SUBNANOSECOND RISE TIME, LOW IMPEDANCE PULSE GENERATOR*

R. Druce and G. Vogtlin
Lawrence Livermore National Laboratory

Abstract

This paper describes a fast rise, low impedance pulse generator that has been developed at the Lawrence Livermore National Laboratory. The design specifications of this generator are: 50 kV operating voltage, 1 ohm output impedance, subnanosecond rise time, and a 2-10 nanosecond pulse length. High repetition rate is not required. The design chosen is a parallel plate, folded Blumlein generator. A tack switch is utilized for its simple construction and high performance. The primary diagnostic is a capacitive voltage divider with a $\dot{B}$ probe used to measure the current waveform.

Introduction

It has been shown repeatedly that short pulse technology is a benefit in many pulsed power applications. Applications such as e-beam generators for inertial confinement fusion and simulation, as well as basic research of breakdown phenomena are continually utilizing ever faster pulses. Flash radiography is one specific application which is seeking shorter pulses. The e-beam generation problem has been addressed at LLNL. One result of this work is a fast, low impedance, low rep-rate pulse generator of simple design.

Design Considerations

The output impedance specification of the pulse generator (1 ohm), coupled with the rise time specification required that a very low inductance system be used. A pulse line was used since the pulse was only a few nanoseconds long. A stripline was chosen for its low impedance characteristics and ease of implementation [1] while a Blumlein configuration made the charge voltage requirements less stringent since the pulse generator is operated with a matched load in most cases [2]. A folded Blumlein configuration allows the pulse generator to be compact [2]. As a result, the chosen design is a folded flat-plate Blumlein generator. The length of the line determines the desired output pulse length, while the insulation thickness and line width are constrained by breakdown at the charge voltage and output impedance of the line. For ease of construction, the outer conductors of the generator are aluminum plates. The center conductor of the folded Blumlein is constructed of copper foil to minimize the mismatch at the output of the line. Mylar insulation was chosen due to its relatively high dielectric strength and ease of manufacture with thin films.

The short rise time specification coupled with the low design impedance placed stringent inductance requirements on the switch. To meet this inductance (< 1 nH), and to simplify implementation as much as possible, a tack switch was chosen [3]. This switch combines the simplicity of a mechanical switch with the extremely low inductance of a solid dielectric breakdown switching element. The tack switch consists of Mylar film dielectric backed by copper foil. The switch package is pierced by a hardened steel point driven by a solenoid to initiate switch closure. The primary disadvantage of the tack switch is that the switch must be changed after each shot. This was not considered a major problem since high repetition rate was not a requirement.

Since one application required that the pulse risetime be preserved into a field emission diode, several 1 ohm outputs were desirable from one generator. Two lines in parallel provide two outputs to this diode [3]. Using a common switch allows two output connections at 1 ohm each without extra switches. Synchronizing such switches would present an insurmountable complication.

Construction Details

Figure 1 shows the configuration of the single output Blumlein generator.

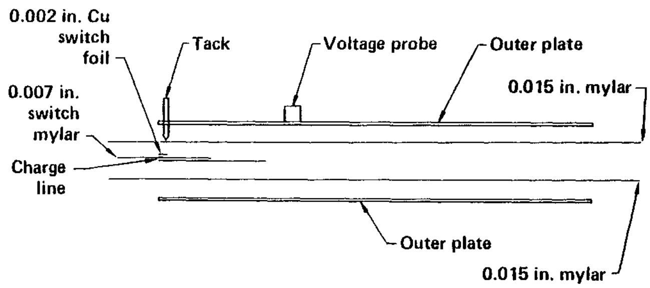

Figure 1. Construction of Single Output Generator.

The propagation velocity of 1.78×10^8 m/sec indicate a length of 0.224 m (8.8 in) for a 5 ns pulse length. An insulation thickness of 0.381 mm (0.015 in) minimu provides reliable operation at 50 kV. This insulatio thickness requires a line width of 0.171 m (6.75 in) to give an output impedance of 1 ohm. The center conductor of the Blumlein (charge line) is constructe of 50.8 µm (0.002 in) thick copper foil to minimize the impedance mismatch at the output of the line. It is necessary to back the copper foil with a thicker steel plate to avoid destroying the line insulation as the tack pierces the switch pack. The tack would pierce the copper foil center conductor and the lower insulation of the Blumlein if this precaution were not taken. The switch (shown in Fig. 2) is situated at the transverse center and near the end of the line to minimize effects from end-of-line reflections.

The switch package consists of a sheet of 0.3 m (1 ft) square by 0.178 mm (0.007 in) thick Mylar film backed by a 0.0254 x 0.0508 m (1 in x 2 in) rectangle of 5.08×10^{-5} (0.002 in) copper foil. The Mylar forms the switch material through which the tack pierces while the copper foil preserves the continuit of the conductor surface (covers up the hole through which the tack must pierce the Mylar). The tack was constructed from hardened tool steel for longevity. The tack is driven by an electrical solenoid which travels at a moderate rate. No special consideratior were taken to ensure that the tack pierced the Mylar at a high velocity.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 1983	**N/A**	**-**

4. TITLE AND SUBTITLE	
Subnanosecond Rise Time, Low Impedance Pulse Generator	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Lawrence Livermore National Laboratory P. 0. Box 808 Livermore, CA 94550**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT
This paper describes a fast rise, low impedance pulse generator that has been developed at the Lawrence Livermore National Laboratory. The design specifications of this generator are: 50 kV operating voltage, l ohm output impedance, subnanosecond rise time, and a 2-10 nanosecond pulse length. High repetition rate is not required. The design chosen is a parallel plate, folded Blumlein generator. A tack switch is utilized for its simple construction and high performance. The primary diagnostic is a capacitive voltage divider with a B probe used to measure the current waveform.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**3**	

The second form of the Blumlein pulse generator is shown in Fig. 3. It can be seen from Fig. 3 that the generator is very similar to the single output line shown in Fig. 1 except that the switch has been moved to the longitudinal center of the line and the line was folded again to give a second 1 ohm output. The switch is also very similar except the foil was widened to be equal in width to the Blumlein (0.171 m).

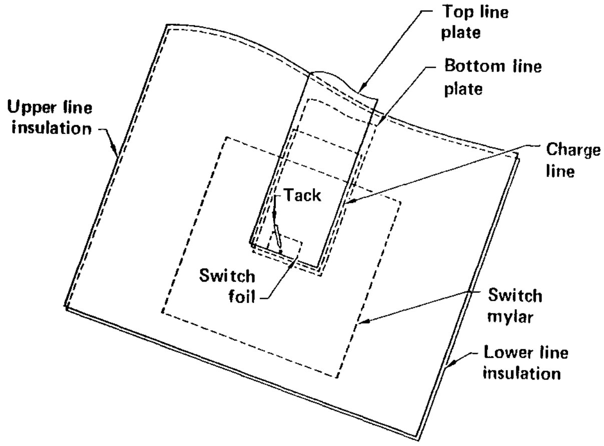

Figure 2. Detail of Switch Construction.

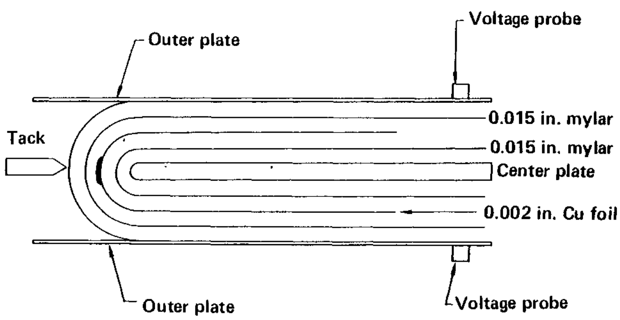

Figure 3. Two Output Generator's Construction Detail.

Diagnostics

The chief parameters important to a pulse generator of this type are output voltage and current, rise and fall times, and pulse length. If the generator is connected to a matched resistive load, the voltage and current will be related by the load resistance. As a result, a voltage divider will be sufficient to diagnose both voltage and current if a resistive load can be produced. A matched 1 ohm transmission line used as a dummy load approximates a resistive load very well and is quite easy to implement at these time scales. A voltage divider was used as the primary diagnostic since construction of an accurate divider is fairly simple at these speeds whereas the development of a current probe is quite complicated. The divider string used consists of a capacitive divider [4] built into the line followed by an aqueous resistive divider. The capacitive divider consists of a 0.0254 m x 0.114 m (1 in x 4.5 in) section of copper foil insulated from the ground side of the line by 25.4 mm Mylar. This gave a divider ratio of approximately 30:1 when placed in the 1 ohm matched load line. The divider foil was connected to the center pin of a General Radio GR-874 connector while the shield side of the connector was used as the ground connection. The output voltage of this divider was approximately 1-2 kV, still too large for an oscilloscope. To reduce the voltage further, a very simple divider consisting of a short section of solid jacket coaxial cable that was cut and reconnected with a small pocket filled with NH_4Cl is used. By adjusting the strength of the solution, the resistive termination of the divider could be easily brought to 50 ohms, and by adjusting the length of the pocket the division ratio could be adjusted over a large range. A division ratio of 500:1 brought the signal to the desirable level. The rise time of the resistive divider was approximately 700 ps. The waveform was recorded on a Tektronix 7104 oscilloscope.

For reasons stated above the current probe was chosen for ease of construction and not for accuracy. To accomplish this a $\dot{B}$ probe [4] was placed in the near fringe fields of the line. The probe was not mounted in the line because any probe that could be constructed would have an effective area large enough to produce an output voltage of several kilovolts at the current rise rates, > 10^{13} A/sec. The effective area of the probe constructed was approximately 1.16 x 10^{-6} m^2 and the rise time was less than 500 ps.

Performance

A 1.5 ohm version of the single output Blumlein generator was discharged into the matched load line to produce the voltage pulse shown in Fig. 4 (results with the 1 ohm generator were very similar).

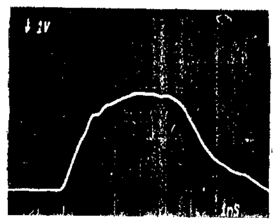

Figure 4. Voltage Waveform From 1.5 Ohm Line.

The charge voltage was 50 kV. The 10-90% rise time is seen to be 1.4 ns. However, the 10-82% rise time (the first knee in the waveform) is 900 ps. The pulse FWHM is 5.2 ns. The fall time (90-10%) is 2.7 ns. Figure 5 shows a hand integrated $\dot{B}$ output for the same discharge.

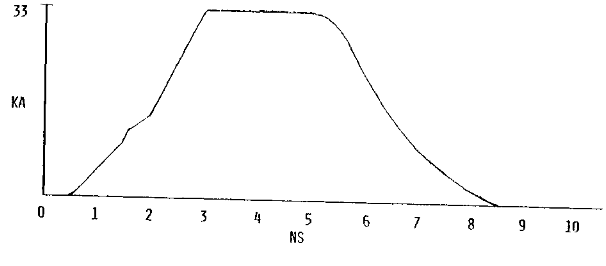

Figure 5. Current Waveform for 1.5 Ohm Line.

It can be seen that the agreement is fairly good. The indicated peak voltage is 54 kV, which is slightly higher than the charge voltage. There are two likely reasons for this discrepancy. First, the power supply was only calibrated at lower voltages and may not be accurate at higher voltages. The more likely reason is that the connector for the capacitive divider affects the total capacitance on the low side and causes a slight discrepancy in output voltage.

Figure 6 shows a voltage waveform for the 1 ohm double output version of the Blumlein generator.

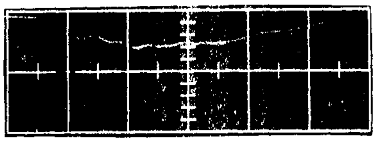

Figure 6. Output Waveform From 1 Ohm Double-output Generator.

The charge voltage was 40 kV for this discharge. The peak voltage from the divider was 40.5 kV, very close to the charge voltage. It can be seen that the rise time (10-90%) is slightly longer at 2.1 ns, but the rise time to the first knee in the waveform is still less than 1 ns (850 ps). The fall time is somewhat slower at 3 ns. The pulse FWHM is 6.5 ns. The small departure from a flat top is probably due to small mismatches in the connections and load in this case since a matched load line was not used.

Conclusion

A low impedance folded Blumlein pulse generator has been constructed which has a rise time on the order of 1 ns. The tack switch performed quite well in all configurations and provided reliable operation for several line impedances and configurations. The pulse generator is very simple in construction since little effort is required to reduce inductances. The generator is also quite versatile since it is quite simple to change impedance and pulse lengths.

References

1. W. H. Hayt, Jr., Engineering Electromagnetics, McGraw-Hill, 2nd Edition, New York, New York, p. 370.
2. W. L. Willis, Lectures on High-Voltage and Pulse Power Technology, "Pulse Voltage Circuits," Los Alamos National Laboratory Report LA-UR-80-2082 (1980).
3. I. D. Smith, Private Communication.
4. W. L. Willis, Lectures on High-Voltage and Pulse Power Technology, "Measurement Techniques," Los Alamos National Laboratory Report LA-UR-80-2272 (1980).