A Multi-Channel Brain Tissue Stimulator
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Department of Biomedical Engineering

BME 400
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Abstract

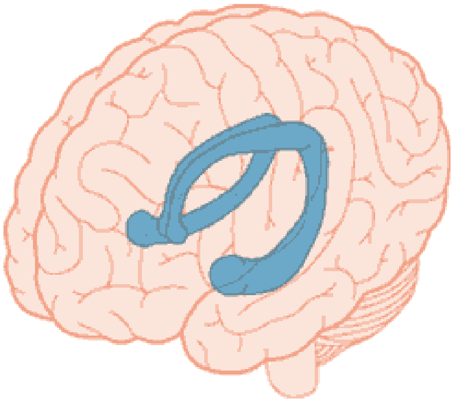
Due to the restrictive nature regarding the current process of studying the circuitry throughout the brain, a new method is sought. The device to be used is a 16-channel stimulator. An ideal current of 1 mA should be sent through each channel, allowing individual neurons to be activated. Utilizing both client requirements and knowledge of electronics a circuit was created to deliver this current to each individual channel. Throughout the report, the roles of the different circuit components are described. Testing was conducted for both the individual components and the circuit as a whole. The testing was done on both high and low voltages. Based on the results of the tests, future work is analyzed.

Problem Statement

In order to more realistically stimulate the brain using the NeuroNexus Technology Inc.'s Acute Research Probe, a current source capable of delivering 0.1 to 1 mA of current to any one of 16 electrodes is required. The amplitude of the pulse must be independently controlled, and the pulse width of the current must be controlled by the input pulse from a computer. The device must be insulated from all noise.

Background

Information in the brain is processed through the transmission of electrical signals. Learning the pathways of these signals would do wonders towards understanding the way the brain works. The hippocampus is the part of the brain in charge of learning and creating new memories. The hippocampus is highlighted below in Figure 1. It is also the part of the brain that is affected during Alzheimer's disease. For these reasons, it is often a part of the brain that is focused on by scientists conducting research. [1]



www.BrainConnection.com
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Figure 1. The Hippocampus. This figure shows the hippocampus, highlighted in blue.
Source: www.BrainConnection.com

Because of the difficulty and ethical considerations revolving around human research, much of the work that is done is on mice and rats. The availability of these animals is high, and there are few, if any, regulations surrounding studies on them. One way of studying the brain of these animals is to isolate the organ, and then section the tissue into thin slices. Then these slices can be stained, viewed under a microscope, or electrically stimulated. [2]

Motivation

The current process to study the circuitry of the hippocampus utilizes a thick, platinum wire. A charge is sent through the wire, which simultaneously fires multiple neurons.

However, this progression is not physiologically accurate. Ideally, the researcher would want the ability to fire one neuron at a time. Accomplishing this would require not only an extremely thin wire, but also a large voltage to supply the necessary current through the high impedance.

The way in which our client has gotten around using this thick platinum wire is by using a Michigan electrode. Michigan electrodes can be used to stimulate the tissue to ensure that only one neuron is firing at a time. A photo of this Michigan electrode is shown below in Figure 2. A four pin system exists, that has four pads at the end of each pin. These pads would be placed on the tissue, and preferably could stimulate individual neurons. One large drawback to this electrode is that it has a very large impedance of anywhere between 1-3 MΩ.

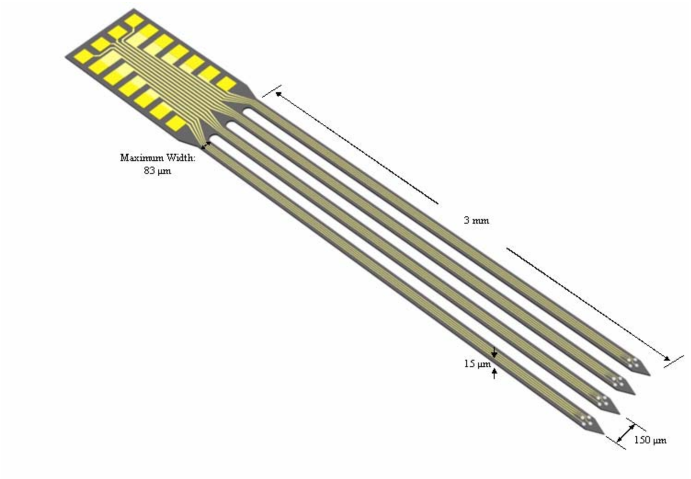


Figure 2. Michigan electrode. The figure shows what the Michigan electrode, along with its dimensions.
Source: Photo provided by Dr. Mathew Jones

There currently are devices on the market that can achieve this function. Yet, these devices and systems have the ability to conduct many other functions, which are unnecessary in the studying of the brain. Because of the widespread uses, these machines cost upwards of $10,000 [1]. This cost is not realistic for many researchers. Therefore, a low-cost solution is necessary.

Client Requirements

The client laid out a list of guidelines that would allow him to conduct his research. One such requirement is that each channel of the sixteen pronged stimulator must operate independently. There can be no cross-talk between the channels, and each one must be able to be gated on and off on its own. Ideally, a current of up to 1 mA could be delivered to each channel. Complications arise when electrical noise enters the system. Therefore, it is also necessary to eliminate or minimize outside noise. The time to deliver the pulse is also an important factor. The client would like the pulse to be delivered in about 100 microseconds (μs) with no lag time.

Circuit Components and Design

Our current design prototype incorporates many circuit components. There are seven main parts to our prototype: the power supply, the rectifier, the low-pass filter, the optical isolator, the field-effect transistor (FET), the capacitive bypass, and the electrode. Each part will be discussed independently for a better understanding of the prototype in its entirety.

Power Supply

We are using an AC transformer to provide the supply voltage. It can output 335V, 710V and 1000V, depending on the voltage our client would like to use. This value can be changed at our client's discretion. This AC waveform must be changed to a constant DC supply in order to provide consistent pulses to the electrode.

Rectifier

The full-wave rectifier acts as an AC/DC converter. It converts the incoming sinusoidal wave to a positive wave. This can be seen in Figure 3, shown below. The input of the rectifier is non-polar, but the output is polar.

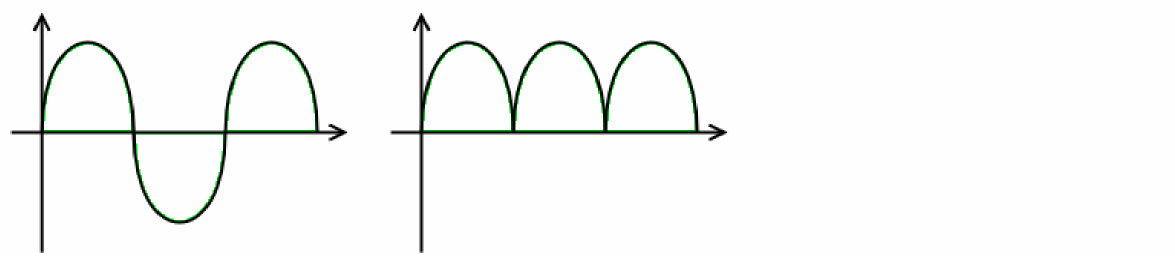


Figure 3. Full-wave rectifier. The graph on the left is the incoming sinusoid. The graph on the right shows the output of the wave after it has been rectified.
Source: http://en.wikipedia.org/wiki/Rectifier

Low-pass Filter

The rectified waveform is not a smooth, constant DC source as can be seen in Figure 3. In order to smooth the waveform and decrease the amount of noise, the signal must travel through a low-pass filter. Due to the size of the final signal supplied to the electrode, noise must be removed so that it does not overpower the output. The capacitors are rated up to 500V, and the resistors act as a voltage divider. The value of the resistors does not matter much, so long as the power to be dissipated is lower then the rated wattage.

Shunt Resistors

In order to improve the safety of the circuit, two shunt resistors were incorporated into the power supply. These shunt resistors are hooked up to a switch, which can be flipped by the user after the system is powered down. The shunt resistors act to bleed off any excess charge in the capacitors after the power is turned off. With the shunt switch off, it takes about 10 minutes to discharge the capacitors. Turning on the switch (closing the shunt circuit) brings this time down to about a minute.

Optical Isolator

The optical isolator contains a photo-diode sensor and an LED. When it receives the 5V pulse the LED turns on, triggering the photo-transistor. This phototransistor allows current from the isolated 12 volt source to flow through the floating resistor between the gate and the drain of the FET, turning it on. The purpose of the optical isolator is to prevent a backflow of electrons through the circuit and into the computer, which provides the 5V TTL pulse. The optical isolator does not require any external power, and can be considered passive. It acts as a switch for the current loop that turns on the FET. The potentiometers modulate the current going into the LED, which can vary the voltage level of the isolator's output.

Field-effect Transistor (FET)

The FET acts as a switch between the high voltage source and the electrode. It has a gate, drain and source, labeled in Figure 4. When there is no voltage difference between gate and drain,, the resistance between the drain and source is very high (on the order of 10^9 Ohms) ; this acts like an open circuit. When the 12V pulse from the optical isolator reaches the gate, the resistance between the source and drain is reduced, allowing the supply voltage to pass. The current that passes through the electrode stimulates the tissue sample. This current will vary depending on the individual resistance of each electrode.

DC-DC Power Supply

Twelve volts is necessary to turn on the FET so that current may flow to the electrode. These 12 volts must be isolated from ground, because the entire circuit will be momentarily charged to a high enough voltage to damage any power supply. The DC-DC power supply provides a constant 12 volts on top of any high voltage while keeping any current from flowing back to the wall outlet. The 5 V TTL pulse turns on the optiosiolator, which itself acts as a switch to allow current from the 12 V source to turn on the FET. Great care must be taken not to plug in the DC-DC power supply with the polarity reversed, as this will destroy the power supply. A capacitor is placed between the output positive and negative to reduce transient noise.

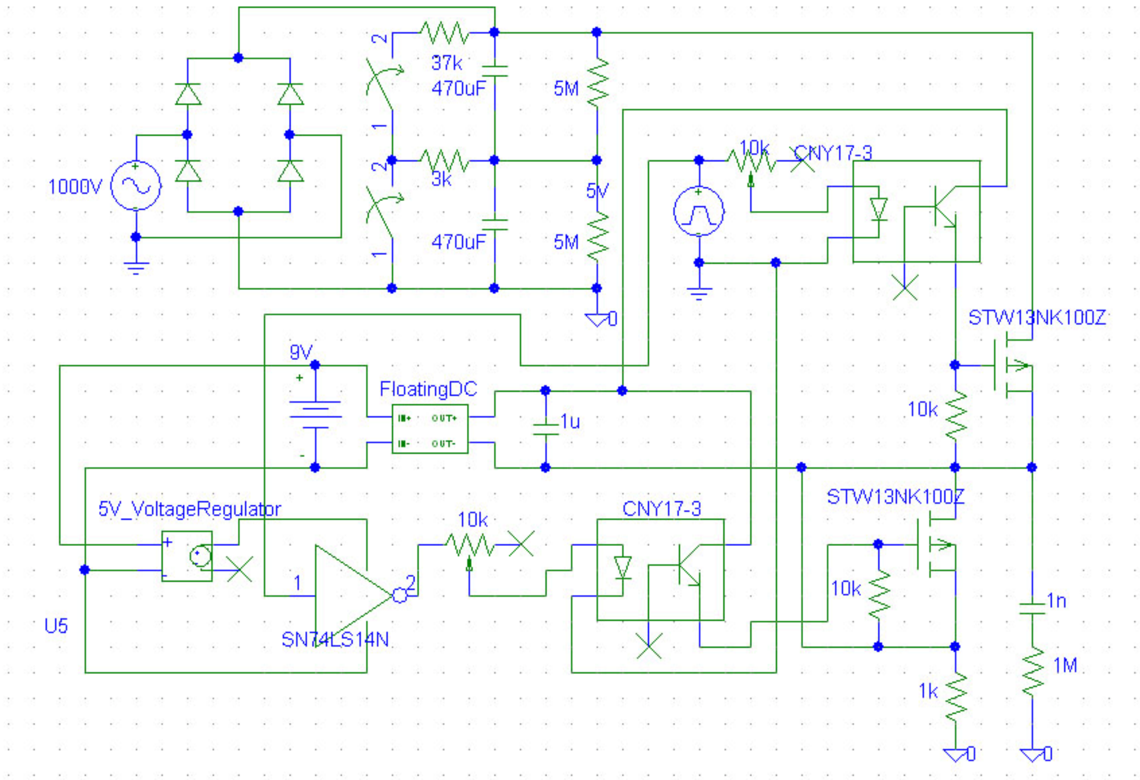
Capacitive Bypass

After initial testing of the circuit components mentioned above, one of the client requirements was not met. The fall time of the pulse was much slower, about 20 ms. The reason for this long pulse width is due to the capacitance in the FET in conjunction with the high impedance of the electrode. These two values together provide a large time constant ($\tau = RC$). In order to decrease the pulse width it was necessary to add a shunt FET that was also triggered by the 5V TTL pulse. The 5V pulse is sent through an inverter, which makes sure the shunt FET is off when the gate FET is on, and visa versa. When the shunt FET is on it immediately discharges any charge remaining on the switch FET. This decreases the pulse width. This circuit also contains a 5V voltage regulator which functions as a power supply to the inverter. There is also an additional optical isolator, which has the same function as the previously mentioned isolator.

Final Prototype

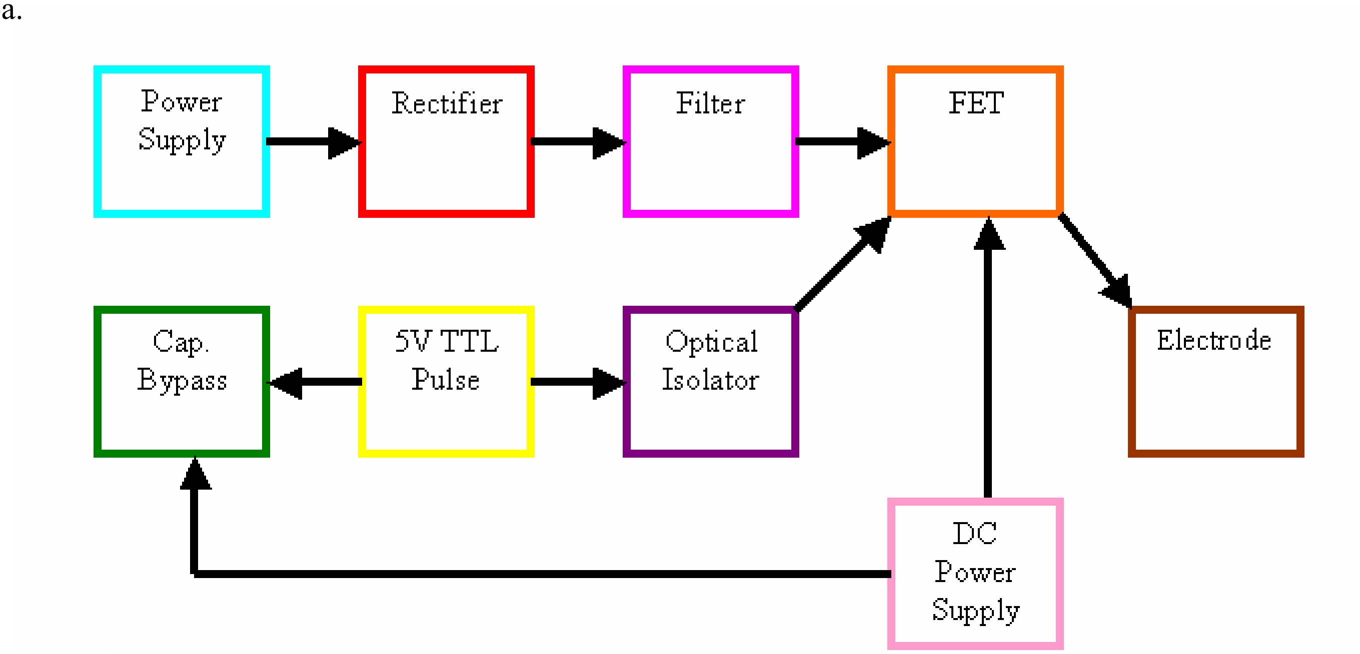
Combining each circuit component produces our final prototype, which can be seen in Figure 4 on the next page. In Figure 4a there is a block diagram to show the relationship of the parts discussed above. Figure 4b is the circuit schematic with the parts of the block diagram overlaid. The cost of the final prototype is \$360. A breakdown of the exact part numbers and the cost of each separate part can be found in the Appendix A. This price is significantly lower than the competition mentioned earlier.

Assuming that each electrode has a resistance of 1 MΩ and the supply voltage is 700V, the current stimulating the tissue can be calculated by using Ohm's Law, $V = IR$. This gives a value for I of 700μA.



Final Circuit Diagram

4a.



4b.

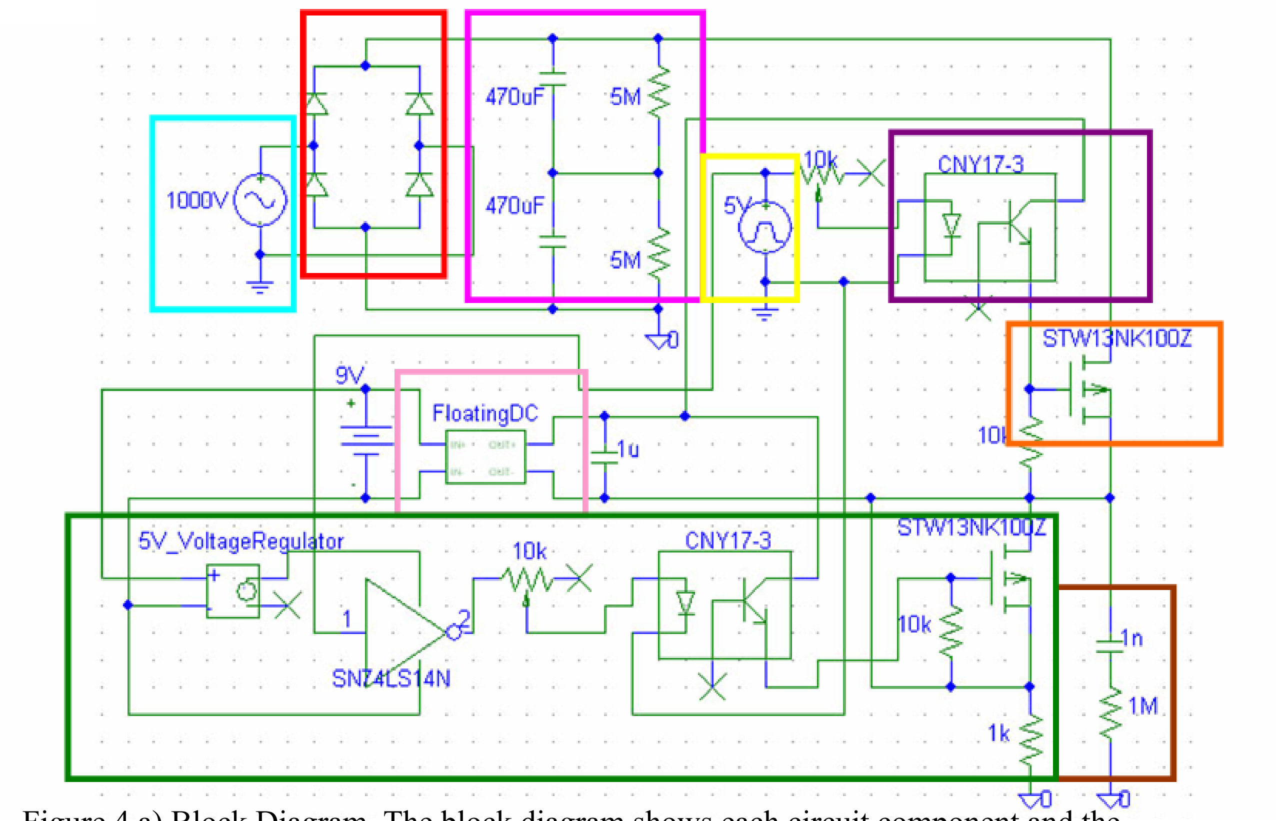


Figure 4.a) Block Diagram. The block diagram shows each circuit component and the path in which the current will flow. b) Circuit Schematic. The schematic shows the final prototype with the corresponding circuit components from the block diagram.

Testing

Low Voltage

The circuit has been tested with a 20 V power supply and a 5V pulse (attenuated due to a potentiometer in the circuit) which had a 200 µs pulse width. The figure shown below, Figure 5, displays the input wave as well as the output wave from our circuit. The output was measured across a 1 MΩ resistor to simulate the resistance of the electrode.

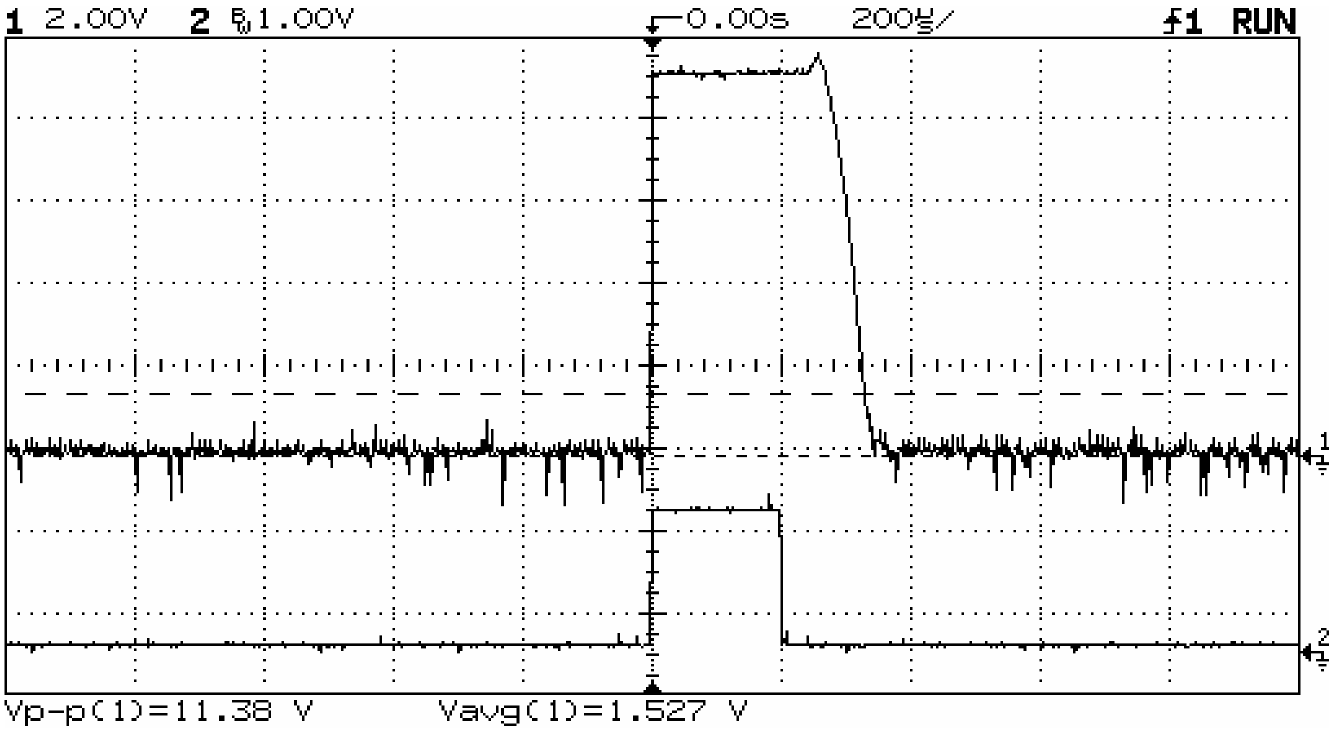


Figure 5. Input and Output Signals from Oscilloscope. The input wave, signified with the number 2, represents the 5V TTL pulse. The output wave, signified with the number 1, represents the voltage measured across the 1 MΩ resistor.

With an input pulse of 200 µs, the width of the output pulse was about 375 µs. Although this value does not meet the original client requirements it has been approved by our client. The figure above also shows some noise in the output wave. This noise is present without the pulse which leads us to believe that the noise is due to electrical interference from the room tested in and noise from the DC-DC power supply. This DC-DC power supply noise is addressed in the “future work” section. The final prototype will be encased in a metal box to isolate our circuit from the noise in the room.

High Voltage

Testing was also conducted in Dr. Jones' lab with a 120 V power supply and a 5V TTL pulse which had a 100 µs width. Immediately following the powering of the circuit with 120 V a short occurred. The result was a loud popping noise along with a shorted circuit to the power supply. There was no smoke or thermal energy detected from the circuit. The circuit was then tested again at low voltage to check for damage. No damage was detected and the circuit produced the same output as when previously tested at low voltage. The problem could have been due to a grounding fault, or to the problem described in the future work section.

Future Work

After our final test, prior to presentations, a problem was encountered. While testing the circuit at 120 V, a loud popping noise occurred, but our group is still unaware of exactly why this occurred. First, the definite problem must be identified, and then something must be changed in the circuit to keep this from happening again. Once this is done, there is still more work that must be completed to get one channel working at high voltage; then all 16 channels can be created.

The first, and easiest, modification is to solder in a 9V voltage regulator after the coupling capacitor of the DC-DC power supply. The coupling capacitor itself should be swapped out with one that will better attenuate the randomly distributed high frequency spikes outputted by the power supply. This coupling capacitor should be in the same position as the old one, between the DC-DC power supply output + and – pins.

Unfortunately, a major fault in the circuit was found. This was probably the fault that initiated the circuit breaker trip when the trigger circuit was first tested. The problem is in the common node of the DC-DC power supply. Figure 6, below, illustrates the current path to ground, outlined in red. The picture is of two channels, which helps to illustrate the problem.

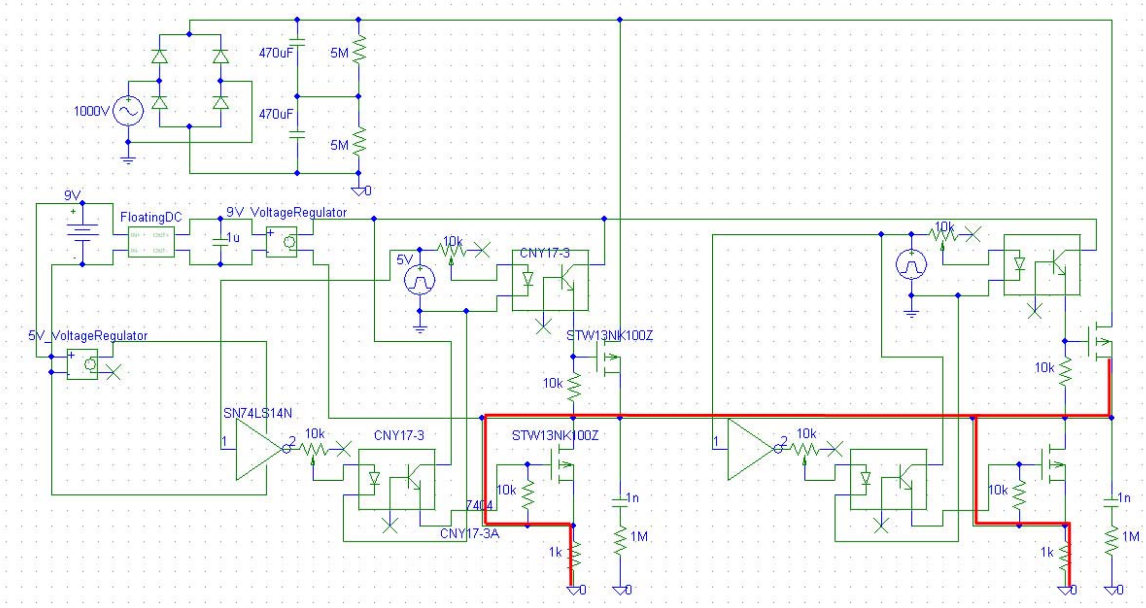


Figure 6. The current path. In red, the current path to ground that could possibly have caused the short is highlighted.

When the gate FET of any channel is open, 120V (or up to 1000V, depending on the power supply) is seen at the emitter. 12V must appear between the gate and emitter in order to turn the FET on, and this requires a current through the resistor to the common pin (-) of the DC-DC power supply. The shunt FET has a similar set up. However, as the red line of the above figure indicates, the current can travel from the emitter of the gate FET through the current return path of the floating resistor and down to the floating resistor of the shunt FET. From there, it can travel through the small 1kΩ resistor to ground. As the figure above illustrates, additional channels exacerbate the problem. A new way to get a voltage difference between the gate and emitters of the FETs is necessary.

The FETs require a floating resistor in order to keep the gate-emitter voltage below 40V. Without the floating resistor, the FET would not work. A potential is required between the gate and the emitter to turn the FET on, however. The simple, expensive solution would be to add another DC-DC floating power supply, so that the shunt FET can be on a different line then the gate FET. There probably is a better solution to this, and some more work on the circuit design is necessary.

After this problem is solved, the circuit must be tested at 120V and higher. A variable voltage supply up to 1000V with a low current auto-shutoff has been located, and would aide testing in this matter. The FET capacitance may still prove to be a problem, as even a small time constant will lead to a long time until charge dissipation at high voltages. The gate FET can have a high output capacitance, but the shunt FET must have either very low output capacitance or no output resistance. Perfect timing between the shunt FET and gate FET is necessary to both keep the output to its target time and to avoid a short to ground through the shunt FET.

In order to give individual control to all channels, a large 5 MΩ potentiometer can be added. As of the writing of this paper, the part has been acquired, but not yet placed on the circuit.

The final problem is to convert the constant voltage output to a constant current. This can be achieved with an active feedback circuit. The output can be sampled via a very small (~100 Ω) resistor between the emitter of the gate FET and the probe. This will act as a voltage divider. The active feedback system will modulate the current running through the floating resistor between the gate and emitter of the gate FET, opening the FET up more when the current through the sampling resistor gets too small. This is an involved project, and will require a rather substantial amount of time to get it designed and working.

Appendix A: Cost Analysis

Listed below are the different parts needed. The final cost was calculated for all 16 channels.

Component	**Vendor**	**Part No.**	**Price**	**Qty**	**Total Price**
Full Bridge Rectifier (3)	Digikey.com	36MB120A-ND	8.53	1	8.53
470 μF, 500 V Capacitor (3)	Newark.com	82DA471M500MG2D	15.46	2	30.92
AC Transformer (3)	SurplusSales.com	9T35Y160	49	1	49
5 MΩ Potentiometer	Mouser.com	526-501-0020	8.37	1	8.37
10 kΩ Potentiometer	ECE Parts Shop		0.10	32	3.20
12V Floating Source	Digikey.com		73.25	1	73.25
Voltage Regulator	Digikey.com		0.99	1	0.99
Optical Isolator	ECE Parts Shop	CNY17-3	0.44	32	14.08
Inverter	ECE Parts Shop	SN74LS14N	1.32	16	1.32
FET Transistor	ST.com	STW13NK100Z	5.25	32	168
Resistors	ECE Parts Shop		0.06	48	2.88

Total (16 channels): $360.54

Appendix B: Product Design Specifications (PDS)

December 12, 2006

Multi-Channel Brain Tissue Stimulator

Ashley Phillips – Team Leader
Steve Noel – BWIG
Steven Skroch – BSAC
Nina Lewis – Communications

Function: Our objective is to develop a multi-channel brain stimulator. This device must generate stimulation current of 250-500 μA on 16 separate channels, filter out external electrical noise, and allow each channel to be independently gated on and off as well as adjust the current amplitude on each channel. Such devices are available but exist as hardware/software packages and are expensive. These packages include many elements that are not necessary for our client's research.

Client Requirements:

- The device should take a signal from a 16-bit analog to digital converter using a 25-pin parallel connection.
- As the parallel logic data bits are turned on and off, current on the corresponding electrode should be turned on and off. There should be very small lag time.
- The device must be isolated; electrical noise (60 Hz) must be minimized.
- There should be an independent gain adjustment for each channel; the current available on each channel should be adjustable between 0.1 to 10 mA.
- When the data bit is turned on, the corresponding electrode should get a square pulse of current with a very fast rise time. When the data bit is turned off, the current should stop almost immediately.
- The square pulse should have a time length of 25 to 200 microseconds, controlled with the computer.
- The impedance of the electrodes is between 0.2 and 1.2 MOhms on each channel.
- The top end of this impedance range has been decreased significantly due to a technique known as "electrode activation."

Design Requirements

1. Physical and Operational Characteristics

a. *Performance Requirements*: Once the device is charged to full capacity (approximately 5 minutes) each channel should fire
b. *Safety*: The user must take safety precautions when using the device by keeping themselves grounded when touching electrical components because of its high voltage. The circuit should be enclosed in a order to prevent arcing of current.
c. *Accuracy and Reliability*: Our client's requirements are very specific, and are on the order of milliamps and even microamps. This means that our device must be very accurate and fall within the time range and voltage output range that he has indicated. Our results must also be reproducible, supplying the same current to each of the 16 channels.
d. *Life in Service*: The device must be able to send a current pulse for several hours at a time. However, this will not normally be the case. It must also be able to withstand daily use for up to ten years.
e. *Shelf Life*: The device should be stored in a dry, moderate temperature. If the device is run using batteries, they should be changed occasionally.
f. *Operating Environment*: The device must be kept in a dry environment, as the circuitry should not be exposed to water. The device should also be isolated from external electrical noise by encasing it in metal.
g. *Ergonomics*: The final prototype must have clearly labeled dials or buttons for each of the 16 channels. They should be easy to manipulate in order to send the stimulation current. The device should be enclosed in a case and have only the necessary connections protruding from the box.
h. *Materials*: All the materials used must be able to withstand high voltage. The circuitry should be encased in steel in order to prevent safety issues with the high voltage to the user.

2. Production Characteristics

a. *Quantity*: One device is needed with 16 operating channels.
b. *Target Product Cost*: No price was set; however, expenses should be kept to a minimum and should be approved by the client.

3. Miscellaneous

a. *Competition*: There are commercial products available that create the current stimulus desired in our proposed project. There products, however, come at a great cost and include many features, as well as software, that is not needed by our client.

Appendix C: Acknowledgements

Our group would like to thank L. Burke O’Neal and Professor Jack Ma for their help this semester.

Appendix D: References

1. Jones, Mathew. Personal interview. Sept. 2006.

2. Masters, Kristyn. "Animal Ethics." BME 601. UW-Madison, Madison, WI. Jan.-Feb. 2006.

3. Yusko, Erik, Danielle Ebben, Marty Grasse, and Tony Wampole. 16-Channel Brain Tissue Stimulator. UW-Madison. 25.