PROGRESS IN DEVELOPMENT AND APPLICATIONS OF PULSED POWER DEVICES AT THE UNIVERSITY OF TEXAS AT DALLAS*

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Abstract

The generic concept for ultra-fast pulsers at the University of Texas at Dallas (UTD) employs a Blumlein based pulse forming system commutated by a fast switching device. Characterization studies of these pulsers have been extensively performed. They are capable of producing high power waveforms with risetimes and repetition rates in the range of 0.1-20 ns and 1-1000 Hz, respectively, using a conventional thyratron, spark gap, or photoconductive switch. In this report we have explored the pulser characteristics and impedance parameter space in our modulator pulse forming lines in order to develop a reliable pulser capable of generating intense ultra-wideband (UWB) electric fields with nanosecond durations for applications in the field of Bioelectrics.

I. INTRODUCTION

In recent years the new field of Bioelectrics has opened a wide range of application areas for pulsed power research and development. Intracellular electromanipulation involves bioelectric processes that require the development of reliable pulsed power sources that produce fast electric fields preferably larger than 30 kV/cm at pulse durations in the nanosecond range. Initial approaches by Schoenbach, et al [1] to apply pulsed electric fields to kill cells by apoptosis has demonstrated success. There, as the applied pulse duration decreased from 300 ns to 10 ns, electric field effects were reduced at the level of the plasma membrane and were focused to the cell interior. At the high enough electric field intensities apoptosis could be induced as indicated by the reduced size of treated mouse tumors [1]. This type of field-cell interaction using nanosecond pulses with high electric field has proved potential to affect transport processes across sub-cellular membranes and it has been widely experimented in last couple of years [2]. These studies have demonstrated that triggering of the intracellular processes could be used for cancer treatment by programmed cell death.

It should be noted that the utilization of pulse power technology to treat cancer in human subjects ideally would use non-intrusive methods such as ultra-wideband (UWB) transmitters. These devices radiate fast-rising electromagnetic pulses with durations in the range of nanoseconds. They could be used to provide necessary electric field strengths and durations at a tumor location in human body to promote enhanced chemotherapy and cancer treatment [3,4]. Recent investigation in this direction has demonstrated that UWB radiation results in immediate non-thermal killing of Jurkat cancer cells in the absence of hallmarks of apoptosis including caspase activation and fragmentation of chromosomal DNA [5].

The development of UWB sources has been pursued in two general directions. The first uses a single pulser to feed a very high voltage to a single antenna transmitter. The pulser can be used to feed a non-dispersive high gain antenna system to achieve high field strength in the far field of the antenna. The second approach employs many radiating elements (array UWB source) switched at relatively low voltage to collectively deliver an additive field at the target of the array. The photoconductive semiconductor switched (PCSS) array method has been employed and demonstrated in the systems such as GEM series of pulsers at the U.S. Air Force Research Laboratory [6]. In addition to the military applications, such UWB schemes can provide non-intrusive probe of human body for medical treatments if suitable electric strength can be arranged.

Blumlein pulse generators described in this work are most suitable for the intracellular electromanipulations applications in the Bioelectrics field because they have low inductance geometry that permits generation of fast rising waveforms easily matched and delivered to the relatively low impedance biological loads or radiating antennas. We have explored the impedance parameter space and output pulse characteristics in order to enlarge the pulser technology base, level of understanding and

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14. ABSTRACT
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design options and to facilitate development of reliable Blumlein pulsers capable of generating intense UWB electric fields for Bioelectrics applications.

II. BLUMLEIN PULSE GENERATORS

The Blumlein pulsers developed at the University of Texas at Dallas (UTD) consist of either a single or several triaxial Blumleins. For multiple lines, Blumleins are stacked in series at one end and charged in parallel and synchronously commutated with a single switching element at the other end.

A. Pulser Design and characteristics

1) General design review

Design and construction of the pulse forming system for the Blumlein generators have been given elsewhere [7-9]. Briefly, a single Blumlein pulse generator consisted of a single Blumlein pulse forming line, and a commutation system capable of operation at high repetition rates. To access voltages above 100 kV, number of stacked Blumlein pulse generators were designed and constructed [8]. Their basic organization consisted of three separate but integrated subassemblies: (1) the switching assembly, (2) pulse forming Blumleins, and (3) the pulse stacking module. A photograph of a simple 2-line stacked Blumlein pulse generator switched with a spark gap is shown in Fig. 1.

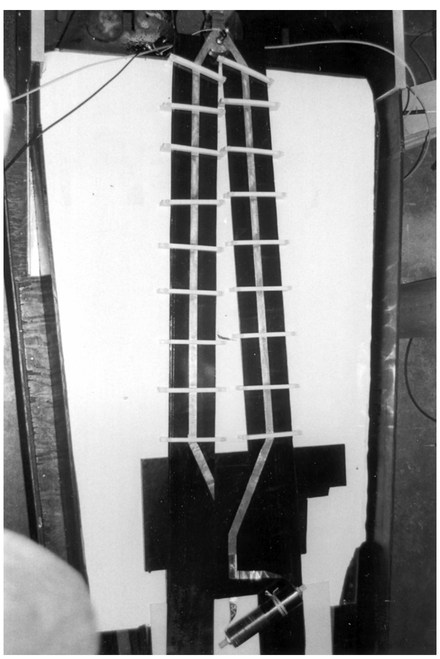

Figure 1. Photograph showing a top-view of a 2-line pulser commutated by a spark gap.

The Blumleins were constructed from copper plates separated by laminated layered Kapton (polyimide) dielectrics. Scaling of both single and stacked Blumlein devices were studied by construction of several separate systems with different lengths, capacitances, and impedances [7,9]. In operation, the middle conductor was charged to a positive high voltage that could be varied to 75 kV, and commutation was affected by a fast switching element such as a spark gap. To characterize the pulsers two modes of open circuit and resistive loading conditions were implemented. In addition, different types of switching devices with different voltage hold off characteristics were used. This resulted in peak voltages available at the load that spanned the range from 5 to 550 kV. The voltage waveform available from a 6-line pulser commutated by a thyratron in the resistive loading condition of operation is shown in Fig. 2.

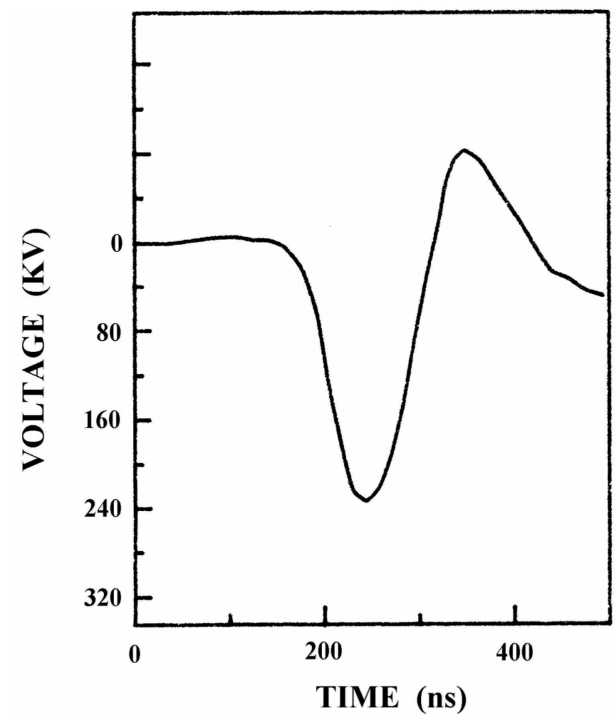

Figure 2. Output resistive load voltage waveform generated by a 6-line stacked Blumlein prototype pulser commutated with a thyratron. This particular pulse correspond to a charging voltage of 50 kV.

2) Photoconductively-Switched Pulsers

Our recent efforts have resulted in implementation and demonstration of several intense photoconductively switched stacked Blumlein pulsers. Presently, these devices operate with a switch peak power in the range of 50-100 MW and activating laser pulse energies as low as 300 nJ [10]. Examinations of output waveforms have indicated pulse durations in the range of 1-5 ns and risetimes as fast as 150 ps. An example of the output voltage generated by a 2-line pulser in both resistive loading and open circuit modes of operation shown in Fig. 3. A GaAs PCSS and a charging voltage of 40 kV were used to obtain these waveforms. The peak resistive voltage corresponded to 72 kV at the matched impedance of 200 Ω. The peak open circuit voltage was 130 kV.

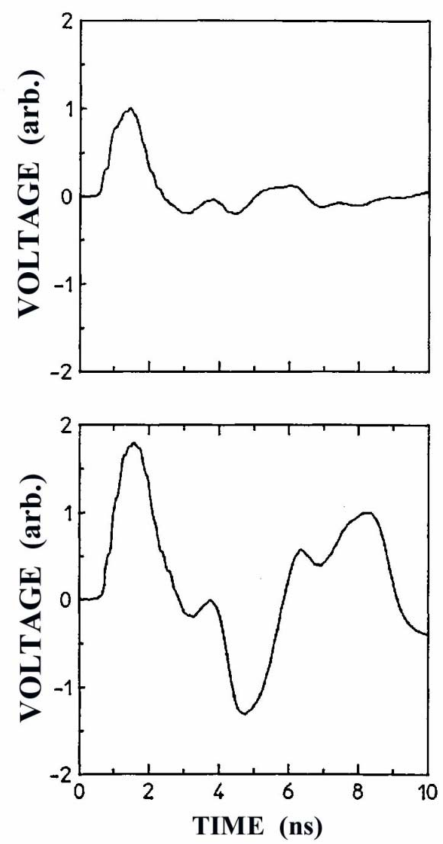

Figure 3. Output voltage waveforms obtained by operating a 2-line pulser with (top) matched resistive load and (bottom) open circuit with no load. Device was operated with a charging voltage of 40 kV.

A 4-line pulser was designed and constructed by combining two units of 2-line device. The commutation assembly was reconfigured to contain two sets of electrodes. The pulse forming lines in each 2-line unit were bent in a manner to bring the stacking sections to the same location one above the other. The units were joined in series and the top and bottom plates were connected to a resistive load built from a stack of four 100 Ω, non-inductive carbon disc resistors. This pulser was synchronously commutated by two GaAs PCSS and was capable of producing 1.5 ns output pulses with risetimes in the range of 200-500 ps. A photograph of this pulser is shown in Fig. 4.

Significant lifetime improvements for the PCSS in these Blumlein pulsers have been achieved by advanced switch treatments with amorphic diamond coatings also developed at UTD [10].

3) Output Characteristics

Our Blumlein pulsers have progressed from relatively simple, single-line devices to the most recent, compact stacked systems. Extensive characterizations of performance have demonstrated the versatility of these pulsers. It is shown that they can be developed into light and compact devices without degradation in their performance [7]. With slight design modifications, they can produce waveforms with a wide range of pulse durations and peak values. Table 1 summarizes the output pulse characteristics available from our Blumlein pulsers. The open circuit waveforms available resemble that of Fig. 3 with corresponding peak voltages and pulse risetimes given in Table 1.

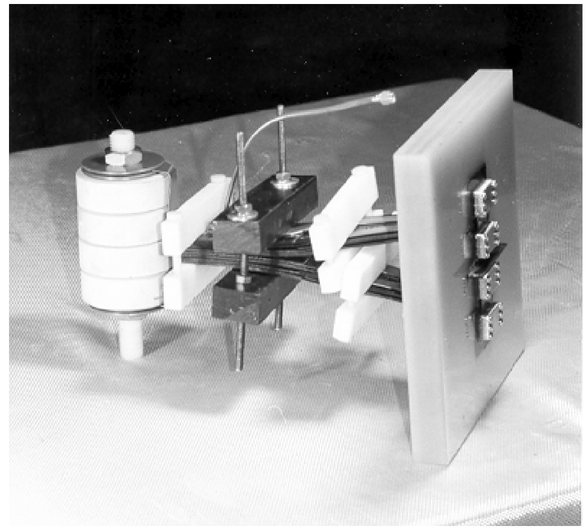

Figure 4. Photograph showing a 4-line pulser commutated by two photoconductive switches.

III. CONCLUSION

It should be noted that the pulse characteristics listed in Table 1 are of great interest for Bioelectrics applications. For example, the outputs from the low impedance pulsers could be used to directly match to biological loads for study of intracellular studies. The open circuit pulses exhibiting bipolar shapes such as that seen in Fig. 3 could also be delivered to the mismatched biological cell suspensions and may be utilized to study bipolar-UWB radiation effects on chemotherapy of cancer cells [5]. Moreover, we would like to emphasize the capability of these pulsers for generating UWB waveforms by matching the outputs to radiating antennas.

There has been a great progress in development, and optimization of impulse radiating antennas (IRA) in recent years. Numerous IRAs with different characteristics such as input impedance, effective gain, field strength and uniformity have been produced [11,12]. The Blumlein pulsers described in this work may be ideal for use with available IRAs. As indicated in Table 1, a wide range of output impedances and characteristics are accessible that may be used with a particular IRA to radiate a necessary field strength for non-intrusive Bioelectrics applications. For example an array UWB radiation would simply be realized by the split of a 200 Ω output into four 50 Ω lines each matched to a separate IRA. One may also use a particular stacked Blumlein pulser without stacking the lines. In this case, individual IRAs matched to each line could simultaneously radiate electric fields in an array fashion.

Table 1. Summary of the output characteristics for Blumlein pulsers.

Blumlein Pulser Configuration	Switching Device	Output Characteristics				
		Impedance (Ω)	Pulse Duration (ns)	Pulse Risetime (ns)	Peak Voltage matched (kV)	Peak Voltage Open Circuit (kV)
Single-Line	Thyratron	1- 200	50-100	10-40	5-75	8-140
	Spark Gap	1-200	20-100	4-10	5-75	10-130
	Photoconductive Switch	50-100	1-40	0.15-1	10-60	15-110
2-Line Stacked	Thyratron	40-100	50-600	15-40	10-120	18-180
	Spark Gap	40-100	20-100	5-15	10-110	20-200
	Photoconductive Switch	100-200	1-5	0.2-1	30-120	45-160
3-Line Stacked	Thyratron	60-150	50-100	20-40	15-170	25-300
	Spark Gap	60-150	20-100	5-20	15-170	30-280
4-Line Stacked	Thyratron	80-200	50-100	25-40	20-190	30-350
	Spark Gap	80-200	20-100	8-20	20-195	30-340
	Photoconductive Switch	400	1.5	0.2-0.5	50-150	80-200
6-Line Stacked	Thyratron	120-300	50-100	25-50	30-270	50-500
	Spark Gap	120-300	20-100	8-25	30-260	55-480
8-Line Stacked	Thyratron	160	150	70	40-310	70-420
12-Line Stacked	Thyratron	480	200	75	60-400	100-530

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