Minimizing Solid-State Switch Transition Times for Compact Spiral Generators

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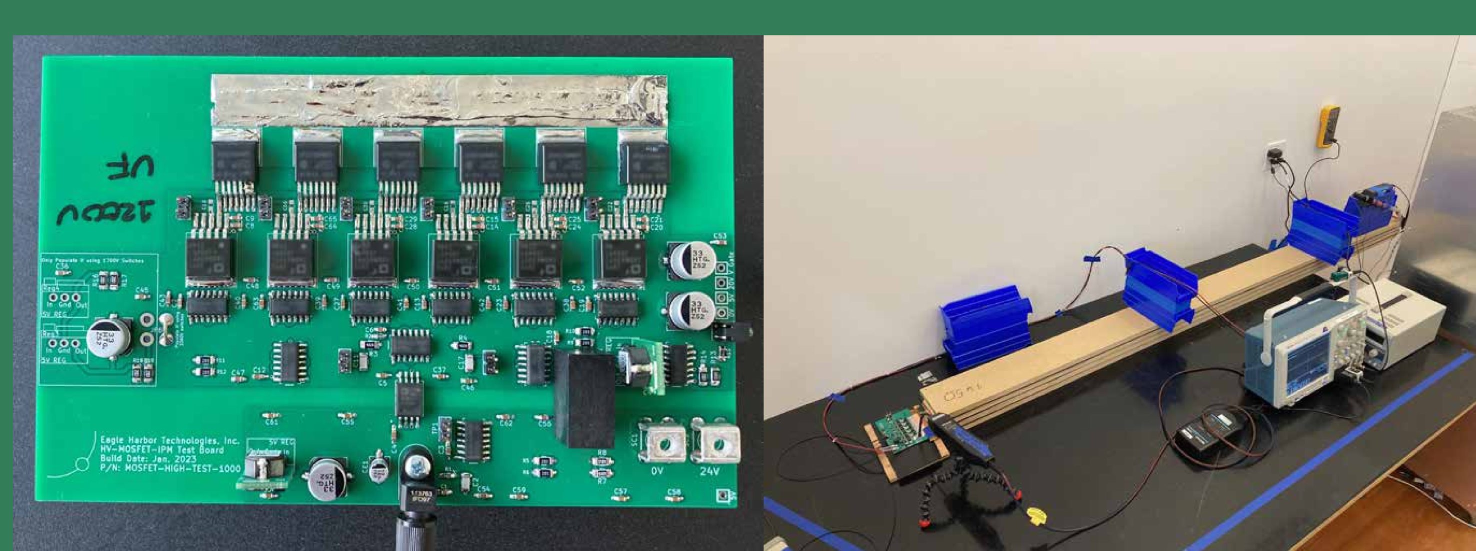
Introduction

Spiral generators offer a compact way of creating high-voltage (HV) pulses on the order of tens to hundreds of nanoseconds. They contain the energy storage and produce a voltage step-up. An instigating pulse aligns electrical fields as it travels around the spiral generator and allows for a summation of fields across the output. For this to occur, the transition time of the switch, which produces the instigating pulse, must be significantly shorter than the propagation time through the spiral. Historically, spark-gap switches have been used due to their high voltage standoff and fast transition times. However, modern solid-state switches can achieve significantly higher pulse repetition frequencies (PRF). This work explores the use of wide-bandgap switches to achieve the fastest possible transition time for triggering spiral generators at high PRF. The performance of silicon-carbide (SiC) MOSFETs and gallium-nitride (GaN) high-electron-mobility transistors (HEMT) are compared. Alternative gate drive topologies are also investigated to further push the limits of the switch transition times. Transition times are evaluated in relation to both charge voltage and current through the switch. We achieved sub-5 ns transition times when charged to 1 kV and a PRF up to 30 kHz. The fast transition times presented will enable the future development of more compact spiral generators.

Switch Fall Time Testing Setup

EHT designed a test setup to measure the V_{DS} fall time for a variety of solid-state switches. Each test board included six solid-state switches operating in parallel. A resistive test load would be too inductive. Instead, the switch board was connected to a transmission line with a known impedance (5, 10, & 15 Ω) that was charged to a specified voltage. The V_{DS} transition was measured with a Tektronix IsoVu probe (200 MHz bandwidth).

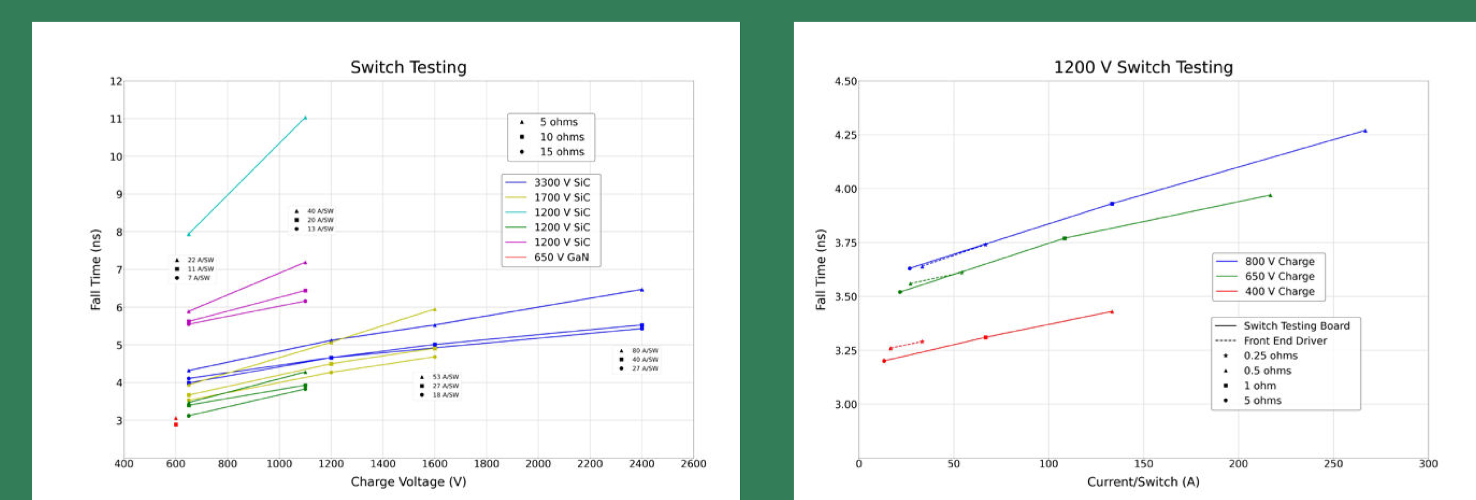


1200 V SiC MOSFET test boards (left). Test board connected to transmission line with V_{DS} measurement probe (right).

V_{DS} fall times of a SiC MOSFET at 650 V into transmission lines of different impedances: 15 Ω (blue), 10 Ω (red), 5 Ω (green), 1 Ω (orange), and 0.5 Ω (brown).

Switch Fall Time Testing Results

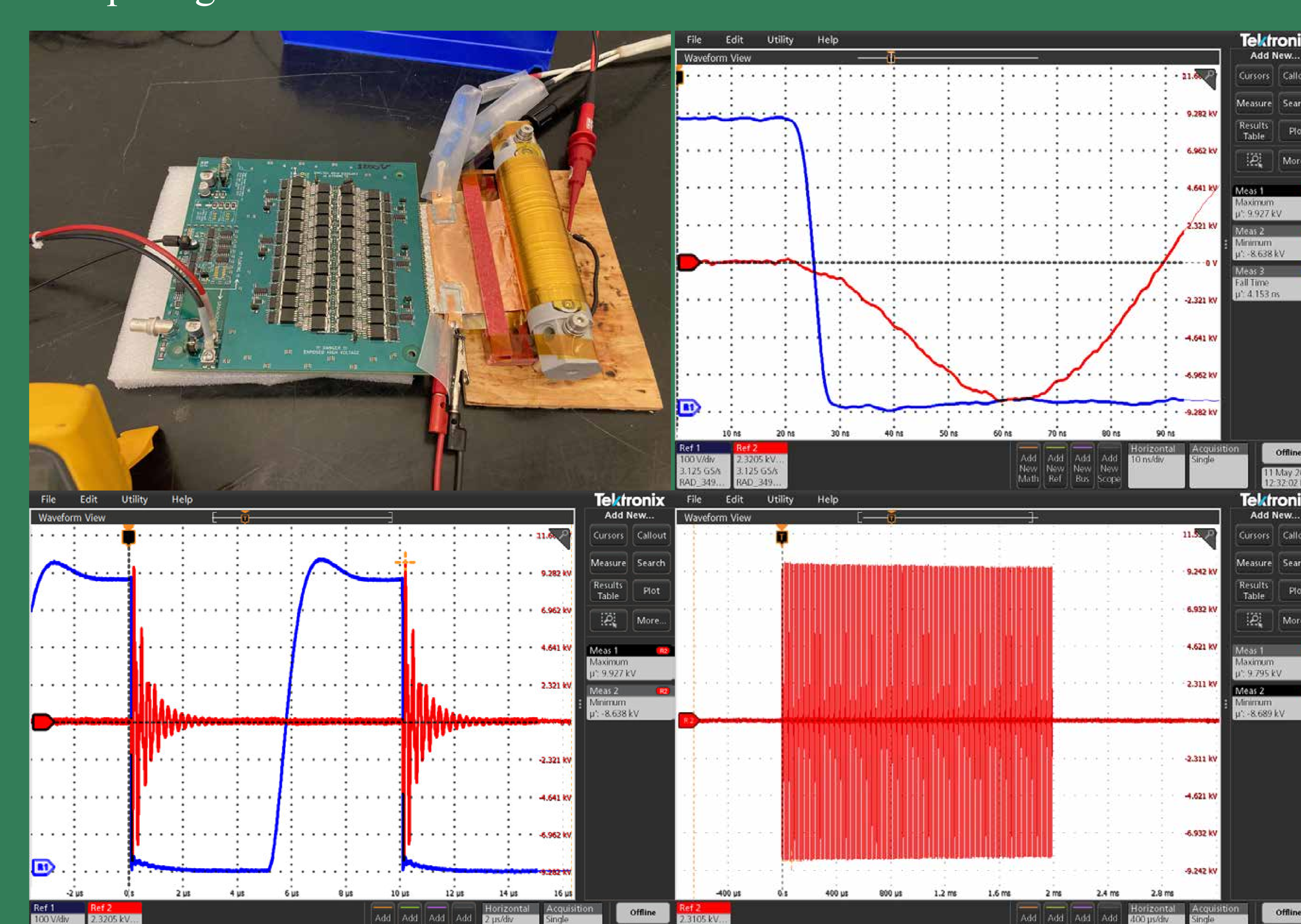
- V_{DS} fall times are much faster than the value supplied on the manufacturers' datasheets.
- V_{DS} fall times typically increase as the current per switch increases.
- Increasing the charge voltage does not increase the V_{DS} fall time by the same factor.
- GaN devices become resistive and fail when operated at high current and voltage, even within their specifications (confirmed by the manufacturer).
- 1200 V switches were tested up to 267 A/switch. Switches did not fail after 100 bursts of 20 pulses at 30 kHz.



LEFT: V_{DS} fall time as a function of charge voltage and current per switch for a variety of GaN and SiC devices. RIGHT: V_{DS} fall time as a function of charge voltage and current for a 1200 V SiC MOSFET at much higher current per switch.

Front End Driver (FED)

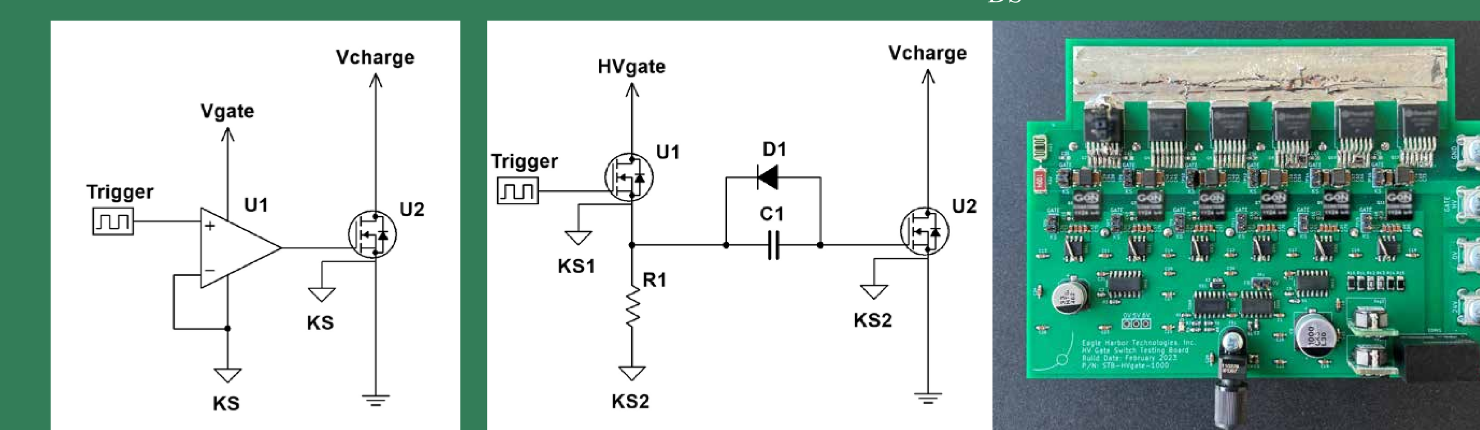
The FED is the closing switch that discharges the spiral generator and contains 48, 1200 V, SiC MOSFETs in parallel. EHT tested the FED with the spiral generator.



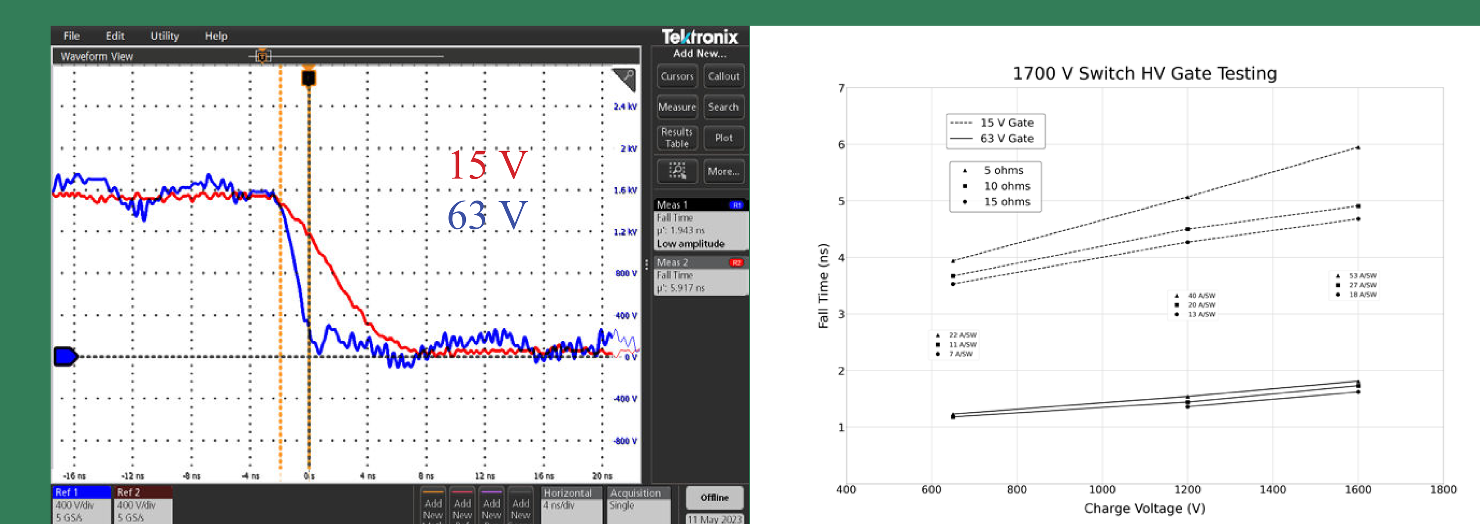
FED connected to the spiral generator (upper left). Testing at 800 V and 100 kHz showing V_{DS} (blue) and generator output (red): single pulse (upper right), two pulses (lower left), and 200 pulse (lower right).

High V Gate Drive

To allow for faster switch transitions on future FED designs, EHT investigated an HV gate drive scheme that can more rapidly charge the switch gate capacitance. The switch is protected by the capacitive voltage division with the capacitor in series. Testing was conducted with 1700 V SiC MOSFETs. The HV gate drive produced faster V_{DS} transitions (< 2 ns).



Circuit diagrams for normal gate drive (left) and HV gate drive (center). Test PCB with HV gate drive (right).



Falling edge of V_{DS} waveforms for standard (red) and HV (blue) gate drive (left). V_{DS} fall time as a function of charge voltage and current with standard and HV gate drives for 1700 V SiC MOSFET (right).

Conclusion

EHT successfully conducted switch testing to evaluate switch transition times. From these tests, switches were selected for the FED, which acted as the closing switch for a spiral generator. Additionally, EHT tested out a HV gate drive scheme to further reduce the switch transition times.

In future work, EHT will incorporate the HV gate drive into the FED, add more switches to the FED to drive lower impedance spiral generators, reduce the parasitics, and increase the FED power density.

For more information: http://www.eagleharbortech.com/

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