Abstract

The electronic control, instrumentation and communication hardware is becoming more and more compact and faster in operation due to the increased use of large scale integration of semiconductor devices operating at higher speeds. The use of VLSI circuit based systems in various industrial and defence sectors is also increasing continuously. Since the operating threshold voltages and currents of these devices are very small they are very prone to electrical disturbance in their operation by the Electromagnetic Interference (EMI) signals. Their proper functioning is very important particularly in the case of systems used in mission mode, critical defence/industrial platforms. EMI can be generated within the electronic system/equipment itself or may result due to some external electromagnetic source. The high power Ultra Wide Band system is one such kind of external High Power Electromagnetic (HPEM) interference source which may cause malfunctioning/physical damage to the sensitive electronic systems. Hence it is necessary to test the susceptibility of electronics to such high power UWB based intentional EMI or IEMI sources. The sources for generating these transient EM fields may also be used in impulse radars and offensive applications to mal-operate/damage non-friendly electronics.

The UWB system consists of a high voltage pulsed power source called pulser along with a high bandwidth (Ultra Wide Band) antenna to radiate the UWB signal. The pulse fed by the pulser to the antenna through a switch is of high voltage type (amplitude of few 10s of kV to about a MV) and has a sub-nanosecond rise time. Most of the UWB systems developed over the world have the switch employing gaseous dielectric switching media used at pressures above the atmospheric level to generate such a fast rise time voltage pulse. Use of gaseous switching media at sub-atmospheric pressures to achieve sub-ns rise time, short duration high voltage pulses required for the high power UWB applications is another possibility. This possibility has not been exploited till date. Hence it was decided to develop a pulser switch with gaseous switching media at sub-atmospheric pressures (up to 50 mbar) and achieve sub-ns rise time voltage pulses of up to 50 kV. The energy delivered out by the UWB system depends upon the pulser output energy per switching shot and the repetitive switching rate of the pulser. To achieve maximum energy output it is required to maximize either the energy per switching shot or the pulse repetition rate (PRR) of the pulser switch. The optimization of the pulser operation to achieve maximum pulser energy output in every switching shot has not been tried so far. In this work it was decided to analyze the circuit so as to achieve maximum pulser output energy per switching shot. Another objective of the study was to systematically characterize the pulser switch using various gases and gas mixtures as the switching media to evaluate the switch performance as a function of gas pressure and switch breakdown voltage. The effect of pulser and antenna performance parameters on the UWB system performance was also decided to be evaluated.

Hence the present thesis work deals with the design, development, evaluation and performance optimization of a 50 kV, 25 MW UWB system based on Half Impulse Radiating Antenna (HIRA) fed by a coaxial capacitive pulser. The spark gap type self triggered pulser switch is designed to have a fixed gap spacing and variable gas pressure in order to vary the switch breakdown voltage. The switch is designed for operation with dry air, nitrogen, sulphur hexafluoride (SF_6) and a mixture of different gases as the dielectric switching media with pressures of up to 5 bar above the atmospheric level and up to 50 mbar below the atmospheric level. Physical placement of the switch just above the coaxial pulser capacitor terminal offered a low inductance geometry. The rise time estimation of the switch has been carried out as a function of gas pressure and the switch arc inductance. These rise time values have been compared with the measured ones and a good agreement was found between the two. The rise time values indicate that an inverse relationship exists between the gas pressure and the rise time. The rise time was found to decrease at increased pressures. SF_6 gas offered the minimum rise time out of all the gases/mixtures studied. The pulse repetition rate (PRR) of the UWB system depends upon the dielectric recovery of the gaseous switch and the charging time of the pulser capacitor. To estimate the PRR a circuit model has been proposed based on these parameters. The model shows an inverse relationship between the switch breakdown voltage (BDV) and the gas pressure with the PRR. The estimated PRR values were found to vary between 800 Hz and 5 kHz in the experimented range of the switch breakdown voltage. The PRR values have also been experimentally measured. There is a good match between the measured and the estimated values up to the switch BDV of 12.5 kV after which the difference is increased to about 20 %.

The feed for the reflector of the HIRA antenna consists of a pair of coplanar conical transverse electromagnetic (TEM) feed plates as they have a better antenna aperture blockage performance. The angles of the TEM feed plates have been chosen using stereographic projections of the feed plates into the HIRA reflector. Each TEM feed plate of 200 Ω characteristic impedance has been terminated by matched resistor.

An analytical expression has been derived to optimize the pulser output voltage at which the energy output per switching shot of the UWB system is maximum. It was found that when the pulser output voltage i.e. the switch breakdown voltage is 75 % of the dc source voltage the output energy delivered is maximum. It was possible to achieve a maximum output energy of 10 J per switching shot for the designed 25 MW high power UWB system.

The HIRA antenna has been analysed for the impedance profile for frequencies up to 3.5 GHz and was found to maintain a reflection performance better than -10 dB over the frequency range. The radiated field analysis of the antenna was carried out using an analytical model and numerically by using a commercially available software. It was found that as per the analytical model, the Figure of Merit (FoM) of the designed UWB system is 1.41 V for a normalized excitation feed pulse of 1 V and the 3 dB spectral content of the radiated field is between 180 MHz-1.8 GHz. The corresponding results using computer simulations of the UWB system indicate a slightly lesser FoM of 1.1. Higher FoM obtained using the analytical model is due to ignoring the antenna aperture blockage and the field diffraction effects over the TEM feed arms as well as from the rim of the reflector of the antenna. The radiated field amplitude and gain of the HIRA antenna were found to be a direct function of the frequency of the radiated signal. Higher gains and narrower beam width for the radiated field were observed with an increase in the frequency. The radiated field spectral waveform in the near field region was observed to have a notch at a particular frequency and its harmonics. The notch frequency was found to be a function of the propagation time difference called clear time. The effect of pulser rise time, antenna feed arm impedance and position on the radiated far field amplitude and wave shape was analysed. It was observed that with decrease in the pulser rise time from 700 ps to 100 ps, the radiated field amplitude increases by about 600 %. A matched termination impedance with position of 30°of the TEM feed arms with respect to the vertical symmetry axis of the antenna provides a higher radiated field amplitude and lower post pulse oscillations in the radiated field waveform.

The pulser switch was evaluated systematically for various performance parameters such as BDV, rise time, PRR, voltage recovery and jitter characteristics as a function of switch gas pressure, type of gaseous switching media and breakdown voltage at pressures above and below the atmospheric level. The switch BDV was found to be a linear function of pressure of the gas used i.e. dry air, nitrogen, sulphur hexafluoride (SF_6) and a mixture of air and SF_6. The measured rise times of all the gases were found to be in inverse proportion to the switch gas pressure. SF_6 gas offered the best rise time and hence was found to be a good contender for achieving higher radiated field amplitudes and bandwidth. The voltage recovery characteristics of SF_6 gas and air were experimentally studied as a function of the recovery time. It is found that both the gases have similar recovery characteristics having a distinct saturation plateau region. It was found that for a given recovery time SF_6 recovers to a higher voltage than air and the recovery further improves for SF_6 at increased pressures (between 0.5-2 bar). The effect of the number of switching shots on the jitter in the switch rise time was measured by operating the switch continuously at a PRR of 1 kHz and for total number shots up to 10.8 M. It was observed that the jitter increases by an order of magnitude after 10.8 M shots. This indicates that for the present switch design, the switch electrodes require maintenance (buffing, polishing, etc.) after every 3.5 M shots to maintain a reasonably low jitter. SF_6 gas was characterized for a fixed source voltage to determine the effect of pressure on rise time in the sub atmospheric regime (up to 50 mbar). It was found that the rise time vs. pressure characteristics follows the Paschen's curve with a value of pressure at which rise time is the lowest for a given source voltage. With increase in the source voltage the rise time was found to decrease.

The HIRA based UWB radiating system was evaluated for radiated fields in the near and far field region for the temporal and spectral characteristics. It was found that for the source voltage of 25 kV, the FoM in the near and far field region are 29.4 kV and 28.9 kV respectively. The fields in the distant far field region have more oscillatory post pulses due to the effect of ground reflections and the low frequency dipole moment mismatch of the antenna.

Since SF_6 gas offered the best rise time of 193 ps at a voltage of 46 kV than the other gases tried, the radiated field is the highest (5.3 kV/m) with SF_6 at a distance of 10 m offering a gain factor of 1.15. Dry air offered a radiated field gain factor of 0.83 which got improved by 33 % by just 30 % addition of SF_6 gas into the air. The field amplitudes measured were in good agreement with those computed using the analytical model and the computer simulations and they follow the 1/R rule as a function of the far field distance, R in the bore sight direction. The measured radiation pattern of the UWB system showed a focussed and narrow radiated field beam at higher frequencies with a half field beam width (HFBW) of 8° at 2 GHz. The UWB system was measured to have dominant highest cut off frequency of 1.79 GHz with a band ratio and percentage band width of 9.56 and 162.11 % respectively. This confirmed that the developed system is of sub-hyper band radiator type.

The UWB system developed through this work is having a better performance than some of the other systems developed elsewhere in the world, in terms of FoM (53 kV) and the PRR (> 1 kHz). The system can be further improved in terms of consistency (jitter) and intensity by use of a triggered switch and hydrogen gas at 100 bar pressure as the switching medium respectively. The profile of the TEM feed plates of the HIRA antenna may be further improved to have a better antenna aperture fill factor. Such multiple systems in an arrayed manner may be used either for higher power output/better agility of the radiated field beam. This system will be fully exploited for the applications of susceptibility evaluation of electronic circuits, non-friendly applications as well as impulse radars.