

# SiC MOSFET Switching Power Amplifier Project Summary

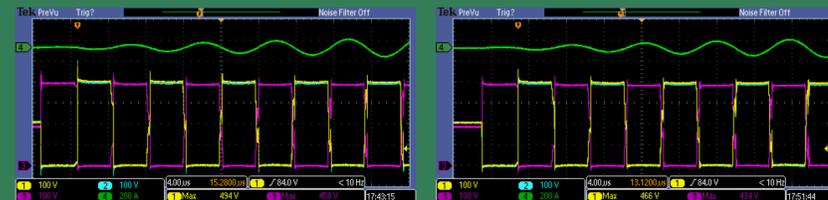
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## EAGLE HARBOR TECHNOLOGIES

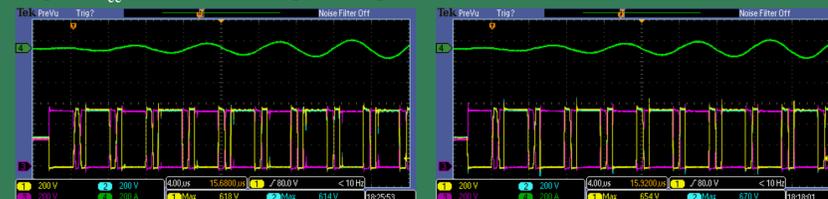
### Introduction

Eagle Harbor Technologies has completed a Phase I/II program to develop SiC MOSFET based Switching Power Amplifiers (SPA) for precision magnet control in fusion science applications. During this program, EHT developed several units have been delivered to the Helicity Injected Torus (HIT) experiment at the University of Washington to drive both the voltage and flux circuits of the helicity injectors. These units are capable of switching 700 V at 100 kHz with an adjustable duty cycle from 10 - 90% and a combined total output current of 96 kA for 4 ms (at max current). The SPAs switching is controlled by the microcontroller at HIT, which adjusts the duty cycle to maintain a specific waveform in the injector. The SPAs include overcurrent and shoot-through protection circuitry. EHT will present an overview of the program including final results for the SPA waveforms.

### Pre-Pulse for Voltage Spike Reduction



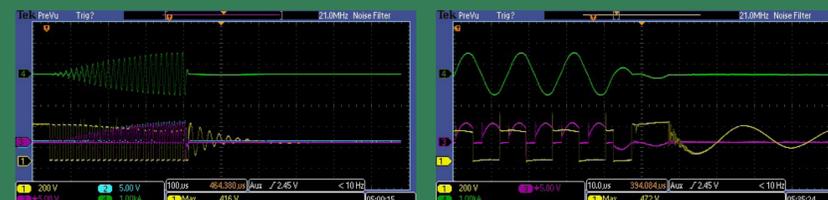
Full duty cycle with pre-pulse (left:  $V_{ce} = 466$  V) and without pre-pulse (right:  $V_{ce} = 494$  V). Charge voltage: 400 V.



60% duty cycle with pre-pulse (left:  $V_{ce} = 618$  V) and without pre-pulse (right:  $V_{ce} = 670$  V). Charge voltage: 550 V.

### Overcurrent Protection

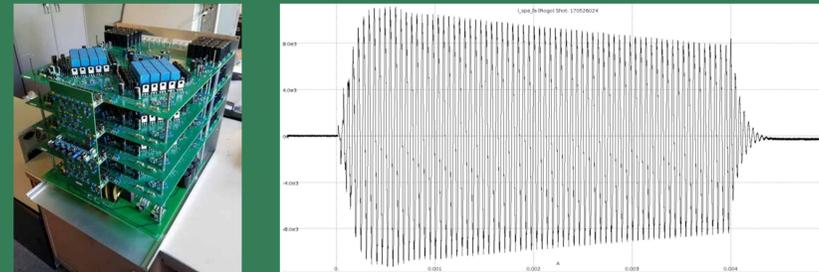
If the load shorts, the current increases rapidly and can damage the SPA. EHT implemented a shunt-resistor based current monitor that measures the full high current path. This current monitor's output is opto-coupled back to the logic circuitry, which can shut off the system if a safe value is exceeded.



Left: Output current (green) and switching waveforms. As the current rings up past the threshold value, the output is cut off as soon as the allowed current is exceeded. Right: Zoom in at time of shutoff.

### SPA Testing with HIT Helicity Injectors

EHT conducted two SPA tests at HIT with the helicity injector resonant loads. During the first test, voltage spikes were identified and ultimately mitigated with Pre-Pulse. Below shows the final testing at delivery.



Left: EHT SPA prior to boxing and delivery to HIT. Right: 12 kA at 100 kHz for 4 ms from HIT Rogowski coil



Left: Two of four SPAs delivered to HIT with the fiber-optic controller and interlock controller. Right: Back of SPA connected to HIT resonant circuit with current and voltage measurements shown.



Left: Resonant capacitors, tuning inductors, and Rogowski coil. Right: Single EHT SPA board connected to resonant load with helicity injectors shown.

### Acknowledgment

This work was funded by a DOE SBIR (DE-SC0011907).

### Final SPA

During this SBIR Phase II program, EHT has developed products which utilized the SPA switching technology. The initial product was a full-bridge designed for high current resonant driving delivered to HIT. Each units had the following specs:

- $\pm 700$  V output
- 16 kA for 10 ms at 100 kHz
- Duty cycle can be varied in real-time from 10 – 90%
- Higher switching frequencies at longer pulses are possible at lower currents.



To compliment the SPA, EHT developed a fiber-optic controller and interlock system to fan out control signals from the HIT.



### 30 kV Arbitrary Pulse Generator

EHT utilized the core full-bridge to drive a transformer isolated resonant converter that delivers 30 kV pulses to a dielectric barrier discharge for medical applications. To date, EHT has sold three of these units. The initial unit had the following specs:

- Charge Voltage: 0 – 600 V
- Output Voltage: 0 – 30 kV
- Max DC Input Power: 1.5 kW
- PRF: 1 kHz at 20 us pulse width
- Pulse Width: 1 – 100 us
- Shot Frequency: Continuous
- Control: External Gated Mode
- Short Tolerant: Up to 3 seconds
- Size: 28" x 17.5" x 10.5" (6U)
- Weight: 75 lb.
- Mount: Rack Mountable with rear support



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