ULTRA-LOW-JITTER REPETITIVE SOLID STATE PICOSECOND SWITCHING*

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Abstract

Ultra-low-jitter repetitive solid state picosecond switching is being developed for application to electromagnetic impulse sources. Ultra-low-jitter and fast risetime are required to synchronize multiple modules of radiating array sources. Laser controlled photoconducting switches provide low jitter but have limited lifetime and are too expensive for many commercial applications. We are studying an alternative method using inexpensive delayed avalanche breakdown semiconductor closing switches in an artificial transmission line configuration to generate powerful electromagnetic shockwaves.

As an example of the new technology, we present experimental results for a miniature (volume < 25 cm^3) 3 kV pulser which provides RMS jitter of 16 ps with 100 ps risetime at 2 kHz repetition rate. The miniature pulser employs 18 delayed breakdown silicon avalanche switches in a differential shockline topology. SPICE-based circuit modeling results are compared to experimental measurements. The circuit modeling includes effects of stray capacity and a Monte-Carlo jitter analysis. The picosecond pulsers can be used for impulse sources, Pockels cell drivers, trigger generators, and pulse power applications. The modeling techniques are applicable to Marx generators and circuits containing large numbers of switches with capacitive cross coupling.

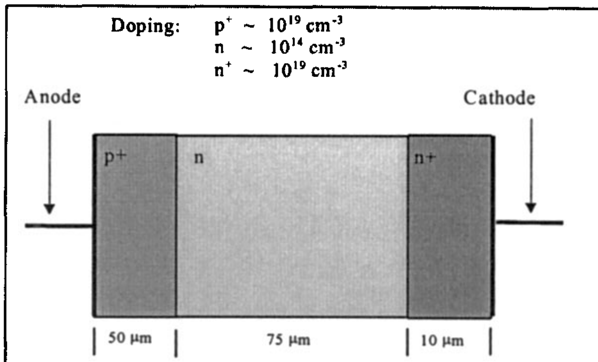

Fig. 1. Delayed breakdown device structure

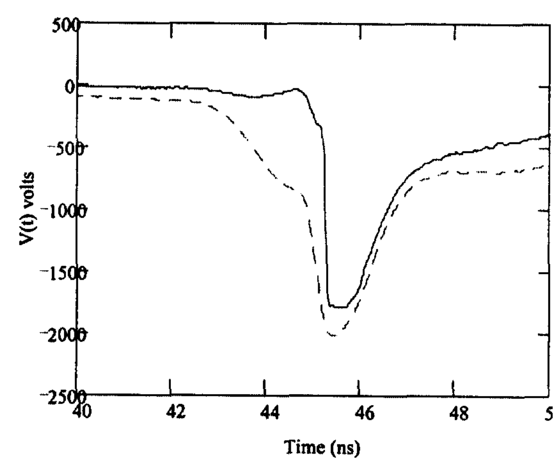

Fig. 2. Measured voltage waveforms show driving pulse (dashed) & sharpened output pulse (solid line)

I. DELAYED BREAKDOWN SWITCHING

The delayed breakdown effect was discovered by I. V. Grekhov and A. F. Kardo-Sysoev of the Ioffe Institute in St. Petersburg, Russia.[1,2] When certain silicon diode structures are rapidly overvolted beyond static breakdown, there is a delay of several nanoseconds before a fast breakdown. Figure 1 shows a typical delayed breakdown device (DBD) structure. Picosecond breakdown occurs as an ionization wave sweeps across the intristic material faster than the carrier drift velocity.

The University of New Mexico School of Electrical Engineering recently evaluated DBD switching technology by testing Russian DBD devices.[3,4] Commercial silicon devices have also demonstrated

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14. ABSTRACT
Ultra-low-jitter repetitive solid state picosecond switching is being developed for application to electromagnetic impulse sources. Ultra-low-jitter and fast risetime are required to synchronize multiple modules of radiating array sources. Laser controlled photoconducting switches provide low jitter but have limited lifetime and are too expensive for many commercial applications. We are studying an alternative method using inexpensive delayed avalanche breakdown semiconductor closing switches in an artificial transmission line configuration to generate powerful electromagnetic shockwaves. As an example of the new technology, we present experimental results for a miniature (volume c 25 cm3) 3 kV pulser which provides RMS jitter of 16 ps with 100 ps risetime at 2 kHz repetition rate. The miniature pulser employs 18 delayed breakdown silicon avalanche switches in a differential shockline topology. SPICEbased circuit modeling results are compared to experimental measurements. The circuit modeling includes effects of stray capacity and a Monte-Carlo jitter analysis. The picosecond pulsers can be used for impulse sources, Pockels cell drivers, trigger generators, and pulse power applications. The modeling techniques are applicable to Marx generators and circuits containing large numbers of switches with capacitive cross coupling.

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delayed breakdown and can perform as picosecond switches.[5] We have extended this technique to low jitter command triggered shockline pulsers using multiple devices.

Figure 2 shows experimentally measured waveforms for a 0.010 cm^2 area silicon device. The data were acquired with a Tektronix 11801 sampling digitizer. The slow rising (dashed line) waveform is the pulse charging waveform, while the fast rising waveform is the output voltage from the diode shaper. The two waveforms are time correlated. The DBD switch was effective at blocking the prepulse and slow rise and switching rapidly near peak voltage giving a risetime of 355 ps to a 1.76 kV peak voltage with a pulse width (FWHM) of 1.45 ns. The pulse charging waveform had a risetime of 2150 ps. To reduce the circuit inductance, we constructed a tight coaxial test fixture. This configuration gave faster switching with risetime of 135 ps to 2.2 kV.

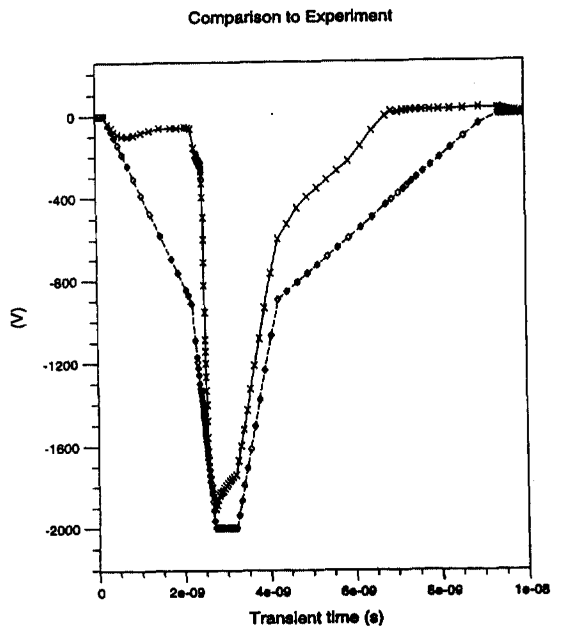

Fig. 3. Simulation of delayed breakdown in silicon

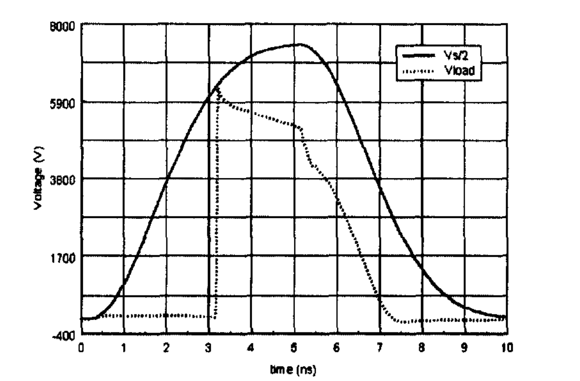

Fig. 4. Simulation of SiC device shows $\Delta V = 6.2$ kV, $\Delta t = 50$ ps, and $dV/dt = 1.24 \times 10^{14}$ V/s.

The Silvaco 2-D device physics code was used to model the structure of figure 1. Figure 3 shows that the simulation gives good agreement with the measurement of figure 2. This is one example of many simulations which were performed to understand the delayed breakdown process. Silicon carbide (SiC) devices were also studied. Figure 4 shows extremely good switching results for a SiC device with a structure similar to figure 1.

II. SHOCKLINE PULSERS

We use multiple delayed breakdown avalanche switches in a tapered artificial transmission line structure to achieve high voltage ultra-fast pulses. The delayed breakdown switches are used in series with the inductors of an LC-ladder-line as shown by figure 5. The first switch is triggered, and all of the other switches are overvolted. The triggered switch can be a bipolar avalanche transistor, MOSFET, or a laser controlled photoconducting switch.

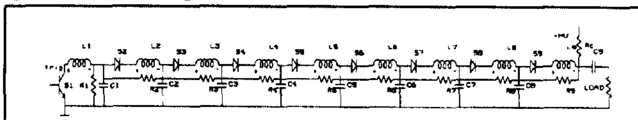
Fig. 5. Closing switches in series with the inductors of an LC-ladder-line generate EM-shockwaves

A higher output level can be delivered to a balanced load by operating two oppositely charged stacks of delayed breakdown devices as a balanced pulser. This configuration provides a pair of simultaneous opposite polarity output pulses. The two switch stacks are synchronized by cross connecting each stage with a capacitor. The high voltage differential output allows efficient coupling to a balanced ultra-wideband impulse radiating antenna without need of a balun network.

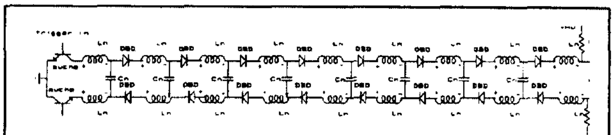
Fig. 6. A balanced version of the LC-ladder-line pulser using delayed breakdown switches gives differential output

Figure 6 illustrates the balanced shockline which evolves from the unbalanced circuit by mirror image reflection about the ground plane. This circuit has the advantage of automatically synchronizing each stage through the cross coupling capacitor.

III. PULSER SIMULATIONS

We modeled the differential 9-stage pulser using SPICE simulation. The voltage controlled latching switch model was repeated 18 times, and statistical variations in switch breakdown voltage were also studied. The breakdown voltage was set at 450 V for each of the 18 switches. An increase of 150 V above the static voltage was required to

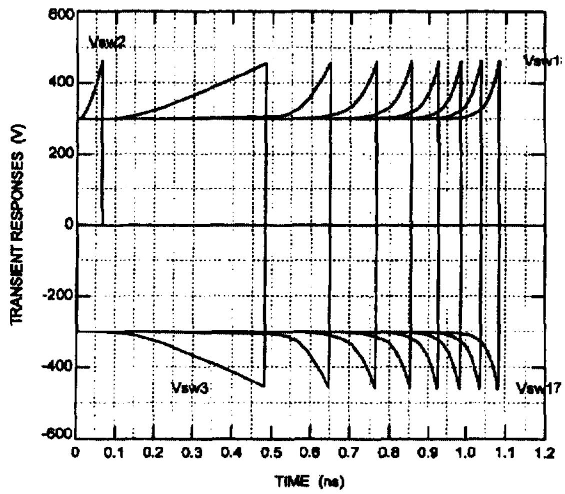

Fig. 7. Pulse charging ramp and discharge for each of the 18 switches

break down the switch. Figure 7 shows the voltage waveform across each of the 18 switches. Switch #1 is fired at time zero, switch #2 breaks down at approximately 63 ps, and each successive switch breaks down with a shorter time interval as the electromagnetic shockwave builds. The two sides of the stack, self synchronized to within 1 ps.

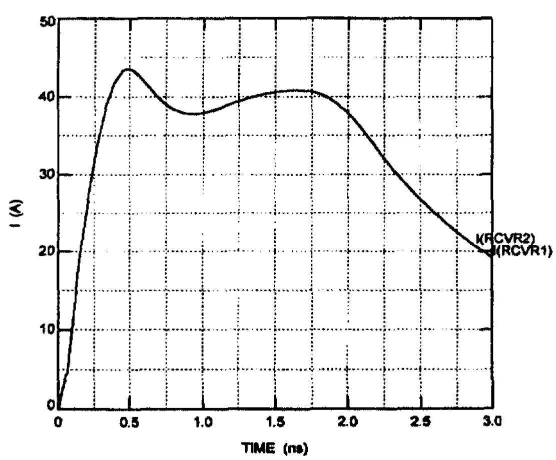

Fig. 8. Simulated current waveform for stage 1 of the 9-stage LC-ladder-line pulser

Figure 8 shows the current waveform passing through the first switch. The current rises to a constant level. A flat current waveform in the first switch indicates proper tuning the stage capacitors. Figure 9 shows the simulation predicts a 94 ps risetime 3.5 kV output pulse into a 100 ohm resistive load.

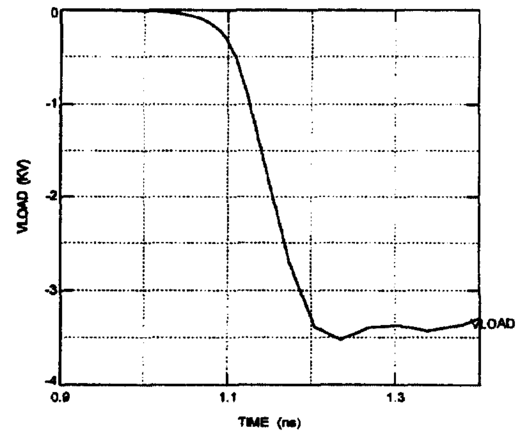

Fig. 9. Simulation result for output voltage waveform into a 100 ohm balanced load

IV. PULSER MEASUREMENTS

We performed experimental measurements on a balanced pulser which validated SPICE based circuit modeling. The dual polarity 9-stage pulser provided a balanced output voltage of 3.18 kV with a 0.1 ns risetime. The positive and negative outputs were well synchronized, and command triggering jitter of below 16 ps was achieved. The experimental results show good agreement with the simulation predictions.

The balanced output pulser circuit was fabricated on a printed circuit board with 9 switches on each side of the board for a total of 18-switches. The two 9-stage switch stacks were synchronized by capacitor cross coupling at each stage as shown by figure 6. The first stage switch on one side only was a base triggered bipolar transistor operated in avalanche mode. All other switches were silicon devices operated in delayed breakdown mode.

Each 50 ohm output fed a separate 50 ohm high voltage attenuator. The Tektronix 11801 sequential sampling digitizer was externally triggered.

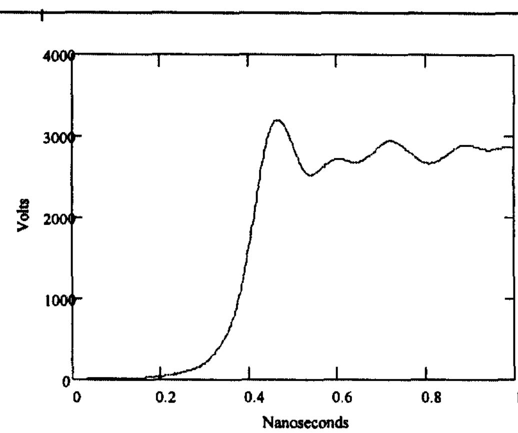

Fig. 10. Differential output voltage waveform

The positive and negative output voltage waveforms were numerically combined to give the differential voltage. Figure 10 shows the resulting output voltage waveform. The risetime is 104 ps to a peak voltage of 3.18 kV. The fast rising edge was then digitized without averaging. A least squares linear fit to the data gave an RMS command trigger jitter value of below 16 ps.

Table 1 gives the values for the key pulser output parameters. The first row of table 1 shows the SPICE simulation where all 18 switches are set to break down at a fixed voltage level of 450 V. The second row shows the results of a Monte Carlo simulation where the 18 switches are each set to break down at a voltage of 450 V ± 1%. The listed variations (±xx) on the table represent the calculated one standard deviation levels for the set of 101 runs.

Table 1. BALANCED 9-STAGE PULSER

Case	Peak Voltage kV	Risetime ps	Peak dV/dt kV/ns	RMS Jitter ps
SPICE	3.52	93.6	36.8	0.0
Monte Carlo	3.52±.02	93.0±.8	37.4±.6	5.3
Measurement	3.18	104	35.2	< 16

V. RADIATING IMPULSE SOURCE

The 3 kV shockline pulser was combined with a 9-inch diameter dielectric lens antenna to form a compact radiating impulse source. The compact source which operates from a 12-volt lantern battery provides a 100 ps impulse with a peak electric field of 1 kV/m at 3 meter range.[6] Figure 11 shows the measured electric field waveform on-axis and 3 meters from the source. Figure 12 shows the source being calibrated outdoors on a nonconducting platform.

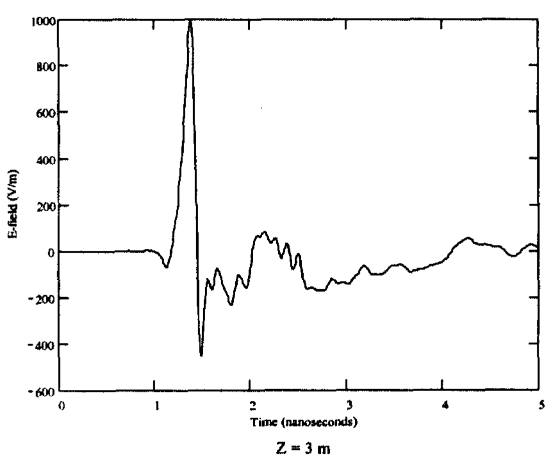

Fig. 11. Measured electric field waveform with the probe on axis and 3 meters from source

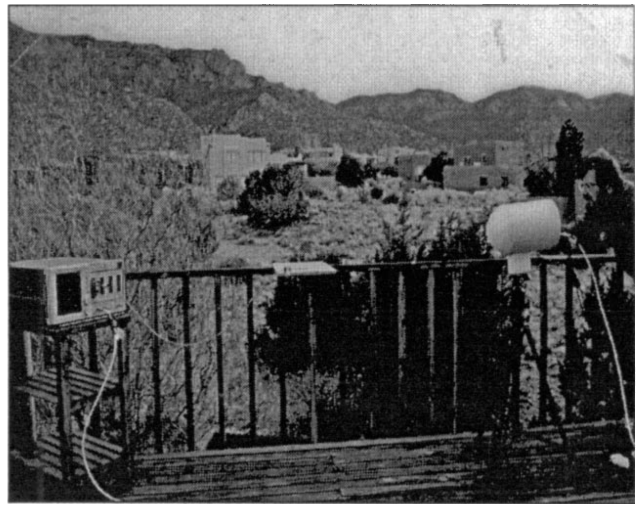

Fig 12. Photograph of the experimental setup used to characterize the compact impulse source

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