A Robust Modular IGBT Power Supply for Innovative Confinement Concepts

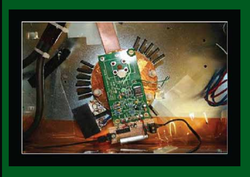
T. Ziemba*; K. Miller; J. Prager, J. Carscadden, Eagle Harbor Technologies, Inc.
*ziemba@eagleharbortech.com

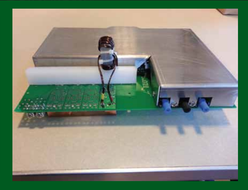
EAGLE HARBOR TECHNOLOGIES

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 overvoltage and overcurrent 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:

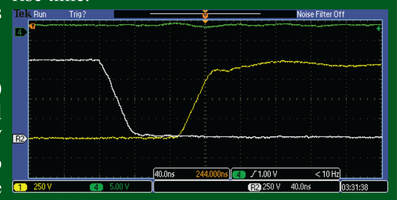




(Left) The pre-Phase I IGBT power supply. This supply could ouput 550 V & 700 A Pk @ 600 kHz for short bust widths (~1 ms). It could not be used in series configurations and required a costly IXYS driver board.

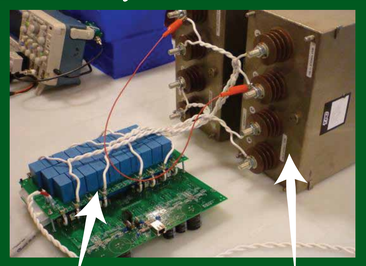
(Right) The final EHT Integrated Power Module (IPM) can deliver over 1 kV & 2.5 kA @ 1 MHz for several milliseconds. It has a continious rating of over 100 kW with heat sinking. The module is isolated with respect to the 48 V input power up to 30 kV and can easlily be operated in high voltage series configurations. All control logic and voltage monitoring is accomplished with high speed fiber optics.

1000 V, 100A, 200 ns single pulse. This shows V_{ce} (yellow) and V_{load} (blue). ~40 ns rise time.



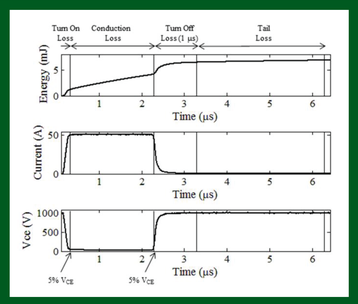
1000 V. Trace showing signal at end of 40 ft. 50 Ω coax cable terminated in 50 Ω. Yellow is V_{load}, white is V_{ce}measured on IGBT board.

Switch Efficiency:

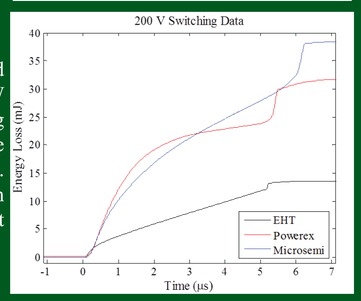


IGBT Module Resistive Load Testing

Energy Storage Capacitors



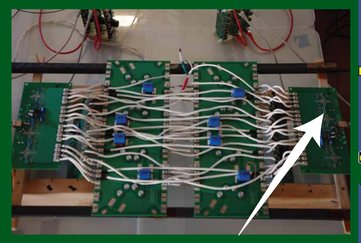
Switching and system efficiency were carefully analyzed during the Phase II program to determine maximum CW operational parameters. Due to the EHT switching technology, energy loss is much lower than comparable "Brick" style IGBT operating under the same conditons. The EHT IPM modules are over 99% efficienct when operated at below 10 kHz. They remain up to 95% efficient up to swithcing frequencies in excess of 250 kHz.



Key Components:

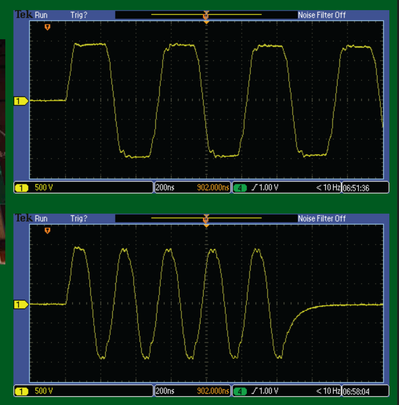
- Individual Integrated Power Modules (IPM) have been operated robustly at their nominal design parameters of 1 kA and 1 kV at 100 kHz switching frequencies.
- Individual modules can be stacked in series for high voltage operation, eliminating the need for step-up transformers. Module-to-module switching jitter has been verified to be less than 3 ns. 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) has been demonstrated.
- Individual boards were tested at 1 kV and over 2 kA for pulse lengths up to several milliseconds.
- Fiber optic and control voltage isolation provide robust, low-noise switching for series application. Nominal design provide over 30 kV isolation.
- EHT's proprietary switching allows for a dramatic reduction in total energy loss potentially increasing efficiencies for inverters use for green energy applications.

H-Bridge Operation/High Speed Switching Demonstration:



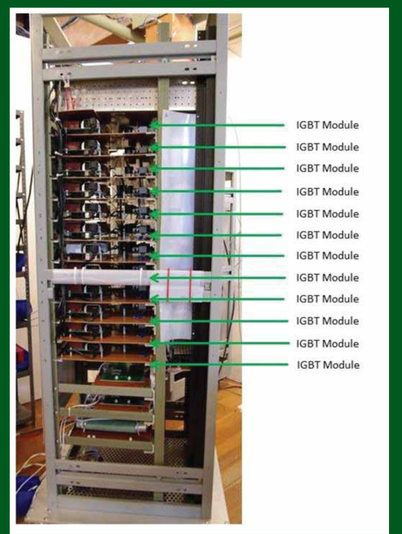
Fully H-Bridge configuration testing using four IPM Modules.

The EHT IGBT IPM have demonstrated robust high speed switching at frequencies not usually obtainable with IGBTs. The EHT IPM are routinely operated at over 1 MHz in both hard and soft switching applications.

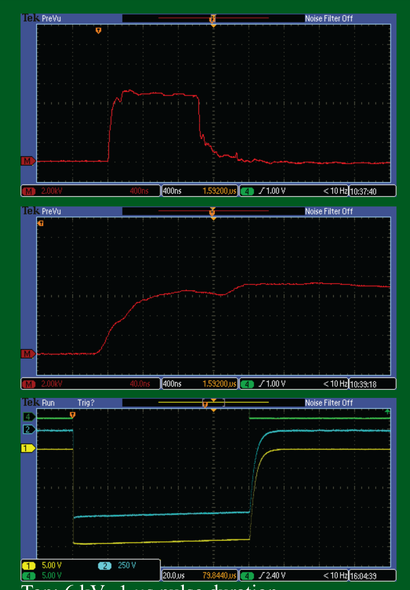


(Top) 1500 V, 30 A (3000 V p-p), 2 MHz. (Bottom) Maximum obtainable switching of 4 MHz. Trace shows 5 pulses and tail current at turn off.

Power Supply Configurations:

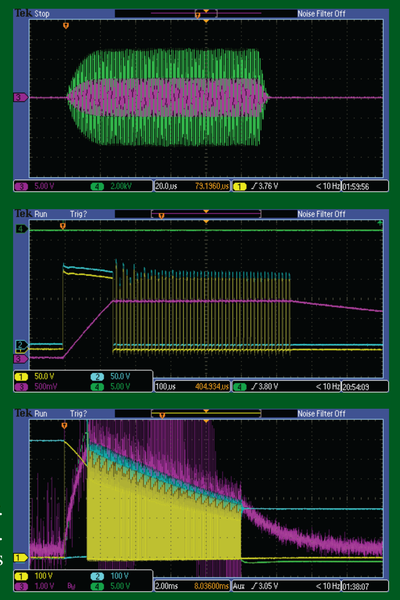


Phase II, 12 Module Series Configuration System was operated at over 10 kV & 1 kA output.



Top: 6 kV, 1 µs pulse duration
Middle: Expanded scale ~ 40 ns rise.
Bottom: 12 board series demonstration at over 10 kV and 1 kA ouput

Phase II, Half Bridge Series Resonant Converter. Utilized for plasma source antenna and magnet drivers. Capable of 1 MHz Switcing at high pulsed power levels (> 5 MW Peak).



Inductive load testing for both RF antenna and pulsed magnetic applications were demonstrated during the Phase II program. (Top) Ouput waveform for antenna current (~ 2 kA Pk) and voltage (~ 10 kV) @ 1 MHz. The exceed the RPPL RMF design parameters. (Middle) Magnet control using PWM to maintain constant current. (Bottom) Single IPM PWM magnet driver, 6 kA Peak current.

Additional Product Development During IGBT Phase II Program:

Single Channel IGBT Power Supply. 1700 V & 100 A pusled. 100 kHz PWM.

Fiber Optic Transmitter, Receiver and Interlock Controller Units. Used for control and safety of the EHT IPM.

Charge dump controller system. Up to 20 kV capactior charge and dump, fiber optic or manual control.

Control Voltage Isolation Board. 3 Outputs (5, 10, 24V) Up to 200 W Output with 30 kV isolation.

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