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80-kW Inductive Pulsed Power System with a Photoconductive Semiconductor Switch

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Abstract—**The performance of the GaAs photoconductive semiconductor switch has been optimized in the current-charged transmission-line configuration to produce a power gain of 45 with an output pulse of 80 kW. The switch was activated by a square optical pulse resulting in a low on-state switch resistance and substantially-improved power gain.**

A jitter-free-opening switch with a fast opening time is necessary in an inductive energy storage pulsed power system (IESPPS)—where energy is stored by current in an inductor or transmission line. The GaAs photoconductive semiconductor switch (PCSS) appears to be ideal for this application [1]–[4], and we have demonstrated its operation in an IESPPS delivering an 80-kW output pulse with a power gain of 45.

The IESPPS used in this work is a current-charged transmission line (CCTL) [2], [5] with PCSS coupled to a capacitor as shown in Fig. 1. This configuration is capable of delivering into the matched load a square voltage pulse of amplitude greater than the initial voltage across the capacitor. When the switch is closed, the capacitor, initially charged to V_o, is the source of a current traveling wave of amplitude $I = V_o/Z_o$, where Z_o is the characteristic impedance of the CCTL. As the traveling wave meets either end of the CCTL, it is reflected back in the opposite direction causing the current to increase by a step of $I = 2V_o/Z_o$ after each round trip in the CCTL. For the purpose of estimating the charging current, the IESPPS may be treated as a lumped circuit by replacing the CCTL with its equivalent inductance L. Taking R_s as the on-state switch resistance and R_l as the load resistance, the current $I(t)$ through the inductor L is given by

$$I(t) = I_o e^{-\alpha t} \sin \omega t \qquad (1)$$

where $I_o = (V_o R_l)/[L\omega(R_l + R_s)]$, $\omega = \sqrt{R_l/[LC(R_l + R_s)] - \alpha^2}$, and $\alpha = (R_l R_s C + L)/[2LC(R_l + R_s)]$.

The GaAs PCSS was tested in the IEPPS configuration of Fig. 1. The switch is activated by a custom-tailored 1.05-μm square laser pulse, generated by a free-running Nd:Glass laser flashlamp pumped just above the lasing threshold. The laser produces a 2-μs pulse. A Pockels cell between crossed polarizers chops the pulse into a 540-ns square pulse that is then sent through a two-stage double-pass amplifier. The final output energy is ~ 10 mJ.

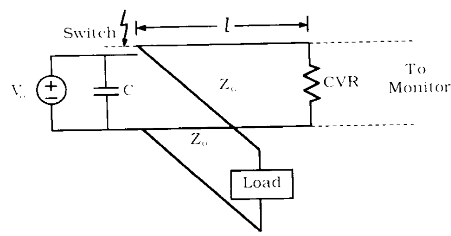

Fig. 1. Current charged transmission line scheme for this experiment, $l = 2.0$ m, $Z_o = 50\ \Omega$, $R_{\text{load}} = 50\ \Omega$, $C = 1.1\ \mu$F, $R_{\text{CVR}} = 0.1\ \Omega$ (current viewing resistor).

The switch under test was a 5-mm cube of GaAs of the p-i-n configuration [6] operated under reverse bias. The $C = 1.1\ \mu$F capacitor was initially charged to $V_o = 300$ V. When the PCSS was closed by the optical pulse, the current through the current viewing resistor, $I(t)$, and the voltage across the matched 50 Ω load, $V_{\text{out}}(t)$, were monitored simultaneously with oscilloscopes. The dynamic switch resistance $R_s(t)$ was then numerically computed according to the equation

$$R_s(t) = \left(V_o - \frac{1}{C}\int I(t)\,dt - V_{\text{out}}\right)/I(t). \qquad (2)$$

The 2.0 kV, the 80-kW output pulse produced by a 2.0-m CCTL is shown in Fig. 2. With $V_o = 300$ V, this output pulse corresponds to a voltage gain of 6.7. If the power gain is taken as the ratio of the peak power delivered through the CCTL configuration to the peak power that would be delivered directly into the load from the capacitor, the corresponding power gain is 45. This is the highest power gain achieved to date using this configuration.

The square optical pulse offers two advantages over the slowly rising pulse that was used in previous work [4]. First, the rate at which current builds up in the CCTL is increased since the on-state switch resistance drops, not gradually, but immediately to a low value. It can be seen in Fig. 3 that $R_s(t)$ quickly drops below 10 Ω and remains low until the switch opens. The low on-state switch resistance combined with a longer charging time produces a much higher current in the CCTL than in our previous work, accounting for the great improvement in power gain [4]. Second, the square pulse produces a nearly constant on-state switch resistance

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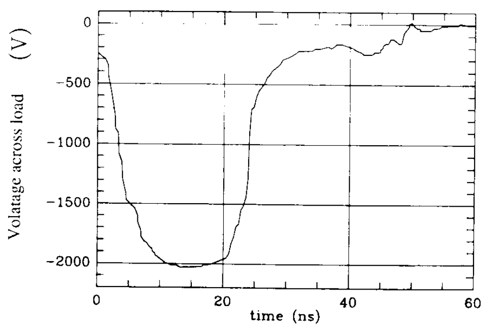

Fig. 2. 2.0-kV output pulse across R_{out} achieved when V_o = 300 V.

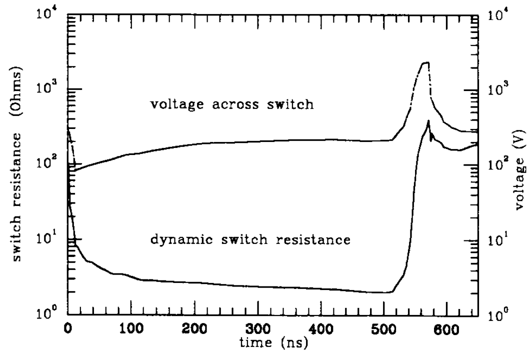

Fig. 3. Dynamic switch resistance $R_s(t)$ and voltage across the switch $V_s(t)$. Switch closes at t = 0 and opens at t = 540 ns, V_o = 300 V.

R_s, allowing direct comparison to the theoretical prediction of (1). Both the theoretical and experimental waveforms of current through the CVR are shown in Fig. 4 . The reasonable fit to the experimental curve suggests that the experimental R_s may be as low as 1.2 Ω.

A prominent feature of the dynamic switch resistance curve shown in Fig. 3 is the drop in switch resistance that occurs after the laser pulse has been extinguished. This occurs when the voltage drop across the switch V_s reaches a critical value of 2.2 kV corresponding to an electric field of 4.4 kV/cm across the switch. That may be compared to the critical lock-on field [7], [8] of ~3.6 kV/cm suggesting that this behavior may be related to the lock-on effect seen in many closing switch experiments. This effect limited the output voltage to ~2 kV even when higher charging voltages were used. In the future this effect will be countered by use of a longer switch that will in turn increase the voltage required to produce the critical field. The characteristics of this phenomenon in the opening switch will also be further investigated.

In conclusion, a power gain of 45 has been demonstrated

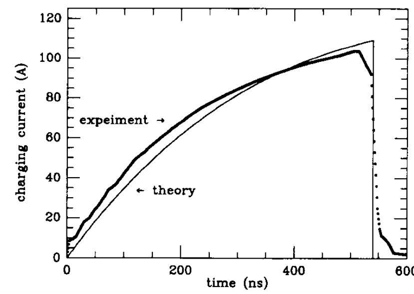

Fig. 4. Charging current waveform monitored by the current viewing resistor (CVR), experimental result (switch opens at t = 540 ns) and theory (switch resistance set to R_s = 1.21 Ω).

in a current-charged transmission line with a GaAs PCSS. The fast falltime of the switch resistance produced by the specially tailored optical pulse that activates the PCSS is mainly responsible for the high power gain achieved in this experiment. An effect similar to lock-on was found to limit the output voltage to ~2 kV.

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