A High Voltage, Solid-State Switch for Magnetron Driving

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EAGLE HARBOR TECHNOLOGIES

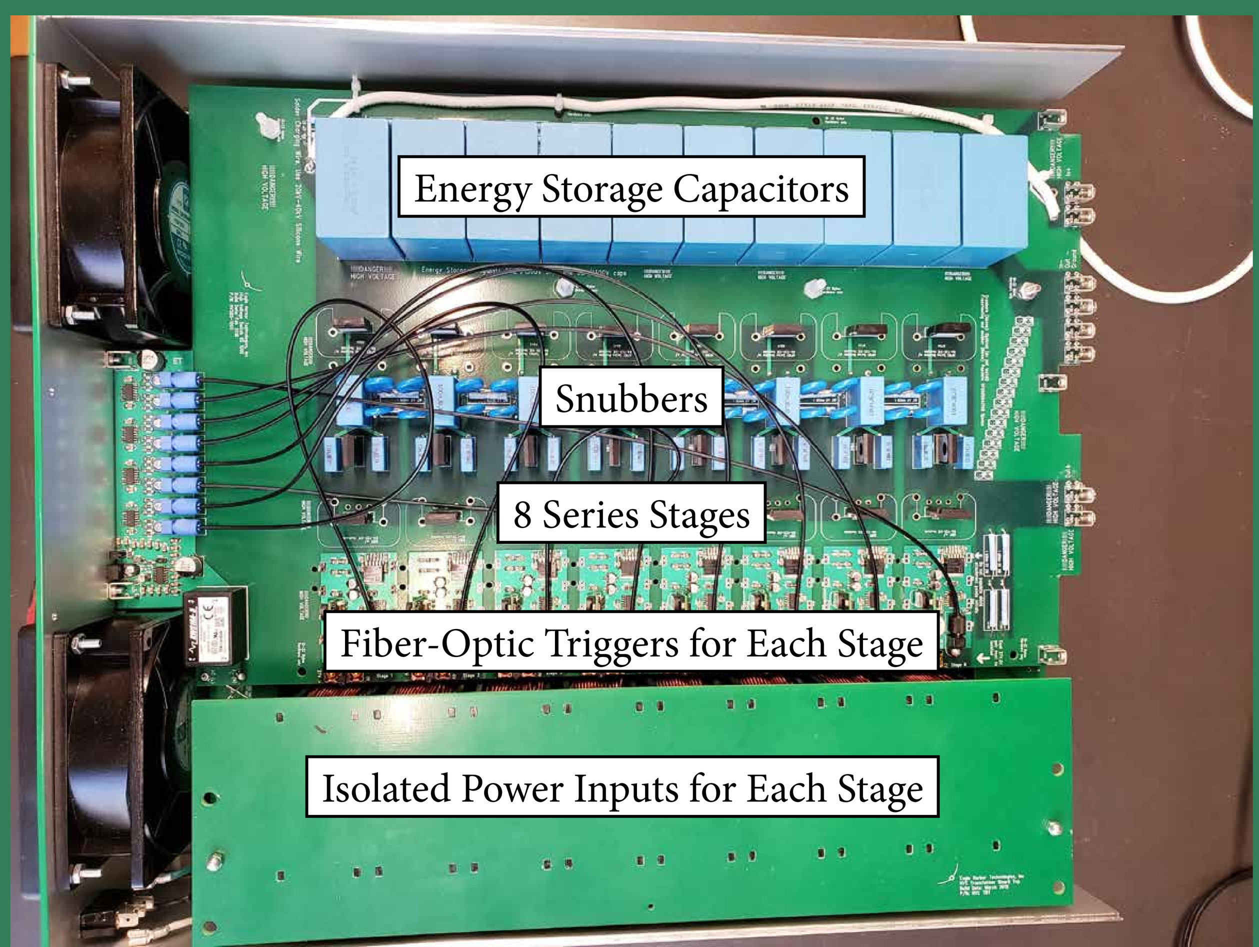
Introduction

Eagle Harbor Technologies, Inc. is developing a series stack of solid-state switches to produce a single high voltage switch that can be operated at over 35 kV for magnetron driving applications. During the Phase I program, EHT developed a 15-kV high voltage switch module with isolated power gate drive that could switch 300 A at switching frequencies up to 500 kHz for 10 ms bursts. Robust switching was demonstrated for both IGBTs and SiC MOSFETs. Now in the Phase II program, EHT is developing a higher voltage version for driving a pulsed magnetron at the Lithium Tokamak Experiment at Princeton Plasma Physics Laboratory. This pulsed magnetron driver will produce high voltage, low ripple waveforms. EHT will present experimental testing results for the new high voltage switching modules and system designs for a pulsed magnetron driver.

Phase II Stand-Alone HV Switch

Achieving dynamic voltage sharing across each switch stage in the stack and accurate, isolated gate control are the two main challenges associated with series stacks of IGBTs and MOSFETs. Voltage sharing imperfections arise due to timing variations in the gate triggering of some stages relative to others and variations in parasitic circuit elements between different stages.

The stand-alone HV switch module contains eight individual stages each independently powered and fiber-optic controlled. EHT limited timing variations by utilizing patented gate drive technology, which minimizes switching jitter to approximately 1 ns. Careful design of the circuit board, equalizes the stray inductance and capacitance to each stage minimizing any switching imbalance. Passive snubber components are also utilized to eliminate any switching voltage spikes. Integrated air cooling allows for CW operation at high average power.



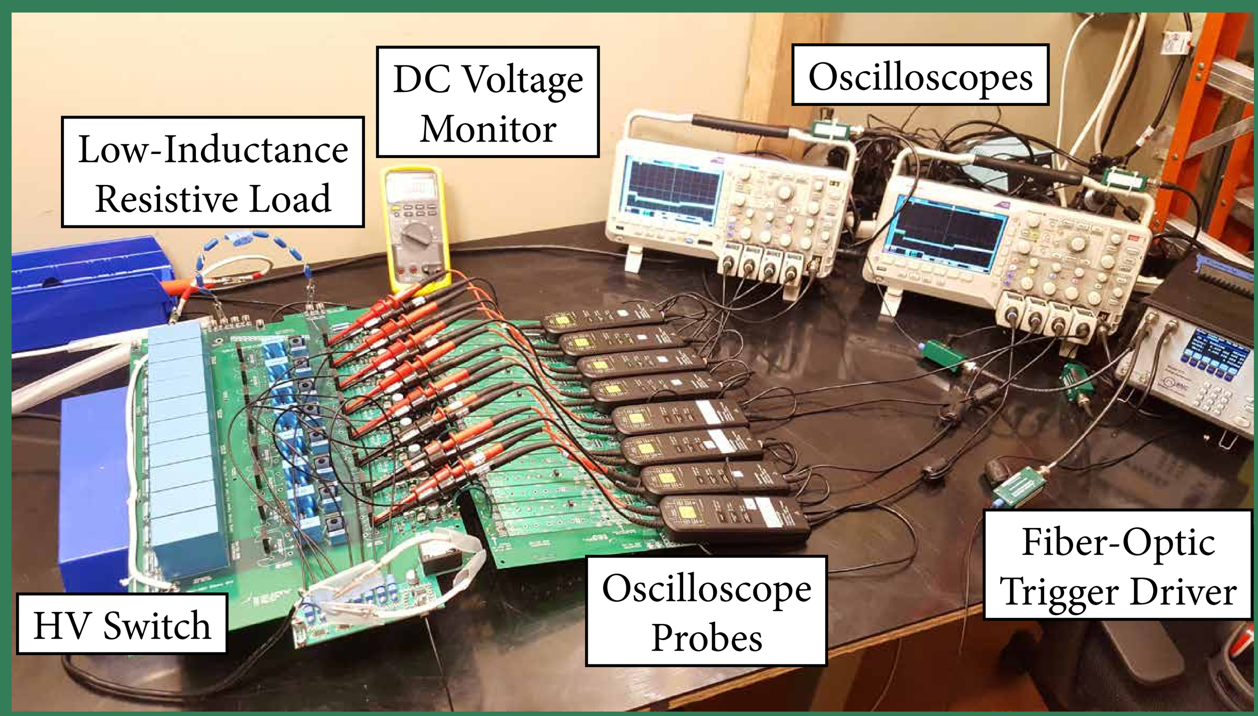
10 kV stand-alone HV switch built in Phase II program

Acknowledgment

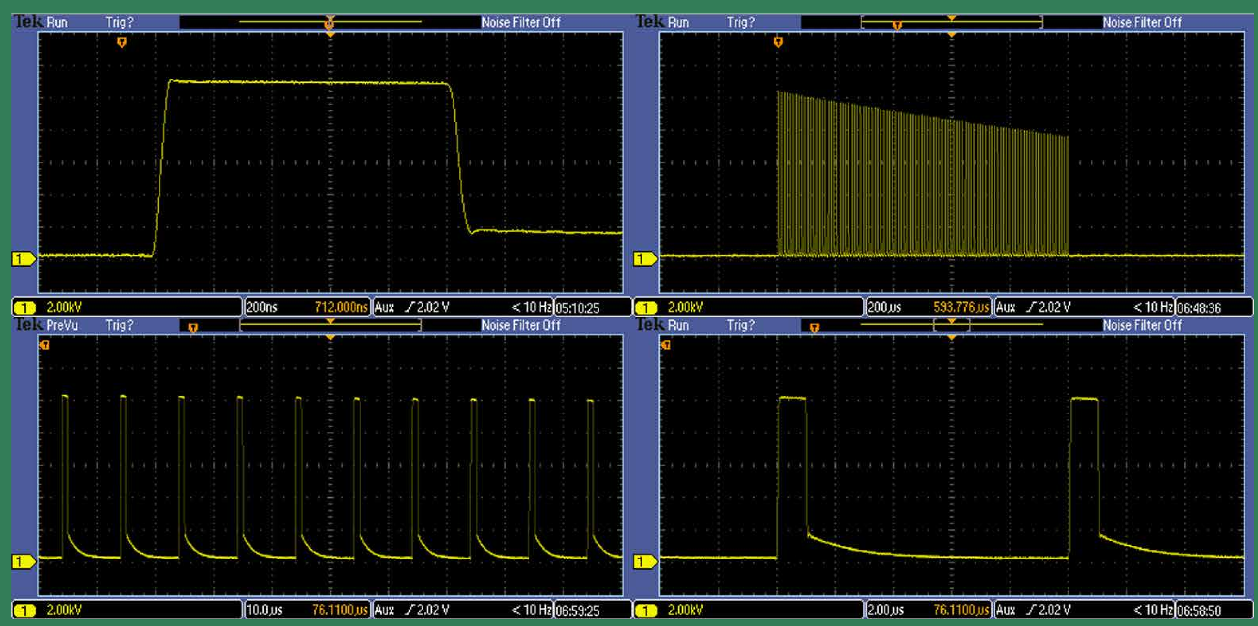
This work was funded by a DOE SBIR (DE-SC0015745).

Stand-Alone Switch Testing

Prior to integration into the chassis, EHT tested the PCB a. The voltage sharing was monitored in standard operation as well as during a fault.



HV Switch test setup.



Stand-alone HV switch output waveforms measured using a 40 kV probe across a load resistor. Top left: A single shot test into a 280 Ω chain of resistors at a charge voltage of 10 kV. Top right: A 1 ms burst at 100 kHz into a 110 Ω chain of resistors also at 10 kV. The droop of the voltage in this waveform is based on the internal energy storage limitation and could easily be reduced by adding external energy storage. Bottom: Zoom in on 10 (left) and 2 (right) pulses, respectively, showing the pulse shape. These waveforms show consistent 1 µs pulse widths at the desired maximum charge voltage.

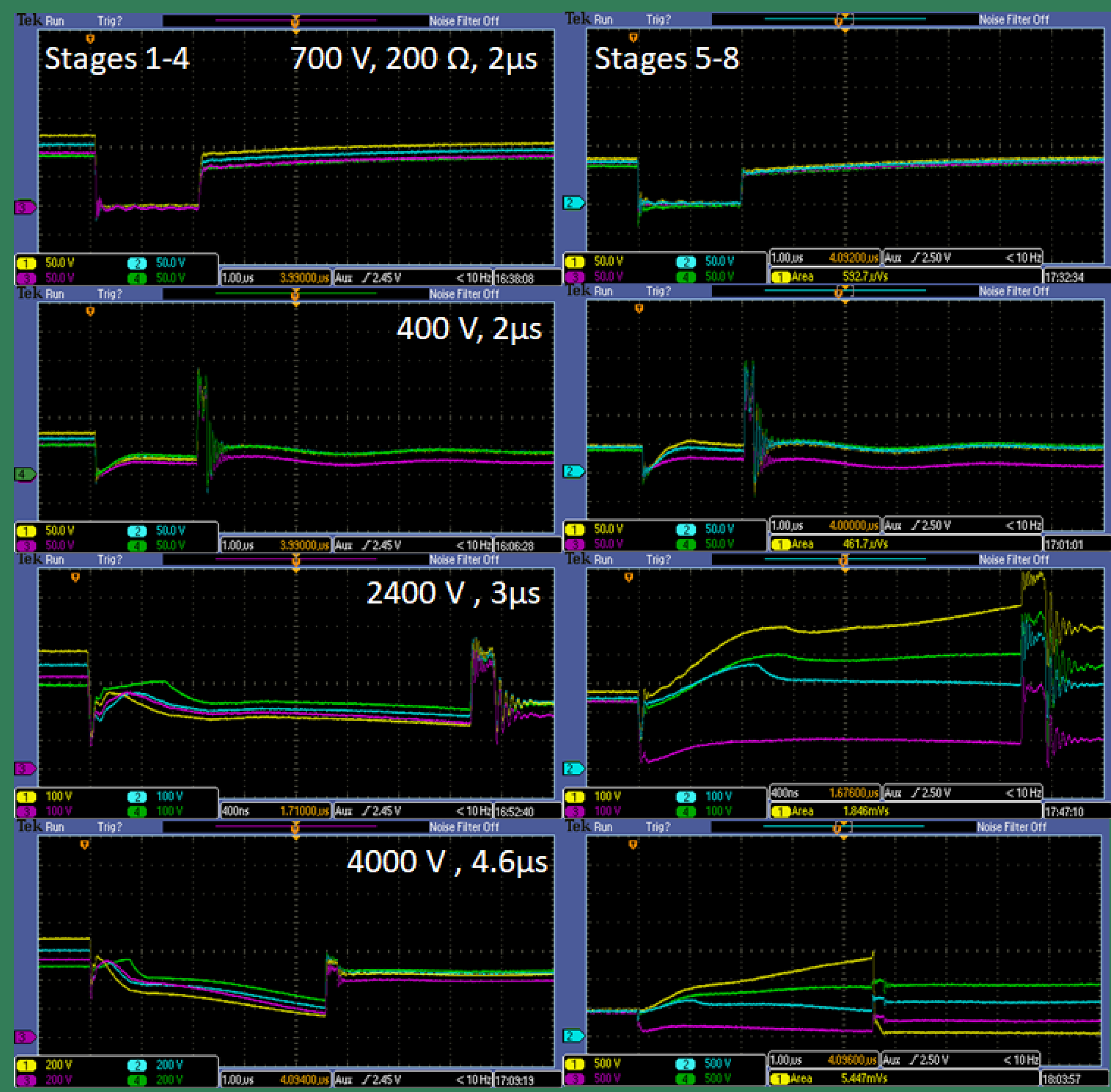
Current Self-Limiting of SiC MOSFETs

With careful control of the gate drive voltage, some SiC MOSFETs will self-limit the current in a short-circuit condition. The output of the MOSFET was connected to a hard, low-inductance, short, with a 300 V charge. The drain-source voltage falls from 300 V to about 220 V and then begins to climb back up again throughout the duration of the shot. This can be exploited to shut down the system safely during a fault

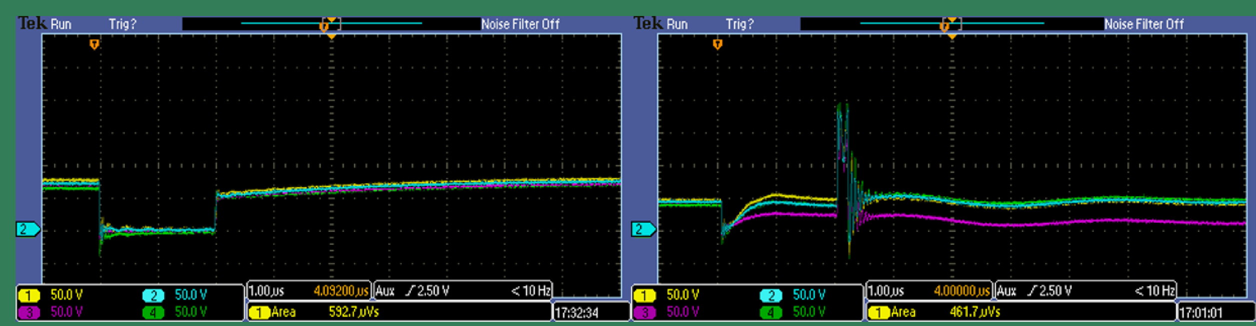
Current self-limiting test of SiC MOSFET. Ch1 is drain-source voltage (yellow). Ch2 is current through the MOSFET (blue).

Short-Circuit Detection

EHT conducted short circuit testing at different voltages and durations. Figure shows different voltage for different durations.



The key features are a large turn-off spikes and the drifts of the conduction voltage. All MOSFETs start sharing voltage well. Slight differences in the MOSFETs junction heating leads to a rapid increase of the junction resistance. The more resistive MOSFETs dissipate more of the power, becoming more resistive faster. This runaway failure process can be seen by the diverging conduction voltages. In the bottom row, the voltage on stage 5 has become high enough for long enough to cause the junction to fail. While the voltage on this device was the highest of any of the devices, it was still well below its 1700 V rating. Therefore, the device failure was not caused by over-voltage but by instantaneous overheating of the junction.



Nominal operation waveforms (left) versus short circuit operation (right). This large difference in voltage can easily be detected by a comparator through a voltage divider.

Conclusion

EHT has built a stand-alone HV switch that can handle voltages of up to 10 kV while switching at over 100 kHz. This system can be integrated with a fiber-optically isolated control system and feedback control system to produce a robust, short-tolerant switch.

10 kV stand-alone HV Switch

The overall goal of the program is to develop a high voltage magnetron driver. Future work includes increasing the output voltage to over 35 kV to be compatible with the magnetron at PPPL.

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