SWITCHING THE STACKED BLUMLEIN PULSERS STATUS AND ISSUES

D.L. Borovina, R.K. Krause, F. Davanloo and C. B. Collins

University of Texas at Dallas
Center for Quantum Electronics
P.O. Box 830688, Richardson, TX 75083-0688

F. J. Agee

Phillips Laboratory, PL/WSR
Kirtland AFB, NM 87117-6008

L.E. Kingsley

Army Research Laboratory, PSD
Ft. Monmouth, NJ 07703-5601

ABSTRACT

The repetitive stacked Blumlein pulse power generators developed at the University of Texas at Dallas consist of several triaxial Blumleins stacked in series at one end. The lines are charged in parallel and synchronously commuted with a single switch at the other end. In this way, relatively low charging voltages are multiplied to give a high discharge voltage across an arbitrary load. To date, the stacked Blumlein pulsers have produced high power waveforms with risetimes and repetition rates in the range of 5-50 ns and 1-200 Hz, respectively, using a conventional thyratron or spark gap. To generate waveforms with sub-nanosecond risetimes at kilo-Hertz repetition rates, fast switching devices such as photoconductive switches must be utilized. This paper describes the feasibility of an intense pulse power source based upon stacked Blumlein technology by adapting the design for use with photoconductive switches.

STACKED BLUMLEIN PULSERS

To fulfill the demand for pulse power sources producing several hundred kV pulses at moderately high repetition rates, the University of Texas at Dallas first introduced and implemented a new approach in 1987 to combine the functions of pulse shaping and voltage multiplication using stacked Blumleins. This yielded the development of pulsers which consisted of several triaxial Blumleins stacked in series at one end.[1,2] The lines were charged in parallel and synchronously commuted with a single switch at the other end. This allowed switching to take place at a low charging voltage relative to the pulser output voltage. These pulsers have been extensively characterized by our group and their versatility has been demonstrated.[1-9] With slight modifications they can produce waveforms with fast risetimes and a wide range of pulse durations and peak values.

It should be noted that the stacked Blumlein pulsers initially were developed to drive flash x-ray diodes.[1-3] The supporting components were originally designed to accommodate 8-18 Blumleins to access a wide range of X-ray energies. The issue of ease of operation outweighed the need for compactness. However, the stacked Blumlein pulsers can be developed into a tactical unit. This was demonstrated by reductions in the Blumlein spacings of a 2-line pulser with the line impedance of 50 Ω and line length of 48.2 m. The device in its original configuration occupied 1.92 m^3 and weighed 769 Kg. This first attempt in reduction of Blumlein spacings resulted in a 60% reduction in volume and 30% reduction in the weight of the device.[6,7] Operation of this pulser showed no

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUL 1995**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE
Switching The Stacked Blumlfin Pulsers Status And Issues

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)
University of Texas at Dallas Center for Quantum Electronics P .0. Box 830688, Richardson, TX 75083-0688

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
The repetitive stacked Blumlein pulse power generators developed at the University of Texas at Dallas consist of several triaxial Blumleins stacked in series at one end. The lines are charged in parallel and synchronously commuted with a single switch at the other end. In this way, relatively low charging voltages are multiplied to give a high discharge voltage across an arbitrary load. To date, the stacked Blumlein pulsers have produced high power waveforms with risetimes and repetition rates in the range of 5-50 ns and 1-200Hz. respectively, using a conventional thyratron or spark gap. To generate waveforms with sub-nanosecond risetimes at kilo-Hertz repetition rates, fast switching devices such as photoconductive switches must be utilized. This paper describes the feasibility of an intense pulse power source based upon stacked Blumlein technology by adapting the design for use with photoconductive switches.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**6**	

degradation of generated waveforms and voltage gains.[6,7] Opportunities for packaging the stacked Blumlein pulsers were further investigated by adapting a modular approach in the small scale prototypes.[8] Results indicated that the stacked Blumlein pulsers can be packaged into a small volume to allow high density energy storage in the device that may not otherwise be possible with conventional techniques.

To date, the stacked Blumlein pulsers have produced high power waveforms with risetimes and repetition rates in the range of 5-50 ns and 1-200 Hz, respectively, using a conventional thyratron or spark gap.[1-9] Performances of 2-line pulsers with Blumlein lengths of 9.2 m, 17 m, 32.6 m and 48.2 m and line impedances of 25 Ω and 50 Ω have been characterized in our earlier work using a thyratron.[6,7] The voltage waveforms for the resistive loading condition of operation for the pulser with the line impedance of 50 Ω are shown in Fig. 1 for reference. The waveforms in this figure indicate voltage gains of about 1.8 and exhibit flat tops. Fast rising waveforms have also been obtained from the stacked Blumlein pulser using a spark gap as the switching element.[9] Figure 2 shows a typical resistive voltage waveform obtained from the 2-line pulser with line length of 1.6 m and line impedance of 50 Ω.

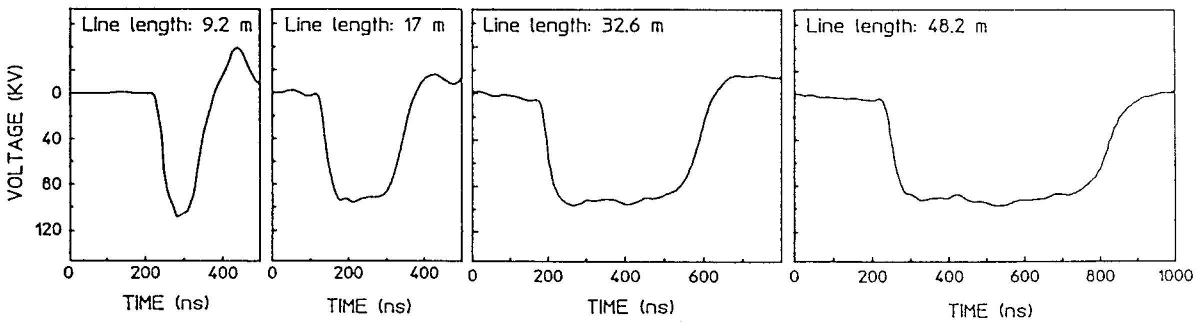

Figure 1. Resistive load voltage waveforms generated by the stacked 2-line pulsers with line lengths of 9.2 m, 17 m, 32.6 m and 48.2 m and line impedances of 50 Ω. These particular waveforms correspond to a charging voltage of 50 kV. A thyratron was used[6,7] to commute the pulser.

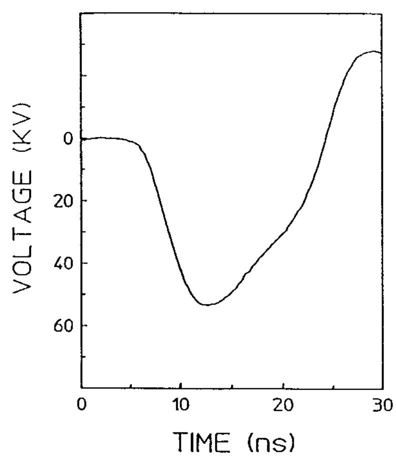

Figure 2. Resistive voltage waveform generated by the stacked 2-line pulser with line length of 1.6 m and line impedance of 50 Ω. This particular waveform corresponds to a charging voltage of 30 kV. A spark gap was used[9] to commute the pulser.

PHOTOCONDUCTIVE SWITCHING OF THE STACKED BLUMLEIN PULSERS

In recent years photoconductive semiconductor switches have gained much attention and have become competitors to the conventional high power switches such as spark gaps and thyratrons for certain applications. These devices operate jitter-free with optical isolation of the trigger and have switching speeds as fast as the optical trigger pulse risetime or faster. Photoconductive switches are divided into two categories of linear and avalanche type devices.

The application of linear switches has been limited by the relatively high optical power required to obtain the closure. In the avalanche type switches the electron-hole pair produced by one photon is multiplied through an avalanche process, thus reducing the optical energy levels necessary for initiation of switch closure.[10] It is interesting to note that the Blumleins may be the most proper pulse-forming lines for use with photoconductive switches. They provide faster output pulse risetimes and reduce the percentage of stored energy deposited in the switch.[11]

In this work we designed and constructed two stacked Blumlein pulsers for commutation by photoconductive switches. A Si and a GaAs photoconductive switch were fabricated in a crude fashion to calibrate the pulsers and to study the stacking functions. The silicon was high purity zone floated having a resistivity of about 13 kΩ-cm and had a rectangular shape. The GaAs was a circular flat and had a resistivity of about 10 MΩ-cm. The photoconductive regions for both switches were about 2.5 cm wide by 1 cm long. At this stage the contacts were prepared only by silver paste.

A low profile switching assembly was constructed to distribute the switching current to each of the two Blumleins in a manner to avoid path constrictions. Blumleins with line impedances of 50 Ω were placed on a test bed and charging plates were extended to the close proximity of the stacking location, 3.8 m from the switch. Copper foils were connected to the ends of the lines and angled together along with the dielectric for another 30 cm, where they were stacked directly on top of one another. The lines were connected in series for about 5 cm and top and bottom copper leads were connected to a load, across which the output of the pulser was measured.

In operation, both pulsers were resonantly pulse charged in the range of 3-10 kV and repetition rate of 10 Hz. The devices were fully charged in about 25 μs, after which a second pulse from the master oscillator Q-switched a Nd:YAG laser and provided trigger photons for the photoconductive switches. The particular laser available at this time had a relatively long Q-switch pulse of about 50 ns. We used 5-10 mJ laser pulses at 1.06 μm to trigger the Si switch and 0.2-0.5 mJ at 0.532 μm to trigger the GaAs switch. Both switches were operated in the linear mode.

To characterize the pulser, the resistive loading condition was implemented as previously described.[6-9] In this mode of operation, the output from the pulser was connected to a nominally matched load built from a stack of ten, 10 Ω non-inductive carbon disc resistors. The output voltage waveforms were measured with a Tektronix P6015 high voltage probe. A comparison of the measured charging voltage and the voltage across the series stack together with the laser pulse are shown in Fig. 3. The voltage waveform of this figure indicates a voltage gain of about 1.8 which is consistent with our earlier results for the 2-line devices. In addition, as expected, the risetime and pulse duration of generated waveforms are similar to those of the laser pulse.

In the case of GaAs, however, the total charge stored in the device could not be switched. It seemed that, because the switch was operated in the linear mode, sufficient number of carriers were not produced for the number of laser photons provided. Figure 4 compares the launching voltage in each line before stacking the lines to the stack voltage, relatively. As seen in this figure the stack voltage amplitude is twice the launching voltage which verifies the proper stacking of the Blumleins.

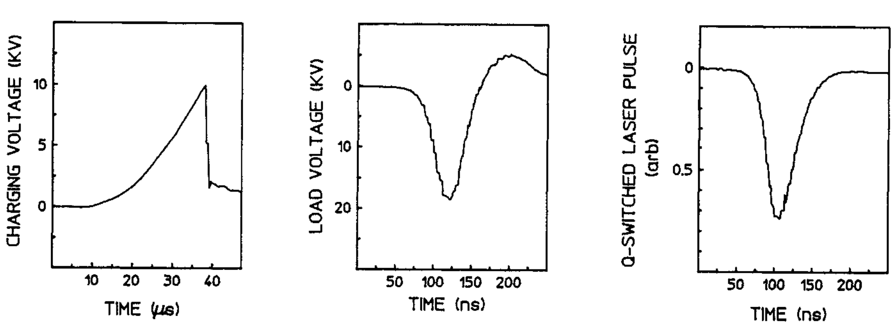

Figure 3. A comparison of the measured charging voltage and the resistive load voltage produced across the stack. A typical Q-switched laser pulse is presented for reference. A Si switch in the linear mode of operation was used.

An attempt to operate the pulser with the GaAs switch at charging voltages greater than 8 kV, in the avalanche mode, failed and the switch was damaged. The failure was due to the operation of the switch in excessively harsh conditions. We operated the switch in the air with the charging voltage durations of about 25 µs. Proper operation of the GaAs switches in the avalanche mode is usually achieved in the SF_6 or vacuum environments with charging durations of less than 500 ns. In addition, the switch contacts must be of high quality to allow reasonable operation. However, these preliminary results obtained by the switching of the stacked Blumlein pulser with the photoconductive switches demonstrated that the stacking function and related concepts are not affected by the photoconductive switches.

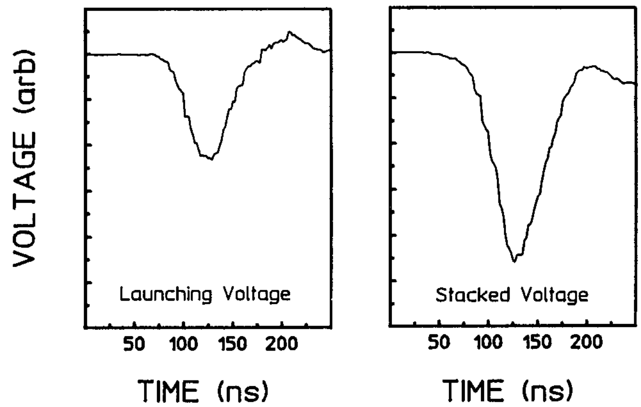

Figure 4. A comparison of the launching voltage and the voltage produced across the stack in the resistive loading mode of operation. A GaAs switch in the linear mode of operation is used as described in the text.

CHARGING PULSE COMPRESSION MODULE

The preliminary results obtained by the linear switching of the stacked Blumlein pulsers with photoconductive switches are encouraging. However, as described earlier, the application of linear switches require relatively high optical power for switch commutation. Conventional attempts to reduce the trigger requirements have focused upon nonlinear commutation such as employed in GaAs photoconductive switches operated in the avalanche mode. In all cases, fast pulse charging, in the order of hundreds of nanoseconds, has been used or recommended to operate the switch reliably.

In this work we introduced an intermediate pulser which might be described as a charging pulse compression (CPC) module. It supports the use of avalanche photoconductive switches in the final voltage multiplication device by conditioning the output of the first pulse charging power supply. The output is limited so the lines in the final module and the photoconductive switches in them would be subjected to voltages with durations less than 200 ns per each cycle of commutation.

Design and construction of the CPC is similar to the single Blumlein pulse generators as given elesewhere.[12,13] Briefly, it consist of two critical subassemblies: (1) a single Blumlein pulse forming line, and (2) a commutation system capable of operation at high repetition rates. The basic organization is shown schematically in Fig.5. The Blumlein was constructed from three copper plates 2.5 m long, potted with epoxy on outer surfaces to reduce corona, and separated by 1.65 mm thick laminated Kapton insulators. The switching and storage capacitances of the Blumlein were measured to be 6.3 nF each. The line had a smooth taper which decreased the width of the line from 20 cm at the thyratron to 10 cm at the load as shown in Fig. 5. This combined the functions of Blumlein and tapered pulse transformer increasing Blumlein voltage gain at the output.

In operation, the CPC was resonantly charged with a pulse power supply[1-3] capable of operation in the range of 3-75 kV and repetition rates of 1-1000 Hz. The middle conductor was charged to a positive high voltage and commutation was effected by a thyratron mounted in a grounded cathode configuration. Synchronization between various components in the system was maintained through a series of timing pulses generated by a master oscillator.[1-3] The output from this intermediate pulser was used to charge a 2-line stacked Blumlein pulser designed to be commuted with a GaAs photoconductive switch. The switching capacitance of this final voltage multiplication module was 305 pF. Figure 6 shows a charging profile obtained without commuting the photoconductive switch and represents a charging time of about 50 ns. A pulse from the master oscillator will be used to trigger a laser and provide trigger photons for the photoconductive switch at the peak of charging voltage seen in Fig. 6. It is expected that the fast charging capability of CPC module can significantly improve lifetime of photoconductive switches used in the stacked Blumlein pulsers.

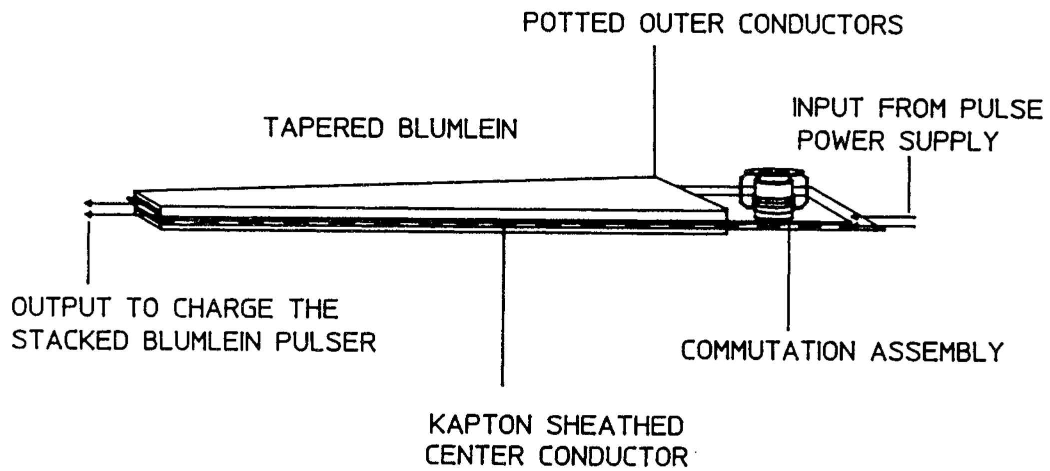

Figure 5. Schematic drawing of a high repetition rate charging pulse compression (CPC) module developed to provide fast charging for the stacked Blumlein pulsers commuted with photoconductive switches.

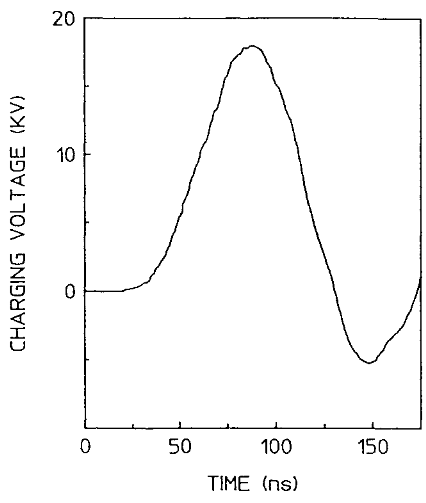

Figure 6. A voltage profile generated by CPC module charging a 2-line stacked Blumlein pulser. This particular waveform corresponds to an initial charging voltage of 7 kV and repetition rate of 10 Hz.

CONCLUSIONS

Advances in stacked Blumlein technology for voltage multiplication, together with the results obtained in this work, would seem to indicate the feasibility of an intense stacked Blumlein pulser commuted by photoconductive switches. The CPC module described here can be used to condition and compress the output of conventional pulse charging power supplies and provide fast charging for the main pulser commuted with the photoconductive switches. This intermediate pulser will support reliable operation of GaAs switches in the avalanche mode.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Air Force Phillips Laboratory, WSR, and U.S. Army Research Laboratory, PSD under contract DAAL01-95-K-3502.

REFERENCES

1. F. Davanloo, J.J. Coogan, T.S. Bowen, R.K. Krause, and C.B. Collins, "Flash X-ray Source Excited by Stacked Blumlein Generators," Rev. Sci. Instrum. 59, 2260 (1988).

2. J. J. Coogan, F. Davanloo, and C.B. Collins, "Production of High Energy Photons from Flash X-ray Sources Powered by Stacked Blumlein Generators," Rev. Sci. Instrum. 61, 1448 (1990).

3. F. Davanloo, R.K. Krause, J.D. Bhawalkar, F. Davanloo and C.B Collins, "A Novel Repetitive Stacked Blumlein Pulse Power Source," in Proceedings of the 8th International Pulsed Power Conference, 1991, pp. 971-974.

4. F. Davanloo, J. D. Bhawalkar, C.B. Collins, F. J. Agee, and L. E. Kingsley, "High Power, Repetitive Stacked Blumlein Pulse Generators Commuted by a Single Switching Element," in Conference Record of the 1992 Twentieth Power Modulator Symposium, 1992, pp. 364-367.

5. J. D. Bhawalkar, F. Davanloo, C.B. Collins, F. J. Agee, and L. E. Kingsley, "High Power, Repetitive Blumlein Pulse Generators to Drive Lasers," in Proceedings of the International Conference on Lasers '92, edited by C.P. Wang (STS Press, McLean, VA, 1993) pp. 360-364.

6. J. D. Bhawalkar, F. Davanloo, C.B. Collins, F. J. Agee, and L. E. Kingsley, "High Power Repetitive Stacked Blumlein Pulse Generators Producing Waveforms with Pulse Durations Exceeding 500 nsec," in Proceedings of the 9th International Pulsed Power Conference, 1993, pp. 857-860.

7. J. D. Bhawalkar, D.L. Borovina, F. Davanloo, C.B. Collins, F. J. Agee, and L. E. Kingsley, "High Power Repetitive Stacked Blumlein Pulse Generators," in Proceedings of the International Conference on Lasers '93, edited by V.J. Corcoran and T.A. Goldman (STS Press, Mclean, VA, 1994) pp. 712-717.

8. F. Davanloo, D.L. Borovina, J. D. Bhawalkar, C.B. Collins, F. J. Agee, and L. E. Kingsley, "High Power Repetitive Waveforms Generated by Compact Stacked Blumlein Pulsers," in Conference Record of the 1994 Twenty-First Power Modulator Symposium, 1994, pp. 201-205.

9. D.L. Borovina, F. Davanloo, C.B. Collins, F. J. Agee, and L. E. Kingsley, "Stacked Blumlein Pulsers Generating High Power Waveforms with Nanosecond Risetimes," in Proceedings of the International Conference on Lasers '94 (in press).

10. M.D. Pocha and R.L. Druce, "35-KV GaAs Subnanosecond Photoconductive Switches," IEEE Trans. Electron Devices, 37, 2486 (1990).

11. W. C. Nunnally, "Photoconductive Pulse Power Switches," in Proceedings of the 4th International Pulsed Power Conference, 1983, pp. 620-623.

12. C. B. Collins, F. Davanloo and T.S. Bowen, "Flash X-ray Source of Intense Nanosecond Pulses Produced at High Repetition Rates," Rev. Sci. Instrum. 57, 863 (1986).

13. F. Davanloo, T. S. Bowen and C. B. Collins, "Scaling to High Average Powers of a Flash X-ray Source Producing Nanosecond Pulse," Rev. Sci. Instrum. 58, 2103 (1987).