SOLID PULSE FORMING LINE FOR DWA*

Linwen Zhang#, Qinggui Lai, Wendou Wang, Jin Li, Xin Li, Bin Ma, Debiao Chen, Yuan Li, Huang Zhang, Jun Zhu
P.O.Box 919-150, Mianyang, Sichuan, 621900 China

Abstract

This paper introduces some research work about the solid pulse forming line for Dielectric Wall Accelerator (DWA). We will discuss the impedance of solid pulse forming line (PFL) due to different material. The PCSS (photoconductive semiconductor switch), which was used for DWA, will also be described.

INTRODUCTION

Compact accelerators based on Dielectric Wall technology are a potential choice for the next generation of flash X-ray radiography and proton therapy [1]. The DWA employs of the high gradient insulator which is powered by the parallel-plate solid pulse forming lines switched by the photoconductive semiconductor switches. Smith [2] proposed a Zero Integral Pulse (ZIP) Forming Line which will produce a bi-polar, zero integral output pulse at the matched load, and the energy transfer efficiency is 100% in theory. Rhodes [3] reported a realizable structure for the stackable ZIP line which is used for the Dielectric Wall Accelerator developed at Lawrence Livermore National Laboratory.

We are developing a parallel-plate Blumlein line switched by the PCSS to serve as the PFL for the DWA. Although the theoretical maximum energy transfer efficiency is only 50% for such a system, the Blumlein can produce a unipolar accelerating field which is the same as the one produced by the ZIP line. We present here the circuit simulation of the output voltage pulse of the Blumlein at a matched load. The impacts of the circuit components are discussed. We also evaluate the operation of the stacked parallel-plate Blumleins by using 3-dimensinal finite-difference time-domain (FDTD) method. The parasitic coupling in a system of two Blumleins was found to be notable.

PARALLEL-PLATE BLUMLEIN

The pulse-forming line is a component of a Dielectric Wall accelerator that is used for generating the accelerating pulse. The basic form of the compact Blumlein is shown in Fig.1.

The characteristic impedance of the line, for a sufficiently large ratio of w/d, is defined by

$$Z_0 \approx \frac{377d}{\sqrt{\varepsilon_r}\,w} \qquad (1)$$

and the pulse duration is expressed by

$$\tau = \frac{2L\sqrt{\varepsilon_r}}{c} \qquad (2)$$

Where d is the thickness of the dielectric material, w is the width of the line, ε_r is the dielectric constant and c is the velocity of light.

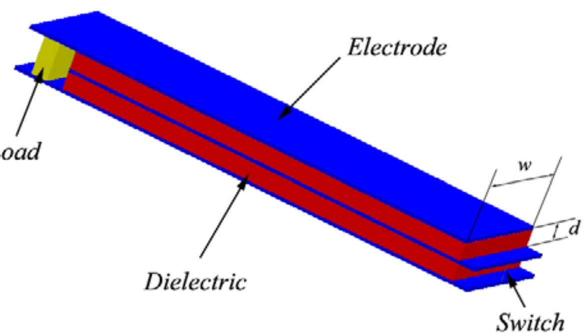


Figure 1: Compact parallel-plate Blumlein pulse-forming line configuration.

The circuit code is used to determine the output waveform for the different circuit components. Fig.2 shows the circuit used to model a single Blumlein discharging to a matched load. In our simulation, we assumed that the dielectric layer is 30 cm long, 10 cm wide, 1 cm thick with an ε_r of 10, and charged to 1 V. Thus the impedance and the one-way transit time of a single layer are approximately 12 Ω and 3.2 ns respectively. We open the switch U1 in series with the voltage source at t=1 ns, and close the switches U2 at t= 5 ns. The transit time for each switch is set to be 1 ns. Fig.3 shows the voltage waveform at the matched load R1 for different on resistance of U2.

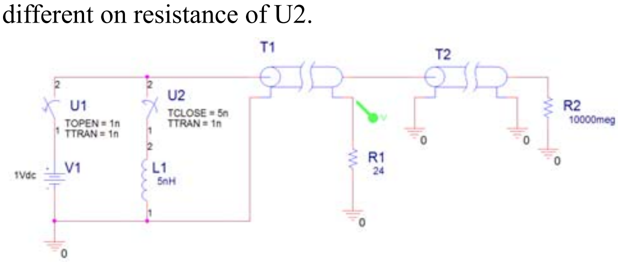


Figure 2: Circuit used to model the Blumlein line system.

As shown in Fig.3, the output voltage is sensitive to the on resistance of the switch, determined by the driving laser's power and the design and impurity properties of the switch. It is obvious that if we increase Z_0, it will reduce the influence by the on resistance of the switch. However, to obtain high accelerating gradient across the high gradient insulator, the stacked Blumleins are charged in parallel and then discharge in series. This ideally allows a voltage of NV_0 to be measured across a matched load, where V_0 is the charging voltage of the system and

*Work supported by the National Natural Science Foundation of China (11035004)
#ifpzlw@caep.ac.cn

N is the number of Blumleins. At the same time, the total impedance of the stacked Blumlein system will be NZ_0, which put a restriction on the capacitance of the load. We calculated the output waveform at a matched load and a 15 pF capacitance connected in parallel for different PFL impedances. The results are shown in Fig.4. It is obvious that if the PFL impedance becomes large enough, not only the rise/fall time deteriorates, but also the shape of the pulse and its magnitude.

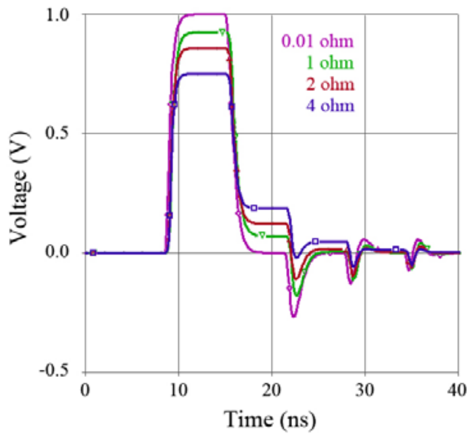


Figure 3: Output waveform from a single Blumlein for various switch on-resistance.

The impedance of the PFL must be a balance between the circuit parameters and the system Design. Thus, to realized the line impedance, we have to balance the value among ε_r, w and d. For a given dielectric material, a change in d will either affect the magnitude of the electric field, or will require some adjustment in the applied voltage (which then affects the voltage on the load). At the same time, a change in w, as well as a change in d, will differently relate to the dielectric breakdown strength.

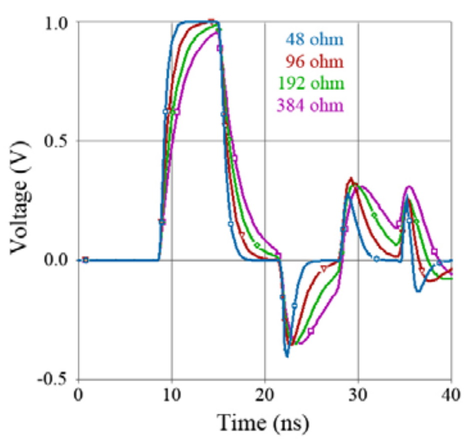


Figure 4: Output waveforms for various Blumlein impedance on a matched resistance connected in parallel with a 15 pF capacitance.

PHOTOCONDUCTIVE SEMICONDUCTOR SWITCH

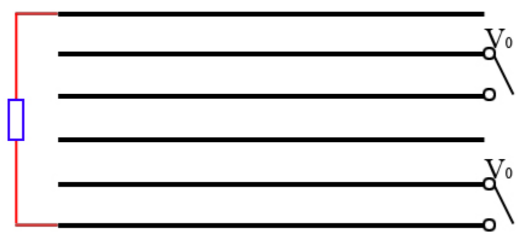
High voltage switches have always been critical components for reliable, efficient pulsed power systems because they control the timing synchronization and amplitude variation of multiple PFLs that combine to produce the total system output pulse. PCSS provides a number of advantageous over the existing triggering techniques. It offers switching improvements in voltage, current, rise time, jitter, optical activation, size, and cost. We have tested both GaAs and SiC PCSS triggered by laser pulse at a wavelength of 1064 nm. Photoconductivity tests of the PCSSs were performed at different bias voltages. Dark current-voltage characteristics of the GaAs PCSS and the absorption depth of GaAs with different wavelength were obtained experimentally [4]. The GaAs PCSS can last for more than 10^4 shots at a bias voltage of 20 kV and a repetition rate of 20 Hz.

STACKED BLUMLEINS

The number of the Blumleins and switches for a Dielectric Wall Accelerator is based on the high voltage breakdown strength of these elements. We have tested the transmission line made of bulk $SrTiO_3$ ceramic and a composite polymer. These samples successfully generate pulse voltages up to 100 kV with duration of 90 ns [5]. However, the present GaAs PCSS only worked well when charging to 20 kV or below. For a DWA constitutes of more than thousands of switches, the reliability and stability of such a system are still a question. Therefore, we are developing a structure that several Blumleins are triggered by a single switch in order to reduce the required number of switches significantly.

In an ideal Blumlein, there is no coupling between the two transmission lines other than through currents flowing on the common electrode. In a parallel plate configuration, there can be significant coupling of the two transmission lines through electric fields instead of currents. This coupling can be included as a parasitic impedance. The parasitic impedance degrades the ideal performance of the Blumlein. As a consequence, the voltage multiplication of the stacking Blumleins can be reduced due to these parasitic coupling terms.

The 3-dimensional FDTD method is used to predict the output for a stack of two Blumleins. Two definitions are used in our simulation. One definition is a conventional configuration that each Blumlein has its own switch, as shown in Fig.5 (a), and another has a switching configuration consisting of a single switch for both Blumleins, as shown in Fig.5 (b).



(a)

(b)

Figure 5: System configurations for (a) each Blumlein has its own switch, and (b) a switching configuration consisting of a single switch for both Blumleins.

The simulation result is shown in Fig.6. Although the transit time of the switches used in the FDTD simulation is only 200 ps, the output waveform is still worse than the previous results simulated by the circuit model. This is the disparity between the practical model and the ideal one. In addition, the parasitic coupling between the two Blumleins is more significant when both Blumleins are triggered by a single switch. The amplitude of the voltage pulse is only about a half of the expected one.

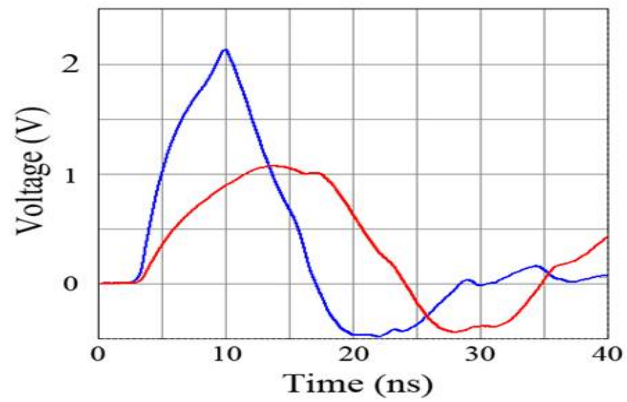


Figure 6: Output waveform for configuration in Fig.5 (a) (blue) and Fig.5 (b) (red).

CONCLUSION

A solid parallel-plate Blumlein pulse forming line developed for Dielectric Wall accelerator is studied in this paper. We have found that the impedance of the Blumlein needs to be designed carefully in a DWA system. We have also presented the stacked Blumlein structure of two different configurations. The output voltage pulse will be destroyed by the parasitic coupling effect significantly in the practical model.

REFERENCES

[1] G. J. Caporaso et al., “High gradient induction accelerator”, in proceedings of the 2007 particle accelerator conference, p.857-861.

[2] I. Smith, “Linear Induction Accelerators Made from Pulse-Line Cavities with External Pulse Injection,” Rev. Sci. Instr., vol. **50**(6), pp. 714-718, 1979.

[3] Rhodes, M.A. “Ferrite-Free Stacked Blumlein Pulse Generator for Compact Induction LINACS,” in proceedings of the 15th International Pulsed Power Conference, 2005.

[4] J. Q. Yuan et al., “Study on high power photoconductive semiconductor switches”, High Power and Particle Beams, **22**(4), 2010.

[5] L. Xia et al., “Design and Experiment on the Compact, Portable Pulse Forming Line”, ACTA PHYSICA POLONICA A, Vol. **115**(6), 2009.