16 Channel Brain Tissue Stimulator

BME 301
April 28, 2006
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I. Abstract

The pathways of brain circuitry can be studied by delivering current impulses to brain tissue and observing the tissue response. The goal of this project is to develop a current source to be used for *in vitro* stimulation of rodent neural tissue. The current source must deliver independently controlled currents to 16 separate electrodes on a 16 microelectrode array. In addition, the currents must be controllable via TTL computer logic and have a short response time to the initial signal. The design described in this report uses a transformer to supply a large isolated voltage to 16 circuits which will convert the voltage to an appropriate current. The current on each channel will be controlled by a potentiometer which varies the magnitude of the impulse received from a TTL computer signal. When the computer program supplies an impulse, a corresponding square wave current pulse will be applied to the tissue.

II. Problem Statement

In order to more realistically stimulate brain tissue, a current source is needed which is capable of delivering 0 to 1 mA of current to 16 electrodes in a microelectrode array. The amplitude and impulse timing of each current must be independently controlled. The impulse timing must be controllable through parallel computer logic and the device must be isolated from 60 Hz noise.

III. Background Information

i. Brain Tissue Stimulation

The mammalian brain is a very complex organ whose mechanism of operation is still largely unknown. It is responsible for innumerable functions varying from regulation of body temperature to food foraging to complex emotions and thought patterns. Further investigation of the brain is necessary in order to understand how and why living beings behave as they do and what happens when this organ malfunctions. One important aspect of brain physiology that is being investigated is the brain’s ability to relay information via electrical circuits. Electrical stimulation of brain tissue is the predominant method of studying these circuits.

The component of brain tissue that relays information is composed of cells called neurons. Neurons are long cells which pass electrical current from one end to the other. Neurons are connected end-to-end by synapses. When current (called an action potential in a neuron) travels down a neuron and reaches the synapse where the cell releases chemicals called neurotransmitters (depicted in Figure 1). These neurotransmitters either stimulate or inhibit the beginning of another action potential in the next neuron [15]. Such interconnections of millions of neurons within the brain comprise a complex electrical circuit which gives rise to the many functions of the nervous system.

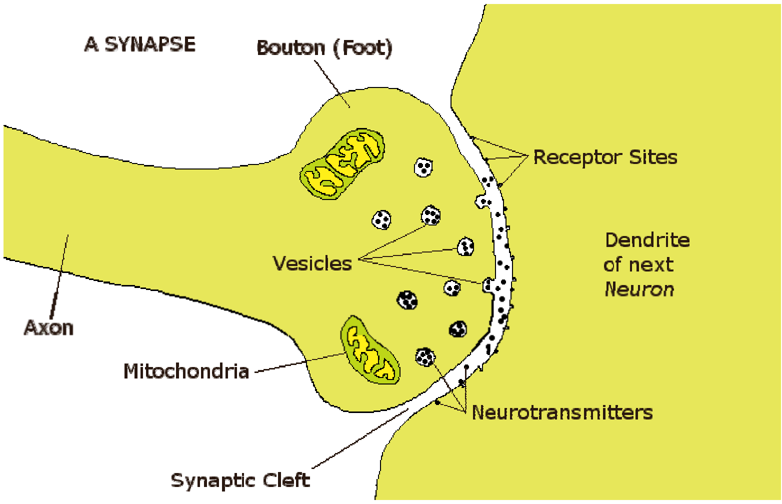


Figure 1: An chemical synapse in the brain [2].

This circuitry can be artificially stimulated in laboratory experiments in order to study the workings of the neurons and synapses. An electrode is placed on the brain tissue and delivers a current to the neurons. The current depolarizes the neurons and begins action potentials which may then spread to other neurons via synaptic connections. This basic principle is currently used to help treat tremors in patients suffering from Parkinson's disease. An electrode is placed in the thalamus of the brain tissue and delivers a current impulse which inhibits the portion of the brain causing the tremors [6]. In addition to clinical treatments, brain tissue stimulation is being used in many lab experiments to study *in vivo* and *in vitro* brain function.

ii. Client Information

Our client is Dr. Mathew Jones of the Department of Physiology. Dr. Jones studies the effect of *in vitro* stimulation of rat brain tissue. His research focuses primarily on the role that the inhibitory chemical messenger GABA plays on the timing and pathway of electrical impulses through the neural circuitry of brain tissue. In order to study these effects, he must apply a current impulse to a slice of rat brain tissue and observe the tissue's response [7].

Presently, he is using a single electrode to deliver a large impulse to the entire tissue. This does not realistically model how the brain tissue really functions because, in live brain tissue, many neurons may be functioning at one time and the signal transmission intensity may vary at each synapse. For this reason, he wishes to place multiple electrodes at several different locations within the tissue and then independently control the amplitude and timing of the current through each electrode. This requires a current source that can supply current to each of the 16 electrodes so that the electrodes can be activated independently of one another. This will allow for non-synchronous stimulation of individual or small groups of neurons.

Products that meet Dr. Jones' needs are commercially available; however, these are all much more sophisticated than the client desires. These devices are generally intended for *in vivo* studies and therefore, contain complex functions to prevent tissue damage. In addition, they often can produce various waveform impulses and can record the tissue response [14]. Dr. Jones only wishes to stimulate the tissue with positive square wave currents and does not need all of the excess expensive functions that accompany the available systems.

iii. Client Design Requirements

Our task is to develop a device to drive a current stimulus of up to 1 mA across each of 16 channels of a microelectrode array that Dr. Jones will be using in his experiments. The microelectrode array has a very high impedance—somewhere on the order of 1 to 3 MOhms—and our device must be able to successfully drive the current waveform regardless of such high load resistance. Secondly, each of the channels must have an independent gain adjustment so the amplitude of the current waveform can be adjusted on each channel between 0 and 1 mA in increments of 0.01 mA. The current waveform square pulse needs to be able to be adjusted between 25 and 200 microseconds, meaning that our device must have a very high bandwidth. The device must be completely isolated from 60 Hz noise that comes from using an alternating current power source. This is because the current stimuli being supplied on each electrode are very small, and any noise could disrupt the experiments. Finally, the final design should be enclosed in a rack-mount chassis that can easily be integrated in the existing laboratory setup. The enclosure should have a chassis ground built in that is isolated from in the internal circuitry.

IV. Components of the Initial Design and Decision-Making Process

We found it beneficial to split the design of the device into three components: Power supply and isolation, control of the amplitude of the current waveform, and the method of current waveform generation. Once the components were split, we came up with several alternative designs for each component.

i. Power Supply and Isolation

Alternative 1: Rechargeable Battery

The first, and definitely simpler, method that we considered to supply and isolate the power for the device is to use a large rechargeable battery. This is very similar to the system that Dr. Jones presently has in place with his single electrode stimulus. When a stimulus is going to be supplied, the device is simply disconnected from wall (AC) power, and left to run solely on battery (DC) power, free of any significant noise.

While using a battery would be simpler, it has several significant drawbacks. First of all, rechargeable batteries can be expensive, and non-rechargeable batteries would have to be replaced often. Secondly, the battery supply unit would be fairly bulky, as many batteries (or several very large batteries) would be needed to supply the current across such large load impedances.

Alternative 2: DC/DC Converters

The other method that we considered to both supply the device with power and to isolate the power from AC noise is to use a bank of DC/DC converters. DC/DC converters work by taking a DC voltage in, and then outputting a DC voltage, typically at a different voltage level than the input. They can be configured to isolate power by including opposing transformers in them (Figure 2). This type of DC/DC converter configuration is called a “Flyback Converter.” The converter takes a DC input, and transforms it first to AC power, and then back to DC power to be output. This double conversion effectively removes any noise in the original DC signal [11].

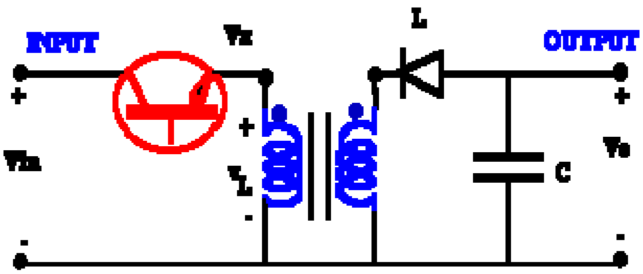


Figure 2: A schematic of a DC/DC converter that will isolate the signal [11]

In addition to power isolation, using DC/DC converters carries with it an added benefit. DC/DC converters can be configured using inductors to step up the voltage. Thus, using a bank of the converters as shown in Figure 3 will allow us to increase our supply voltage from an initial 12 volts, to somewhere in the area of 200 volts [3]. The high voltage is necessary to ensure that we can successfully supply up to 1 mA of current regardless of the load impedance.

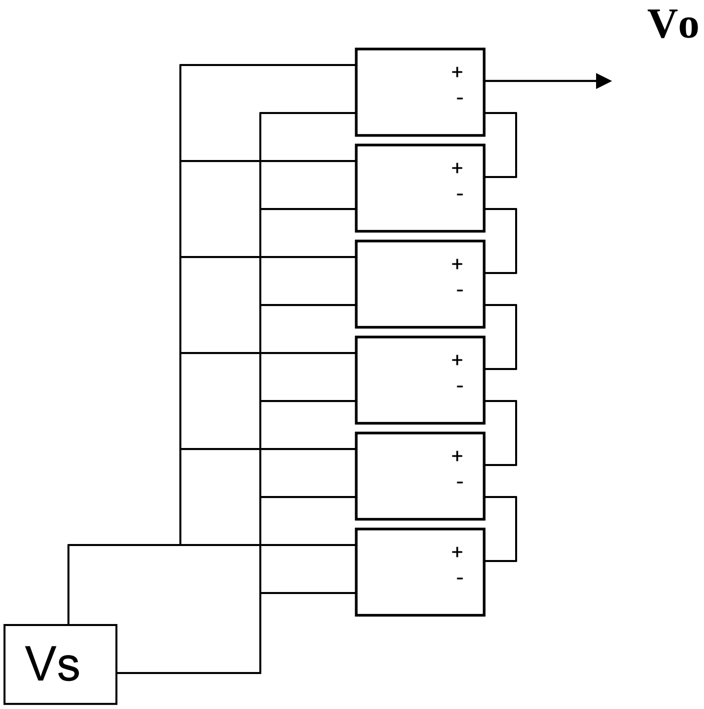


Figure 3: A bank of DC/DC converters in series to amplify the voltage supplied

After evaluating both alternatives for supplying and isolating power to the device, we decided to move forward using DC/DC converters. DC/DC converters will not only provide a more elegant solution in that they allow us to isolate the power and amplify the voltage at once, but they avoid bulky and expensive batteries that would have to be replaced often.

ii. Current Control:

There are two aspects of current control that we need to deal with. According to our client's specifications we need to have a square pulse that is simply either "on" or "off." Therefore one aspect of controlling the current requires controlling when the pulse is "on" and for how long it should remain "on." The second aspect of current control involves controlling the amplitude of the current waveform, or the magnitude of the stimulus supplied. As stated earlier our client would like to be able to adjust the current amplitude on each channel independently.

a. Pulse Duration and Amplitude Control:

Using Potentiometers & Transistors

Dr. Jones will be using a 25DIN parallel port from an Apple computer to send the control signal for all 16 channels. The signal will pass through an analog-digital converter and then output through another 25DIN digital port. The client currently uses a Digidata 1322A converter. The output levels for this device are CMOS level TTL logic. CMOS level output logic is slightly different in that range of 0-0.05V is '0' or off, and the range from 4.95-5.0 v is '1' or on [1]. The digital outputs specify an output at 4mA at these voltages. The client would like to control these outputs to '1' when the pulse is on and '0' when the pulse is off. We have two circuit designs that will use this pulse and modulate a V_{out}. The modulated V_{out} will be converted to a corresponding current via a voltage-to-current converter (VIC).

Alternative 1:

The first circuit uses a MOSFET to gate the circuit on/off, Figure 4. When the TTL pulse is 5V the transistor will turn on. This effectively allows current flow and a voltage to be produced at Vo. This voltage can be modulated and seen by the VIC. The circuit is governed by the following equations:

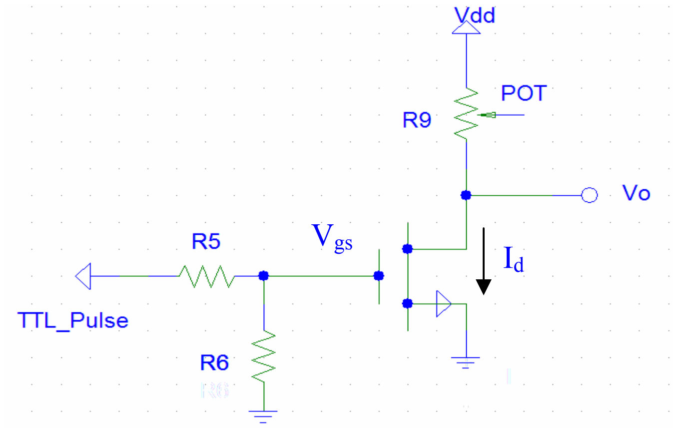


Figure 4: The transistor will be gated on when the TTL level exceeds the threshold voltage Vt of the transistor. Vo can be modulated by the potentiometer R9.

Eq1: $Id = \frac{1}{2}\frac{Kn\,W(Vgs - Vt)^2}{L}$

Eq2: $Vo = Vdd - IdR9$

Where Kn, W, L and Vt are all properties of the transistor. As one can see, Vgs will remain constant and therefore a constant current will pass through the transistor. Modulating the resistance at R9 will change Vo accordingly for the VIC.

This solution is relatively simple and has several important advantages. This alternative presents the largest advantage in terms of signal resolution. As noted above the 'on' voltage for CMOS varies between 4.95 and 5.00v. This means Vgs could vary by +/- .025v if designed to be at 4.975v. The change in current with this variation is much less because Vgs exists in the squared term for Id, which results in +/- 0.625mV. In addition, the voltage change at Vo with respect to changing R9 has a linear response which is not the case with alternative 2. Also, Vgs can be controlled by adjusting the values of R5 and R6. This allows control of the current passing through the circuit. As Vdd does not appear anywhere in the equation governing the current flow through the transistor, having multiple channels operating simultaneously will not change Vo.

Alternative 2:

The second alternative would be to use the CMOS TTL pulse as the voltage source and vary a Vo by potentiometer directly, Figure 5. When 'on' the TTL pulse will be between 4.95-5.00 V. Vo can be varied by the potentiometer R11. Vo is governed by the Following equations:

Eq3: $$Vo = \frac{Vttl\ R11}{R11 + R10}$$

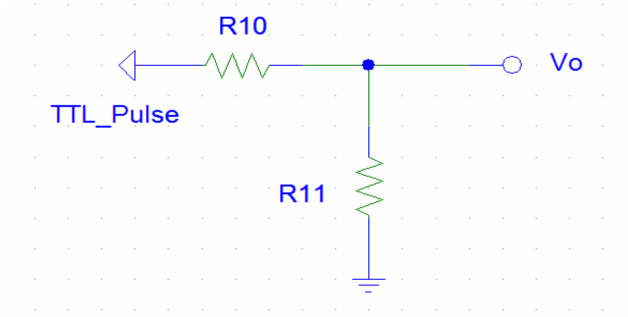


Figure 5: Alternative circuit design 2. Vo can be varied by varying the potentiometer R11.

This solution is much simpler then the first alternative however, there are many disadvantages. First, the Vo response to a changing R11 will not be linear. Second, the +/- 0.025 V that is possible from the TTL pulse will not be reduced at all in Vo.

b. Pulse Amplitude VIC*:*

Based on Vo from one of the alternative design circuits above the VIC will output a corresponding current. This is based on the Transconductance, g_m, of the VIC. The equations governing

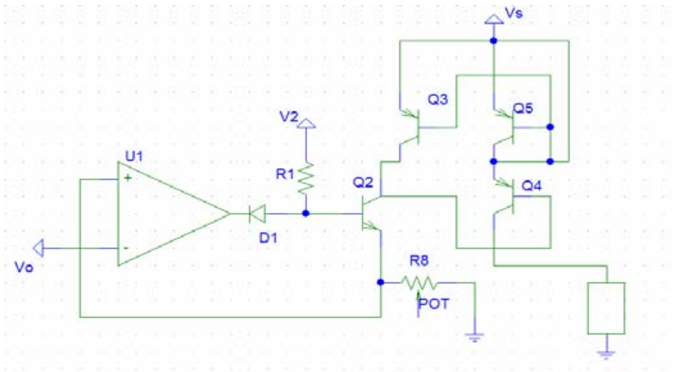


Figure 6: Example of a simplified VIC. The voltage Vo will appear across R5 and this modulates gm. [8]

the VIC seen in figure 6 are below:

Eq4: $\frac{Il}{Vo} = \frac{0.99}{R8}$

From Eq. 4 it can be seen that an additional method of varying current can be to simply vary R8 and provide a constant Vo [8]. However, this is not advisable due to the large variation required for R8 to achieve an output current range of 0-1mA. Transconductance is defined as Io/Vin so the value in equation 4 is essentially the transconductance. The value 0.99 is derived from the transistors properties and can be selected.

Digital Pulse and Amplitude Control:

It may be possible to control the operations above entirely with the PC. This is advantageous for increased output resolution and versatility in programming. The client has one available analog output that has a 16 bit resolution over the range of +/- 10v. This is sufficient to control one channel at a time but not all 16 simultaneously. It may be possible to use a microcontroller to record and set current amplitudes for the various channels. However, the code for this operation may be somewhat complex. In addition the design will still require much of the circuitry described above to convert voltage values to current values. We have decided to pursue the earlier described method at this time, and leave digital pulse and amplitude control as a potential later addition.

V. Proceeding from Midsemester

i. Design Decided on at Midsemester:

Due to the fact that the problem statement for this project was very specific, there were limited options for design alternatives of the entire system. Despite this limitation, it was possible to break the project into its components and choose the best alternative for each. The first of these alternatives is regarding the form and amount of isolation needed in the device, either DC/DC converters, or an AC transformer. DC/DC converters were our initial plan for the final design but limitations in DC/DC step ups and cost led us to use an AC transformer. Converters would have isolated the voltage from 60 Hz noise by themselves, so other design components had to be made to rid the circuit of this noise (full-bridge rectifier). An amplified voltage is needed to guarantee the current amplitude over the high impedance micro-electrode array.

Current control and pulse control were the other two aspects of the design that allowed for variation. The current is produced by a transconductance amplifier (also known as a voltage to current converter or VIC). Since commercially available voltage to current converters do not meet the criteria of this project, the VIC was constructed by hand. Constructing our own VIC allowed us to use transistor and resistor combinations which meet the specifications of the design. Altering the combination of transistors and resistors enables us to change the bandwidth and transconductance range. The voltage input to the VIC is varied using a standard potentiometer, and it is gated on and off by a transistor using the TTL pulse which is controlled by a computer program. In summary, the VIC is powered by an AC transformer and turned on and off via TTL pulses from a computer, thus converting the voltage to a current.

ii. Problems Encountered, Changes to Design

A major problem that has confronted us throughout this project was the necessarily high voltage needed to drive a stimulus of 1 mA across an electrode with an impedance of up to 3 MOhms. Ohms Law tells us that we need a voltage supply of 3000 volts to do this, which seems very impractical and somewhat dangerous. To decrease the necessary voltage, two solutions were possible. We could either decrease the amplitude of the stimulus pulse delivered, or we could decrease the impedance of the electrode array. This problem can be avoided by electrochemically activating the electrodes, which significantly reduces their impedances.

Activation of the Iridium electrodes causes the formation of a hydrous oxide layer on the surface which increases the charge capacity and reduces the impedance of the site. One means of activation is cyclic voltammetry, which involves placing the Iridium electrode in an electrolyte solution with a large platinum electrode connected to a voltage source. The platinum electrode is then cycled between positive and negative voltages such that the Iridium electrode shifts between functioning as a cathode and an anode. During the anodic stage, the Iridium on the outer surface of the electrode forms a porous hydrous oxide layer. For optimal results, the following parameters should be followed during activation: An electrolyte solution of 0.3 M Na_2HPO_4 should be used, the activation potential should be shifted between -0.85 and 0.75 Volts using a 0.5 to 1 Hz square wave, and the electrode should only be activate until it reaches a charge capacity of 30 mC/cm^2 [18]. Following these steps should reduce the impedance of the electrode such that an acceptable voltage may be used in the current source.

This technique allows us to only supply 1000 volts (1 KV) rather than 3000. While this is still a large voltage, it is much, much easier to supply. Once we solved this problem, we decided to modify our voltage supply design significantly in order to decrease cost and make the design simpler.

Rather than use a bank of DC/DC converters like we had planned, we decided to instead use a large AC transformer and a full-bridge rectifier to supply the necessary voltage. The basic idea is that the transformer can be plugged into 120 volts AC (an ordinary wall-socket), and will output 710 volts AC rms (1004 volts peak). The rectifier will then convert the AC voltage to DC, and an LC filter will be used to eliminate any “ripple” or noise in the voltage signal. This design will be described in detail in the *Overview of Final Design* section.

VI. Overview of Final Design

i. Voltage Supply and Isolation

As described earlier, one of the biggest challenges that we confronted was how to supply a voltage large enough to drive 1 mA across an electrode array with a very high impedance. The activation technique described by NeuroNexus partially solved this problem, by decreasing the electrode impedance to levels around 1 MOhm, thus requiring only 1000 volts.

To generate this voltage, we are using a high voltage AC transformer (General Electric 9T35Y160).The transformer is supplied with 120 volts AC, and outputs a voltage of 710 volts AC rms, or about 1000 volts peak. After being output, we use a full-bridge rectifier (International Rectifier # 36MB120A) to convert the voltage to DC. After conversion to DC, the voltage still has a fairly large “ripple,” a form of electrical noise. This ripple is a remnant of the 60 Hz noise found on the AC voltage from the wall socket that we use to supply the transformer. We minimize this noise using an LC filter. Using equation 5, we determined the values for the capacitors, resistors, and the inductor shown in figure 7 [17]. Note that all passive elements are rated for proper high voltages.

$$fp = 60 = 1/2/(pi*(Lf*Cin)\wedge(1/2)) \qquad (5)$$

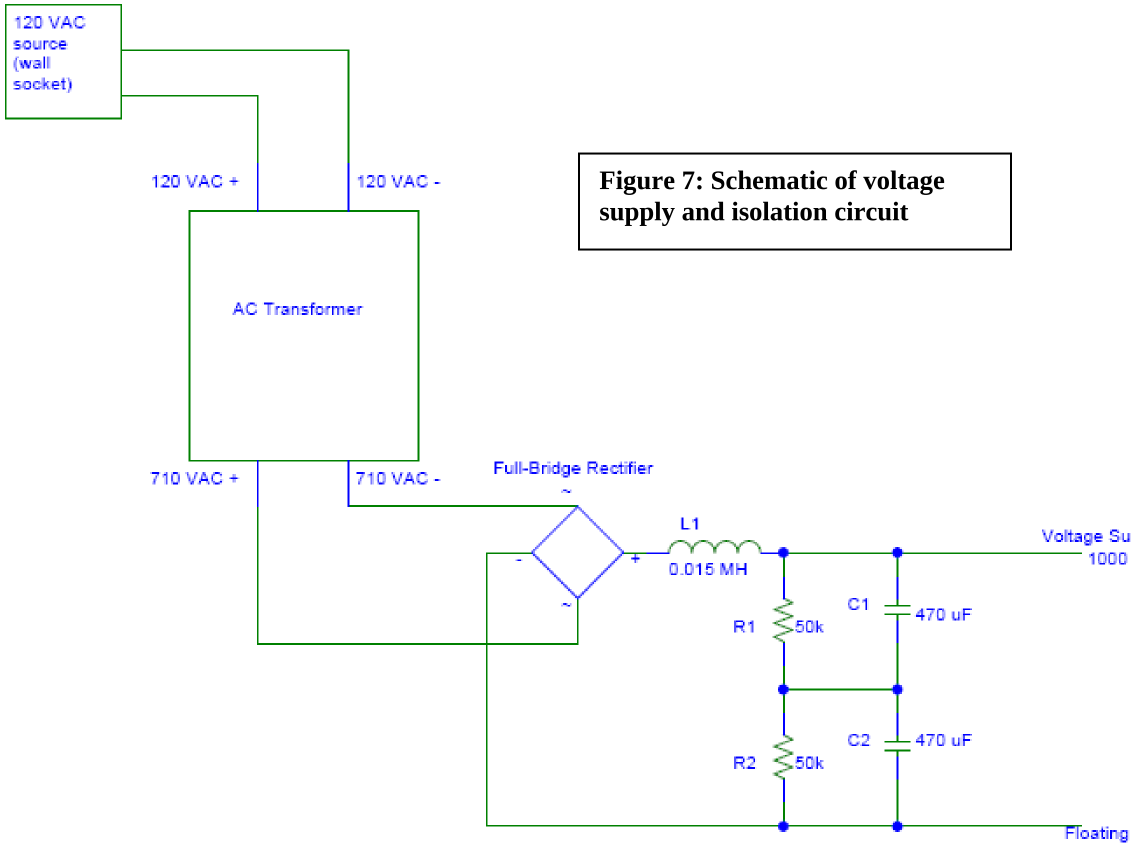


Figure 7: Schematic of voltage supply and isolation circuit

We enclosed the transformer, rectifier, and filter circuit in a steel case to eliminate any capacitive coupling between the high voltage AC and the sensitive equipment in Dr. Jones' lab. We are also using a shielded power cable rated for 1000 volts to pass the power from the transformer to the pulse control circuitry.

As a safety measure, it is important to include a chassis ground for both the voltage supply and isolation component and the stimulus gating and generation component. To do this, we will simply pass the ground from the 120 VAC wall socket through from component to component. From the wall, the ground will be separated from the two leads that supply the 120 volts. The ground will bypass the transformer and isolation circuitry, and will travel with the 1 KV supply from the first enclosure to the second. Thus, each enclosure will have access to a chassis ground to prevent cross-coupling with other equipment in the lab.

ii. Stimulus Gating and Control

Figure 8 depicts the final circuit design for current control. The circuit acts as a voltage to current converter. Several modifications have been made to the simplified circuit depicted earlier. All transistors are biased in active mode. The bias point is established in the range of 0.5mA – 1.0mA by resistors R_2, R_{11}, R_{13}.

Vin is provided by adjusting the 5KΩ potentiometer. Vin is reflected by the op-amp into the circuit. As a result:

$$i_{11} = \frac{Vin}{R_{11}} \qquad (6)$$

and

$$i_{C2} = \frac{\beta I_{11}}{\beta+1} \qquad (7)$$

i_{C2} is the reference current for the Wilson current mirror of the circuit. The current mirror is composed of transistors Q_3, Q_4, and Q_5. Q_3 and Q_4 are thermally matched to prevent excess thermal variations in β. Given that all transistors have a similar β, the current through the load is defined by:

$$i_L = \frac{1}{1+2/(\beta^2+\beta)} \qquad (8)$$

Combining equations 6 and 8, a transconductance transfer function can be established. This assumes all β is approximately equal to 100.

$$i_L/v_i = \frac{0.99}{R_{11}} \qquad (9)$$

Capacitors C2 and C3 decouple the load from excess DC currents. They also prevent any AC noise from reaching tissue. These capacitors would have to fail in conjunction with the transistor Q_5 for any current to leak through and reach the tissue.

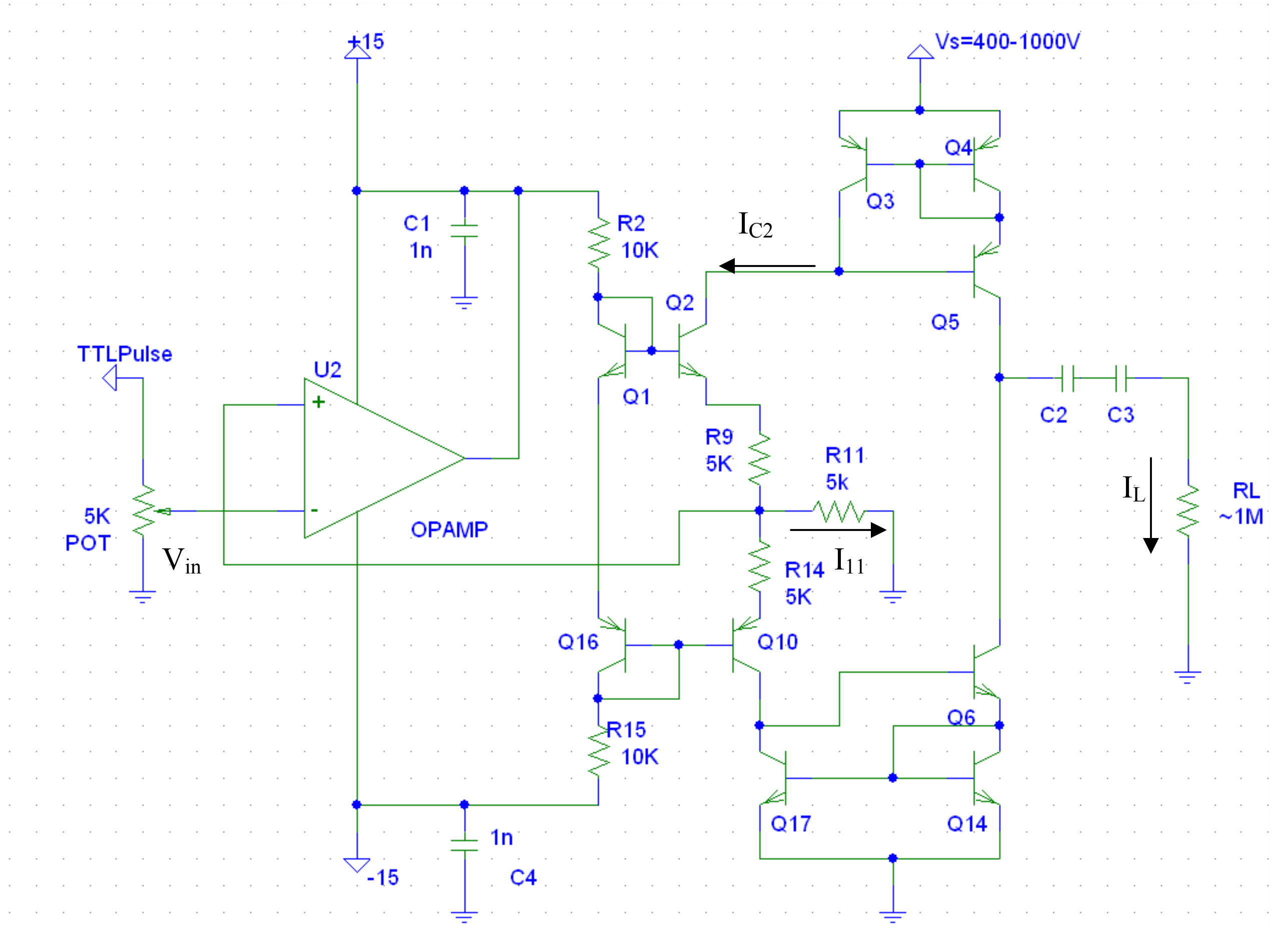


Figure 8: Voltage to current converter final circuit design.

iii. Safety Concerns

Since the design requires an input voltage of 1000 volts to guarantee the current stimulus, certain safety considerations needed to be taken into account in the designing to ensure the safety of the individuals working with the device. 1000 Volts (1 kV) is a very high voltage, and could be dangerous to the user.

Also, because there are multiple circuit elements in the voltage supply portion of the device, there is a concern that placing them too close to each other will cause unwanted results. To accommodate for this the circuit elements are placed on non-conducting “Perf-Board”. “Perf-Board” is phenolic or fiberglass circuit board with perforations, for our use, every half to one inch, which will increase the distance that each element is typically from one and other. It is important that the board not be copper-coated.

Also, given that the voltage is so high, we felt it necessary also to isolate the voltage supply element from the other part of the device, and to protect it from accidental contact. Thus, the transformer and all high voltage circuitry (in the voltage stage) will be encased in a metal box. This will ensure that a person will not accidentally brush against the circuitry. For the same reasons the current supply stage will be contained in a separate metal box, and located across the room. These metal enclosures will also serve to insulate the device from any cross-coupling that could occur from using such high voltages, especially when the voltage is in AC. Between the boxes there will be a high-voltage, shielded cable running to connect the two portions of the device. The cable will be well insulated to protect from any discharge that could occur.

Another safety device will eventually be found in the current supply portion of the device. The current stimulus will be regulated using a safety controller that will ensure no more than approximately 2mA can be supplied at any time, regardless of the resistance. Thus, if something were to happen and an arc occurred, the maximum current that could run through any object or person would be 2mA; a much safer amount of current than if it were un-regulated.

iv. Maintenance and Service of Device

Once the circuit is completed, it should require minimal maintenance. The external cables should be inspected regularly for damage since the design involves high voltages and damaged wires could be very dangerous. In addition, an ammeter should be used periodically to determine if the proper currents are being delivered and that the potentiometer dials are still calibrated correctly.

While we have carefully chosen elements to withstand the high operational voltage, components of the circuit are likely to degrade over time and need replacement. Should this occur, someone with knowledge of circuits will have to investigate to identify and remedy the problem.

VII. Testing Plan

We intend to finish a rudimentary version of one channel for testing purposes before the other 15 channels can be completed. The channel will be connected to the computer in Dr. Jones' laboratory and the power source. We will then use an ammeter to test a range of current amplitudes as impulses are supplied by the computer. Then, the device will be connected to an electrode and we will conduct tests on real neural tissue to qualitatively determine the effectiveness of the stimulation. If test results are satisfactory, the project may proceed into the next stage of building the rest of the channels.

VIII. Future Work

Our biggest concern for the remaining portion of the semester is developing at least one fully functional channel with the correct supply voltage and gating mechanism that can be used by our client. We are currently working on assembling the voltage supply, and have been working on a scaled down circuit for the current control. The first step toward providing a working channel will be the assembly of the voltage supply, outputting a ripple-free (or relatively-so) 1 KV in direct current. By the semester's end, all of the components for this part of the design should be in, and the supply should be functional.

Concurrently we will be working on making the scaled-down version of the current control system functional. Once this system works we will purchase the high voltage elements that will be used and then construct the design that will be connected to our high voltage supply. When a working channel is function it would be optimal to test the device with the client's instrumentation to ensure it is functioning correctly. Additional work time would be dedicated to developing and testing a functional 16-channel device.

XI. Possible Problems

The microelectronic circuitry involved in this design is very sophisticated and the design is quite complex. Also, with time limitations as the semester is coming to an end, any problems experienced will be difficult to correct in that we will need to order new circuit components and reintegrate them in the prototype. Additionally, due to the increasing complexity of the design as the semester proceeded, we are still finding different elements that are need ed for the device to be fully functional in the lab.

X. Ethical Issues

We encountered few ethical issues in the course of this design project. We are taking the safety of the user very seriously, including many features to protect against electrical shock. The end prototype will be use to do testing on rodent neural tissue *in vitro*, so we do not need to be concerned with treatment of the subjects during testing.

X. Conclusion

This project's goal is to design a multichannel brain tissue stimulator device. At the end of the semester, we are currently in the process of assembling a scaled-down prototype. The prototype will initially have only one channel, and if time permits and the design works, we will reproduce the channel to make it a 16 channel device.

This project has been very challenging in that we have little experience with microelectronics, or circuit design in general. This lack of experience led to a comparatively large lead-time before we could actually begin building a prototype, during which we did a large amount of research and acquainted ourselves with the subject.

As described in this report, the present design has not yet been tested, and again, due to our lack of experience, there exists the possibility that it will not perform as desired. Because of this, we feel that this project is a strong candidate for a multiple-semester project.

Appendix A: Product Design Specification (PDS)

Multichannel Brain Tissue Stimulator Project – April 27, 2006

Team Members - Roles

- Marty Grasse - Team Leader
- Erik Yusko – Communications
- Danielle Ebben – BSAC
- Tony Wampole – BWIG

Function

In order to stimulate neurons in a more realistic manner, a controller device is needed to independently control current on 16 electrodes in a multiple-electrode array. The device must use parallel logic from a computer to control the current. The device must be isolated from electrical noise so the measurements are accurate.

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." This technique is described in detail in the body of this report.

Design Requirements

1. **Physical and Operational Characteristics**
    - **a.** *Performance requirements:* See client requirements.
    - **b.** *Safety*: As with any device using electricity, the risk of electrical shock is always present. However, in our case this risk is especially great because we will be working with very high voltages and supplying direct current to electrodes. The finished prototype

needs to be fully enclosed to prevent accidental shock, and the connection to the electrodes should be secure. The device should use several fuses to ensure that electrocution does not occur. Additionally, care needs to be taken during the design and testing stages of the project, to prevent electrical shock before safety features are in place.

- **c.** *Accuracy and Reliability*: Each of the 16 channels must be capable of consistently producing the current desired by the operator. The operator may choose from a series of current options which vary by 0.1 mA increments from 0.1 mA to 1 mA. Therefore, the device should supply a current that is accurate to within 0.01mA of the set current.
- **d.** *Life in Service:* Although the device is unlikely to be used in such a manner, each channel must be able to produce a steady current for several hours at a time. In addition, the device must be able to withstand daily use for a minimum of 10 years.
- **e.** *Shelf Life:* If stored in a dry, clean area of a moderate temperature, the device may be stored for many years without causing damage. If batteries are used as a power source, they should be removed before storage for long periods of time and replaced when the device is returned to operation.
- **f.** *Operating Environment:* The device will not be subjected to very strenuous conditions. It will be kept in a dry, room temperature, laboratory setting and will not often be moved from one place to another. It should be kept clean and as dust free as possible to avoid interference with the circuitry. Only the electrode will be subjected to fluids and organic material and therefore may need to be replaced periodically.
- **g.** *Ergonomics:* The device should be designed such that it is as easy as possible to operate. Any dials and buttons should be clearly labeled in a font that is easy to read and should require minimal force to adjust.
- **h.** *Size:* The prototype should be easily contained in a laboratory setting. The voltage supply component of the design is enclosed in a steel case. The gating and current supply circuitry will be enclosed in metal enclosure that can be mounted in a standard-sized test equipment rack.
- **i.** *Weight:* Because the device will be installed in a laboratory, weight is not a big issue. It should not be prohibitively heavy so as to make the rack that it is mounted on unstable, but great care need not be taken to design a light-weight prototype.
- **j.** *Materials:* The materials used in the device will mostly be electrical components. The voltage supply and isolation circuitry will be housed in a steel enclosure to prevent capacitive coupling between the high levels of AC voltage within and the sensitive laboratory equipment in the rest of the lab.

   - **k.** *Aesthetics, Appearance, and Finish:* While the appearance of the device is relatively unimportant, it would be preferable to have the finish of the prototype match similar finishes on other devices used in the lab for aesthetics.

2. **Production Characteristics**
   - **a.** *Quantity:* A single prototype is expected. If this prototype is effective, more devices may be constructed.
   - **b.** *Target Product Cost:* No set ceiling for project cost was set. It is probable that the net cost will be relatively low compared to commercially-available multielectrode stimulator devices.
3. **Miscellaneous**
   - **a.** *Standards and Specifications:* As the research is preformed in vitro minimal guidelines and restrictions apply. However, because samples are obtained using sacrificed rodents animal research ethics and restrictions apply. Federal Restrictions:

     Very general guides:
       - USDA-Animal Welfare Act
       - U.S. Government Principles for the Utilization and Care of Vertebrate Animals Used in Testing, Research, and Training

     More specific guidelines:
       - National Research Council publishes the Guide for the Care and Use of Laboratory Animals
       - AAALAC (American Association for Accreditation of Laboratory Animal Care) accredits institutional compliance with the Guide

   - **b.** *Customer:* The customer had some specific requests that are also common similar commercially available stimulus generators:
     - i. The device should take standard TTL signals from a 25DIN connection as the signal input.
     - ii. Current should be in an “On” or “Off” position with a very small rise time (~10 μs).
     - iii. Stimulus must have all 60Hz noise removed. It was suggested to do this by separating the supply voltage from a land line voltage via batteries or DC/DC converters. Additionally, no additional electrical noise should be introduced into the system or the surrounding lab because of the prototype.
     - iv. Independent current amplitude control (exact current range has yet to be determined)
     - v. The length of the square pulse should be able to hold 25-200 μs, controlled by a software program on an Apple computer in the lab.
   - **c.** *Patient-related Concerns:* This stimulus generator will be used specifically on rodent neural tissue segments *in vitro*. As a result

typical safety and comfort concerns are most likely negligible. However, the generator should be designed with the user in mind in that, their will likely be researchers and expensive equipment (microscopes, computers, etc.) in proximity of the generator and electrodes. Care should be taken to prevent shock to these researchers and equipment.

d. *Competition:* There are various commercial variations capable of creating the stimulus our client requires. However, all commercial variations are capable of much more then a simple “on”, “off’ pulse and this increases their cost significantly. In addition many commercial products are designed to operate *in vivo* which requires additional circuit control to prevent electro-metal plating. Commercial stimulus generators also are usually capable of recording in addition to stimulating. The excessive amount of hardware and capabilities leads to a cost that places most stimulus generators out of reach for the common research laboratories. Two stimulus generators can be found:

http://www.a-msystems.com/physiology/Instruments/Model3600/default.aspx
http://www.alascience.com/products/mcs_stg2000.html

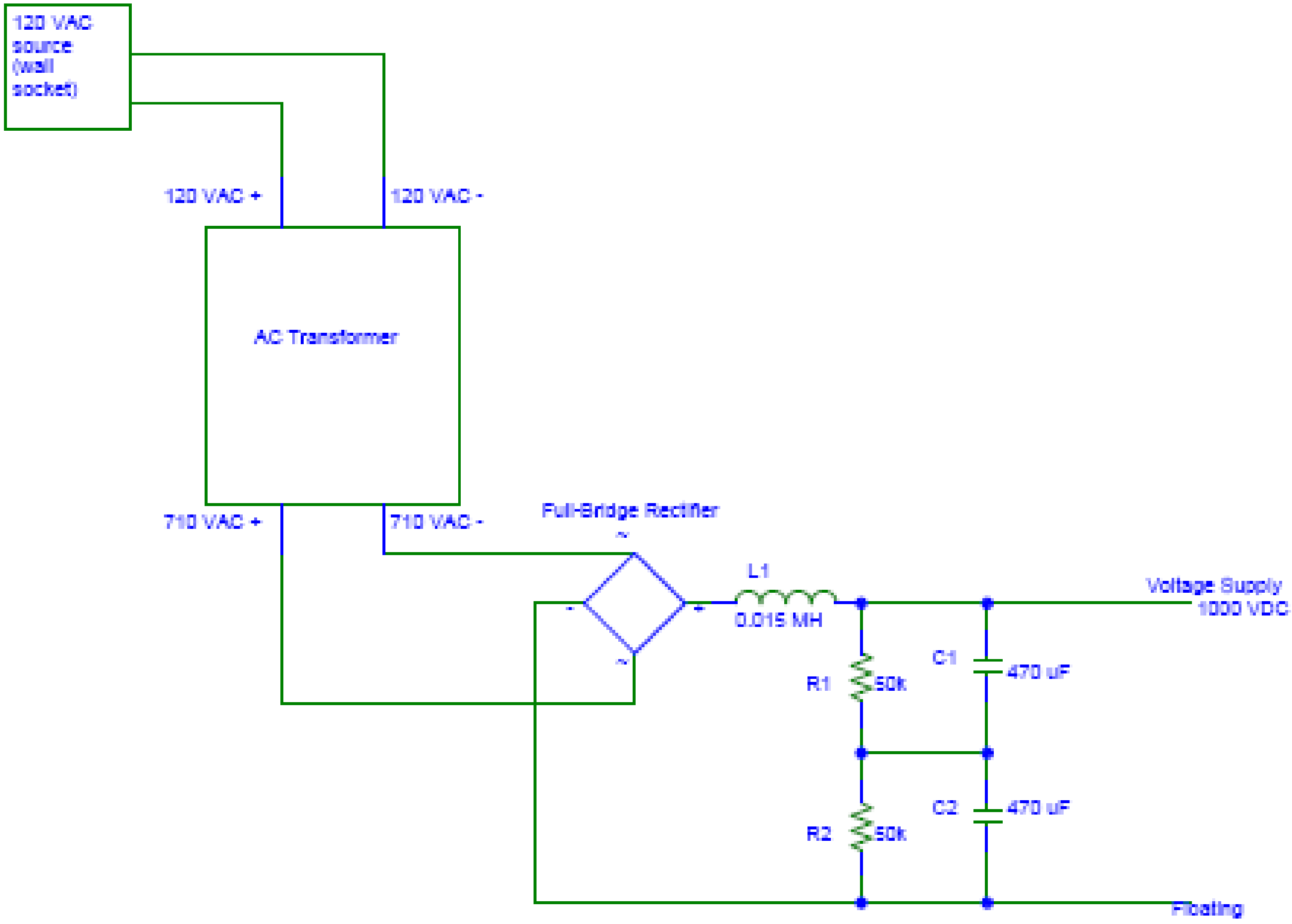
Appendix B: Acknowledgments

We would like to acknowledge the following individuals for their significant contributions to this project:

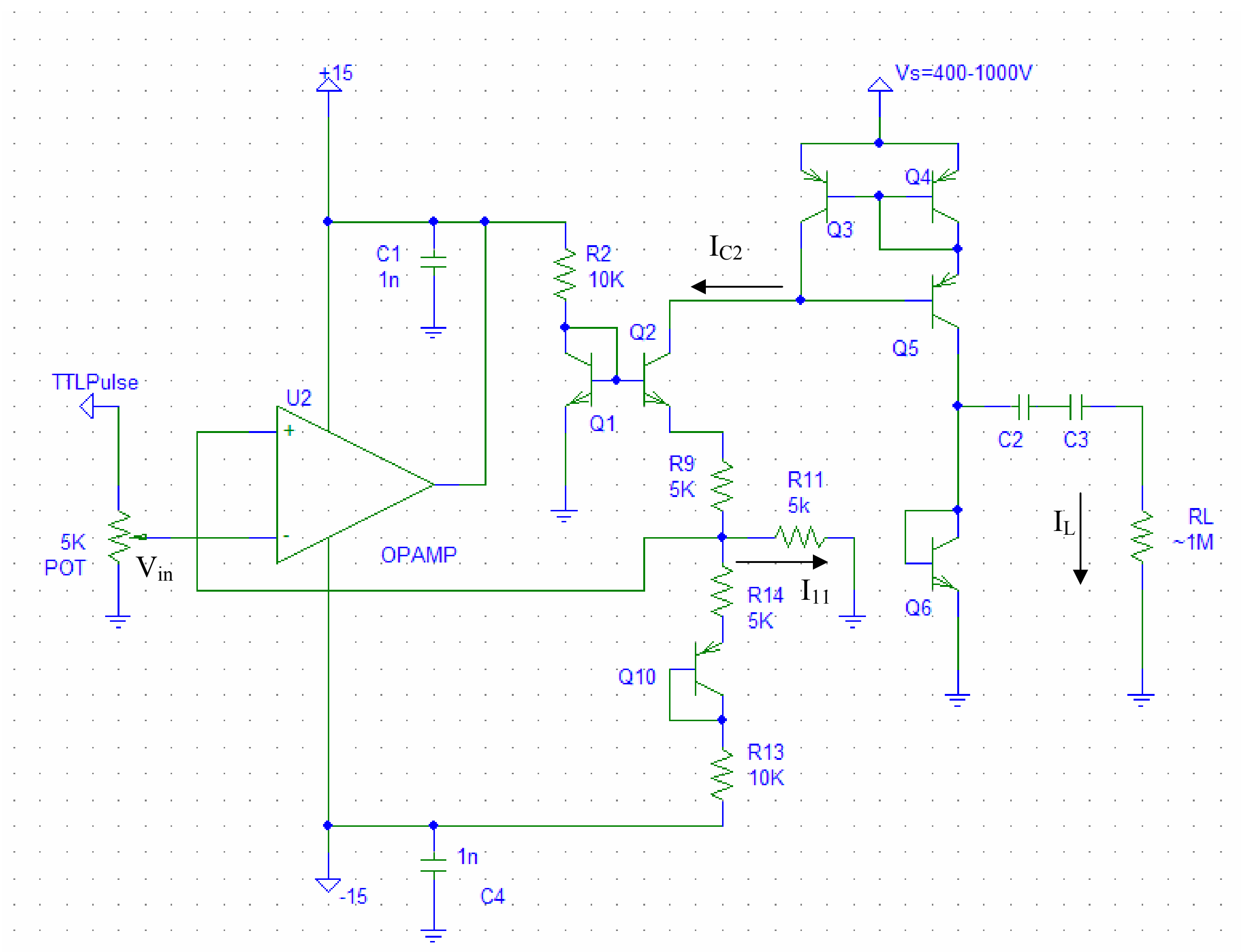
Burke O’Neal, Justin Williams, Kurt Kaczmarek, Hongrui Jiang

Appendix C: Circuit Diagrams

Voltage Supply and Isolation:



Stimulus Gating and Supply Circuit:



Appendix C: Bill of Materials

Component	Manufacturer	Vendor	Part #	Datasheet	Price	Quantity	Total
Full-Bridge Rectifier	International Rectifier	Digikey.com	36MB120A-ND	http://www.irf.com/product-info/datasheets/data/36mb	8.53	1	8.53
470 uF, 500 Volt Capacitor	United Chemi-Con	Newark.com	82DA471M500MG2D		15.46	2	30.92
15 mH Inductor	JW Miller	Newark.com	70F152AI-RC	http://www.jwmiller.com/pdf2/70F.pdf	2.57	2	5.14
AC Transformer	General Electric	SurplusSales.com	9T35Y160		49	1	49
High Voltage PnP Transistors	MultiComp	Newark.com	2N3902	http://www.datasheets.org.uk/search.php?q=2N3902&sType=part&ExactDS=Starts	4.5	2	9
Potentiometers	Bourns	Digikey.com	91A4A-B24-B13-ND	http://www.bourns.com/pdf/90sers.pdf	4.74	2	9.48
NPN	Motorola	ECE Parts	2N914 7142 M		0.20	7	1.40
PNP		ECE Parts	2N5022		0.49	2	0.98
NPN		ECE Parts	40324		0.50	2	1.00
PMOS		ECE Parts	RF 9631		0.92	4	3.68
NMOS		ECE Parts	1N310		1.10	4	4.40
OP AMP		ECE Parts	LF411CN		1.63	1	1.63
						Total	125.16

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