Adjustable, High Voltage Pulse Generator with Isolated Output for Plasma Processing

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EAGLE HARBOR TECHNOLOGIES

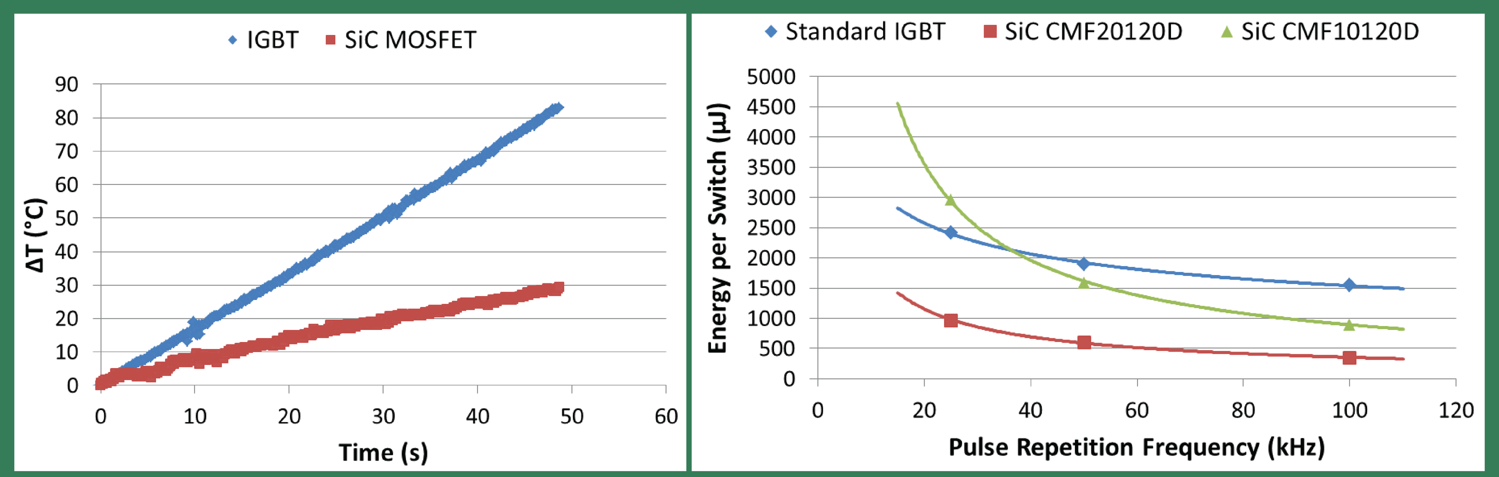
Introduction

Eagle Harbor Technologies (EHT), Inc. has developed a high voltage pulse generator with isolated output for etch, sputtering, and ion implantation applications within the materials science and semiconductor processing communities. The output parameters are independently user adjustable: output voltage (0 – 2.5 kV), pulse repetition frequency (0 – 100 kHz), and duty cycle (0 – 100%). The pulser can drive loads down to 200 Ω. Higher voltage pulsers have also been tested. The isolated output allows the pulse generator to be connected to loads that need to be biased. These pulser generators take advantage modern silicon carbide (SiC) MOSFETs. These new solid-state switches decrease the switching and conduction losses while allowing for higher switching frequency capabilities. This pulse generator has applications for RF plasma heating; inductive and arc plasma sources; magnetron driving; and generation of arbitrary pulses at high voltage, high current, and high pulse repetition frequency.

Motivation

There is a need both the experimental scientific and industrial communities for an arbitrary power supply system which can be configured to drive a wide range of loads for various applications. Power supply efficiency is a critical parameter for both high peak power (> 1 MW) and high average power systems (> 10 kW). There is also a need to increase system switching frequency to provide shorter output pulse widths or to drive higher frequency resonant loads at high power. To meet these needs EHT surveyed commercially available SiC MOSFETs and IGBTs and selected devices for in house testing based on maximizing switching and conduction efficiency at the highest possible current per device. The goals of this testing were to investigate if the EHT gate drive technology would improve SiC MOSFET switching, measure the overall switch efficiency, and determine the maximum current per device. After device selection both moderate and high power switch modules were made to investigate system capabilities.

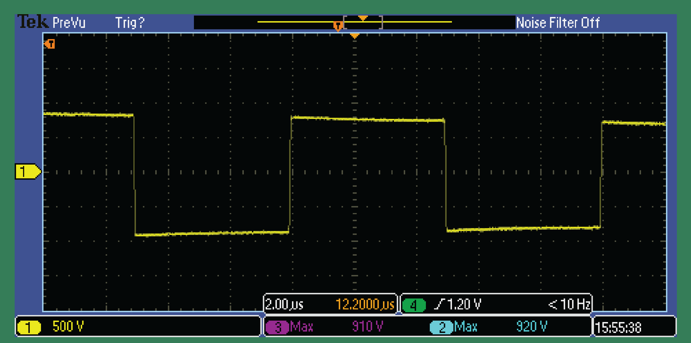
Manufacturer	Switch Description	Rated DC Current (A)	Rated Pulsed Current (A)	Current at which Rated Values are Specified (A)	Rated Rise Time	Measured Rise Time, 12 A (ns)	Measured Rise Time, 24 A (ns)	Rated Fall Time	Measured Fall Time, 12 A (ns)	Measured Fall Time, 24 A (ns)
IR	IGBT	40	120	20	20	12	26	24	31	21
Microsemi	IGBT	40	160	40	25	4	5	40	30	10
IR	IGBT	50	105	35	25	5	6	105	50	12
Microsemi	IGBT	75	100	25	10	4	5	20	29	7
IR	IGBT	80	160	40	46	6	9	28	50	29
ST Microelectronics	IGBT	80	160	40	15	5	5	135	281	201
IR	IGBT	90	90	30	36	6	9	74	20	10
ROHM	SiC M	14	35	4	19	12		29	17	
ROHM	SiC M	20	45	10	17	10		16	9	
Cree	SiC M	24	49	10	21	12	39	34	17	18
Cree	SiC M	36	80	20	20	5	9	19	15	5



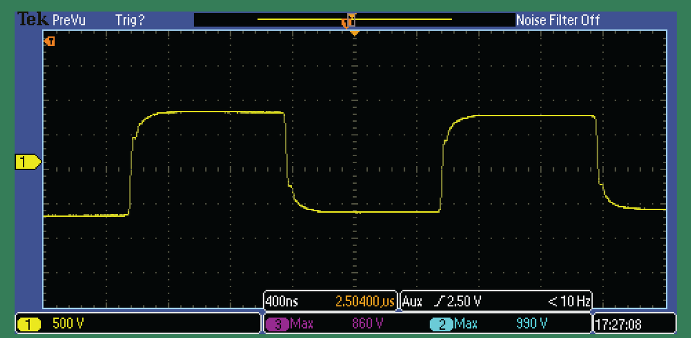
Thermal tests conducted at 600 V and 24 A/device. (Left) IGBT and SiC MOSFET temperature change showing lower total energy loss for the SiC MOSFET device. (Right) Energy dissipation per switching cycle at various pulse repetition frequencies.

Pulser Output into Resistive Load

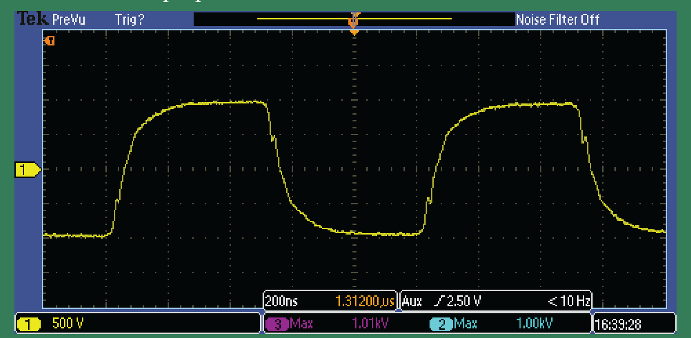
EHT has conducted full-bridge testing into a variety of low-inductance resistive loads to demonstrate high power switching at high peak power levels. The new pulser system is capable of very high current switching (> 3 kA) into resistive loads at switching frequencies of 1 MHz under pulsed conditions. The pulser has been tested at lower current levels and switching frequencies and demonstrated average output levels in excess of 5 kW at continuous operation. The wide range of switching conditions and power levels allows the same system to be utilized for multiple applications as demonstrate below.



1.8 $kV_{pk\text{-}pk}$ and 720 A at 100 kHz PRF.



1.5 $kV_{pk\text{-}pk}$ and 8 kA at 500 kHz PRF.

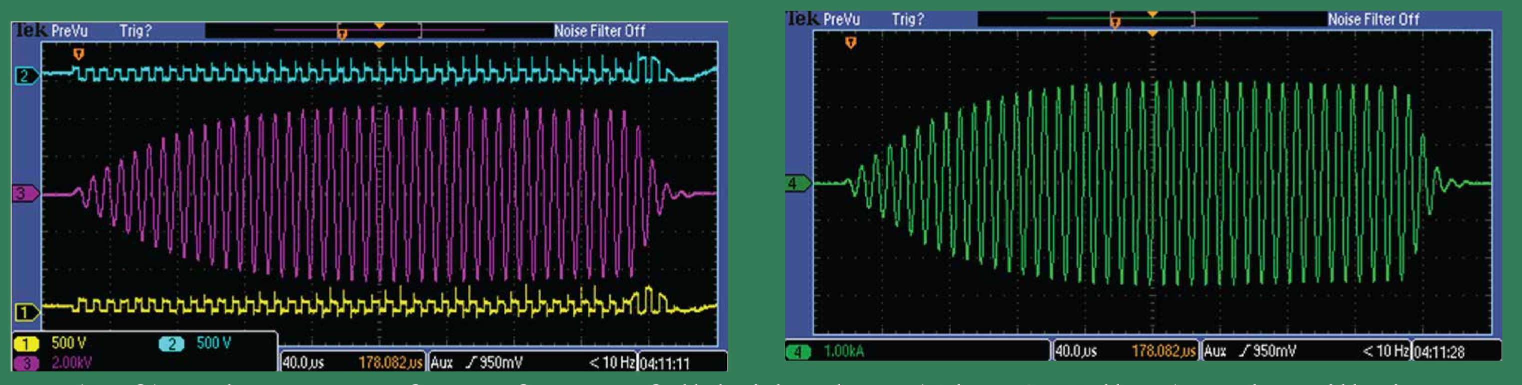


2.0 $kV_{pk\text{-}pk}$ and 3.2 kA at 1 MHz PRF.

Full-Bridge Testing with Series Resonant Tank Circuit

EHT tested the ability of the full-bridge to drive a series resonant tank circuit at two resonant frequencies. During the high frequency test, the full-bridge achieved a peak-to-peak current of 5.4 kA. The 1 MHz switching test achieved 1 kA through the resonant load. The limitation of both tests was the voltage rating of the series resonant capacitor. The both tests demonstrated capability for precision magnetic control with fast PWM.

	High Frequency	Very High Frequency
Resonant Frequency ($\omega_0/2\pi$)	120.9 kHz	1 MHz
Charge Voltage	150 V	300 V
Total Storage Capacitance	25 mF	128 μF
Resonant Inductance	1.7 μH	2.5 μH
Resonant Capacitance	1.0 μF	10 nF
Oscillating Current (pk-pk)	5.4 kA	1 kA



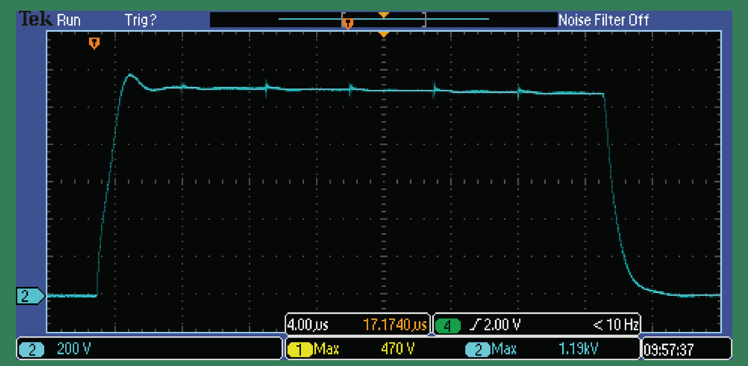
(Left) Voltage waveforms for two full-bridge legs (Blue & Yellow) and oscillating voltage on the resonant network. (Right) Oscillating current in the resonant network.

High current switching test set-up

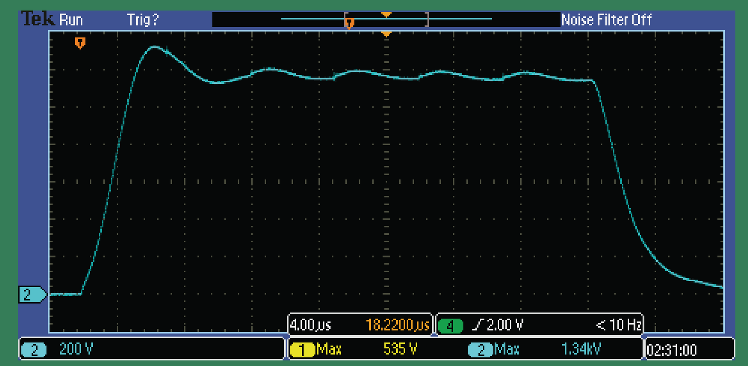
High power inductive plasma generation using high current resonant tank network

Arbitrary Pulser Output

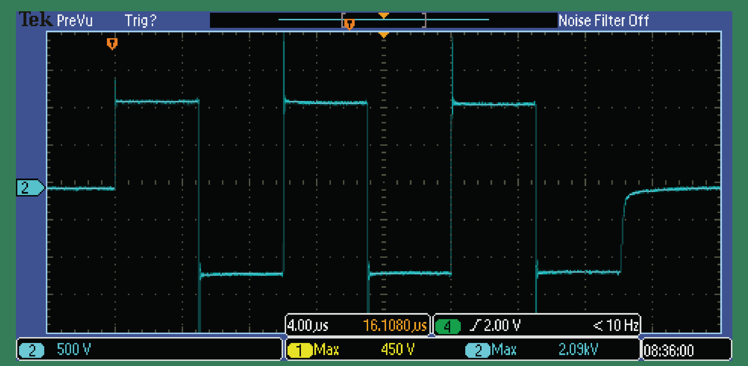
Applications that require high voltage arbitrary pulse generation include semiconductor etch, sputtering, magnetron driving, high voltage beam kickers, electron/ion beam generation. This pulser can produce up to 10 kV pulses from DC to 100 kHz pulse with a duty cycle from 0 - 100%.



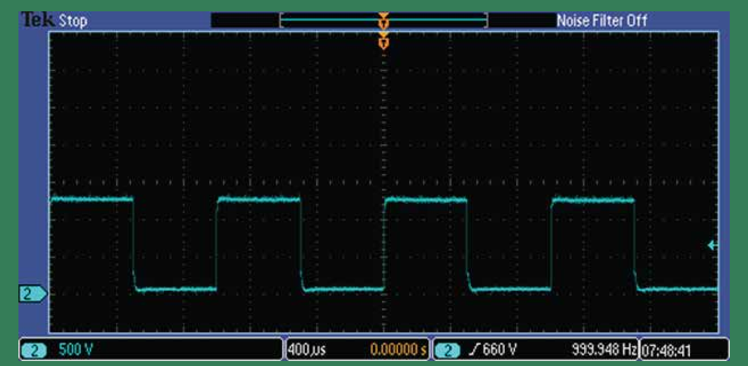
30 μs pulse generation into 250 Ohm load.



30 μs pulse generation into 1000 Ohm load.



100 kHz square wave generation.



1 kHz positive pulse generation

Conclusions

EHT has developed a high voltage, isolated pulser product series (APG Series) capable producing arbitrary square wave pulses for driving resistive, inductive, tank circuit, and plasma loads with the following characteristics:

- Floating (galvanic isolated) output that can be biased with respect to other systems
- Pulse repetition frequency DC - 100 kHz
- Duty cycle can be varied in real-time from 0 to 100%
- Clean square wave with 20 to 200 ns rise/fall time (load dependent)
- Front panel control with remote interface options
- Output voltage (adjustable) up to 10 kV (load and application dependent)
- Average Power levels: 0.1, 0.5, 1.0, 5.0 kW
- Peak Power levels: > 1 MW

First generation EHT full-bridge pulser.

These pulsers can be used in research areas including plasma science linear particle accelerator supplies, high voltage ion implantation supplies, and RF cyclotron power supplies. This system enables new capabilities for etch, ion implantation, and sputtering applications for the materials science and semiconductor processing communities.

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