

# A Robust Modular IGBT Power Supply for Considerable Series/Parallel Operation at High Power and Frequency

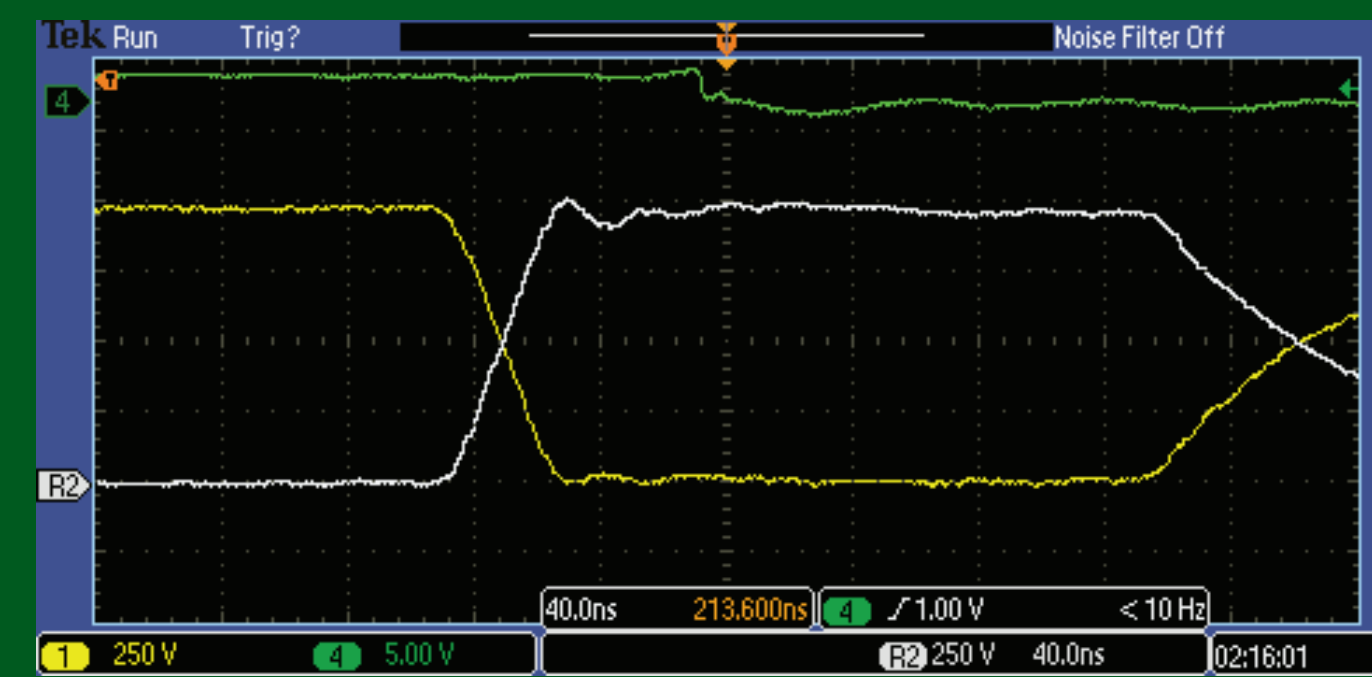
T. Ziemba\*; K. Miller; J. Prager, J. Carscadden, Eagle Harbor Technologies, Inc.  
\*ziemba@eagleharbortech.com

## EAGLE HARBOR TECHNOLOGIES

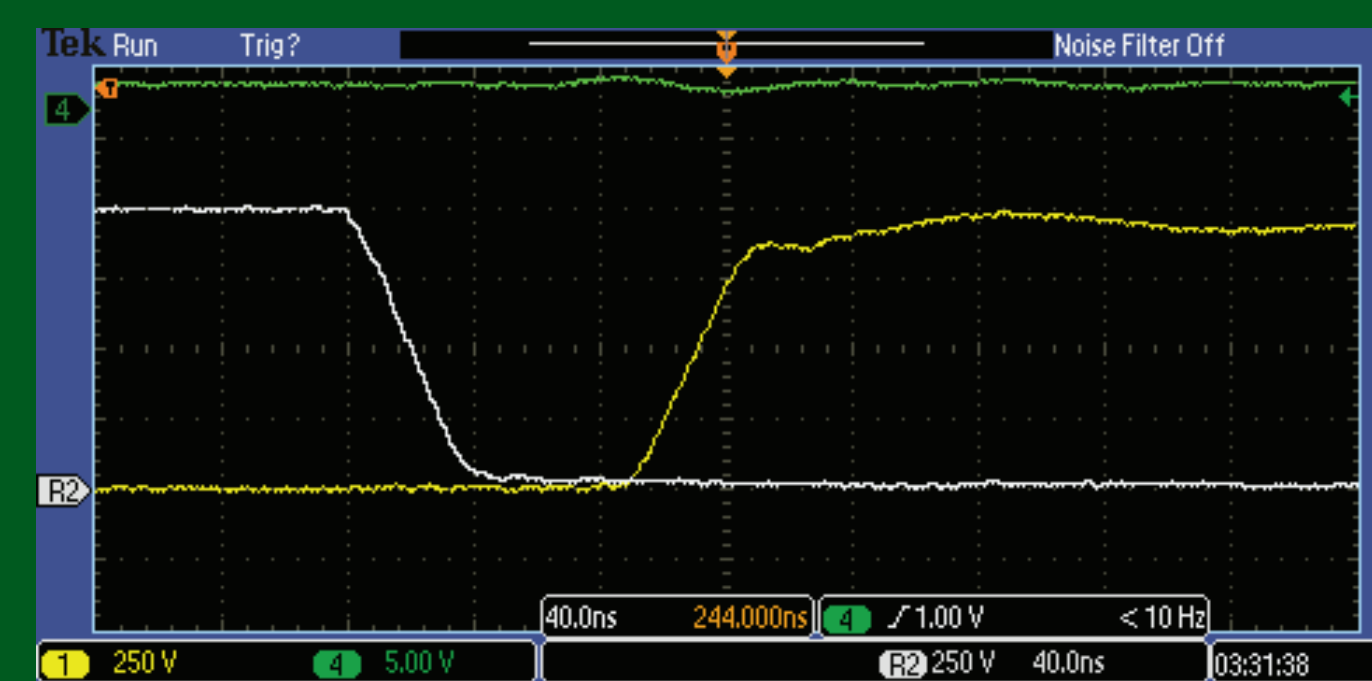
### Abstract:

Eagle Harbor Technologies (EHT) is developing a modular, solid-state power supply for pulsed high power (> 10 MW) RF applications supported by a DOE SBIR Phase II. The prototype modules utilize a low-cost IGBT based system that can be assembled in multiple ways for a wide range of applications. Each module is capable of switching 2 kA at 1 kV up to megahertz frequencies with rise times of ~40 ns. Experimental testing of the modules demonstrated both parallel (high current) and series (high voltage) configurations. The modules are designed for precise switching control, which reduces jitter (< 5 ns) between modules, enabling robust series operation. Present work is focused on building individual modules with active over voltage and over current fault detection. Two prototype supplies will be demonstrated: one capable of switching 2 kA at 10 kV and the other capable of switching 20 kA at 1 kV. The prototype costs are estimated to be three times less than older generation IGBT based power supplies for similar high current pulsed applications and twenty times less for the pulsed high voltage and high power tube based RF applications.

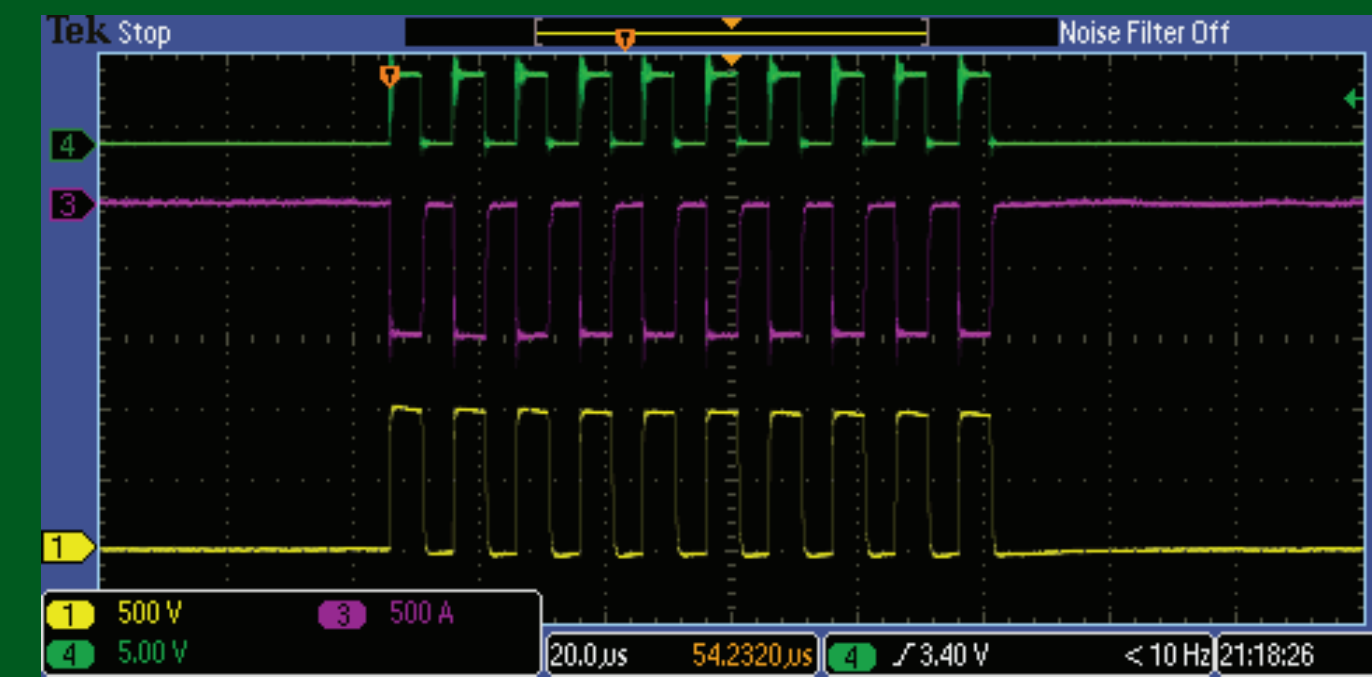
### Single IGBT/Module Results:



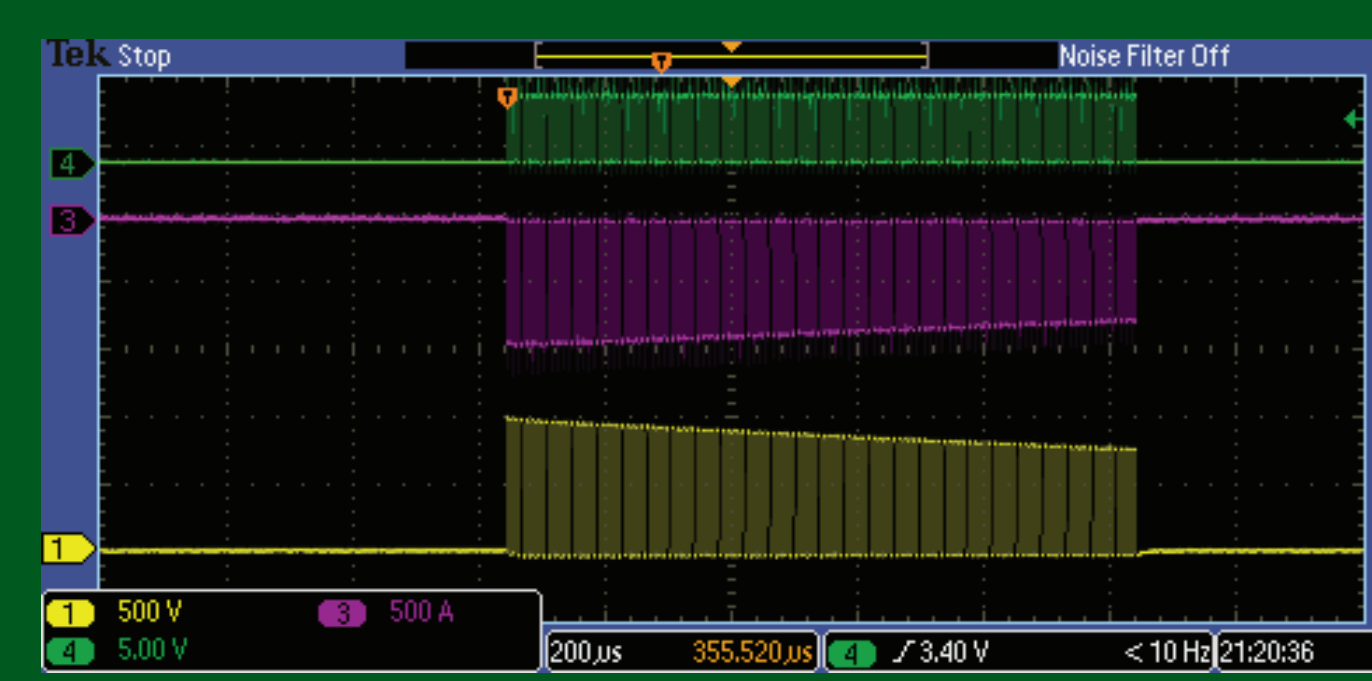
1000 V, 100A, 200 nsec single pulse. This shows Vce (yellow) and Vload (white). ~40 nsec rise time



1000 V. Trace showing signal at end of 40' 50 Ohm coax cable terminated in 50 Ohms. Yellow is Vload, white is Vce measured on IGBT board.

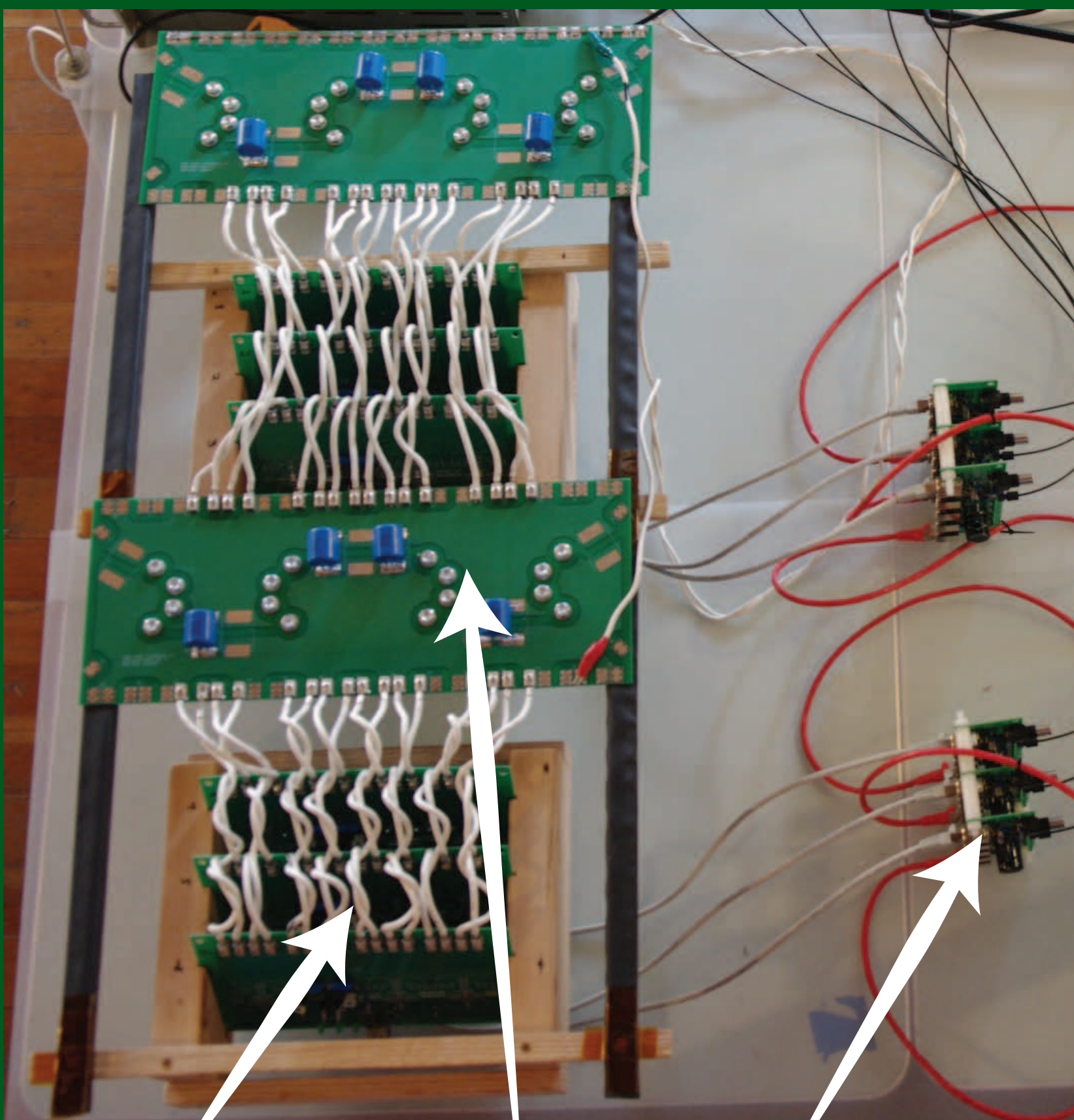


High power, 1000V, 1000 A, 100 kHz Switching. Full module, 4 IGBT boards in parallel.



1 ms operation at 1kV and 1kA at 100 kHz, the decrease in voltage is due to draining of the 10 kJ capacitor bank.

### Series Configurations:



Single IGBT Board, Interconnect Board & Resistive Load, Gigabit Ethernet Communication and Trigger System



6kV, 1 us pulse duration



Expanded scale ~ 40 ns rise time Slew rate in excess of 100 kV/ms!

### Key Components:

- Individual modules consist of 1 to 4 individual PCB boards operated in parallel. Modules have been operated robustly at their nominal design parameters of 1 kA and 1 kV at 100 kHz switching frequencies.
- Individual modules can be stacked in series for high voltage operation, eliminating the need for step-up transformers. Module to module switching jitter has been verified to be less than 3 nsec. This is well within the constraint of 200 ns switching jitter needed to prevent device series failure, as identified with SPICE modeling.
- High frequency switching speeds (1-5 MHz) have been demonstrated.
- Individual boards were tested at 1 kV and up to 2 kA for pulse lengths up to several ms.
- Fiber optic and control voltage isolation provide robust low-noise switching for series applications. Nominal design provides over 20 kV isolation.
- EHT's proprietary switching allows for a dramatic reduction in total energy loss, potentially increasing efficiencies for inverters used for green energy applications.

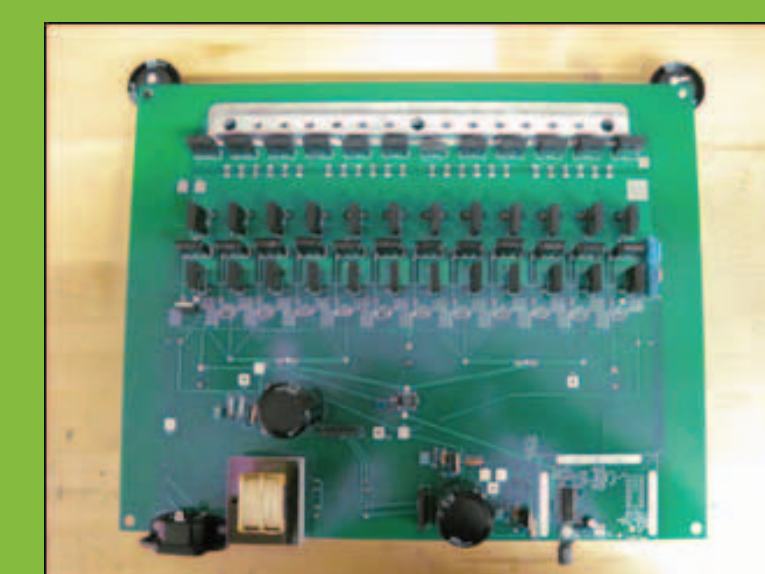
### Applications that Utilize the EHT Fast Switching and Standard Power Supply Configurations

#### Micro-Pulsed Plasma Discharge



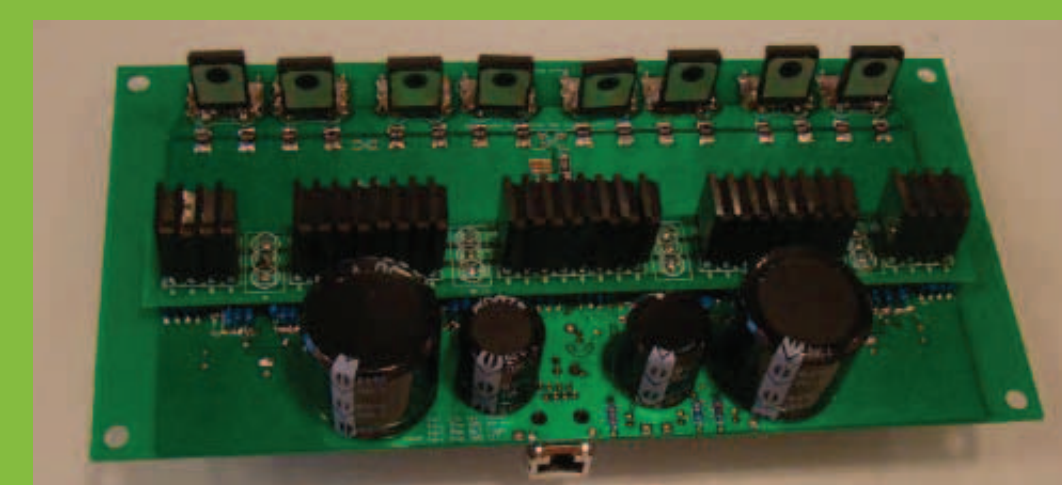
IGBT PS was designed to be very small for micro-thruster applications. PS operated at 100-200 kHz switching speed at ~500 V and 800 A

#### Electrode-less Plasma Source



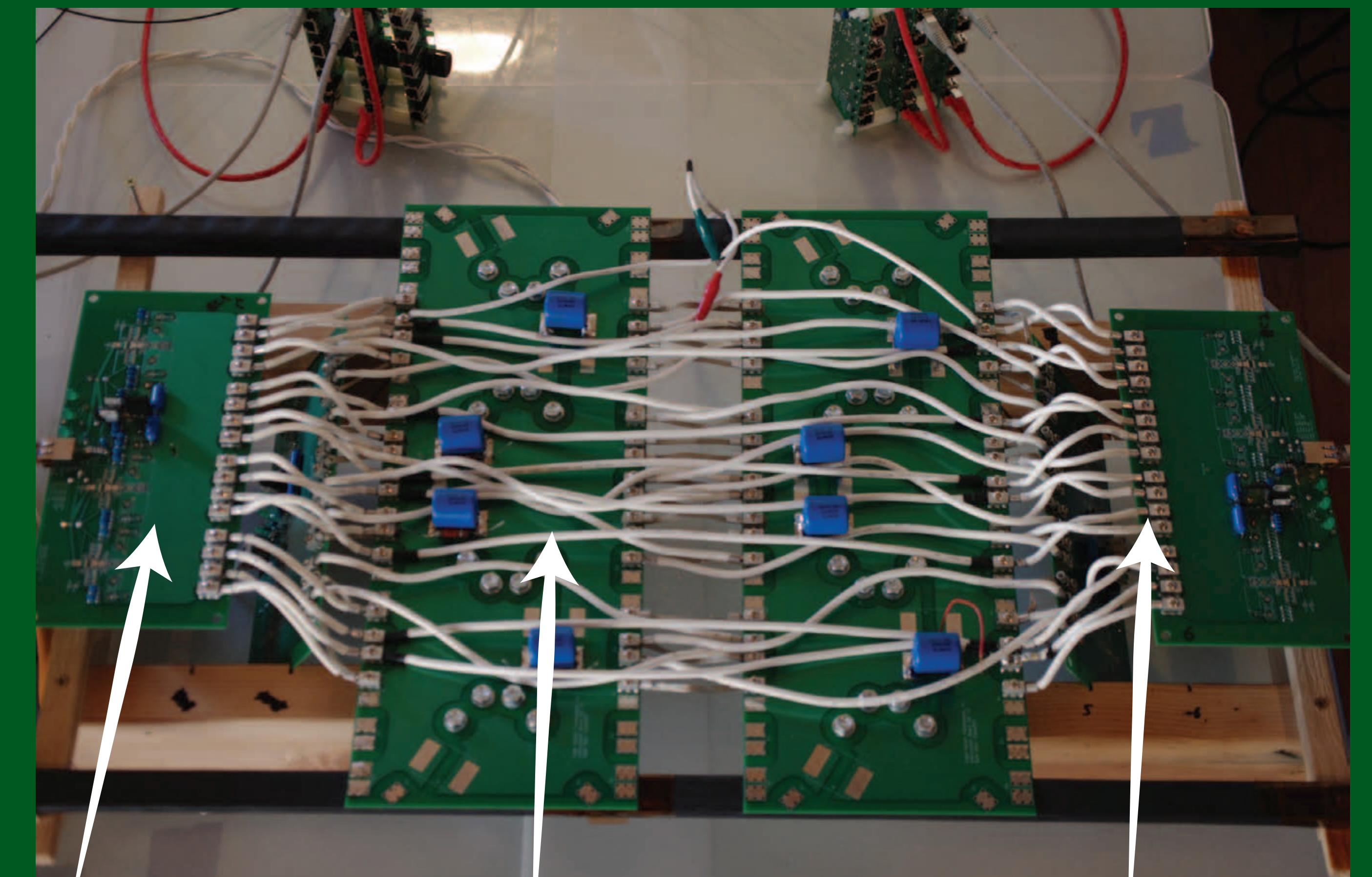
IGBT PS designed to operate at over 800 kHz switching speeds to drive an inductive plasma source at 1.5 kA (p-p) and 10 kV (p-p)

#### High Current IGBT Switch



Standard IGBT PS Design with High Current Adaptor allows for over 12 kA switching at over 1 kV.

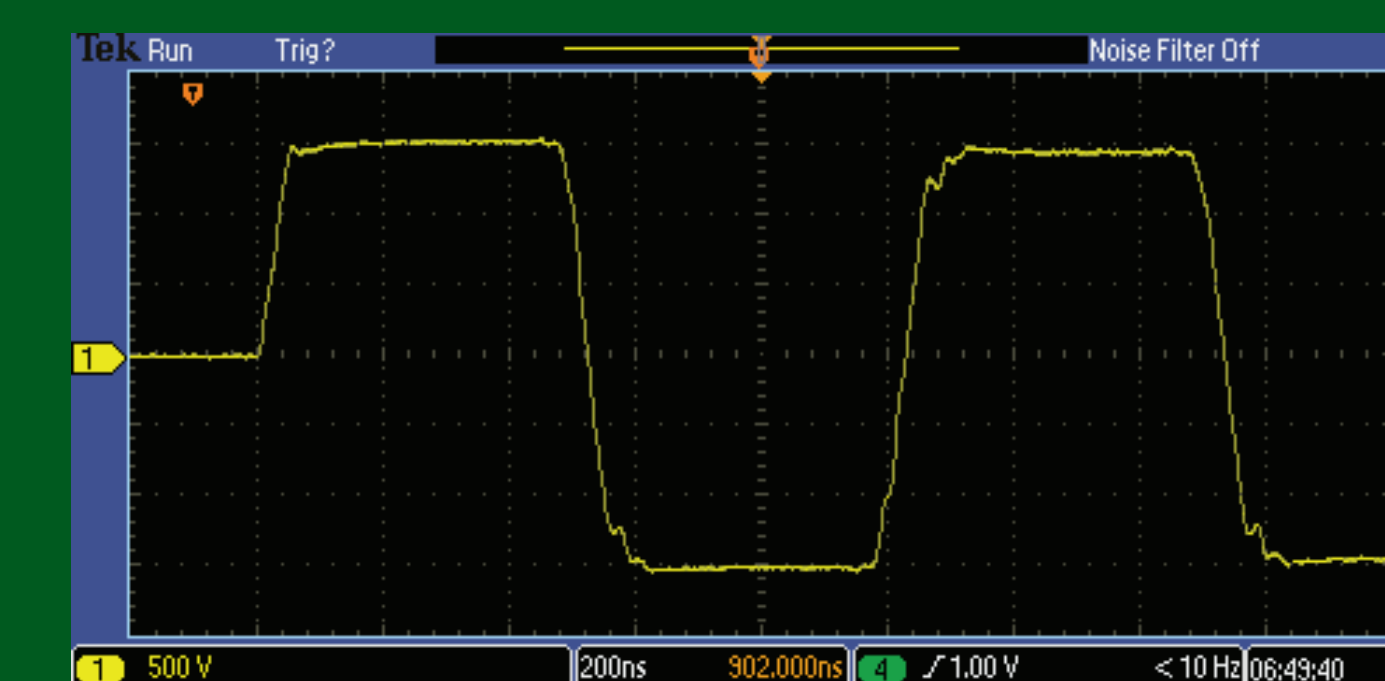
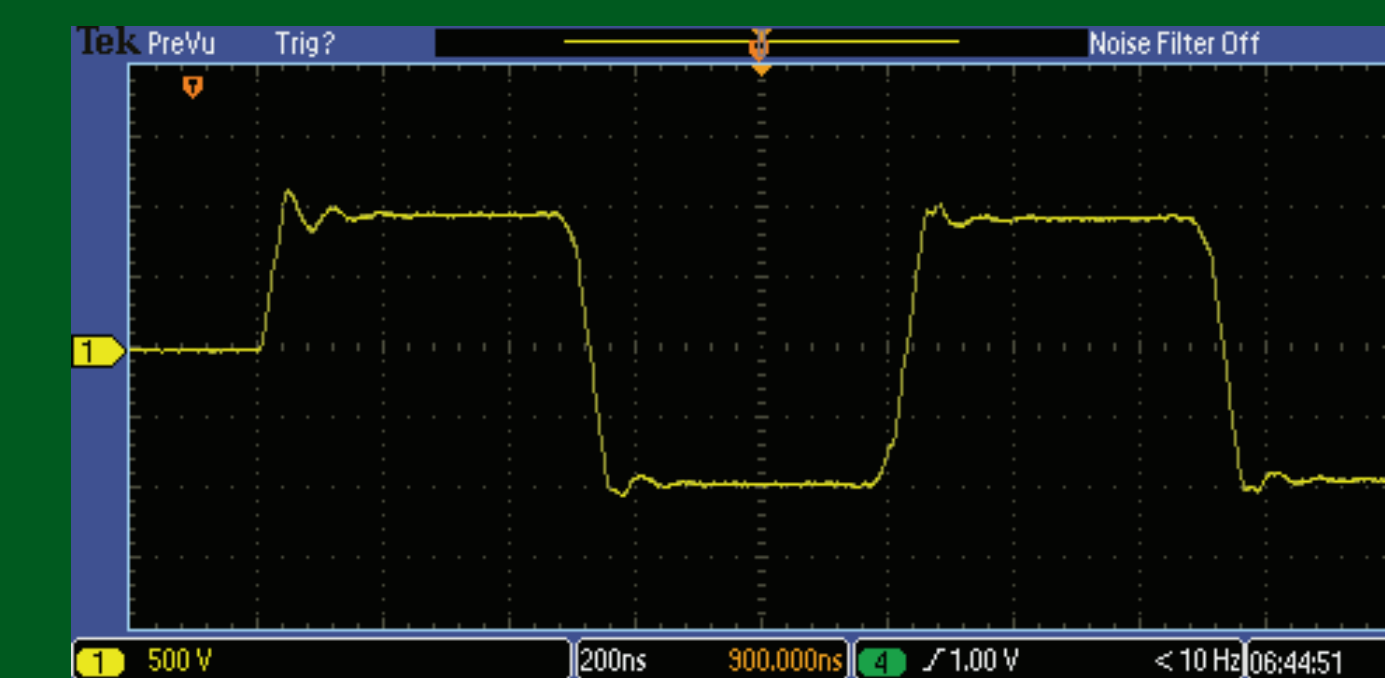
### H-Bridge Operation:



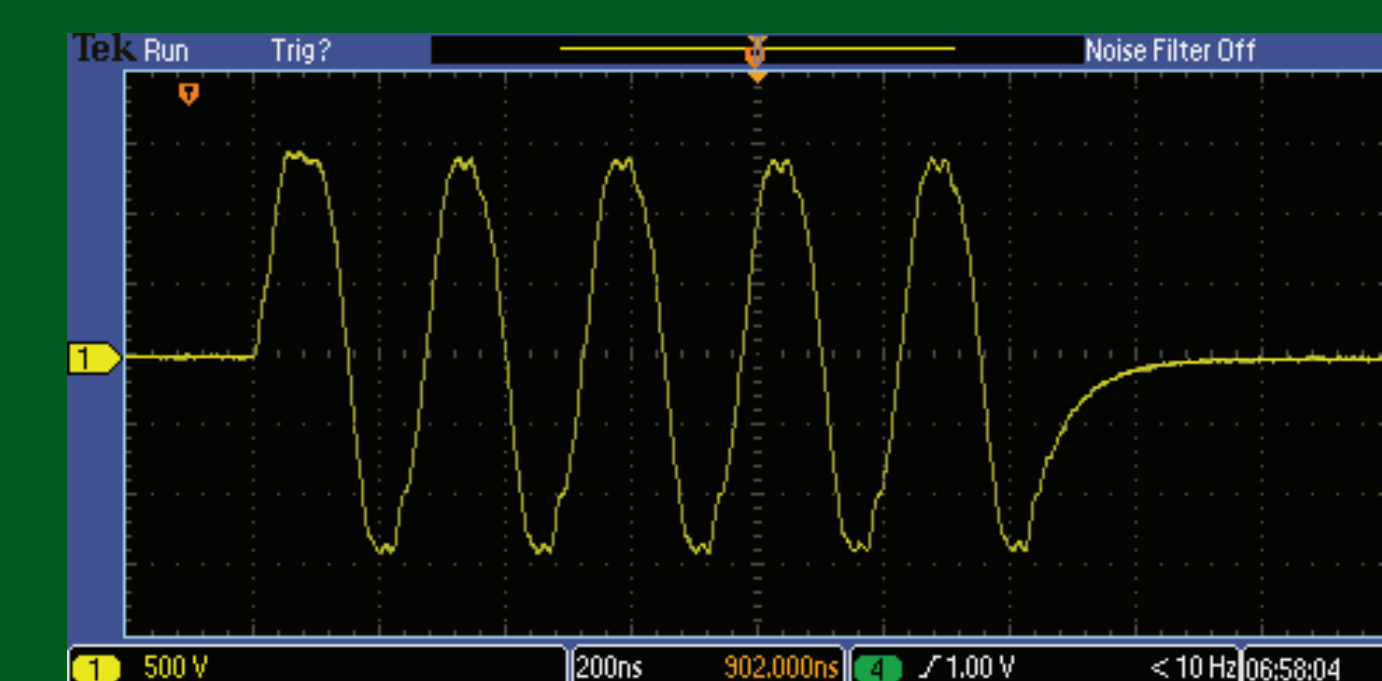
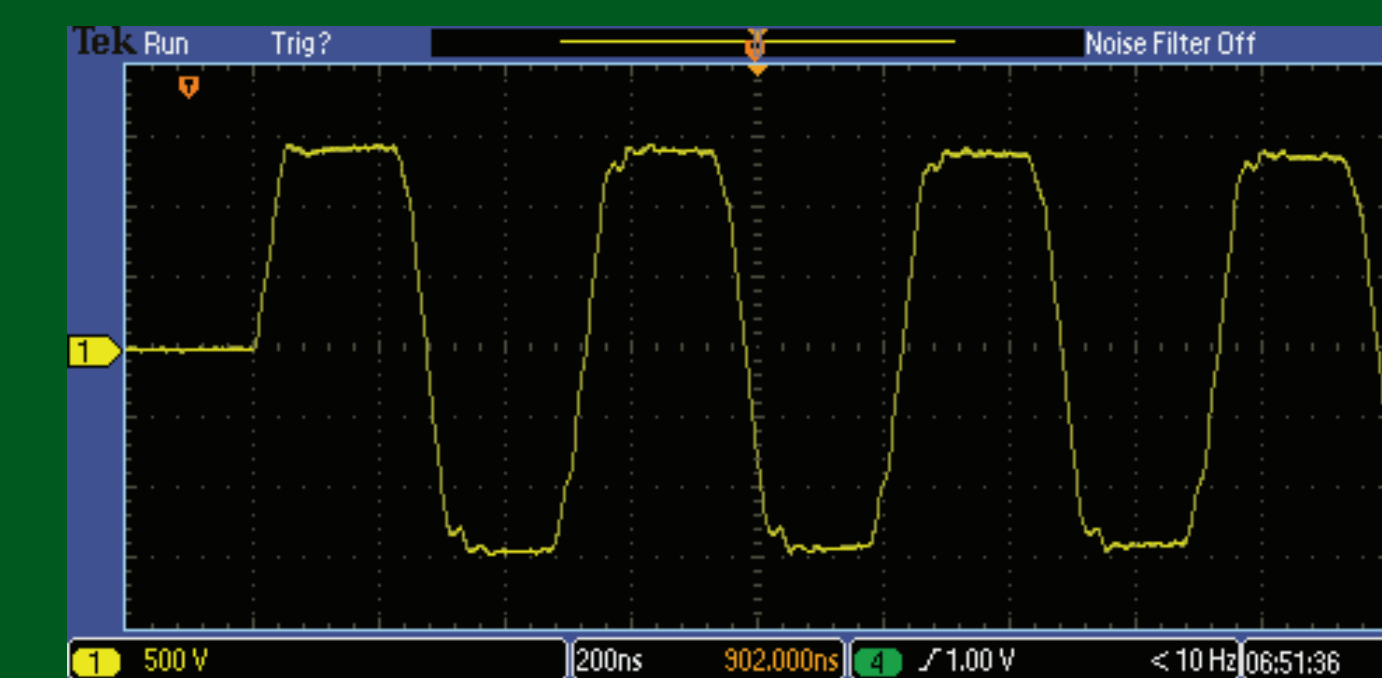
Single IGBT Board 4 Boards in H-Bridge Arrangement

Interconnect Board Resistive Load and Energy Storage

Data acquired with single IGBT per board showing robust operation at over 3kV p-p and > 2 MHz.



(Top) 1000 V, 20 A (2000 V p-p), 1 MHz. (Bottom) 1600V, 32 A (3200 V p-p) This is 400V over the rated voltage and shows robustness of the switching configuration.



(Top) 1500 V, 30 A (3000 V p-p), 2 MHz. (Bottom) Maximum obtainable switching of 4 Mhz. Trace shows 5 pulses and tail current at turn off.

### Summary and Future Work

EHT has demonstrated an IGBT based modular design for series/parallel configurations that can be utilized for many applications. Continued work in the second year of the DOE SBIR Phase II program will result in several demonstration supplies including a 15 kV, 1 kA supply with nominal switching at 100 kHz.

A parallel configuration for a 10 kA, 1 kV supply for fast magnet control and waveform programming will also be built and tested.

This work was funded under a DOE SBIR contract number #DE-SC0002682

Estimated cost comparison:

| Parameter             | RPPL,RMF Tube Supply | NSTX IGBT Based SPA | EHT, 20 Module Series Supply | EHT, 20 Module H-Bridge Supply |
|-----------------------|----------------------|---------------------|------------------------------|--------------------------------|
| Voltage (kV)          | 15                   | 1                   | 15                           | 1                              |
| Current (kA)          | 1.2                  | 10                  | 2                            | 10                             |
| Max Frequency (kHz)   | 120                  | 0.1                 | 1000                         | 1000                           |
| Impedance (Ohm)       | 12                   | Unk                 | 1.5"                         | Variable                       |
| Output Power (MW)     | 9 <sup>a</sup>       | 10 <sup>b</sup>     | 15 <sup>c</sup>              | 10 <sup>c</sup>                |
| Total Cost (Dollars)  | 2,000,000            | 310,000             | 80,000                       | 80,000                         |
| Cost/Watt (Dollars/W) | 0.22                 | 0.031               | 0.005                        | 0.008                          |

<sup>a</sup> Output power in RMF applications. In theory, tube based supply can operate at higher output levels.  
<sup>b</sup> Maximum Pulsed Output Power Level.  
<sup>c</sup> Optional current limit resistance for power supply protection.

Table 2. Comparison of the power supply examples with the EHT modular IGBT power supply

This supply is intended as a low cost option to high power tube based supplies for pulsed plasma creation and heating schemes in the range of 0.1 to 1 MHz and power levels up to 10 MW.