Design and development of High Power Ultra Wideband Systems

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Abstract

High power ultra wideband (UWB) systems can be used for various applications like buried target detection, electrical characterization of materials, space debris detection and as a source for vulnerability studies on electronic circuits. Two high power UWB radiator systems have been developed at APPD, BARC Mumbai. The first one is a 120 kV, 66 Ohm system which uses balanced Transverse Electromagnetic (TEM) horn antenna for radiation of UWB pulse into the atmosphere. Pulse power system for this radiator consists of a Marx Generator and a pulse forming line which can generate a 110 kV, 5 ns pulse with a rise time of ~ 300 picoseconds. A balanced TEM horn type antenna was used in this system. Impedance of this antenna is matched to 66 Ohms at feed end and then gradually varies to match with free space impedance. This antenna can effectively radiate this kind of ultra-short sub-nanosecond rise time pulse. This system has generated an electric field of 10 kV/m at 10 m distance from the source. Second system is a Half Impulse Radiating Antenna (HIRA) based UWB system. HIRA based UWB system consists of three components, MARX generator, pulse forming line and HIRA antenna. MARX can generate maximum of 1000kV voltage pulse to charge the pulse forming line. Voltage pulse generated via discharge of pulse forming line sparkgap is radiated by HIRA. This system has generated an electric field of 20 kV/m at 10 m distance from the source. This article discusses the overall system performance with an emphasis on antenna design details and results.

Introduction

Extensive work is going on in the field of compressed high voltage high energy pulses for its immense importance in strategic applications [1]. Different laboratories in the world, are persistently giving efforts in the generation of shorter pulses (in the range of 5-10ns) of very fast rise time (hundreds of picoseconds). This kind of high energy pulses (1-5 Joules) or more can be fed directly to a matched broad band antenna to launch into the environment [2, 3]. These pulses will contain high power wide band frequencies ranging from 100MHz to 2GHz and can be extremely susceptible and lethal for modern day electronics of wide range and variety [2].

To be ideal, a perfect UWB pulser should be defined as a system capable of generating all range of pulses starting from dc to infinite frequency and amplitude of all the frequencies should be identical. Mathematically it can be shown that an impulse function can fulfill such requirement. It is impossible to generate extreme high frequency beyond few GHz by electrical discharges. Hence a practically feasible higher frequency limit is decided for designing UWB pulser. As stated above, an UWB pulser output is radiated into atmosphere using an antenna by the user. Minimum size of an antenna suitable to launch an electromagnetic wave depends on wavelength λ. Hence, if frequency of the launching wave goes low practical size of the required antenna goes very high. In this article details of two high power UWB systems developed at APPD, BARC are narrated.
These systems can be used for industrial as well as strategic applications. These systems are mainly composed of three distinct components high voltage pulse generator, a pulse forming line and an UWB (ultra wide band) antenna [1, 4, 5]. First system uses a balanced TEM horn antenna as a radiator while the second system uses HIRA antenna for radiation of electromagnetic waves into the atmosphere.

**UWB System Description**

Block diagram for a general UWB system is shown in figure 1. Any high power UWB system is composed of three main subsystems: the primary source/power supply, the high voltage pulser or generator (which can be decomposed into several subsystems), and the antenna system along with feeding arrangement, as illustrated in figure 1. The first UWB system consists of 240 kV Marx generator, 66 Ω pulse forming line and a Balanced TEM horn antenna matched to PFL impedance. The second UWB system has a 1 MV Marx generator followed by a solid dielectric pulse forming line of 86 Ω impedance and Half Impulse Radiating Antenna.

**Balanced TEM Horn Antenna based UWB System**

In this system 30kV high voltage power supply is used for charging of the MARX generator. High voltage pulse generator part in this system consists of a Marx Generator, pulse forming line and low inductance switch just before the antenna. Antenna system in this system is a balanced TEM horn antenna along with an unzipped type of balun which converts the coaxial source geometry to a parallel plate feed type geometry. Actual system photograph is shown in figure 2. MARX generator has a maximum output voltage of 240 kV, which is used for the charging of pulse forming line. Pulse forming line terminated with a matched dummy load of 66 ohms, generates a 120 kV, 5 ns pulse with ~300 ps rise time. This is a very compact system with a foot print of 1.7 m*1.5m and weight of the system is less than 200 kg. In actual system pulse forming line feeds the antenna system using a low inductance sparkgap switch which gets fired on reaching the breakdown voltage.

**Balanced TEM Horn Antenna Design**

TEM Horn antenna is a wideband, non dispersive, travelling wave antenna which consists of two metal plates which are flared in the shape of a horn. If the aperture height is comparable to wavelength, antenna can radiate at that frequency. In this system we have an unbalanced coaxial source feeding a balanced TEM horn antenna. For the interfacing of this unbalanced coaxial source with balanced antenna coaxial feed structure is gradually unzipped into parallel plate geometry [6, 7].
Here taking consideration of dimensions of UWB system we have to use a transition for centre conductor of coaxial line also. Antenna performance was evaluated along with this feed arrangement using CST Microwave studio.

Any unipolar pulse has got frequencies from DC to higher frequency limited by pulse rise time. It is not practically feasible to design an antenna which can radiate extremely low frequencies. That is why in case of ‘UWB’ systems for unipolar pulses, lowest frequency of interest is determined by the pulse width and highest frequency is determined by the rise time. In our case lowest frequency of interest will be around 200 MHz and highest frequency is 875 MHz according to rise time of the system. Taking the margins in account bandwidth for antenna was chosen to be 150 MHz to 1 GHz.

Spacing in between the electrodes at feed end was chosen in such a way that only TEM mode is excited onto the antenna. In this kind of transition as it is being fed by a single ended source, common mode currents at outside surface of line are caused by summation of reflections which originate over entire transition length. But the balun transition is smoothly tapered in such a way that net reflection at balun input is very small. Balun design before parallel plate feed was done in such a way that it provides matching in between coaxial geometry of UWB system (66 Ohms) and parallel plate line (170 Ohm) at TEM horn antenna feed. An unzipper type balun was chosen for. At 150 MHz half wavelength corresponds to one meter, practically balun length was chosen to be 60 cm so that antenna along with feed can be limited in 1 m. Design optimization was done in CST Microwave studio to meet performance parameters[6,7].

Simulation and Experimental Results

Model of TEM horn antenna used for simulation in CST Microwave studio is shown in figure 3. Waveguide port was used for exciting the structure in CST microwave studio. Antenna simulation results are shown in figure 4. These results clearly show that reflection coefficient of the designed antenna is better than -10 dB within required frequency range of 150 MHz to 1 GHz. Simulated gain of antenna 6.1 dB at 350 MHz. E plane pattern of antenna is slightly unbalanced as shown in figure 4. Simulated time domain response of designed antenna at boresight for a Gaussian pulse input is shown in figure, which is similar to Gaussian differentiated pulse waveform.

Experimental results for above system include testing of high voltage pulser with a dummy matched load and system’s radiated electric field response at boresight when high voltage pulser is connected to antenna. These results are shown in figure 6. For measurement of fast rising pulse (approximately hundreds of Pico second) of small pulse width (approximately 5ns) specific voltage divider of fast response time, was designed. Experimental results show that the system is capable of generating a pulse of maximum 120kV, 5ns pulse width with rise time of about ~ 300ps as shown in figure 5. Output radiated field of around 10 kV/m at 10 m is recorded. Radiated electric field waveform and waveform across matched load are shown in figure 5. Figure of merit for UWB system is achieved upto 100 kV. UWB gain of ~0.9 is achieved with an antenna of aperture size 75 cm and length 100 cm. Personal computer operation was disrupted at 15 m distance from the source using this system.
HIRA Based UWB System

This system consists of a 20 stage Marx Generator which charges a solid dielectric pulse forming line of 100 ohm characteristic impedance using an inductor. Solid dielectric pulse forming line consists of a low inductance spark gap which acts as a peaking switch; output of pulse forming line is fed to HIRA with 100 ohm impedance. HIRA antenna used in this system is a highly directive antenna with 3 dB beam width is 5 degrees. Actual system is shown in figure 6. This system has been successfully generated an electric field of 20 kV/m at 10 m distance from the source.
Half Impulse Radiating Antenna Design

Half Impulse radiating antenna is used for radiation of UWB pulses in this system. This antenna is a paraboloidal reflector antenna with a TEM feed. Antenna diameter was chosen to be 2 m for appropriate electromagnetic field radiation. Antenna design was carried out using analytical formulas [8]. Same structure was modelled and simulated in CST microwave studio. Two constant impedance coplanar TEM feed lines are used for feeding the reflector antenna. Impedance of each feed line was 200 Ω. Each feed arm is terminated with a 200 Ω copper sulphate aqueous resistor to provide low frequency impedance matching.

Far field $E_{far}$ for a Half Impulse radiating antenna is calculated using following formula.

$$E_{far} = \frac{1}{2\pi c f_g} \frac{D}{4\sqrt{2}} \frac{dV(t)}{dt}$$

(1)

Where $D$ is antenna diameter, $f_g$ is impedance ratio of antenna impedance $Z_a$ to free space impedance $Z_0$, i.e. $f_g = Z_a/Z_0$, $c$ is velocity of light in free space. $V(t)$ is the applied voltage function at input of antenna.

Experimental Results

Far field for this system was measured using half TEM horn type of sensor. An electric field of 20 kV/m was recorded at 10 m distance from source. Radiated electric field was measured at different angles in Horizontal plane. Using this peak power pattern was obtained in horizontal plane. From the results it is clear that 3 dB beam width for this system in horizontal plane is 5 degrees, which indicates that the designed antenna has got a very good directivity. Experimental results for this system are shown in figure 8. This system has achieved a figure of merit of 200 kV. Personal computer operation was disrupted at 20 m distance from the source using this system.
Conclusion

Two high power UWB systems using balanced TEM horn antenna and Half Impulse Radiating Antenna have been developed at APPD, BARC. These systems have respectively got a figure of merit of 100 kV and 200 kV. Personal computer operation was disrupted at 20 m distance from the source using these systems. These systems can be used for vulnerability and susceptibility testing of electronic circuits and systems. These types of systems are also used in shielding effectiveness testing, buried target detection.

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References: