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Physics 406

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Construction of Full-Bridge Plasma Speaker

Introduction

Similar to conventional loudspeakers which vary air pressure using a solid diaphragm, plasma speakers accomplish the same task using a high energy arc of plasma. My project consisted of assembling a full-bridge mode plasma speaker, with the goal of getting it to reproduce the audio signal input from a function generator. In this report, I will provide some background on the theory behind the operation of the plasma speaker as well as the setup process in order to provide a guide for future students who may wish to assemble a plasma speaker themselves.

Theory Behind Functionality

A plasma speaker acts to ionize air between two high voltage electrodes, thus creating a plasma. By doing so, the plasma releases thermal energy into a small concentrated volume. In addition, we know that since the time between high voltage pulses is so small, the air heats up incredibly quickly and does not have time to cool down again. Therefore, we can model this volume of air to be roughly constant. Combining the ideal gas law with the energy-temperature relation of a diatomic gas, we can find a relationship between the energy of the plasma pulses and the change in pressure:

$$\Delta P = \frac{2n}{3V}\Delta U$$

Where ΔP is the change in pressure, ΔU is the change in energy, n is number of molecules in moles, and V is the volume of the air.

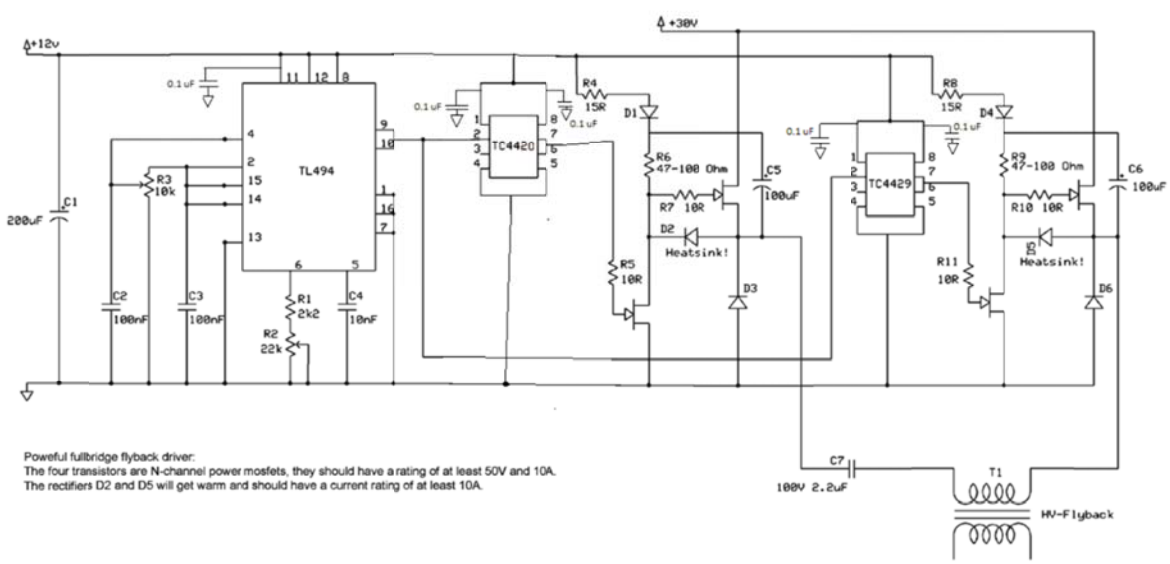
Furthermore, for incoming pulses of period T and frequency f_0, we can describe the change in energy with an infinite impulse train:

$$\Delta U(t) = \sum_{n=-\infty}^{\infty} \delta(t - nT)$$

One can therefore show that by modulating the high voltage pulses in the form of a sine wave of frequency f_1, DC peaks located at $f_0 - f_1$ fall into the range audible for humans when f_0 is larger than 40kHz (I drove my speaker at about 50kHz). These peaks are manifested as overpressure waves which humans interpret as sound.

Assembly of Circuit

I mainly adhered to the schematic included in a project report by students who took Physics 406 a previous semester, which I shall include below. I will also discuss details of specific circuit components.



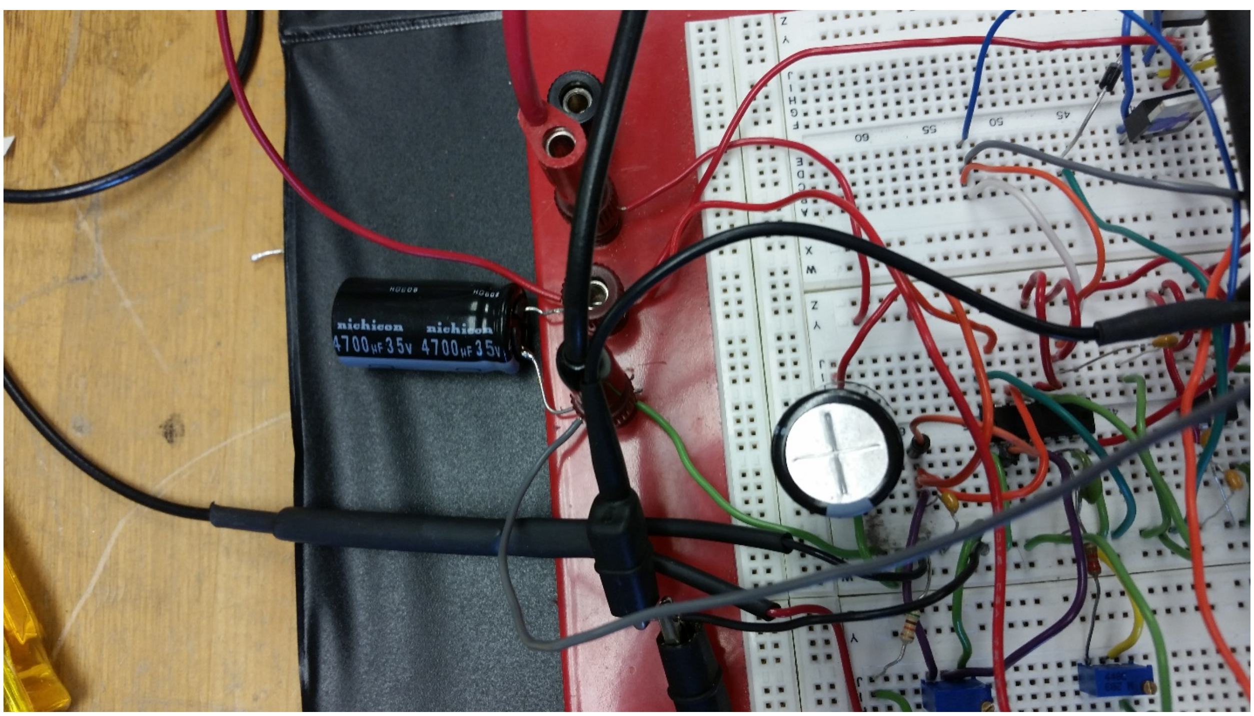
First and foremost are the power supplies. I used a 15V power supply as well as a variable power supply set to 25V, both of which came from the Physics 406 Laboratory Room.

Not shown in the schematic is an additional 4700uF capacitor loaned to me from Professor Errede across the 30V power source in order to stabilize the input voltage, similar to the one across the 15V power source. Originally did not have this component and we tried using three separate power sources, none of which would supply the necessary 25V. Problem was remedied by adding the capacitor.

Additionally, resistors 6 and 9 should be reasonably high power (at least 0.5W), as they will get warm. I actually caused one to smoke when doing testing, and replacing it with a higher power solved the problem.

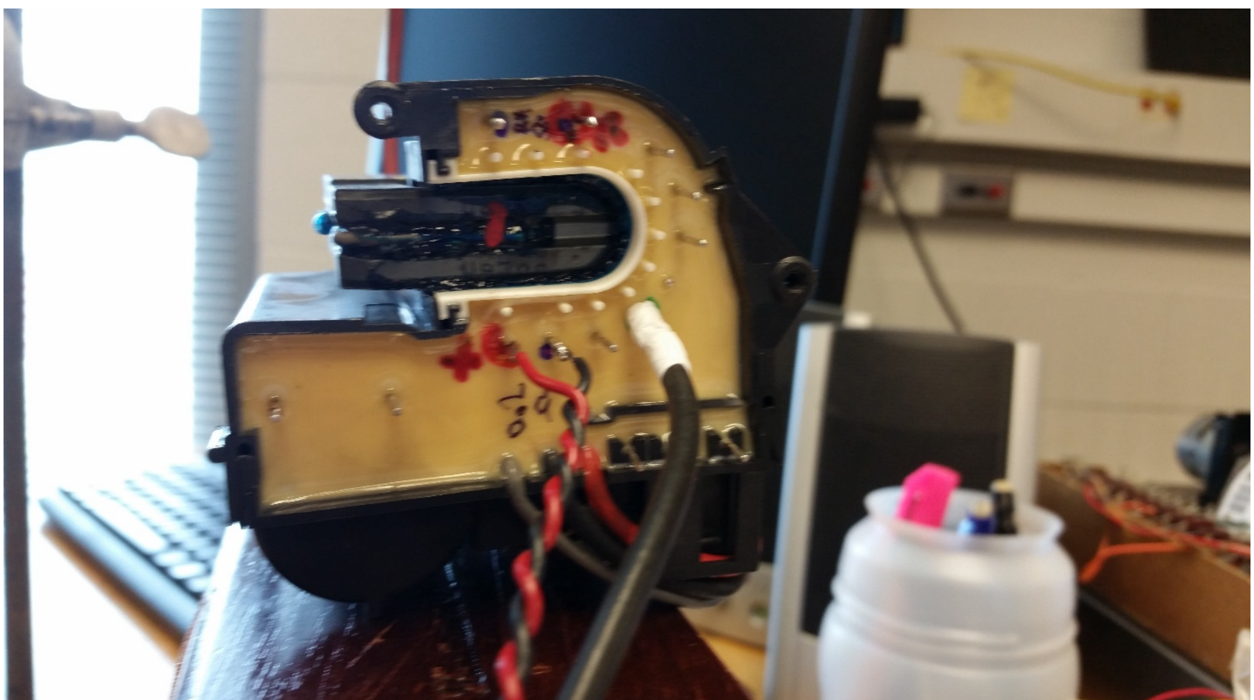
There are also four IRFZ46NPBF – N Channel MOSFETs. Diodes D2 and D5 are MBR1645G Diodes, and the rest are all UF4002.

Setup of Capacitors and Power Source to Breadboard



Can usually be found in most old television or computer monitors, I acquired my transformer from an old television lying around the high energy machine shop across the street from ESB. Purpose is to significantly increase voltage of output signal in order to actually produce arc of plasma when connected to electrodes. Theoretically it increases voltage proportional to number of coils on the primary and secondary loops. We used a high voltage, high wattage resistor as a dummy load to simulate the impedance of the transformer while taking measurements and tuning the frequency and the voltage of the input signal from the function generator. It is important to note that the flyback transformer has numerous pins which require testing with the multimeter to determine which pins correspond to different coils. The one I used had resistances of 0.4Ω and 0.2Ω for the coils with high and low numbers of turns, respectively. The speaker worked successfully when connected to the low turns coil, since that makes the ratio of primary to secondary number of turns larger and thus provides a larger output voltage.

Underside of HV Flyback transformer detailing which pins were used. Black and red connect to circuit as per the schematic, black wire connects to bottom electrode, wire not shown on top of transformer connects to top electrode.

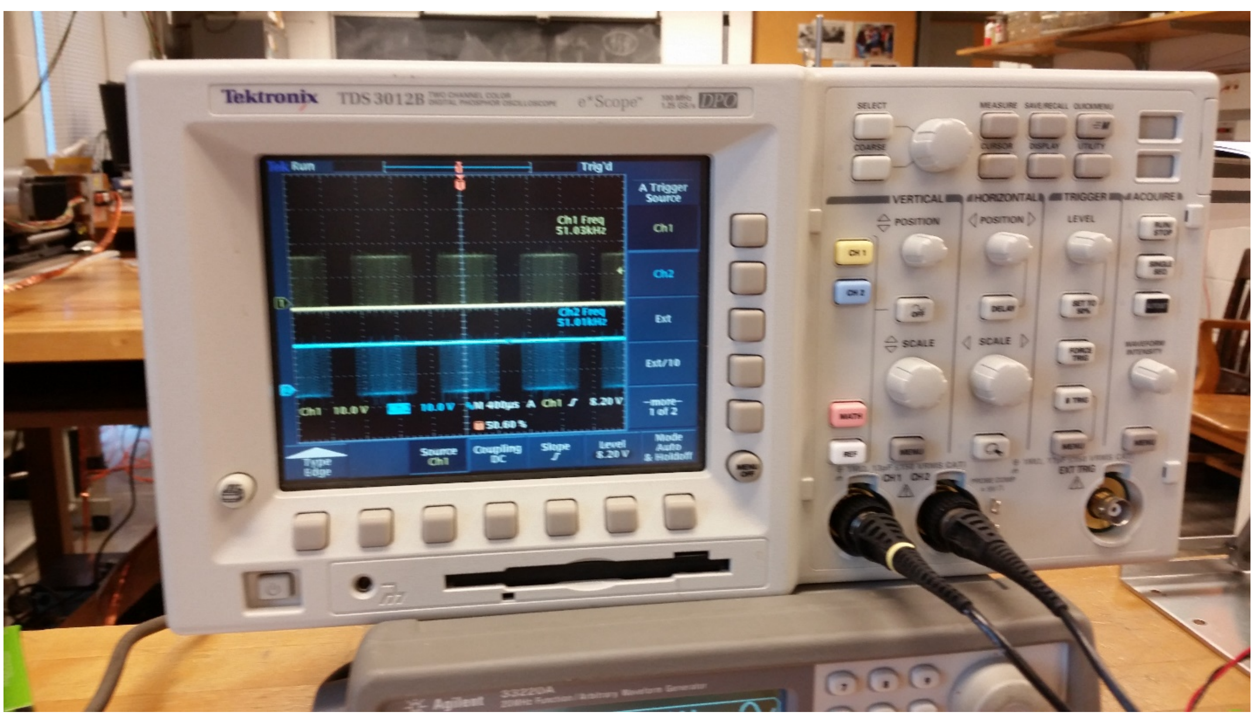


Vital to the plasma speaker, this chip is what ultimately modifies the signal to be output by the transformer. Its primary functions are to control the width of the signal pulses as well controlling the frequency of this signal sent to the transformer, which was tuned to be approximately 50 kHz (well above the hearing range for humans) using a potentiometer variable resistor. This frequency was chosen so that the only audio signal from the plasma arc was due to the input audio signal. The theoretical output frequency F can be calculated as such:

$$F = \frac{1}{2\pi R_t C_t}$$

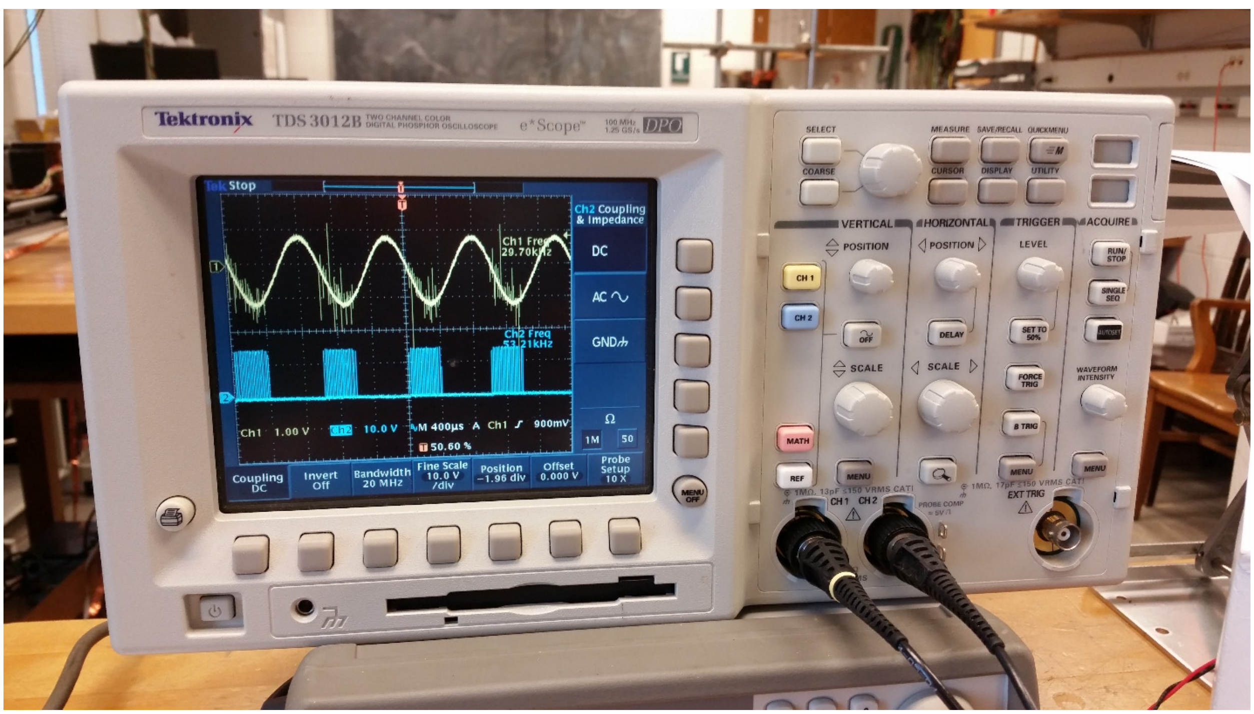
Where R_t is the total resistance input to pin 6 and C_t is the total capacitance input to pin 5. The voltage and frequency input to the circuit are proportional to the duty cycle, which is essentially the amount of time the output wave spends at max voltage vs minimum. For an ideal square wave, the duty cycle would therefore be 50%. This pulse width modulating chip acts to change the duty cycle, which will gradually alter the amount of energy released in subsequent plasma arcs in order to modulate audio signal into the plasma.

Oscilloscope reading showing that the pulse width modulation is successful at ~50kHz



the TC4429 drivers, both of which take signal directly from the TL494. These are both MOSFET drivers, which stands for metal oxide semiconductor field-effect transistor, and act to quickly overcome the gate capacitance of the 4 MOSFETs in the circuit. This essentially acts to clean up the signal and also mitigates the overheating tendency of the MOSFETs. The TC4429 takes the signal from the TL494 and phase shifts it 180° while the TC4420 does not alter phase, so the signals become perfectly out of phase at the primary coil. During each cycle of the input signal, the primary coil alternates twice which end receives the maximum signal while the other end is grounded, which is why this phenomena is called push-pull – the two drivers essentially take turns on sending signal through the transformer.

Successful implementation of MOSFETs. Noise is due to poor quality of breadboard connections.



Electrode Setup

One of the challenges of this project was finding an appropriate way to contain the plasma arcs. This was accomplished by taking some TIG welding electrodes made of thoriated tungsten which I acquired from the Mechanical Engineering lab's welding shop. These electrodes are typically used for plasma welding so they were more than suitable for a plasma speaker. I then mounted these rods inside of some MACOR, which is a type of special machined glass ceramic provided to me by Professor Errede from his laboratory. The MACOR is quite brittle (essentially like chalk) but could withstand the large amounts of heat and energy given off by the electrodes. This was all held together with just a simple metal stand (wrapped in electrical tape so as not to conduct any electricity). The electrodes were held apart vertically by approximately 1cm.

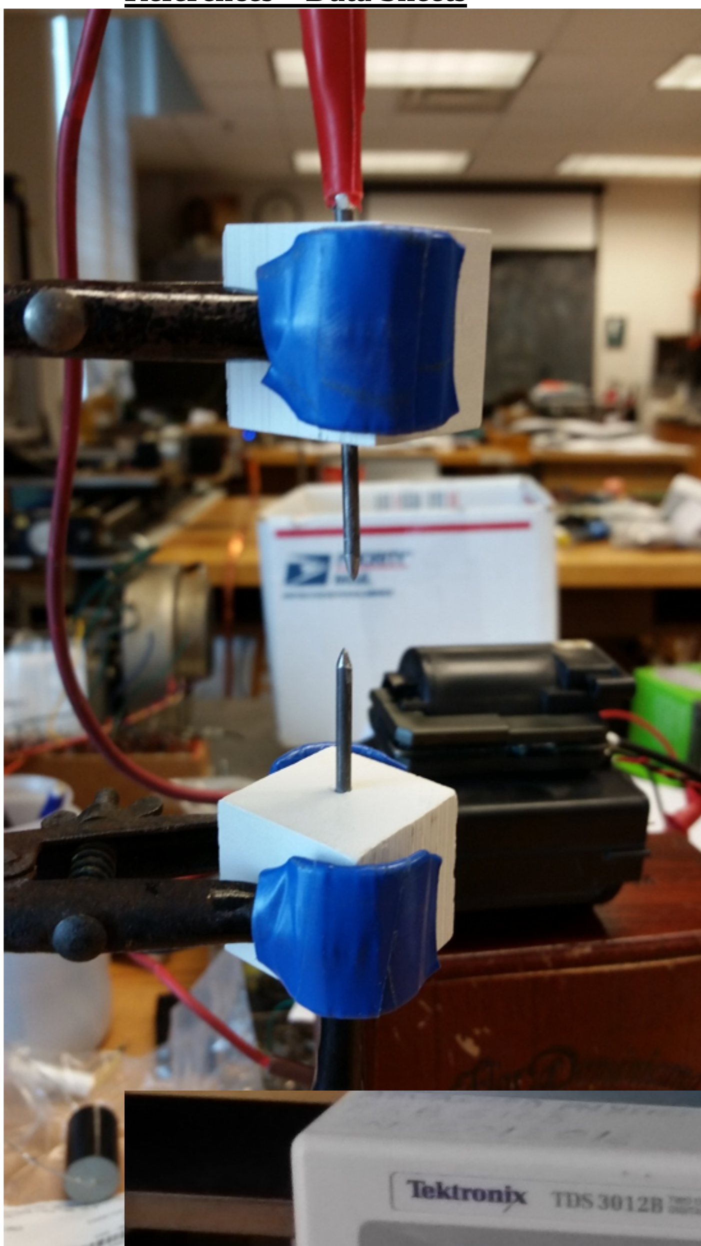
General Setup Commentary and Conclusions

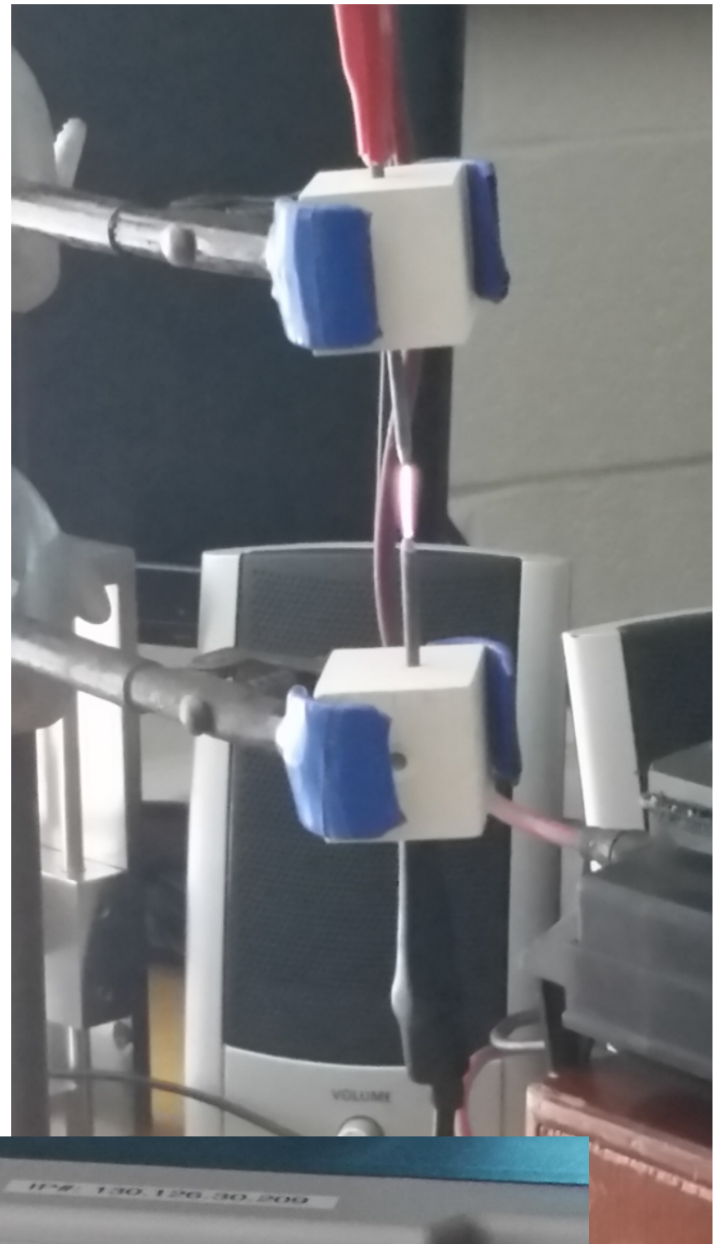
It is important that anyone wishing to repeat this project order plenty of extra parts for each component, all of which I acquired from the online Mouser electronics store. It is very easy to blow out one of the little chips if something is improperly connected, and it is more than a bit of a hassle to have to wait the couple days it takes to ship more parts, especially when it costs more in shipping than it does components. Furthermore, anyone looking to repeat this project should certainly avoid doing so on a breadboard if possible. The connections are finicky which is far from ideal when it comes to something like plasma. I had a lot of fun constructing this throughout the semester, and if given more time would have performed tests on the frequency responses and performance of the speaker. I also would have reconstructed the speaker independent of a breadboard, and would have found voltage sources of my own in order to keep the speaker when I was finished. Finally, I would like to give a special thanks to Professor Errede for all of his time spent helping me with this project, for I could not have done it without him. I also would like to credit the report by Michael Hopkins and Thomas Houlahan from the Spring of 2012, as this provided me with guidelines on how to properly understand and assemble my speaker.

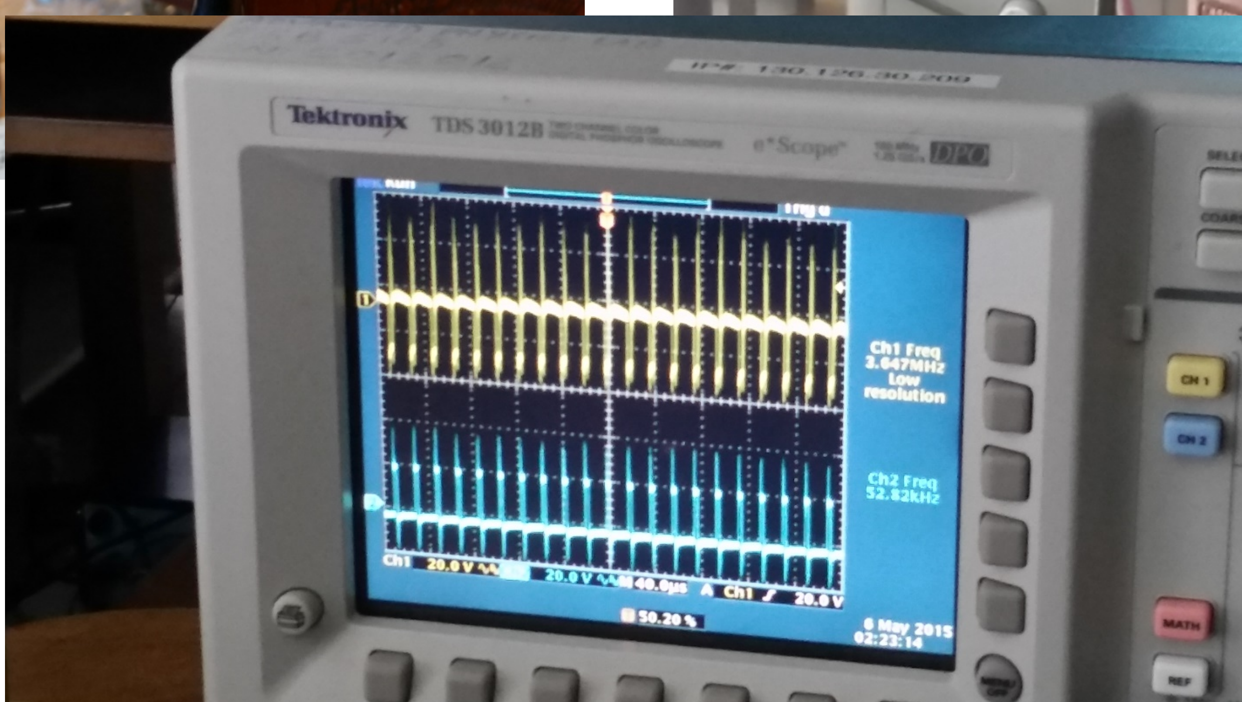
Left: Electrode setup and spacing. Right: Plasma speaker turned on and fully functioning.

Bottom: Oscilloscope reading while speaker is on.

References – Data Sheets







TC4429EPA – http://www.mouser.com/ds/2/268/21419c-23818.pdf

TC4420VPA – http://www.mouser.com/ds/2/268/21419c-23818.pdf

TL494CNE4 – http://www.mouser.com/ds/2/405/tl494-556737.pdf

MBR1645G – http://www.mouser.com/ds/2/308/MBR1635-D-76328.pdf

IRFZ46NPBF – http://www.mouser.com/ds/2/200/irfz46npbf-222260.pdf

- Note: GDS labels not included in data sheet. Refer to picture below.