

Generation of Ultrawide Band Electromagnetic Pulse from Blumlein Pulse Forming Line

Yun Sik Jin*, Jong Soo Kim*, Chuhyun Cho* and Young Su Roh†

Abstract—A high voltage pulse generator was fabricated to radiate ultrawide band electromagnetic pulse. A coaxial type of Blumlein pulse forming line is employed to produce a pulse of high voltage (>300 kV) and short pulse duration (~5 ns). A helical strip/wire type of air-cored pulse transformer was used to charge the Blumlein pulse forming line up to more than 300 kV. A peaking switch is essential to make the pulse rise time as fast as possible. Typically, the rise time is ~500 ps. The output pulse of the generator is radiated into air through an exponentially tapered TEM horn antenna. The electric field intensity of a radiated pulse was measured as a function of the distance from the transmitting horn as well as the output voltage of the peaking switch. The peak-to-peak value of the electric field intensity at 10 m from the TEM antenna was ~100 kV/m.

Keywords : Blumlein PFL, High voltage, TEM antenna, Ultrawide band, EMP

1. Introduction

Modern digital electric power equipment is composed of a great number of electronic devices. As semiconductor technology grows, the devices become multi-functional, compact and complicated. However, these integrated circuit devices accompany with vulnerability against external electromagnetic interference. Especially, malfunction or destruction of electronic devices may be caused by an intense electromagnetic (EM) pulse which can be generated from various phenomena such as nuclear explosion, electrostatic discharge, lightning, and radiation of a high voltage pulse. Thus, the protection of modern electronic systems against the fast transient electric field of an ultrawide band (UWB) EM pulse is of great interest [1-3]. It is, therefore, meaningful to study how electronic devices operate under the environment of UWB EM pulse. Generally, a high voltage pulse source is demanded to generate fast transient electric fields, thereby creating such environments [4].

In this paper, a high voltage UWB pulse generator was fabricated to radiate fast transient UWB electric fields to electronic devices. To collect basic data for the quantitative examination of the effects of the electric field on various devices in the future, the electric field intensity of the radiated pulse was measured at many locations. The electric field intensity was also measured as a function of the output voltage of the peaking switch

2. Descriptions of UWB Source

Fig. 1 shows three-dimensional drawings of the high voltage UWB pulse generator and the radiating antenna. The generator mainly consists of a charging circuit, a pulse transformer, a spark gap switch, a Blumlein PFL, and a peaking switch. All components except the charging circuit are installed in a single cylindrical vessel which is filled with a transformer oil to ensure high voltage insulation. A

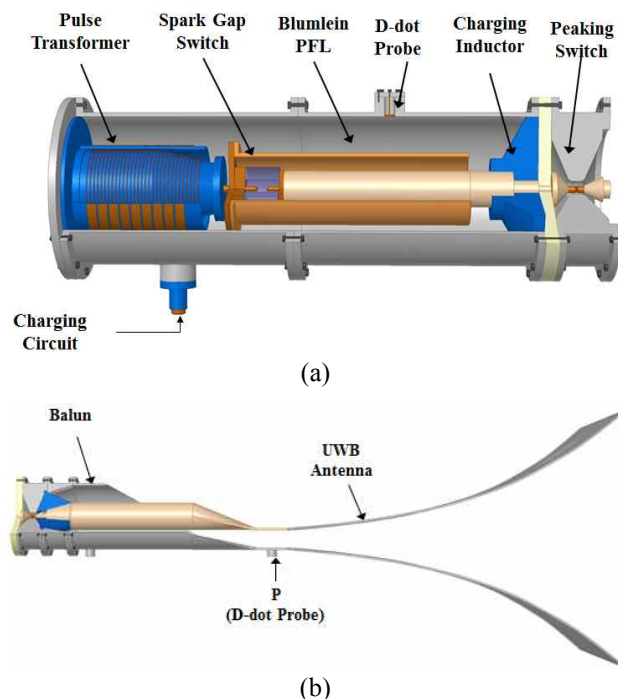


Fig. 1. Three-dimensional drawings of (a) the high voltage UWB pulse generator and (b) the radiating antenna.

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detailed explanation of the generator is given in ref. [5], together with the operation principle of pulse forming; hence, the main components directly associated with the topics of the paper are described briefly in the following.

A helical strip / wire type of air-cored pulse transformer is employed to transmit a high power pulse of fast rise time to the Blumlein PFL. The characteristics of the pulse transformer have been discussed in ref. [6]. When the Blumlein PFL is fully charged by the pulse transformer, the spark gap switch closes automatically and the pulse forming process is initiated in the Blumlein PFL. Typically, the self-breakdown voltage of the spark gap switch is greater than 300 kV when the gas (a mixture of SF₆ and N₂) pressure of the spark switch is 1.8 MPa.

In the cylindrical configuration of the Blumlein PFL, there are three aluminum electrodes. They are concentrically placed to construct two coaxial transmission lines. According to the theory of the Blumlein PFL [7, 8], the pulse duration of the Blumlein output is $2l\sqrt{\varepsilon_r}/c$ [s], where l and ε_r are the length and the dielectric constant of the dielectric medium of the Blumlein PFL, respectively, and c is speed of light in vacuum. The characteristic impedance of the coaxial transmission line can also be expressed in terms of the outer radius R_i of the inner conductor and the inner radius R_o of the outer conductor in the transmission line: $Z_0 = 60\sqrt{\mu_r/\varepsilon_r} \ln(R_o/R_i)$ [Ω], where μ_r is the relative permeability of the medium. In Fig. 1, the effective length of the transmission line is ~ 50 cm; hence, the pulse duration is ~ 5 ns. Since the diameters of inner, middle and outer electrodes are 10 cm, 20 cm and 40 cm, respectively, characteristic impedances of the middle-inner transmission line and the middle-outer transmission line are $\sim 23 \Omega$ and $\sim 27 \Omega$, respectively. Therefore, the load impedance must be matched to be 50Ω .

The peaking switch plays a crucial role of shortening the rise time of the Blumlein PFL pulse, thereby increasing the high frequency spectrum of the pulse. It should be addressed that the electrode attached to the balun is surrounded by a wedge-shaped dielectric material to minimize the abrupt change of impedance inside the peaking switch; otherwise, the output pulse of the peaking switch may be distorted. The gap distance between electrodes in the peaking switch is one of important factors to determine the rise time [9]. Obviously, the shorter the gap distance is, the bigger the electric field intensity becomes. It was found that 3 mm is the minimum value of the gap distance to sustain 300 kV under the condition of the maximum gas pressure (1.8 MPa).

An exponentially tapered TEM horn antenna [10] was fabricated to radiate the output pulse of the peaking switch. The length and aperture size of the antenna is 2 and 1.5 m, respectively. It can radiate electromagnetic pulse with frequency range between several tens of MHz to 1.5 GHz with reflection less than -10 dB [5].

3. Operation Characteristics

The peaking switch is required to operate at a voltage of 300 kV at maximum. As a matter of fact, it is extremely difficult to control the breakdown voltage (V_b) because the peaking switch operates in a self-discharge mode. Therefore, it is necessary to identify an operation condition of obtaining a breakdown voltage of 300 kV. Generally, the breakdown voltage is determined by the gas pressure (p) and the gap distance (d). Fig. 2 shows the characteristics of the breakdown voltage that was measured as the gas pressure changed with respect to two gap distances (3 and 5 mm). When a slowly increasing voltage is applied across two electrodes, as stated in Paschen's law, the breakdown voltage is expressed by only a function of the product of gap distance and gas pressure (pd). That is, $V_s = f(pd)$. As can be seen in Fig. 2, in contrast, the characteristics at $d=3$ mm are somewhat different from those at $d=5$ mm. This implies that the breakdown voltage must be expressed by a function of two different variables, i.e. gap distance and gas pressure.

In the case of $d=3$ mm, the breakdown voltage is ~ 300 kV at $p=1.8$ MPa. In other words, the maximum electric field intensity is ~ 1 MV/cm.

Fig. 3 illustrates a typical waveform of the output pulse of the peaking switch. Note that this waveform was measured at a purely resistive load of 50Ω using the D-dot probe. The integration of the probe output is required to obtain the waveform in Fig. 3. The peak voltage is greater than 300 kV, the rise time is ~ 500 ps, and the pulse width is ~ 5 ns.

The output voltage pulse of the peaking switch is applied to the TEM antenna to radiate transient electric fields via the balun. Fig. 4 depicts a schematic diagram to measure the electric field intensity of the pulse radiated from the transmitting antenna. Here, a double ridged waveguide horn antenna is employed to receive the radiated pulse, which is sent to an oscilloscope through a coaxial cable and an attenuator.

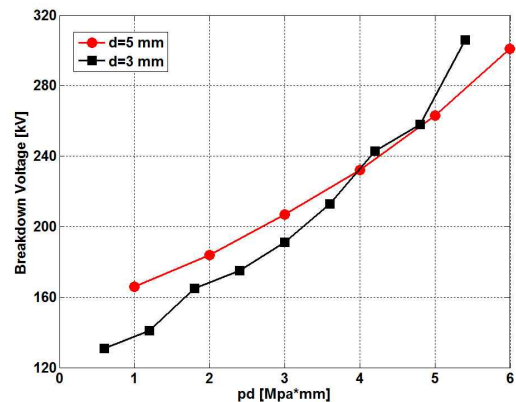


Fig. 2. Breakdown voltage of the peaking switch as a function of the product of gas pressure and gap distance.

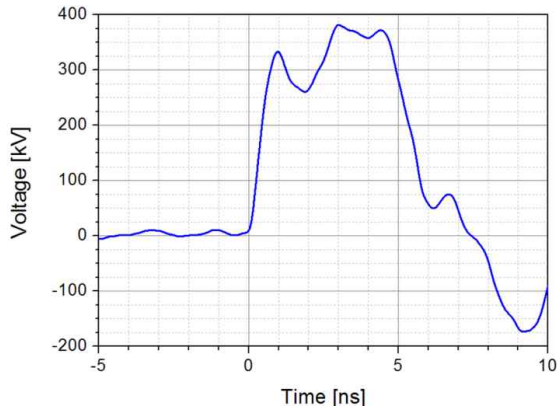


Fig. 3. Typical waveform of the output pulse of the peaking switch with $d=3$ mm.

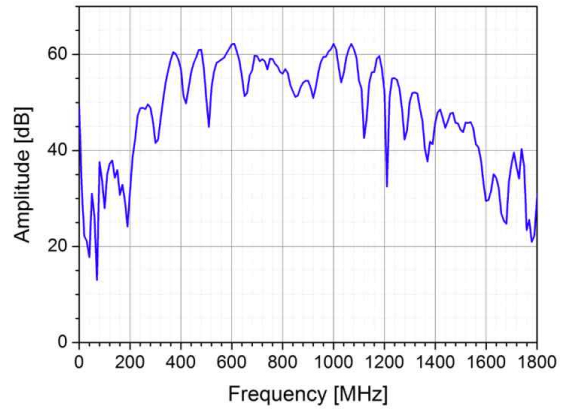


Fig. 6. Fast Fourier transform of the radiated pulse

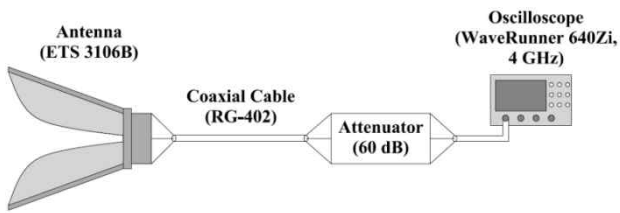


Fig. 4. Schematic diagram to measure the electric field intensity of the pulse radiated from the transmitting antenna.

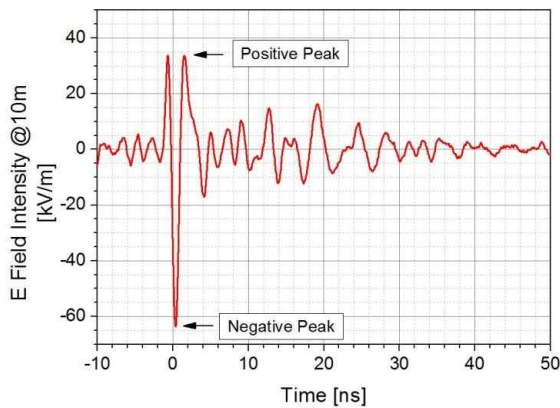


Fig. 5. Waveform of the radiated pulse measured at 10 m from the transmitting antenna

Fig. 5 shows a waveform of the radiated pulse measured at 10 m away from the transmitting antenna. It can be observed that a negative peak appears between two positive peaks in the main part of the waveform. The peak-to-peak value of the electric field intensity is ~ 100 kV/m. The Fourier spectrum of this signal can be calculated as shown in Fig. 6. As can be seen, the majority of the signal resides in the frequency components ranging from 200 MHz to 1600 MHz.

As mentioned previously, the pulse generator will be used as a simulator to produce transient electric fields for electronic devices test in future. Therefore, it is necessary to know the characteristics of the radiated pulse for the

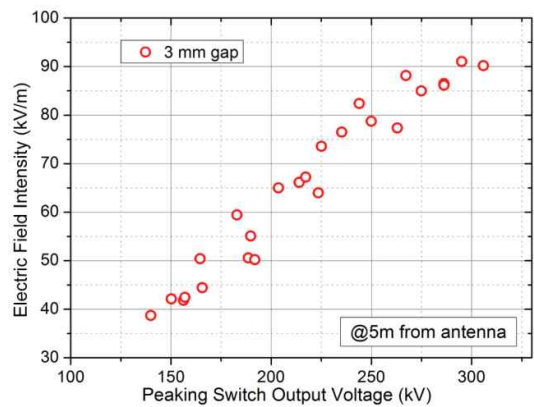


Fig. 7. Electric field intensity as a function of the output voltage of the peaking switch.

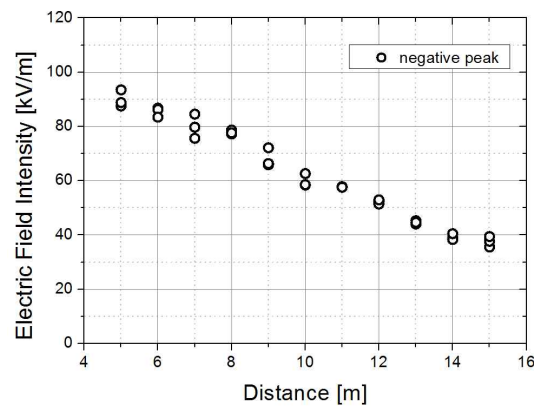


Fig. 8. Electric field intensity as a function of distance

quantitative examination of the effects of the electric field on electronic devices. For this purpose, the electric field intensity was measured as a function of the output voltage of the peaking switch. The measurement results are shown in Fig. 7. Here, the y-axis indicates the electric field intensity measured at the negative peak with the receiving antenna positioned at 5 m from the transmitting antenna. It seems to be challenging to formulate the dependence of the electric field intensity on the output voltage of the peaking

switch because of irregularly scattered data points. This may be related to the inaccuracy in regulating the output voltage of the peaking switch.

The electric field intensity of the radiated pulse was also measured at the distances between 5 m and 15 m away from the transmitting antenna. Fig. 8 illustrates the measured electric field intensity when the transmitting antenna is driven by the maximum voltage (~300 kV). As expected, the electric field intensity attenuates gradually as the distance increases.

4. Conclusion

A high voltage pulse whose rise time is ~500 ps, peak voltage is greater than 300 kV, and pulse duration is ~5 ns was successfully generated using the high voltage UWB pulse generator. The waveform of the radiated pulse is characterized by two positive peaks and one negative peak. The radiation characteristics of the pulse were examined by measuring the electric field intensity of the pulse with respect to two variables. One is the distance from the transmitting horn and the other is the output voltage of the peaking switch. According to the experiment results, the measurements of the electric field intensity on the former can provide much more reliable data than those on the latter. In the future, therefore, Fig. 8 will be used as a reference data to adjust the electric field intensity for the quantitative examination of the effects of the electric field on various electronic devices

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