Solid-State Medical Pulsed Power

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EAGLE HARBOR TECHNOLOGIES

Introduction

Electroporation is the process of applying electric fields to cells to increase the permeability of the cell membrane. Reversible electroporation (RE) can be used to deliver drugs, DNA, nanoparticles, or other material to the interior of cells, while irreversible electroporation (IRE) results in cell death. Electroporation techniques are being used to develop cell therapies, treat solid tumors, and address atrial fibrillation with cardiac ablation. The field strength, pulse duration, frequency, and total treatment time can determine whether this process is reversible or irreversible and how it impacts patients. Eagle Harbor Technologies, Inc. (EHT) has been developing medical power systems that allow for precision control of the electroporation process. The use of wide bandgap semiconductors enables high-frequency burst application (>1 MHz). These power systems operate at 1–10 kV with pulse widths from nanoseconds to milliseconds. The topologies and waveforms for different systems will be presented.

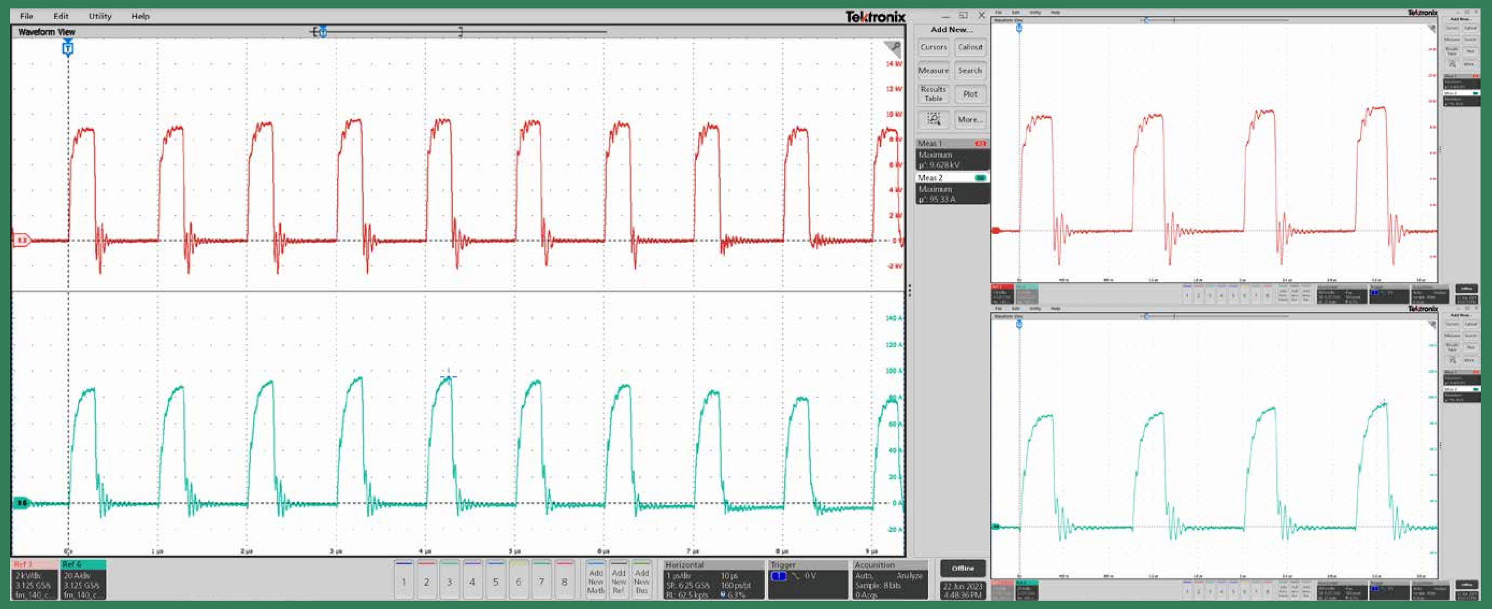
Nanosecond Pulses for Irreversible Electroporation (IRE)

EHT has leveraged our high-power nanosecond pulser designs to produce a high-frequency pulse generator for IRE. Most biological loads have an impedance of 50-150 Ω; however, the pulse generator must be able to operate over a wider load impedance range as this can change over the burst of pulses.

Additionally, the pulse generator must be safe to arc conditions. In initial system, arc protection is achieved through cable isolation.

Design Specifications:

- Output Voltage: 10 kV
- Output Current: 200 A
- Pulse Width: 200 – 400 ns
- Max Pulse Repetition Frequency: 1.2 MHz
- Number of Pulses per burst: 1 – 40
- Tested Burst Frequency: 100 Hz
- Safe to arcing events: Yes
- Applications: soft-tissue ablation, cardiac ablation, etc.



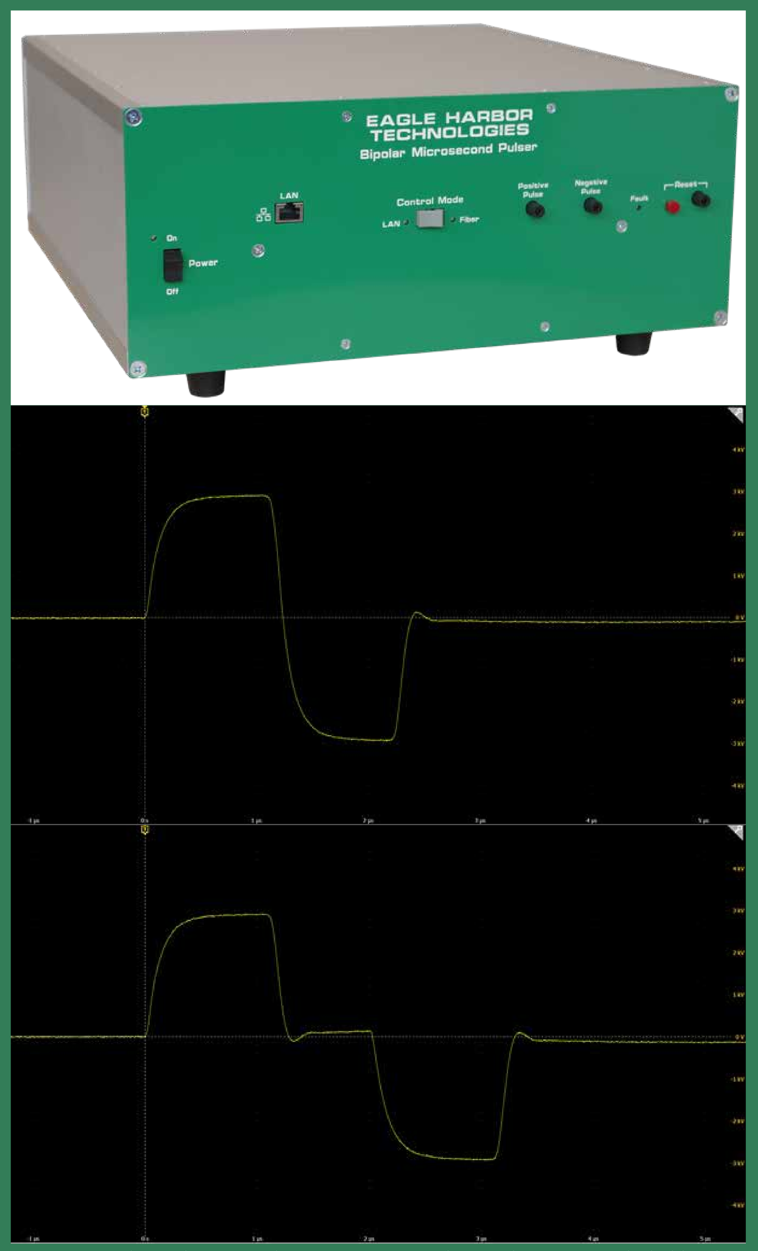
Left: 9.6 kV, 400 ns pulses into a 100 Ω load at the end of a long cable. Pulses are repeated at 1 MHz. Peak current: 95 A.

Bipolar Microsecond Pulser for RE/IRE

EHT developed a 3 kV full bridge that allows the user precision control of the waveforms via a simple GUI. The load impedance of biological material can change dramatically over a single pulse, pulse to pulse, patient to patient. Power systems must have a wide safe operating area.

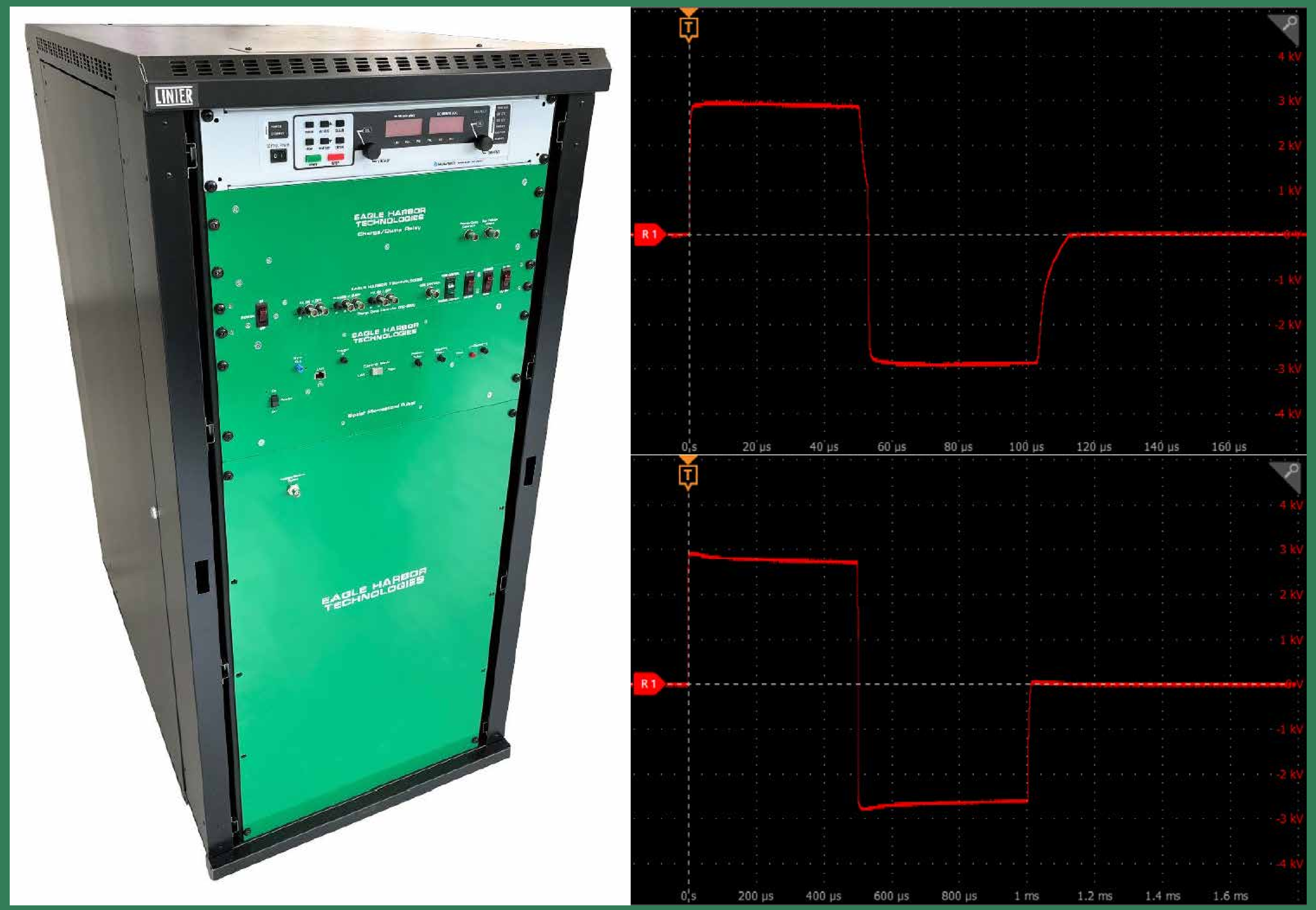
Design Specifications:

- Output Voltage: ±3 kV
- Output Current: 0 – 150 A
- Pulse Width: 0.5 – 500 µs
- Dwell: 0.2 – 500 µs
- Pulse Repetition Frequency: 0.1 – 10 kHz
- Number of Pulses: 1 – 2500
- Burst Frequency: 0.1 – 1 Hz
- Overcurrent Protection: Yes
- Internal Energy Storage: 24.5 J (external energy storage can be added - see example below)



Top: Bipolar Microsecond Pulser. Middle/bottom: 3 kV output voltage measured across a 70 Ω load.1 µs pos/neg pulse width for, 100 ns (middle) and 1 µs (bottom) dwell time between pulses.

Bipolar Pulse Generator for Cardiac Ablation Research



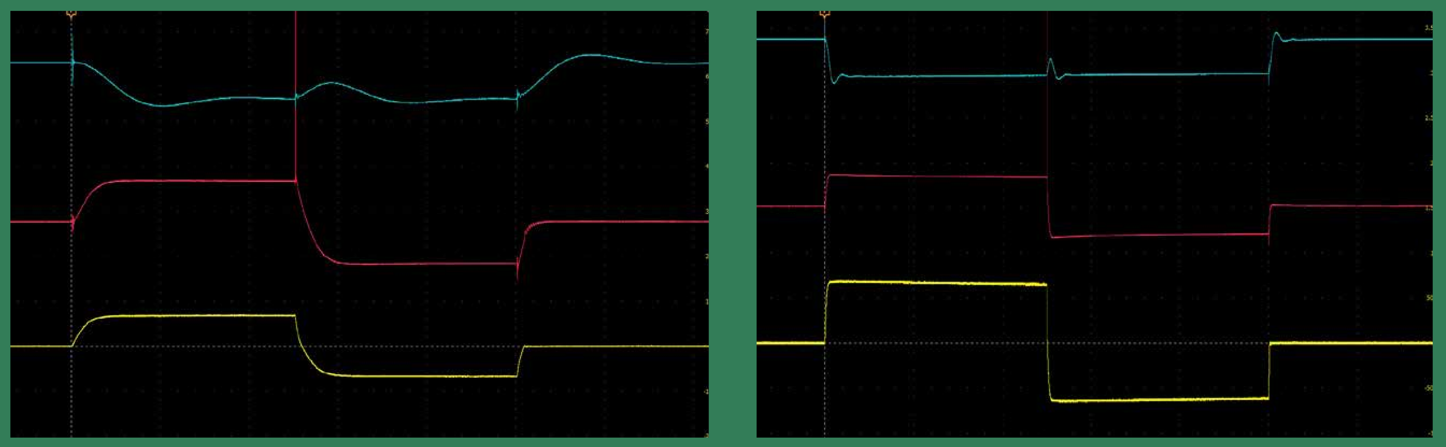
Left: Bipolar microsecond pulser with capacitor bank, charge/dump system, and DC charging supply. Right: Output voltage measured across a 70 Ω load, 3 kV charge, 50 µs (top) and 500 µs (bottom) pulse width for both the positive and negative pulse, no dwell between pulses.

High Current Full Bridge for CAR T-Cell Therapy

Applying CAR T-cell therapy at scale requires pulse generators that can produce the precision waveforms at higher current levels. EHT leveraged our high-current full-bridge design. System is tightly integrated with the user's control system and reports the pulse voltage through a 100:1 resistive voltage divider.

Specifications:

- Output Voltage: ±700 V
- Output Current: 0 – 800 A
- Positive/Negative Pulse Width: 50 – 1000 µs
- Rise/Fall Time: < 5µs
- Pulse Repetition Frequency: < 1 Hz
- Duty Cycle: < 0.04%
- Control: 24 V BNC into 500 Ω termination
- Overcurrent Protection: Yes
- Arc Report Duration: 700 ms



700 V charge with a 2.5 Ω load, 50 µs (left) and 500 µs (right) pulse width for both the positive and negative pulse, no delay between pulses. Blue is the shunt voltage, red is the output voltage measurement at the front panel (1:100), and yellow is the actual output voltage (differential HV probe).

Conclusion

EHT has been leveraging existing EHT pulse generator designs for biomedical applications. EHT has developed nanosecond pulsers, high-current full bridges, and high-voltage full bridges for these applications. These solid-state systems allow for precision waveform control with the necessary high voltage, high current, short pulses, and high pulse repetition frequency required for RE and IRE. These pulse generators are enabling new capabilities for reversible & irreversible electroporation applications including CAR T-cell therapy, cardiac ablation, drug delivery, and soft tissue ablation.

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