Department of Electrical and Computer Engineering

Group 14

32-Channel Pulser for Histotripsy

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Introduction

Histotripsy is a non-invasive surgical technique by which unhealthy cells can be destroyed using ultrasound waves.

Dr. Jeremy Brown's previous histotripsy design, focusing on neurosurgery applications, is capable of tissue cavitation of volumes less than one mm^3 at a single focal point:

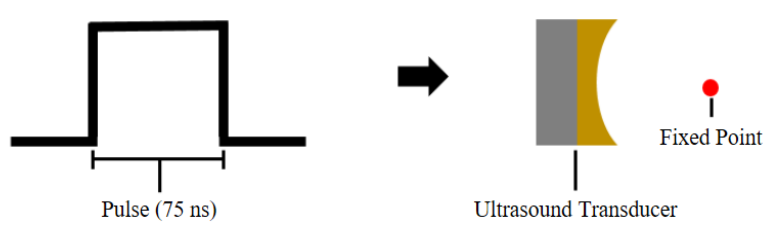
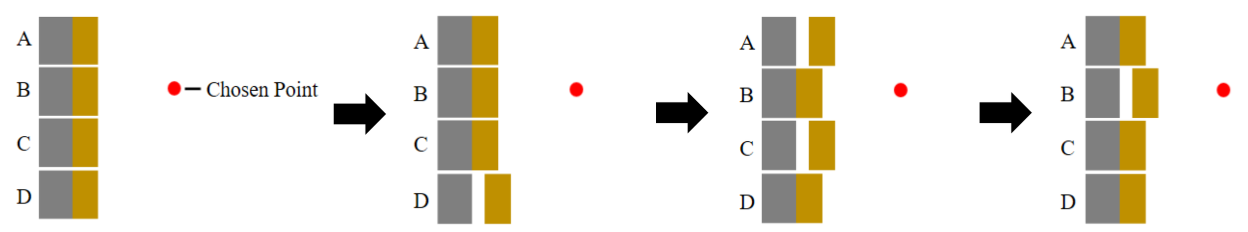


Figure 1- Single Channel Design

Dividing the ultrasound transducer into multiple channels allows for variation in the vertical axis, along with depth control of the focal point. Delaying the individual channel waveforms in time produces constructive interference at the desired location:



Step 1: Choose transducer focal point.

Step 2: Farthest channel (D) is pulsed.

Step 3: Equidistant channels (A & C) are pulsed.

Step 4: Closest channel (B) is pulsed.

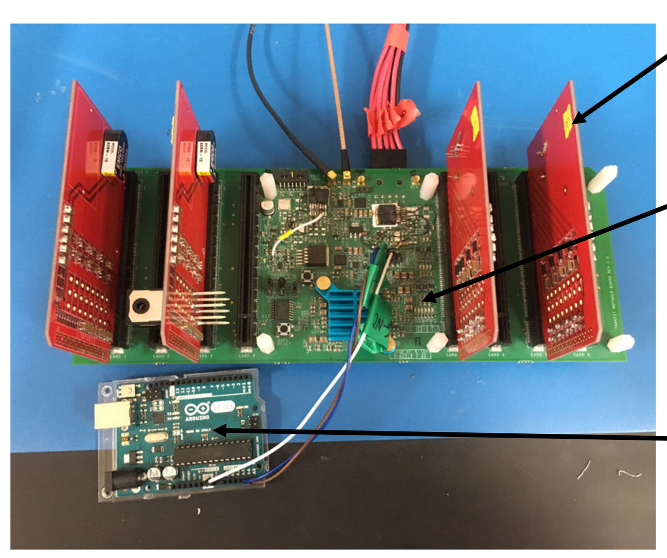
Figure 2- Multiple Channel Design

Design Process

The goal of this project was to produce a total of 32 channels that could generate the waveforms required to perform histotripsy. Each channel was designed to output a 1kW, 500V pulse with rise and fall times of less than 15ns.

The circuit design was simulated on LTSpice to confirm the waveform specifications. After selecting suitable components, the schematic and board layout were completed using OrCAD.

The 32 channels were divided into 4 printed circuit boards, which interface with the motherboard through an FPGA, as demonstrated in Figure 3.



PCB: Delivers the high voltage pulse to the transducer.

Motherboard: Includes the low input voltage sources and the FPGA that creates the input pulse.

Arduino: Controls the low input voltage value from the motherboard during testing.

Figure 3- Test Setup

Details of Design

Circuit Schematic

Individual Channels:

Each channel performs two main functions. The gate driver shifts the 3.3V input pulse to 12V, and the N-channel MOSFET connects the high voltage line to the output pins.

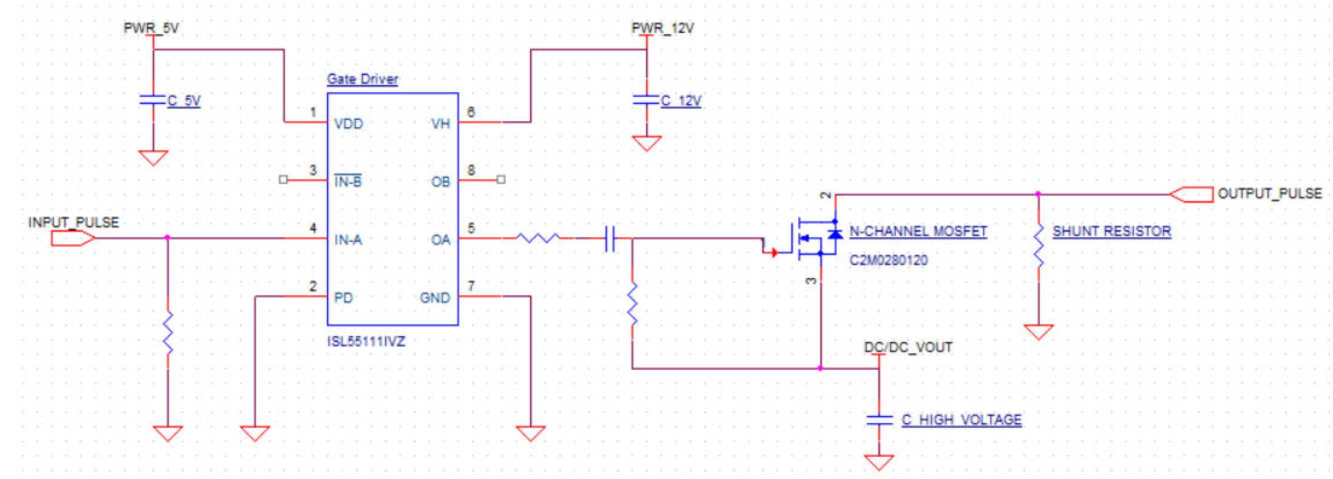


Figure 4- Individual Channel Circuit Schematic

DC/DC Voltage Conversion:

The DC/DC voltage converter takes an input of 0-12V and outputs 0-500V. The relationship of this conversion can be approximated as linear.

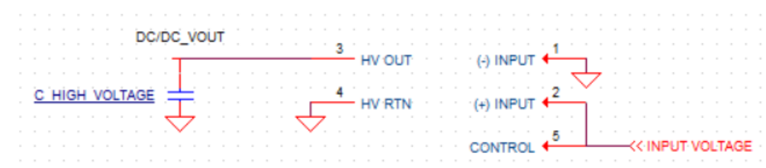


Figure 5- DC/DC Voltage Conversion Circuit Schematic

PCB Layout

Printed Circuit Boards:

Each board contains 8 channels, with a connector to the motherboard containing the 5V and 12V power sources, and 3.3V input waveform. Considerations included the trace length and width requirements of the high voltage lines. The boards are four layers, with the top and bottom layers shown below.

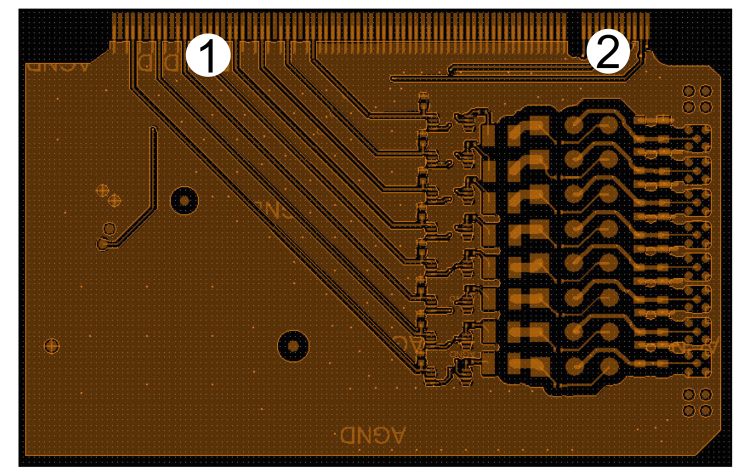


Figure 6- PCB Bottom Layer

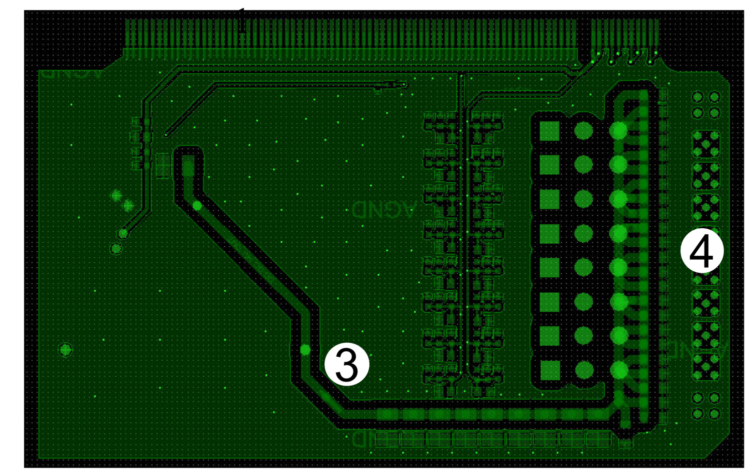


Figure 7- PCB Top Layer

1. Input waveform from motherboard (3.3V).
2. Input power from motherboard (5V, 12V).
3. High voltage output from DC/DC converter.
4. Output waveform to transducer.

Results

Voltage Control

The output voltage was controlled through the input to the DC-DC voltage converter. The voltage magnitude of the pulses shown below demonstrate the resulting range of the output voltage, which determines the power applied at the transducer.

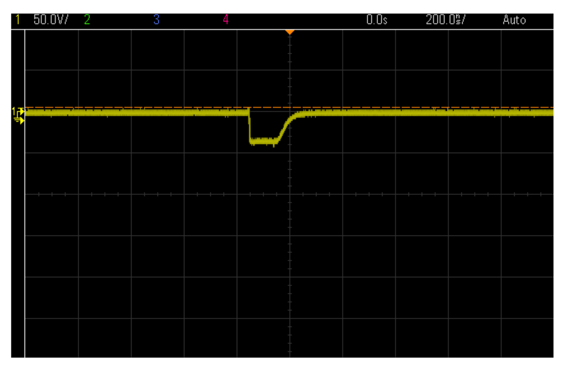


Figure 8- Output Voltage -40V

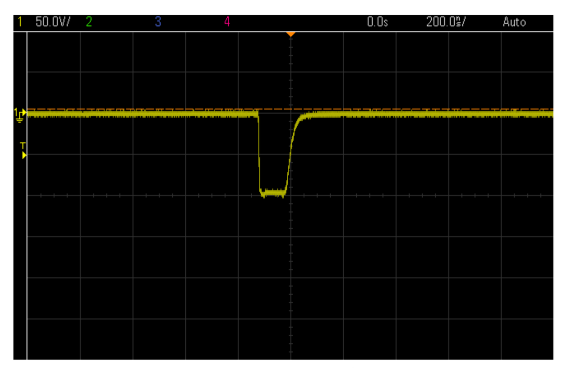


Figure 9- Output Voltage -103V

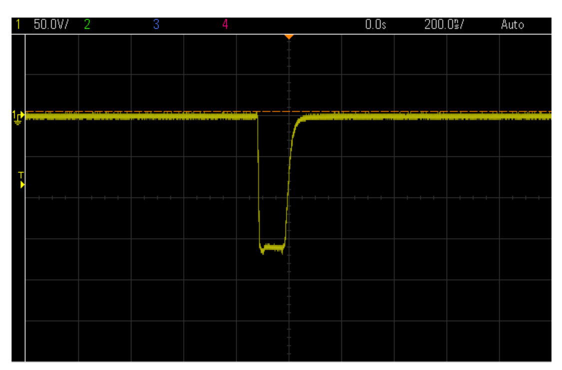


Figure 10- Output Voltage -167V

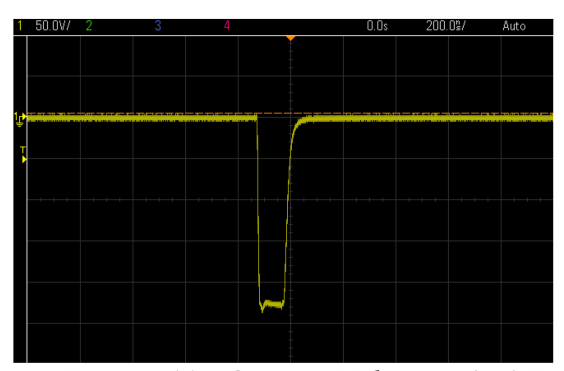


Figure 11- Output Voltage -240V

Multiple Channel Control

Using four individual channels per board, consecutive voltage pulses were generated with the required rise time of 15ns. This provides proof of concept that the elements of the ultrasound transducer can be signaled with sufficient time accuracy to vary the focal point.

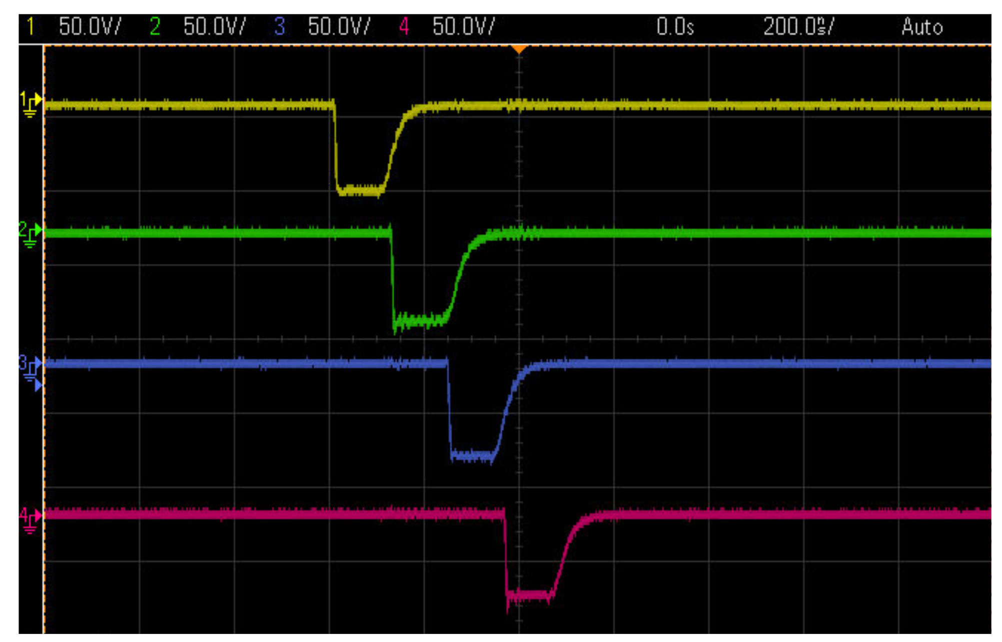


Figure 12- Multiple Channel Pulses

Conclusion

The final design is capable of delivering up to 500V pulses through 16 channels, producing a total instantaneous power of 16 kW. The output voltage is variable to account for various power requirements, and the MOSFET switching speed allows for consecutive pulses. The boards are capable of delivering a pulse suitable to move forward with proof of concept testing to vary the focal point of a histotripsy cavitation bubble.

Recommendations

The 16-channel design should be tested with a histotripsy transducer to test for cavitation potential. Once all 32 channels are populated, testing can resume to determine the effect of the multiple channel design on placement of the focal point.