LA-UR- 97-2359

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CONF-9706113--20

Author(s): R. L. Carlson, M. Kang, J. G. Melton, G. J. Seitz, and L. T. Trujillo

Submitted to: 11th IEEE Pulsed Power Conference, June 29 - July 2, 1997, Baltimore, Maryland

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A 600-KV DOUBLE-PULSER FOR THE PHERMEX ELECTRON GUN*

R.L. Carlson, M. Kang, J.G. Melton, G.J. Seitz, and L.T. Trujillo
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, New Mexico 87545

Abstract

The PHERMEX Radiographic Facility is a 50-MHz, 3-Cavity, RF-Linac driven by a pulsed, thermionic electron-gun Injector. The PHERMEX is used to take flash radiographs using x-rays at a single time in an explosively driven event. To investigate the time evolution of these events requires two things: (1) a multiple-pulser to drive the electron-gun Injector and (2) a large-format, gamma-ray, camera system to record a scintillator at the different times. We report the recent success of developing a reliable double-pulser that consists of two Marx generators that independently charge two PFLs that are switched out at about 1.4 MV. The PFLs are connected in series by large diaphragm switches that are independently laser triggered by two quadrupled-YAG lasers. Recent tests of the system into a dummy load, produced two high quality 600 kV pulses separated by 1.0 μs. Each pulse has a FWHM of 90 ns, a 50 ns flat-top ± 3 %, and a risetime of 25 ns and a falltime of 35 ns. The interpulse time is variable up to about 275 μs; the first switch is kept closed by a "keep alive" inductor. The system has produced a 50 shot sequence of two pulses with a 1-sigma jitter <1 ns. The system has been modeled using TOSCA-3D, FLUX-2D, and a transmission line model run with the circuits code Micro-CAP.

Introduction

The PHERMEX (Pulsed High Energy Radiographic Machine Emitting X-rays) Facility [1] is a 50-MHz, 3-Cavity, RF-Linac driven by a pulsed, thermionic electron-gun Injector. The PHERMEX has been used for 35 years to take flash radiographs using x-rays of explosively driven events. Historically, the electron gun has been driven by an 11-stage, 275-ohm, cable-pulser, known locally as the Femcor (Field Emission Corp., McMinnville, Oregon), which can produce a 550-kV, 180-ns (FWHM) pulse into a matched load. The output of PHERMEX is a series of ten, 5-ns micro-pulses each separated by 20 ns; a shorter cable version of the Femcor (~100 ns) produces five of these micro-pulses. This micro-pulse structure is caused by the rf frequency of 50-MHz "chopping" the injected electron beam in the first of the three accelerating cavities even though the Injector continuously delivers current while being driven by the pulser.

In May of 1976, Physics International Company began the design of a "Triple-Pulser" [2] and the hardware was delivered to Los Alamos in early 1980. This pulser was to drive the electron gun with a train of three pulses, each about 40-ns FWHM, and deliver two x-ray micro-pulses per gun pulse. It was hoped that near-Femcor radiation levels could be achieved with three sets of two micro-pulses each by operating the gun at up to 1.5 MV. Unfortunately, the electron gun was not reliable at ~1

*Work performed under the auspices of the U.S. Department of Energy.

MV and additional concerns for the reliability and jitter of the electrically triggered diaphragm switches [3] led to the pulser not being used to support the hydrodynamics program at Los Alamos. Instead, a program to develop a more reliable electron gun capable of delivering 1 kA at 1 MV was undertaken [4]. A parallel effort by Pulse Sciences, Inc. in August of 1983 resulted in the design of a connection using the Los Alamos, Antares-type cable [5] (3-inch-diam, 145 kVAC utility cable, pulse tested to 1 MV). The first pulse of the pulser became operational in June 1985 and was used to support electron beam propagation programs [6] at the PHERMEX through 1986. This configuration produced about 855 A in a 50-ns FWHM pulse at an electron gun voltage of ~900 kV.

The success in 1990 of a flat-cathode used in the development of the REX Injector [7] was further investigated as to its application [8] to the PHERMEX. This effort led to the design and deployment of a new flat-cathode thermionic gun [9] having 2.5 times the perveance of the original gun while simultaneously reducing critical field stress areas by a factor of two. With the installation of the improved electron gun and the advent of laser-triggered switch technologies by the pulsed power community, we embarked on a redesign and modification to the Physics International Company pulser hardware. A corresponding commitment to the multi-pulse detection issue has led to the development and recent deployment of a large-format, gamma-ray camera system [10].

Double-Pulser Description

Fig 1 shows the present double-pulser which consists of two Marx generators that independently charge two PFLs (each 15.5 Ω for ethylene glycol with ϵ_r=43) to about 1.4 MV at switch out. The available real estate (tank dimensions are 36x36x230 inches) has been used to provide two longer pulses (i.e. higher dose) rather than the historical three shorter pulses. This configuration directly compliments the gamma-ray camera system. The PFLs (7-inch-diam inner lines) are connected in series by 36-inch-diam (13.5-inch thick), Furane epoxy, diaphragm switches that are independently laser triggered. The two lasers (Spectra Physics GCR-170) are quadrupled YAG at 266 nm capable of delivering >100 mJ in a ~ 5 ns pulse. The beams are transported radially through acrylic tubes,

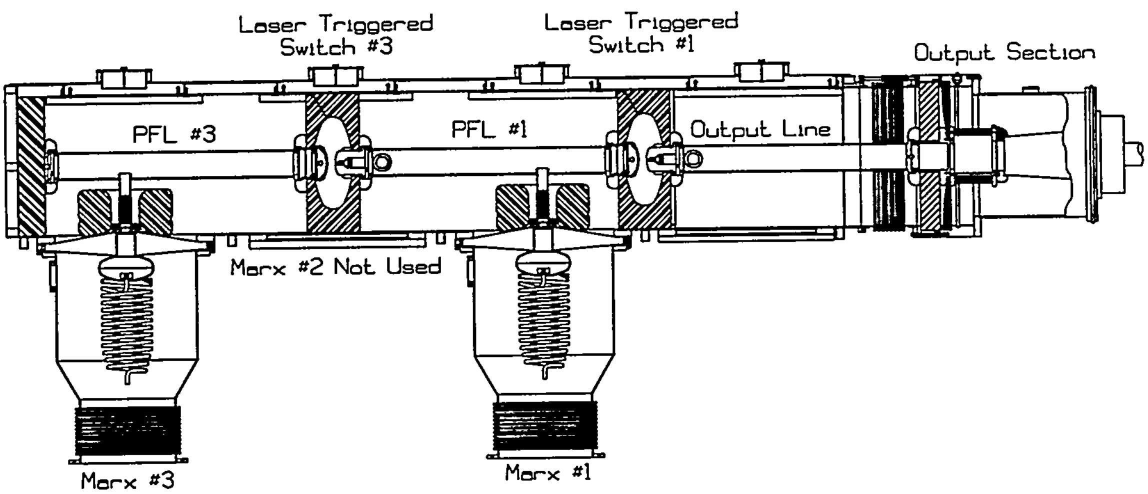


Fig 1. PHERMEX Double-Pulser as modified from the "Triple-Pulser".

turned at right angles, and focused (f=255 mm lens) on axis between the switch electrodes (see Fig 4). The system utilizes a square cross-section tank to hold the ethylene glycol that makes up the dielectric fluid of the PFLs. Each PFL is charged by its Marx through inductive charging feeds (~15 μH) isolated by 41.25-inch-diam, polyurethane, feed diaphragms (aperture is 36-inch-diam) in the bottom of the tank. A Furane epoxy torus surrounds each feed to displace the higher permitivity ethylene glycol further reducing the coupling between the pulse traveling down the center conductor and the Marx generator. The Marx generators consist of 27 plus and minus stages utilizing Aerovox 100 kV, 0.07 μF capacitors which provides a good match to the PFLs. Marx #1 is generally charged to 34 kV and Marx #3 is charged slightly higher to 37 kV to compensate for the reverse polarity voltage generated by the "keep alive" inductor in Marx #1. The purpose of this 1 mH "keep alive" inductor is to drive a low (~kA's) current through Switch #1 keeping it closed until Switch #3 is triggered. Both switches have adjustable gaps set at 5 cm and are fired before the peak charge of the PFLs at about 1.4 MV which produces a 750 kV pulse on the Output Line. Switch #1 and Switch #3 operate at 50- and 90-psig, respectively.

The 15.5-Ω Output Line is matched to the 35.5-Ω Antares cable utilizing a 25-Ω radial resistor followed by a 5-Ω series resistor as shown in Fig 2. The electron gun is transient time isolated by 70 ns of Antares cable. Previously, the radial and series resistors were set at 20.6-Ω and 26.7-Ω that provided a forward going match into the cable and, to first order, a match for returning reflections from the electron gun. The present design (see Fig 3) incorporates a matching radial resistor at the electron gun which allows a lower value of series resistor thus reducing the voltage division penalty for the forward going pulse. At 600 kV the new electron gun delivers about 1.25 kA; the cable impedance of 35.5-Ω is matched to this gun impedance of 480 Ω by adjusting the radial resistor to about 38-Ω. Fig 3 also shows the filament plunger that is used to keep the thermionic gun filament energized; it is retracted about one second before firing the system. The canisters that contain the ends of the Antares cables are pressurized with 5 psig of SF_6.

Double-Pulser Modeling

Based upon the previous performance of the "Triple-Pulser" with only PFL #1 driving the electron gun as shown in Fig 5, it was anticipated that the system would need to be tuned after initial operation for pulse flatness and risetime. The PFL portion of the system is clearly 3-D and necess-

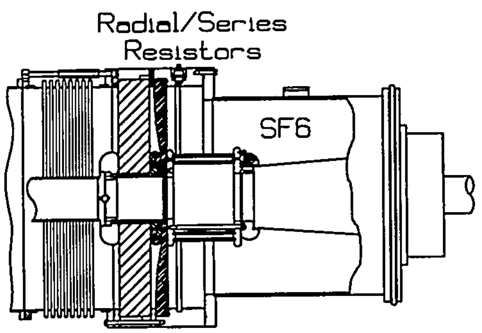


Fig 2. Output Section of Pulser.

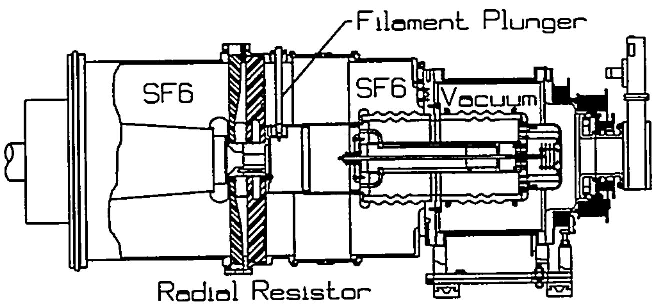
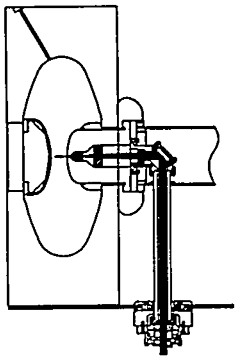


Fig 3. Connection to Electron Gun.



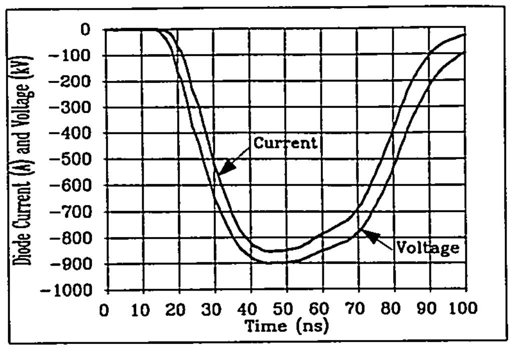
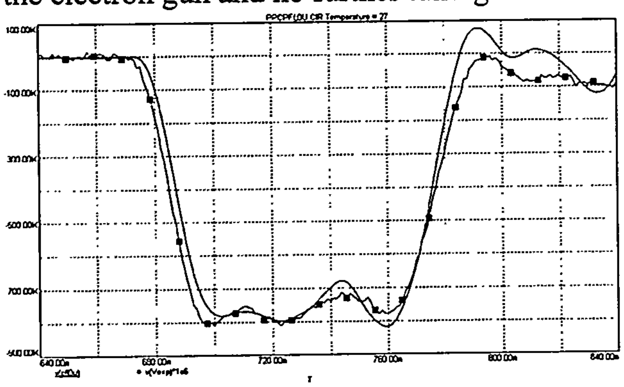


Fig 4. Laser-triggered Switch Assembly.

Fig 5. PFL #1 pulse from "Triple-Pulser".

itated the use of a 3D electro-magnetic field program; the TOSCA-3D code [11] was chosen for this task. The cylindrical sections were modeled using FLUX-2D [12]. The outputs of these codes give L's and C's that enable a 1D transmission line model to be made. As can be seen in Figs 6 and 7, results of simulations using the circuit code Micro-CAP [13] agree quite well with the detailed measurements of system performance as measured into the dummy load. The effect of the ~430 nH of inductance at each end of the Antares cable connections (see Figs 2 and 3) can be seen to substantially degrade the computed rise/fall times from 17/16 ns to 25/23 ns while the flattening of the top of the pulse is beneficial. The pulses presently obtained are considered acceptable to drive the electron gun and no further tuning has been attempted.



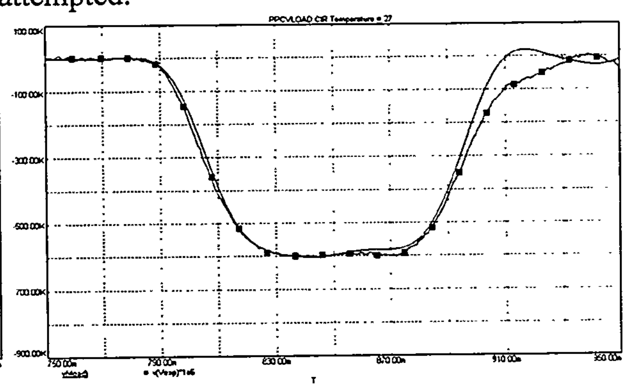


Fig 6. PFL #1 pulse at Output Line exit.

Fig 7. PFL#1 pulse at Dummy Load.

(V = 100 kV/div and H = 20 ns/div for both computed (solid line) and experimental (■) traces)

Double-Pulser Performance

The system was recently demonstrated with a 50 shot sequence producing two 625 kV pulses separated by 1.0 μs with a 1 sigma jitter of <1 ns as shown in Fig 8. These tests utilized the dummy load shown in Fig 9 which replaced the connection to the electron gun of Fig 3. The input capacitance of the electron gun was simulated by an ethylene glycol capacitor (~120 pF) and the voltage was recorded by an integrated E-dot probe indicated as V(load) in Fig 9. The two pulses are shown in greater detail in Figs 10 and 11. Each pulse has a FWHM of 90 ns, a flat-top portion of ± 3% over 50 ns, and a rise/fall time of 25- and 35-ns, respectively. The low switch jitter will allow synchronization of the pulser to the 50 MHz RF effectively centering four micro-pulses within the

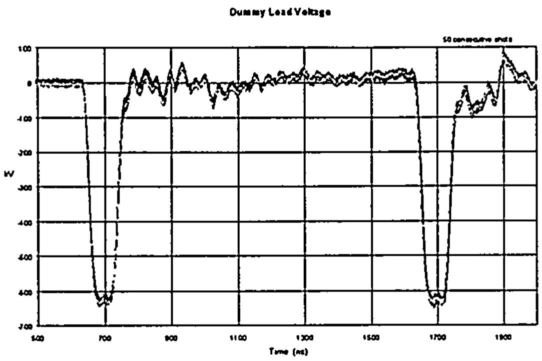


Fig 8. 50 shot overlay at V(load) giving - 625 kV for two pulses separated by 1 µs.

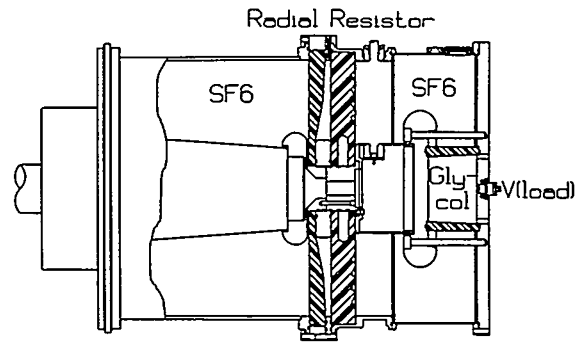


Fig 9. Dummy Load used to simulate the electron gun input capacitance.

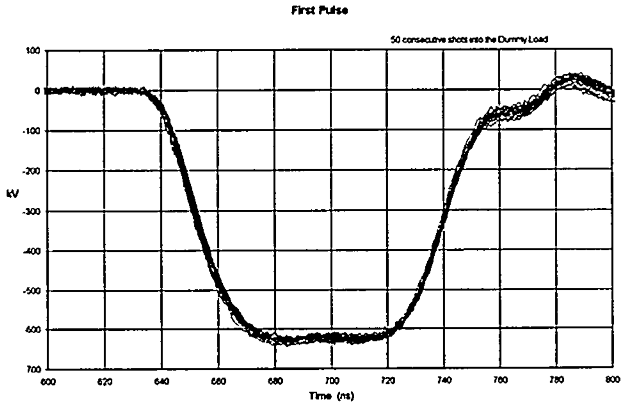


Fig 10. 50 shot overlay at V(load) from PFL #1, (V = 100 kV/div, H = 20 ns/div).

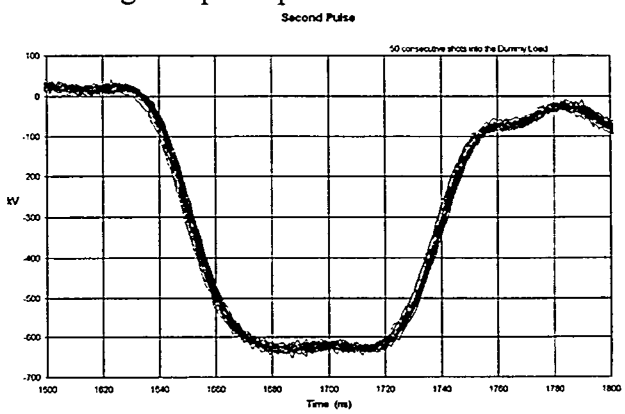
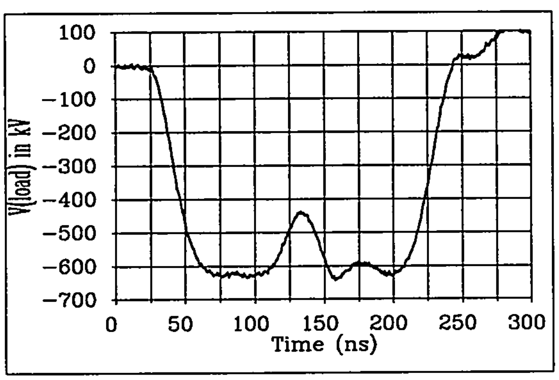


Fig 11. 50 shot overlay at V(load) from PFL # 3, (V = 100 kV/div, H = 20 ns/div).

electron gun pulse envelope eliminating the need for any faster rise/fall times than those presently achieved. Fig 12 shows the two PFLs triggered one transient time apart producing, to first order, a single electron-gun drive pulse. Fig 13 shows the second pulse at 10 ms interpulse separation. Switch #1, almost recovered, reflects the leading 10-ns edge while re-closing to let the remainder of the pulse through. The reflected edge appears as a second pulse ~4 PFL transit times later.



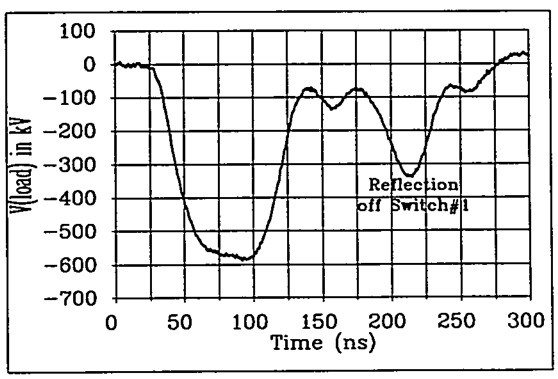


Fig 12. PFL #1 and PFL #3 pulses merged.

Fig 13. PFL #3 pulse delayed by 10 ms.

Conclusions

The use of laser-triggered switches has allowed the construction and demonstration of a reliable double-pulse, PFL-based system that reproducibly generates 600 kV pulses with jitter ~1 ns. The fact that the switches can be operated well above self-break yet be reliably triggered by the lasers, allows the switch-out time to be precisely controlled and can be used to tune the pulse shapes. Although the lasers were capable of delivering >175 mJ to the switches, reliable triggering was easily achieved with ~15 mJ. The next step is to connect the pulser to the electron gun and complete the integration to the PHERMEX facility. The PHERMEX will soon make history using this new multiple-pulser coupled to the gamma-ray camera system in taking the first double-pulse radiograph this summer.

Acknowledgments

Special thanks go to Lee Builta, now retired from Los Alamos, who worked on the pulser from its inception over 20 years ago and has offered the authors invaluable of advice and help. Much of the fabrication and installation of controls and facility improvements are due to the efforts of Bernard Hawkins III, Chris Moore, and Art Villalobos of Bechtel Nevada. Harley Lane and Don Rodriguez were responsible for the mechanical design and installation supported by Dan Custer, Steve Gonzales, and Alan Tubb of design/drafting. Finally, thanks to the engineers at Physics International Company whose ideas were ahead of their time in conceiving of this pulser.

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