load almost instantaneously giving the rise time in the order of 500ps. The high gas flow allows the replacement of the gas in the discharge region on a time scale necessary, to sustain the required repetition rate.

In peaking spark gaps, inter electrode spacings are much smaller in order to achieve faster transit time across the gap, but this leads to high spark gap capacitance. Though the fast charging time leads to strong displacement current, there is an undesirable pre-pulse on the load voltage. The pre-pulse observed on the output pulses is related to the spark gap capacitance (C) by –

$$V_{pp} = Z_o C \frac{dV_c}{dt}$$

Where Z_o is the output impedance and V_c is the voltage applied to the spark gap. Since fast charge is critical for peaking operation, smaller diameter electrodes have been used to reduce pre-pulse effect.

IV. ULTRA WIDE BAND GENERATION

High power electromagnetic radiations are directly generated when the erected voltage pulses in excess of 100kV with rise time better than 500ps (10 to 90%) drives an antenna which is connected across the termination resistor. This fast rise time gives us frequency components ranging from 20MHz to 600MHz. It is most convenient to consider electromagnetic radiation in frequency domain. The rise time can be converted to an equivalent frequency by simple relation $\mathbf{f = 0.25/t_r}$. Where f is the equivalent frequency and $\mathbf{t}_r$ is the 10 to 90% rise time of the pulse. The far field measurement of the radiated impulse waveform is shown in figure -3.

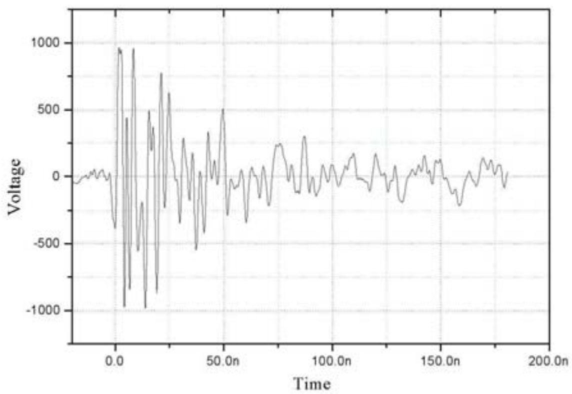

Figure 3. Radiated Impulse from Half TEM Horn

The FFT response of the radiated signal as shown in figure -4, shows that the radiation is in very broadband with most of the energy residing in the hundreds of MHZ range.

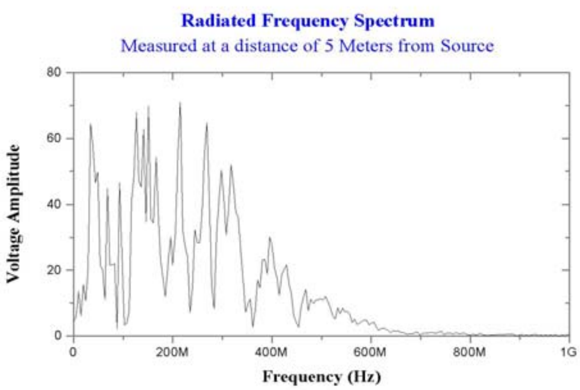

Figure 4. FFT response of the radiation

Because ordinary wide band antennas are not able to radiate high magnitude pulses, special pulse radiation antenna has been used. The key parameter of any impulse antenna design are – gain, radiation pattern and field polarization over the frequencies of interest. The gain of an antenna is the measure of antennas ability to concentrate radiated power in particular direction with losses included.

Here, we have used linear half TEM Horn antenna, as it offers simple solution for radiating impulse. This antenna is shown in figure -5. As shown in the schematic, the single plane of the TEM Horn extends over a ground plate and linearly expands in both **E** and **H** directions as the wave propagates towards the output.

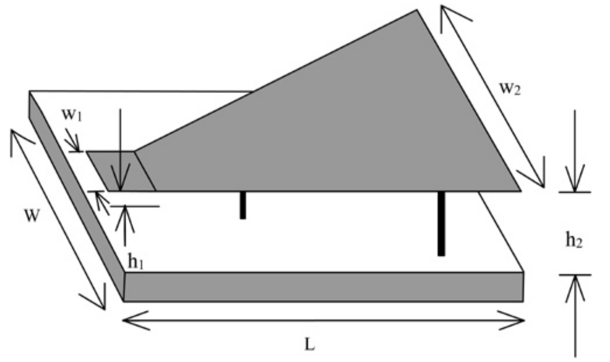

Figure 5. Geometry of the Half TEM Horn Antenna

For reducing the reflections that occur at the aperture of the horn, its upper plate is designed to have varying width so as to continuously change the characteristic impedance of the equivalent transmission line over the length of antenna. At the feed point, the characteristic impedance is set equal to that of the feeding transmission line, and the aperture is set equal to the wave impedance of free space i.e. typically 377Ω. Transmission line equations for parallel plate have been used for design.

$$Z_{in} = \frac{377}{\left(\frac{w}{h}+2\right)\sqrt{\varepsilon_r}} \quad \text{......for Input Side}$$

$$Z_{out} = \frac{377 x h}{w x \sqrt{\varepsilon_r}} \quad \text{.........for Output Side}$$

The height of the aperture has been taken approximately half the wave length of the lowest frequency to be transmitted. Typical dimensions defined by figure -5 are –

$W = 500mm$ $L = 1500mm$
$w_1 = 75mm$ $h_1 = 25mm$
$w_2 = 500mm$ $h_2 = 500mm$

The entire setup was made and tested in open field with configuration as illustrated in figure -6.

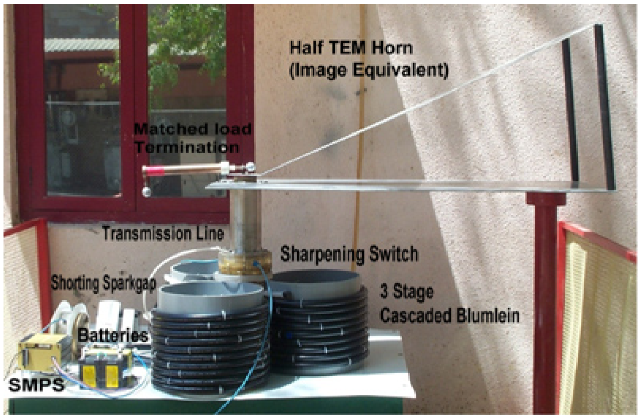

Figure 6. Experimental layout of the RF Source system

V. CONCLUSION

A compact and portable ultra wide band generator has been successfully demonstrated. It offers as testing source for applications requiring portable systems to investigate effects of high power electromagnetic radiations on electronic systems. However, radiation efficiency will still be improved with faster switch rise times. This may be achieved by redesigning the switch profile and making it in coaxial configuration to lower down the inductive effects. Energy storage capability of the source can also be improved by further cascading. For attaining higher repetition rates in the kHz range, high charging rate constant current charging power supply will be used, so that by the time spark gap deionizes and re-establishes high voltage stand off, it can inhibit re-application of charging voltage in the shortest possible duration.

VI. REFERENCES

[1] J. R. Mayes and W. J. Carey, "The Marx Generator as an Ultra Wideband Source" 13th IEEE International pulsed power Conference, Las Vegas, NV, July 2001.

[2] Jane M Lehr, Carl E Baum, William D Prather and Robert J Torres, "Fundamental Physical Consideration for Ultra fast Spark gap Switching", Ultra Wideband Short Pulse Electromagnetics 4, pp 11 – 20, 1999.

[3] G A Mesyats, S N Rukin, V G Shpak, M I Yalandin "Generation of High Power Sub - Nanosecond Pulses" Ultra Wideband Short Pulse Electromagnetics 4, pp 1 – 9, 1999.

[4] J. O. Rossi, M. Ueda and J.J. Barroso, "Design of a 150kV, 300A, 100Hz Blumlein Coaxial Pulser for long pulse operation", IEEE Trans. on Plasma Science Vol. 30, no. 5 pp. 1622-1626, Oct 2002.

[5] I. C. Somerville, S. J. Mcgreagor and O Farish, "An efficient stacked – Blumlein HV pulse generator" Meas. Sci. Technol. Vol. 1, no. 9, pp. 865-868, sep 1990