PERFORMANCE OPTIMIZATION FOR THE STACKED-BLUMLEIN *

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Abstract

For the applications of the Dielectric Wall Accelerator (DWA), the stacked-Blumlein pulse generator comprised of parallel-plate transmission lines is being developed. The peak output voltage of the stacked Blumlein will be much lower than expected due to the parasitic coupling among the individual pulse forming lines of the Blumlein stack. The finite difference time domain (FDTD) method is used to model the stacked-Blumlein structure and determine the outputs. We present the optimization of a 20-Blumleins-stack in this paper. The results for different structures are discussed.

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 photoconductive semiconductor switch to serve as the pulse forming line 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 3-dimensinal finite-difference time-domain (FDTD) simulation of the output voltage pulse of the parallel-plate Blumlein. We have evaluated the influence of parasitic coupling on the stacked-Blumlein by computer simulation. Structure optimization for the stacked-Blumlein is also presented.

PARALLEL-PLATE BLUMLEIN

The pulse forming line is a component of a Dielectric Wall Accelerator that is used for generating the accelerating pulse. The characteristic impedance of the line, for a sufficiently large ratio of w/d, is defined by

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

The pulse duration is expressed by

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

Where L, w and d is the length, width and thickness of the single layer pulse forming line respectively, ε_r is the dielectric constant and c is the velocity of light.

The output voltage of the parallel-plate Blumlein is sensitive to the on-resistance of the switch and the capacitance of the load. The on-resistance of several ohm was observed in our experiments using GaAs photoconductive switches. Therefore, the impedance of the Blumlein should at least be tens of ohm to avoid a notable reduction of the output voltage. However, to obtain high accelerating gradient across the high gradient insulator (HGI), the stacked Blumleins are charged in parallel and then discharge in series. The total impedance of the stacked Blumlein system will be NZ_0, where N is the number of Blumleins. In order to obtain the highest accelerating gradient on the dielectric wall accelerator, the accelerating pulse duration should be as short as possible [4], which put an upper limit on the capacitance of the load.

For a given impedance and pulse duration of a Blumlein, the parameters of the Blumlein should be chosen carefully to produce a well-shaped pulse [5]. In our simulation, we assumed that the dielectric layer is 150 mm long, 15 mm wide (the width of the electrode is 4 mm), 1 mm thick with ε_r of 20, and the central electrode was charged to -1 V. Thus the impedance and the transit time of the Blumlein are approximately 42 Ω and 4.47 ns respectively. The simulation model is shown in Fig.1. In our simulation, the turn-on time of the switch was set to 20 ps, and the on-resistance of the switch was neglected. The dielectric width extension can increase the high voltage strength of the Blumlein and improve the shape of the output pulse [6]. The simulation result for the above Blumlein with different dielectric width is shown in Fig.2. The pulse width is prolonged about 0.16 ns when the dielectric width is extended from 4 mm to 8 mm, and become invariant when the dielectric width further increases. In addition, there is a spike at the end of the main pulse.

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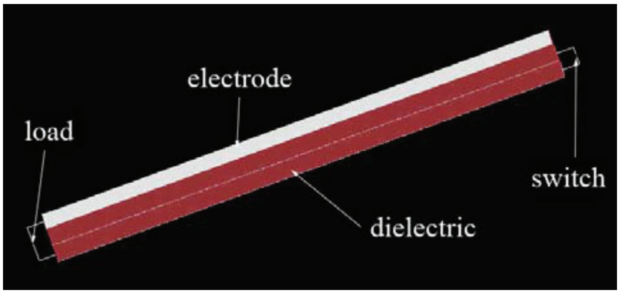

Figure 1: Model of a parallel-plate Blumlein.

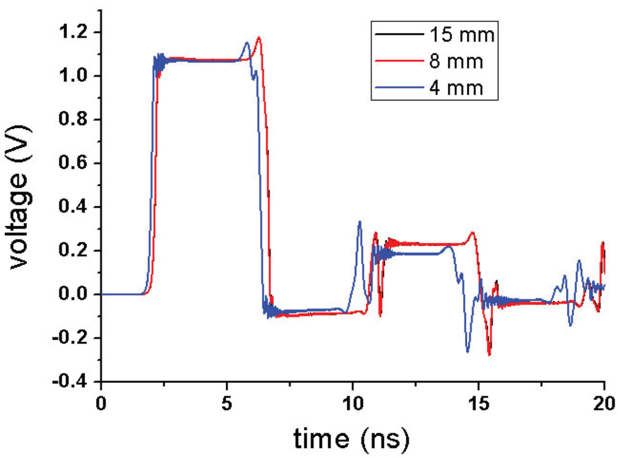

Figure 2: Output pulses for a 4-mm-wide Blumlein with different dielectric widths

It is obvious that the output voltage is about 1.1 V for a theoretically matched load of 42 ohm. The simulation result of the output pulses on resistive load with various resistances is shown in Fig.3. The characteristic impedance of the Blumlein was found to be 36 ohm instead of the theoretical result of 42 ohm. However, reflection pulses were observed in all the cases.

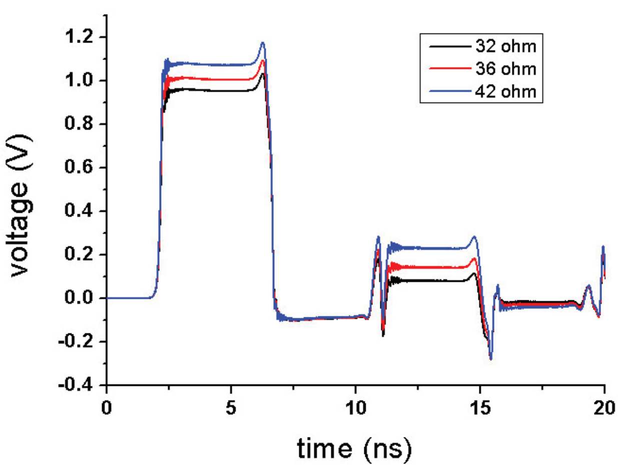

Figure 3: Output pulses on a resistive load with various resistances.

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. Moreover, the high accelerating gradient demands that these elements should be as small as possible. Our goal is to obtain a 300 kV output across the 1.5-cm-thick high gradient insulator triggered by GaAs switches with high voltage strength of 15 kV, which determines that the number of Blumleins is 20. 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 adjacent Blumleins through electric fields instead of currents. This coupling can be included as a parasitic impedance. The parasitic impedance degrades the ideal performance of the stacking Blumleins. As a consequence, the voltage multiplication of the stacking Blumleins can be reduced due to these parasitic coupling terms.

The simulation result for stacked-Blumlein with different number of Blumleins is shown in Fig.4. The result was normalized by the number of Blumleins in the stack. It is obvious that the waveform deteriorates and the amplitude of the main pulse decreases as the number of the Blumleins increases. However, the width of the spike at the end of the main pulse increases quickly as the number of the Blumleins increases. For a 20-Blumleins-stack, the width of the spike is even longer than the width of the flattop. The amplitude of the reflection pulse also increases quickly when the number of Blumleins in a stack is less than 10.

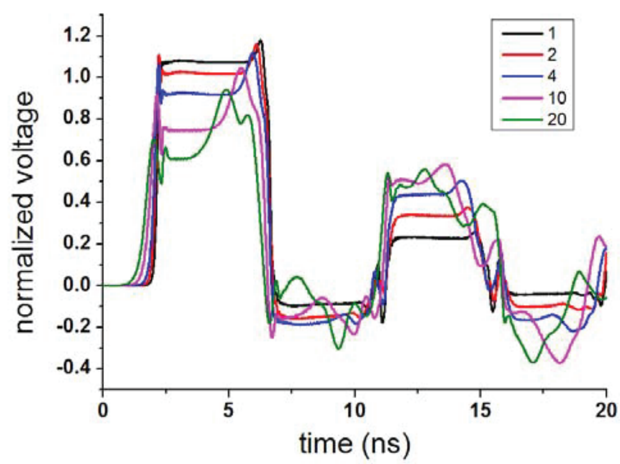

Figure 4: Normalized output pulses for stacked-Blumlein with different number of Blumleins.

To alleviate the parasitic coupling effect, we proposed to separate the adjacent Blumleins for a small gap. The output waveforms for different Blumlein separations are shown in Fig.5. The simulation results indicate that the separation of the adjacent Blumleins is beneficial for the amplitude of the output pulse. However, when the separation increases from 2 mm to 4 mm, the

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performance of the stacked Blumleins can not be improved further.

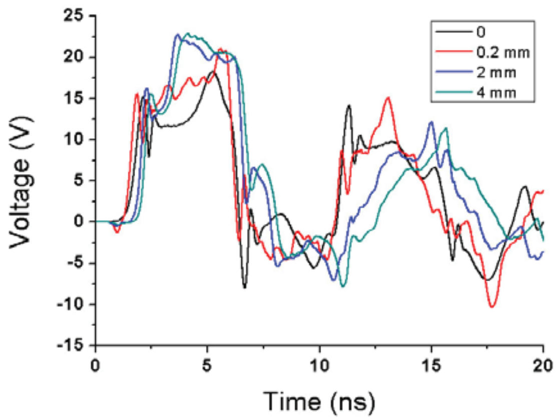

Figure 5: Output pulses with different adjacent Blumlein separations.

We also studied the output pulse across the HGI discharged by a 20-Blumleins-stack with a 2 mm separation between adjacent Blumleins. The turn-on time of all switches is 0.4 ns. A resistive load of 840 Ω is connected parallel with the HGI. The HGI is made of 15 layers of 0.8 mm thick Kapton and 16 layers of 0.2 mm thick conductor. The model is shown in Fig.6 and the simulation result is shown in Fig.7. The peak voltage of the output pulse is only about 18 V. However, this value is still much higher than that from a stacked-Blumlein without separation.

Figure 6: Models for a 20-Blumleins-stack with a HGI load.

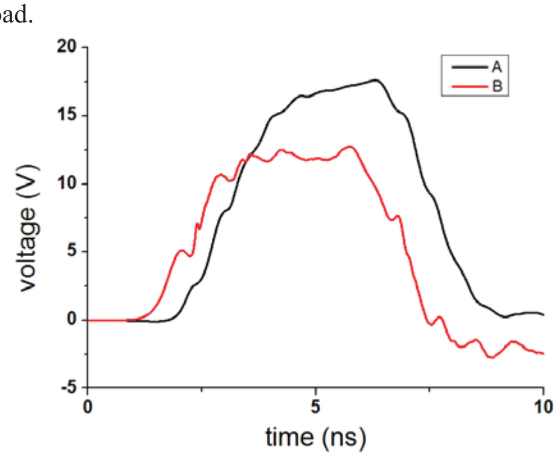

Figure 7: Output pulse across the HGI, A - 2 mm gap between adjacent Blumleins, 0.4 ns turn-on time of switches; B – no gap between adjacent Blumleins, 20 ps turn-on time of switches.

CONCLUSION

A solid parallel-plate Blumlein pulse forming line developed for Dielectric Wall accelerator is studied in this paper. The parasitic coupling between the adjacent Blumleins will deteriorate the output pulses seriously. The parasitic coupling can be alleviated by separate the Blumleins with a small gap. We also found that the structure of the HGI has a considerable impact on the output pulse.

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