High Voltage, Solid-State Switch for Fusion Science Applications

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EAGLE HARBOR TECHNOLOGIES

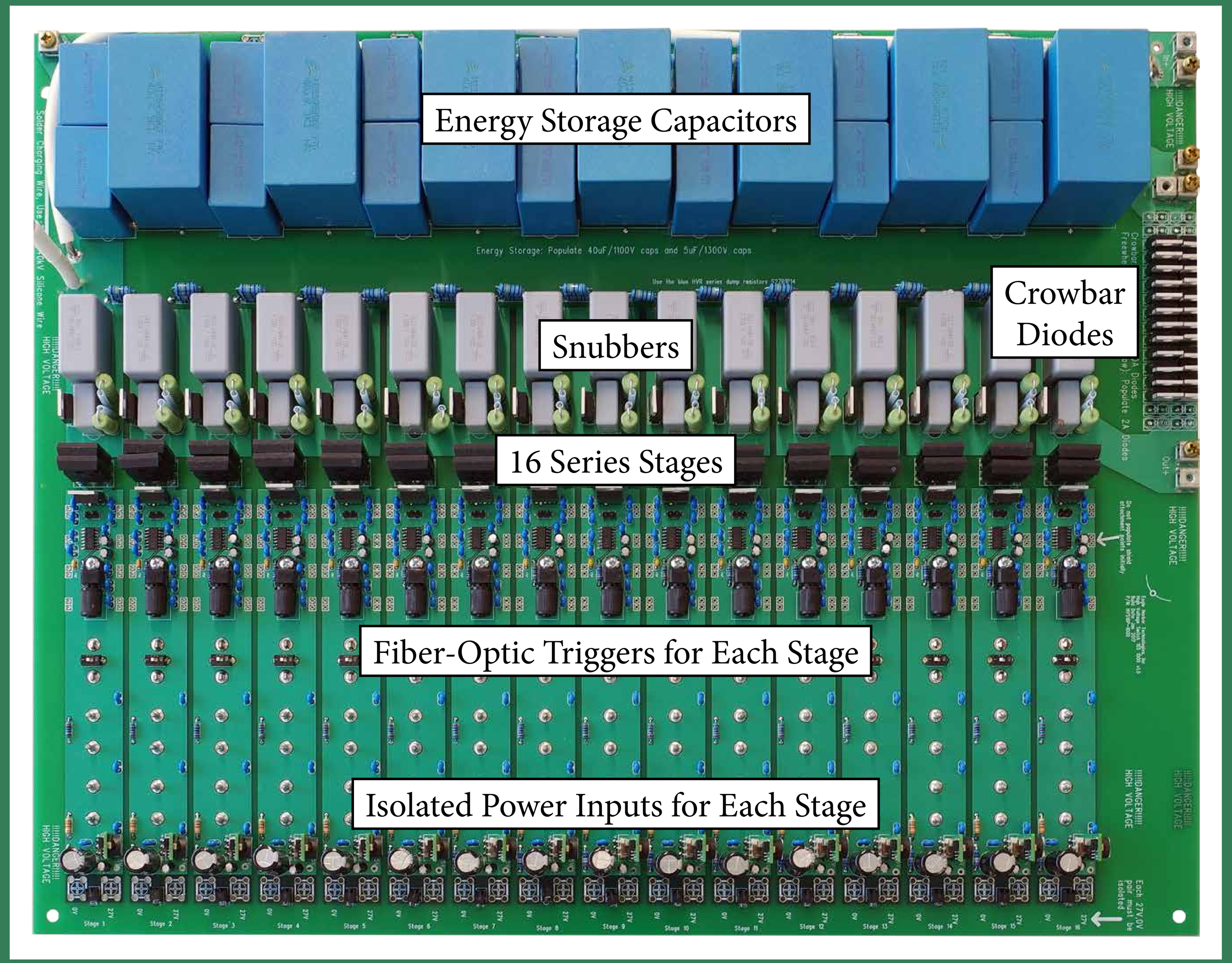
Introduction

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. During the Phase I program, EHT developed two high voltage switch modules: one with isolated power gate drive and a second with inductively coupled gate drive. These switches were tested at 15 kV and up to 300 A at switching frequencies up to 500 kHz for 10 ms bursts. Robust switching was demonstrated for both IGBTs and SiC MOSFETs. During the Phase II program, EHT will develop a higher voltage switch (> 35 kV) that will be suitable for high pulsed and average power applications. EHT will work with LTX to utilize these switches to design, build, and test a pulsed magnetron driver that will be delivered to LTX before the completion of the program. EHT will present data from the Phase I program as well as preliminary results from the start of the Phase II program.

Phase I HV Switch PCB

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.

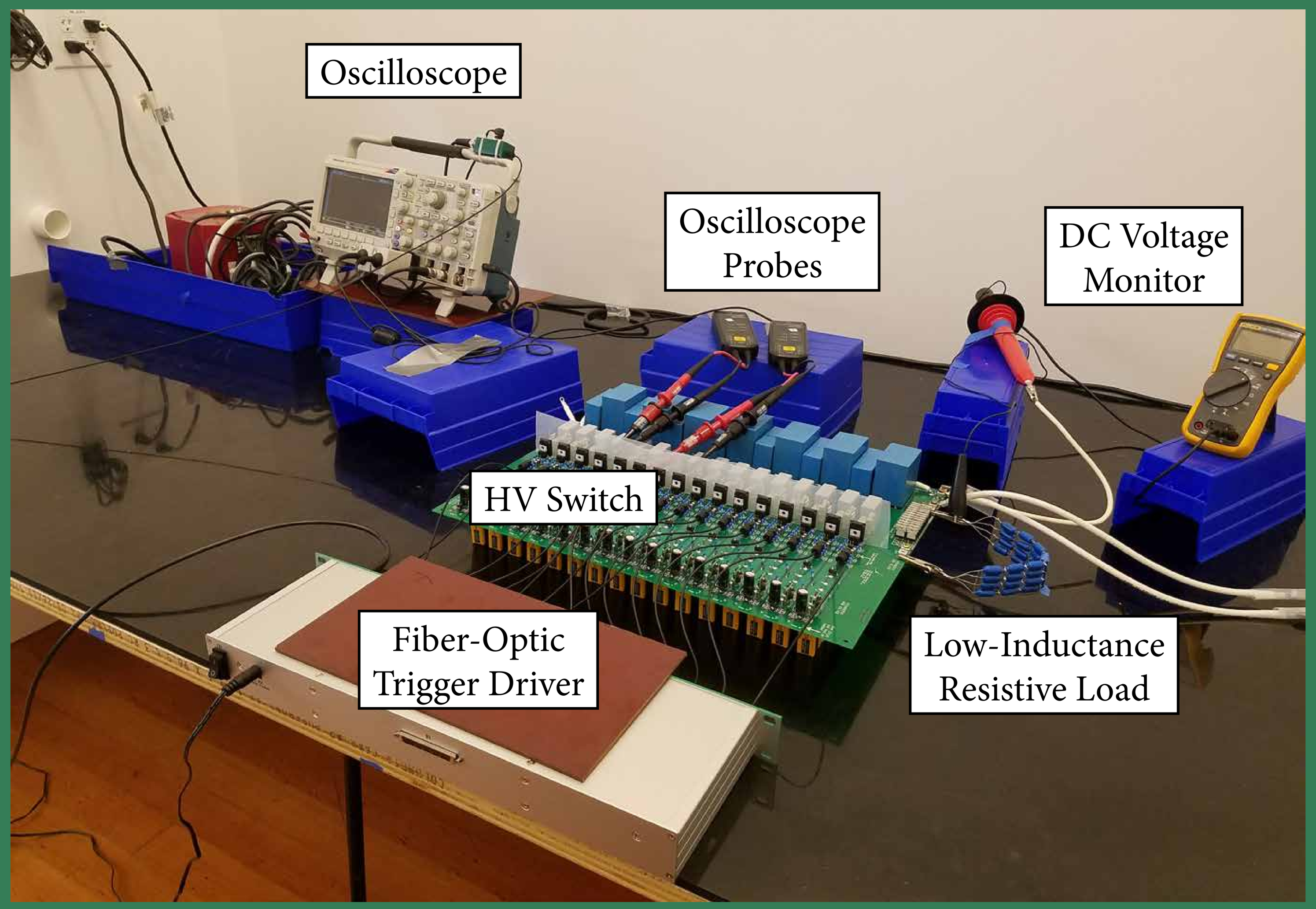
The HV switching module contains 16 individual stages each independently fiber-optic controlled. Control voltage is fully isolated to over 20 kV. EHT limited timing variations by utilizing patented gate drive technology, which minimizes switching jitter to approximately 1 ns. Careful design of the circuit 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.



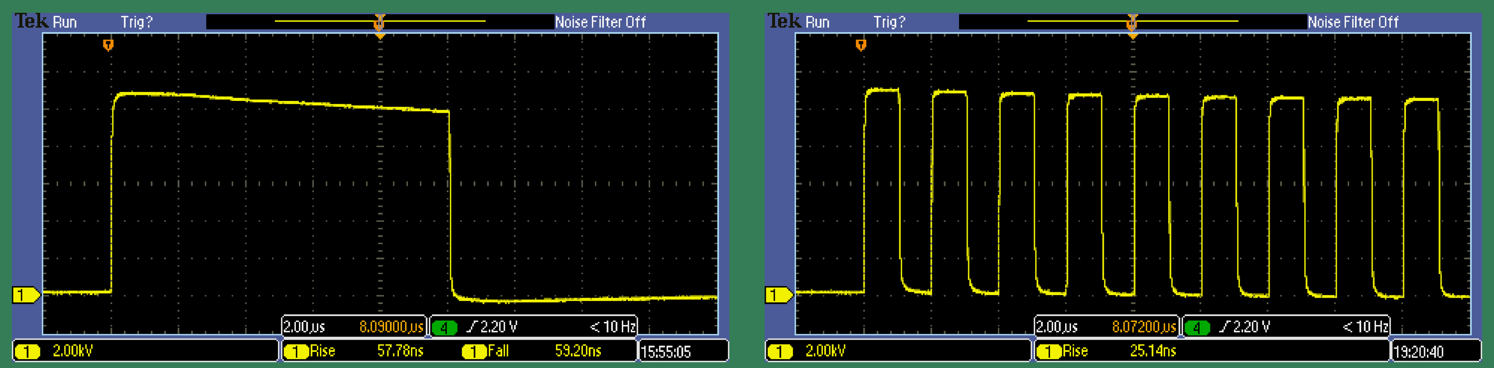
HV Switch PCB that was designed, built, and tested in the Phase I program.

Initial Board Testing

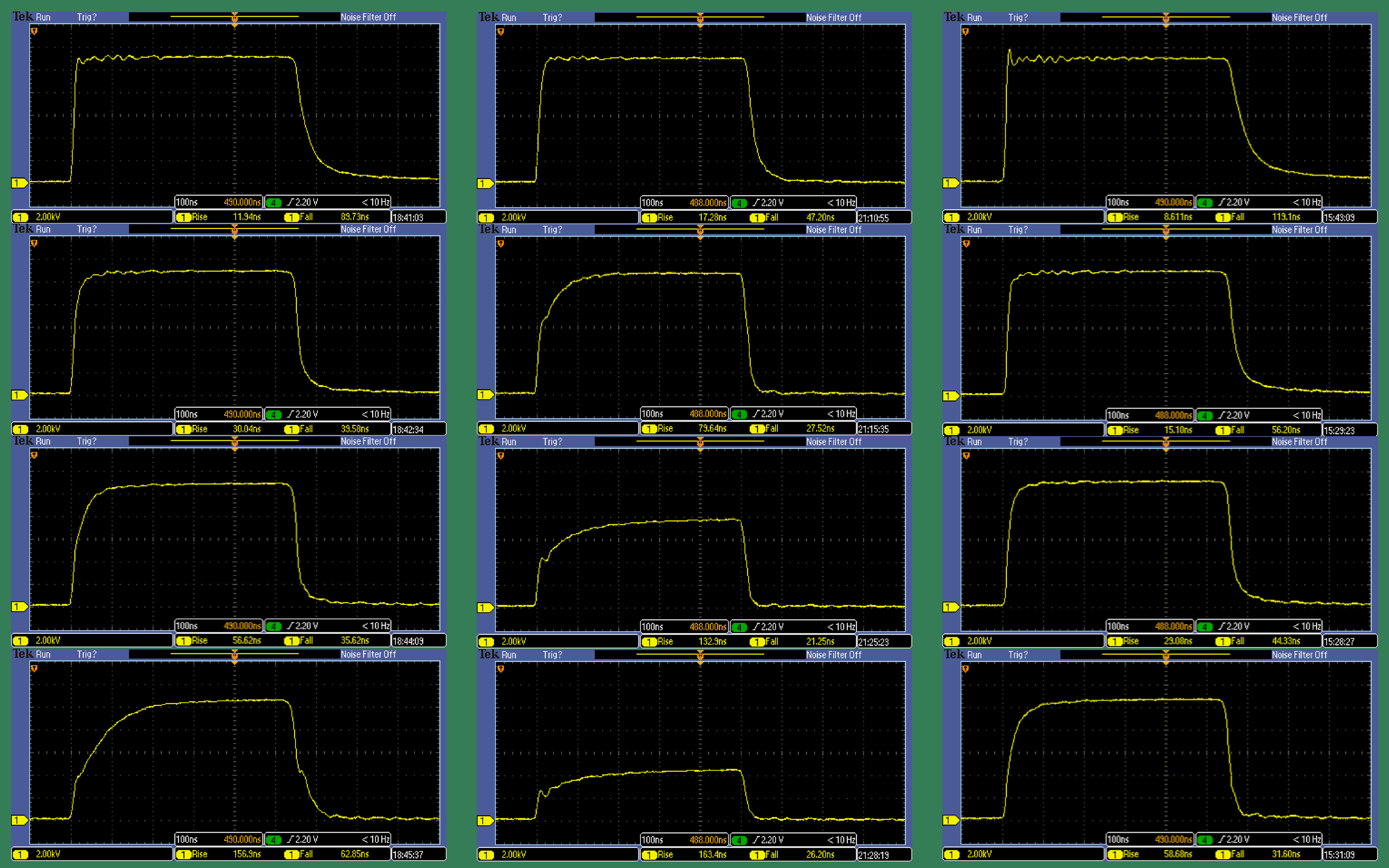
EHT conducted initial board testing with both IGBTs and SiC MOSFETs. The IGBTs could switch faster and handle higher currents while the SiC MOSFETs are more efficient and turn off faster (due to lack of tail current).



HV Switch test setup.



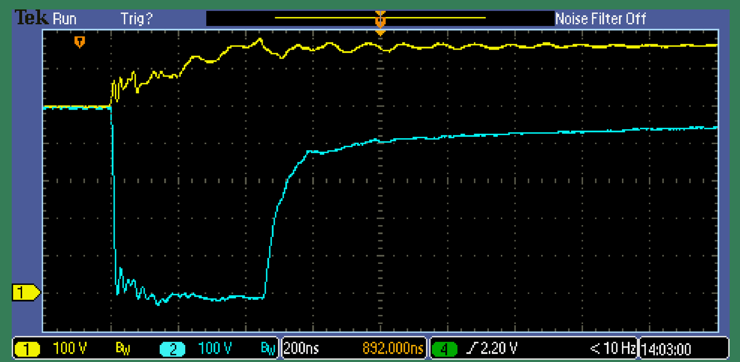
Left: 15 kV into 50 Ω load for 10 µs. Middle: 15 kV into 500 Ω load for 500 ns. Right: 500 kHz burst of 15 kV into 200 Ω load. Pulse width is 1 µs. In all three cases, IGBTs were installed as the switch.



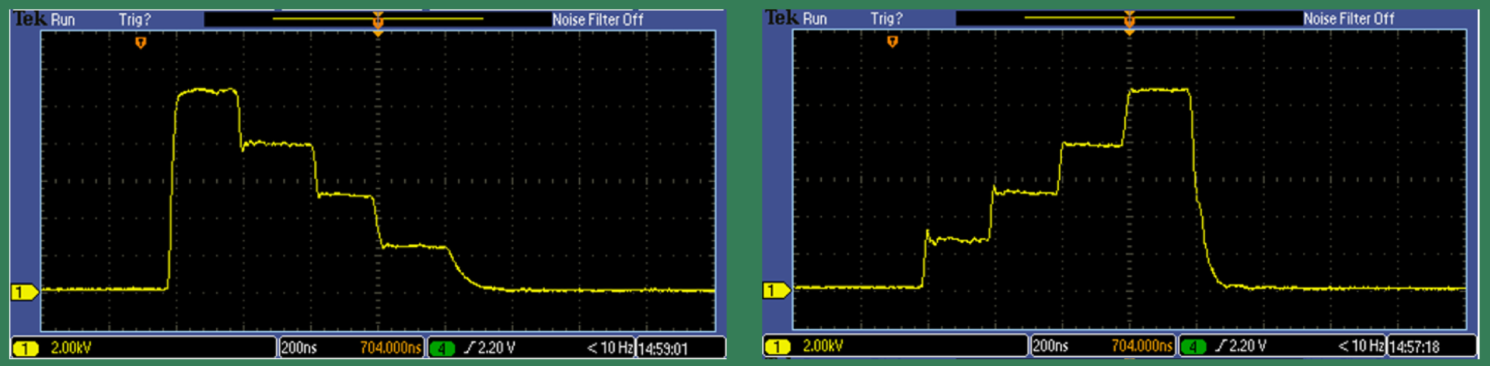
Single pulse test: 15 kV, 500 ns pulses into different resistive load (from top to bottom: 500 Ω, 200 Ω, 100 Ω, and 50 Ω) with IGBTs (left), SiC MOSFETs (middle), and IGBTs in parallel (right).

Fault Tolerance and Jitter Testing

If 15 of 16 switches close, current will flow through the circuit, charging the snubber capacitor of the faulted stage. At 10 kV operation with a 200 Ω load, 50 A will flow, charging the 100 nF snubber capacitor by 50 V per 100 ns. The system can withstand a timing fault of up to 750 ns. Since timing errors should be limited to 1 ns by gate triggering system, the large passive robustness against timing errors is considered more than adequate. This long passive robustness can be used to modulate the load voltage, which could be useful in applications for feedback control, where amplitude modulation of the waveform could be used as an alternative to pulse width modulation.



Effect of trigger fault on snubber capacitor charge (yellow) and V_{cc} (blue).



Amplitude modulation of the load waveform, 10 kV 20 A.

Conclusion

EHT has designed, built, and tested an HV Switch using both SiC MOSFETs and IGBTs. The choice between device types depends needs of the specific HV switching application. EHT successfully demonstrated the HV Switch into a variety of loads and pulse widths. Bursts to 500 kHz have been demonstrated. The switch has been fault tested for switching errors, and it is robust to 750 ns jitter (much longer than the jitter of EHT gate drive). This hardware robustness can be utilized for amplitude modulation of the output waveform.

In the Phase II program (awarded), EHT will develop a switch capable of producing 35 kV. During the second year of the program, this switch will be utilized to build a pulsed magnetron driver. The Lithium Tokamak Experiment at Princeton Plasma Physics Laboratory will test this driver with a high power (0.1-2 MW) magnetron for plasma startup and localized electron heating. The magnetron will be operated for 5-10 ms after the initial conditioning with shorter pulses has occurred.

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

Acknowledgment

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