Construction of Full-Bridge Stereo Plasma Speaker

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INTRODUCTION

A conventional speaker works by using a magnet and inductor to drive a diaphragm, generating pressure waves which can be heard by the human ear and interpreted as sound. A plasma speaker differs by using a plasma arc between two electrodes to generate pressure waves. In this way, the plasma speaker is not limited in its frequency output by moving parts like the diaphragm. In order to create this plasma arc, a circuit acting as a pulse generator is stepped up by a flyback auto transformer connected to two electrodes, drastically increasing the voltage enough in the electrode gap in order to create a plasma arc. This is applying a certain change in energy ΔU to the cylinder of air between the electrodes. The air being ionized is mostly atmospheric N_2 and O_2, diatomic molecules, so we can write,

$$\boldsymbol{\Delta T = \frac{2}{3R}\Delta U} \tag{1}$$

where ΔT is the change in temperature of the gas and R is the ideal gas constant. Using the ideal gas law, and approximating the volume of the cylinder of air being ionized as roughly constant, we can write,

$$\boldsymbol{\Delta P = \frac{nR\Delta T}{V}} \tag{2}$$

Plugging in (1), we obtain the relation,

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

Thus, if we know the input energy, we know the varying pressure and can tune accordingly to get sound that can be heard by a human. Stereo plasma speaker simply means we will have two of these plasma arcs at the same time (meaning two circuits and four total electrodes) in order to create a stereo effect with two speakers. A rough schematic of the system is shown in Figure 1.

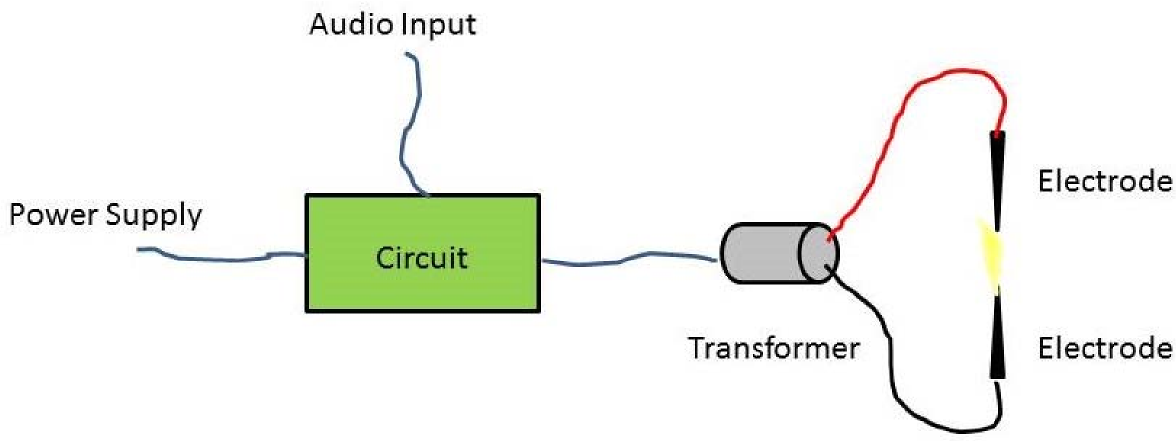

Figure 1

CIRCUIT OVERVIEW

The circuit used to accomplish is a full-bridge circuit which utilizes a push-pull method of voltage pulses to drive the flyback auto transformer. The circuit diagram is shown in Figure 2. The basic concept driving the plasma speaker is relatively simple; a square wave is modulated and applied to the transformer to generate varying voltage pulses. In our circuit, we use a TL494 chip with a 12V power supply to generate a square wave, and this square wave goes to two chips, one TC4420 and a TC4429 chip. The TC4429 inverts the square wave while the TC4420 lets it pass through so that the pulses coming out of the two chips are opposite in magnitude. This gives the push-pull characteristic behavior of the circuit. The two outputs of the circuit are connected to the flyback transformer which ups the voltage substantially based on the equation,

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \tag{4}$$

where V_s and V_p are the secondary and primary voltages and N_s and N_p are the number of turns on the secondary and primary coils of the transformer. This increased voltage is enough to cause plasma arcs between the two electrodes. The audio input is connected to the TL494 and it modulates the base frequency of the square wave, modulating the frequency of the plasma arc and thus generating sound.

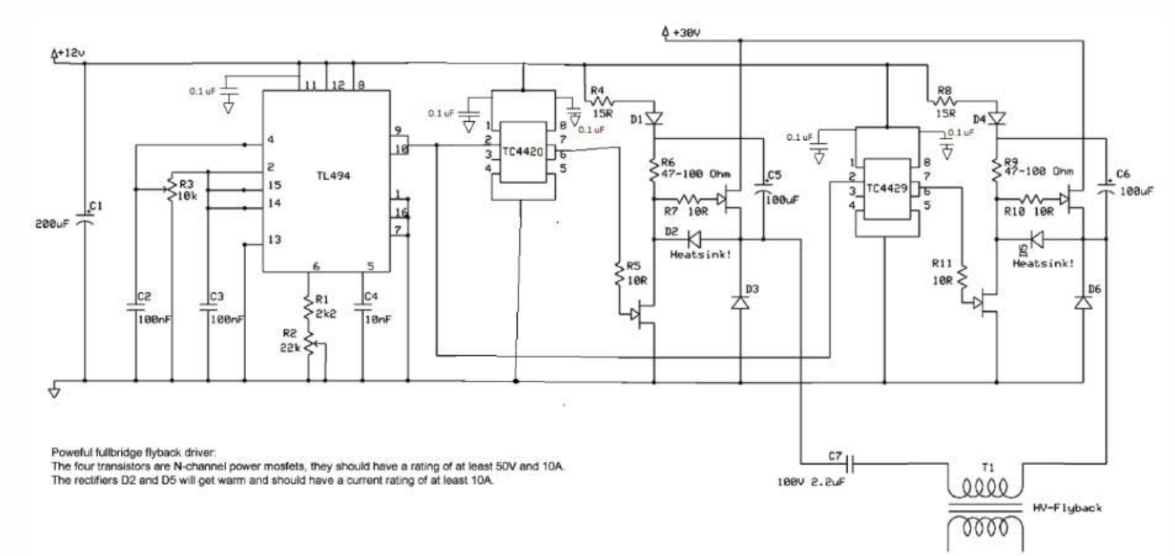

Figure 2

CONSTRUCTION OF CIRCUIT

Originally the circuit was going to be built on printed PC boards made and printed through Express PCB. Due to time and experimental constraints we decided to pursue another method. We were originally using this schematic, but it was later modified and redrawn in a clearer fashion, shown in Figure 3. The circuit eventually was built on project boards that were covered in copper tape in order to create an adequate ground-plane. With the copper covering the surface of the board, each component needed its own area to be removed from the copper for all pins not going to ground. Each component, minus the diodes and MOSFETs that would reach high temperature were installed this way. Special care was also needed to ensure that no loose pieces of copper were left on the board to cause a short and potentially damage the circuit. Circuit components were installed on the top of the board while connections and wires were consolidated on the bottom. Each component needed to be soldered to the connect components or the ground plane to create the circuit as depicted in the schematic. Two identical copies of the circuit were made and installed on the board in order to create left and right channels for stereo audio. The finished circuit is shown in Figure 4.

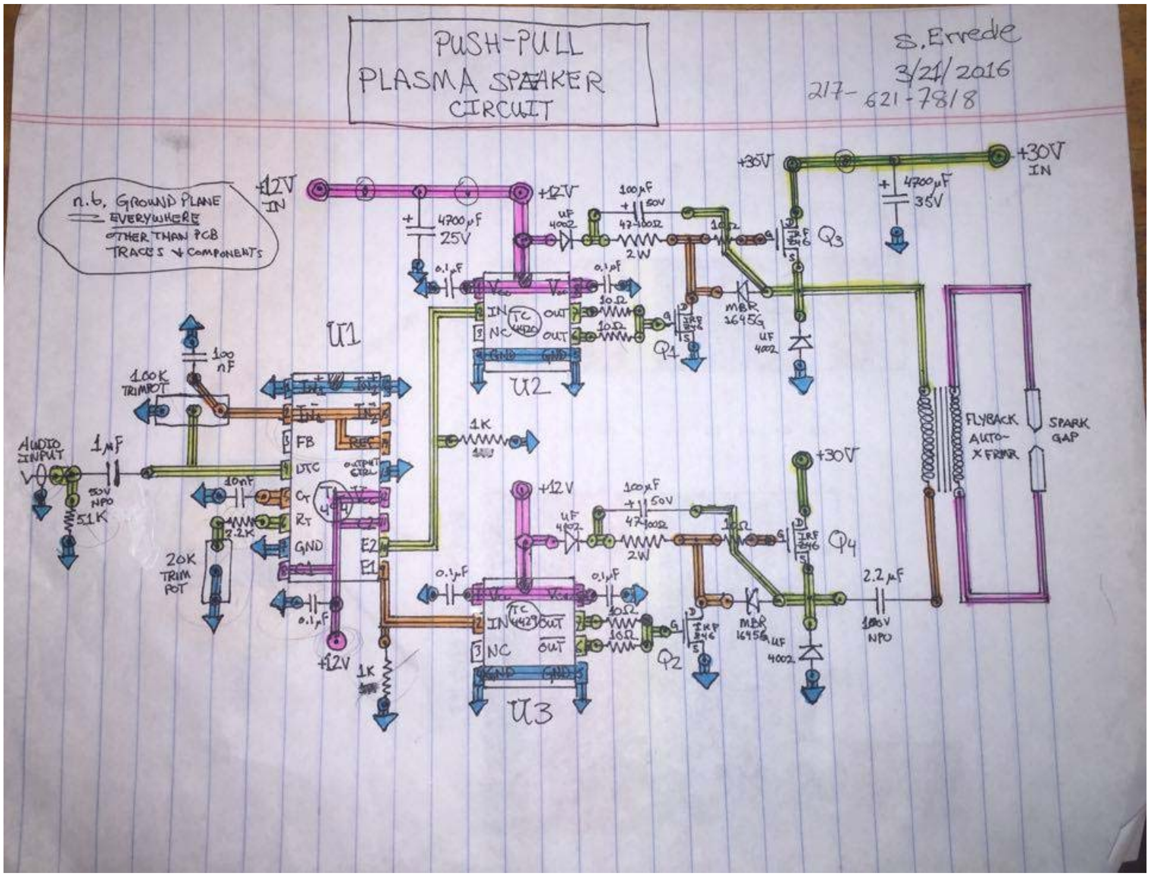

Figure 3

After attaching the components that were present on the project board, the board needed to be attached to additional components and fitted in to the box. To do this, holes were prepared in the project box being used in order to accommodate the number of wires and the input that needed to pass through the box. A stereo 3.5 mm jack was installed on the front of the box. One channel went to each of the two speaker circuits and the ground was used to connect the ground-plane to the metal box which would hold the circuit. The MOSFETs and some diodes used in this circuit can reach high temperatures so they needed to be attached to a heat sink. The UF4002 diodes were not put on the sink, but all other diodes and MOSFETs were. This heatsink was mounted on the back of the project box and held all 12 of the higher temperature components.

Figure 4

With the circuit and box assembled, we needed to connect the outputs of the circuit. On each channel the push and pull sides of the circuit were attached to their respective pins and wires. The transformer then had two outputs of its own; these were connected using alligator clips to the tungsten rods that would cause the arc of plasma.

SETUP & TESTING

To monitor our circuit we had each channel connected to an oscilloscope. While turning the circuit on we needed to be able to compare the signals of all channels to make sure that both sides of the circuit were running correctly in unison. Being a push-pull style circuit, in each channel the two chips needed to put out equal magnitude but opposite signed waves to achieve the desired effect with the transformer. The circuit was tested at many different test points that we had installed along the circuit to allow us to monitor different points and troubleshoot the regions that were problematic. The output from the TC4420 and TC4429 are shown in Figure 7, matching with what we expected. In addition to the two oscilloscopes we also had a wave form generator set up into the input to allow us to alter the waves being put through the circuit and make sure that the output matched the input. We tested to see if the audio input from the function generator modulated the pulses, shown in Figure 6.

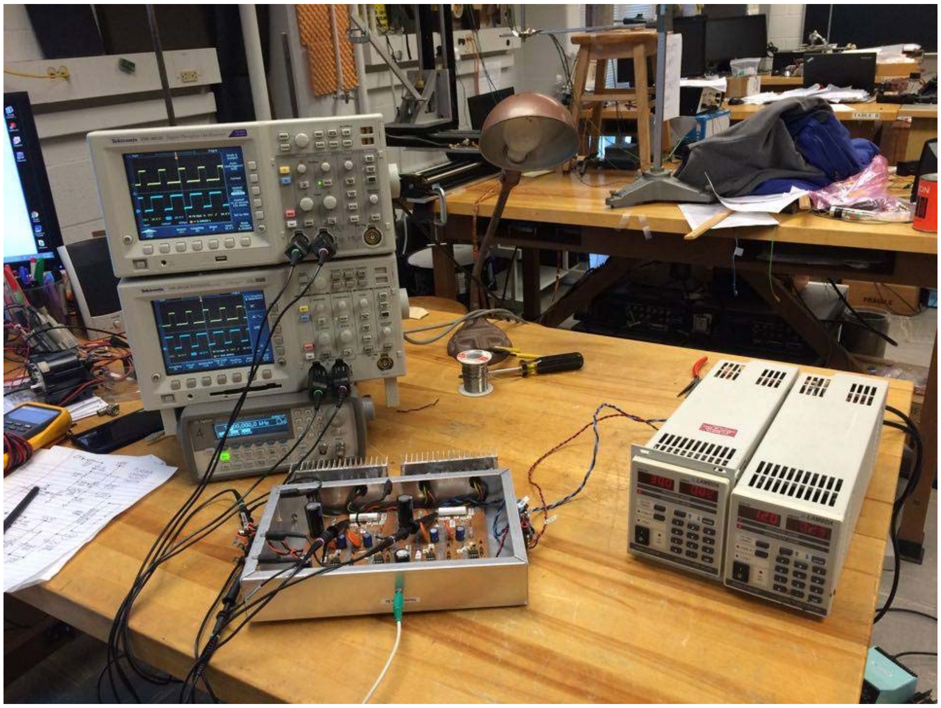

Figure 5

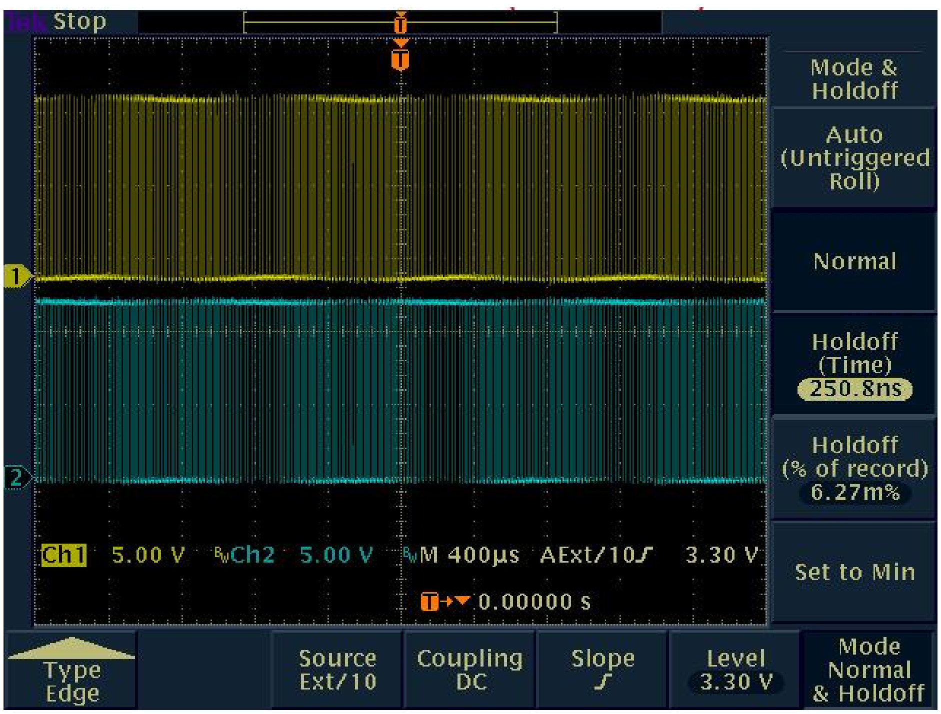

Figure 6

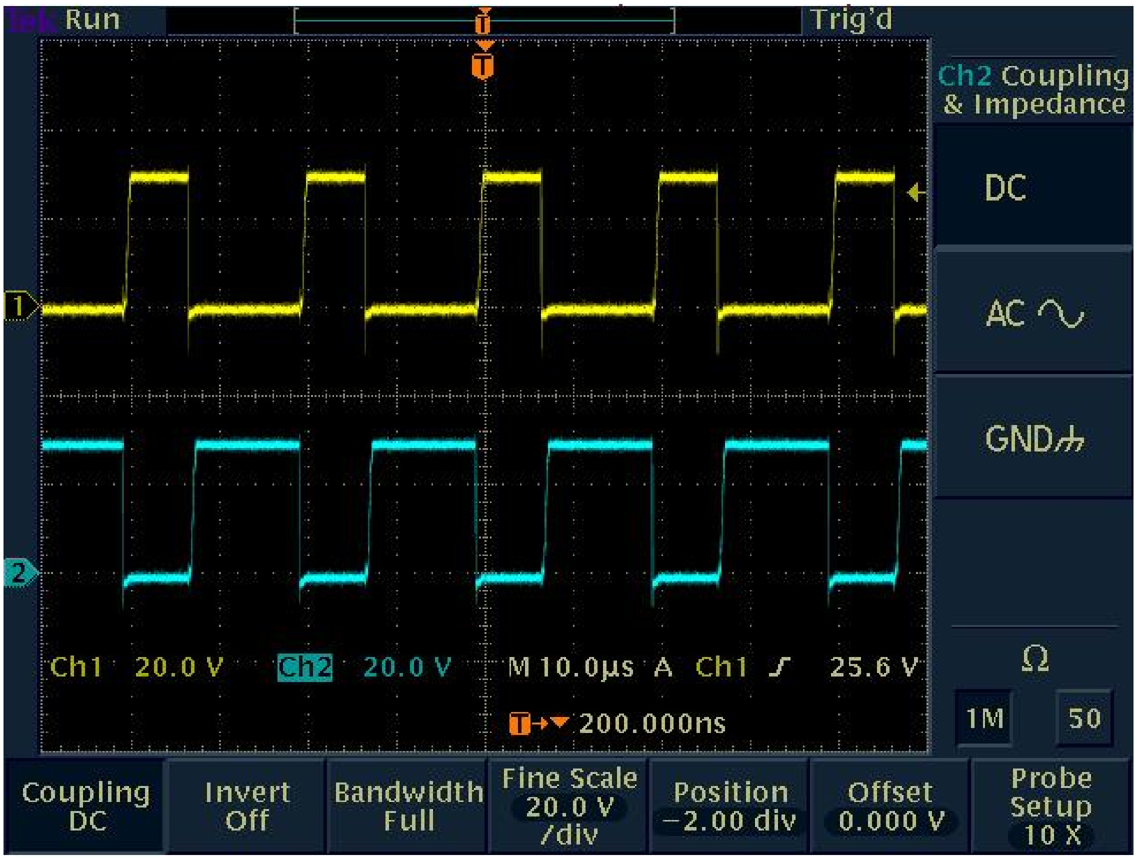

Figure 7

The circuit also needed to be powered at two different voltages. Initially both power supplies were set to 12 V, but the second power supply was later stepped up to 30 V in order to power the transformers to achieve a plasma arc. To achieve the arc the tungsten rods needed to be placed very close together. The closer the rods are to each other, the less volume the speaker can achieve but it makes it easier for the plasma arc to form.

Prior to actually connecting the transformers we tested the circuit with dummy loads. A resistor was connected in place of the outputs to the transformers in order to simulate the resistance of the latter portion of the circuit. This was a safer way to monitor the outputs and ensure that the circuit would run as intended. Once it had cleared all initial tests we were able to connect the transformers and power them. The power supplies that we were using initially were not able to maintain the current necessary to power the circuit, larger supplies were needed, shown in Figure 8. In future tests the transformers will be replaced and additional power supplies may be added to power each channel independently.

Figure 8

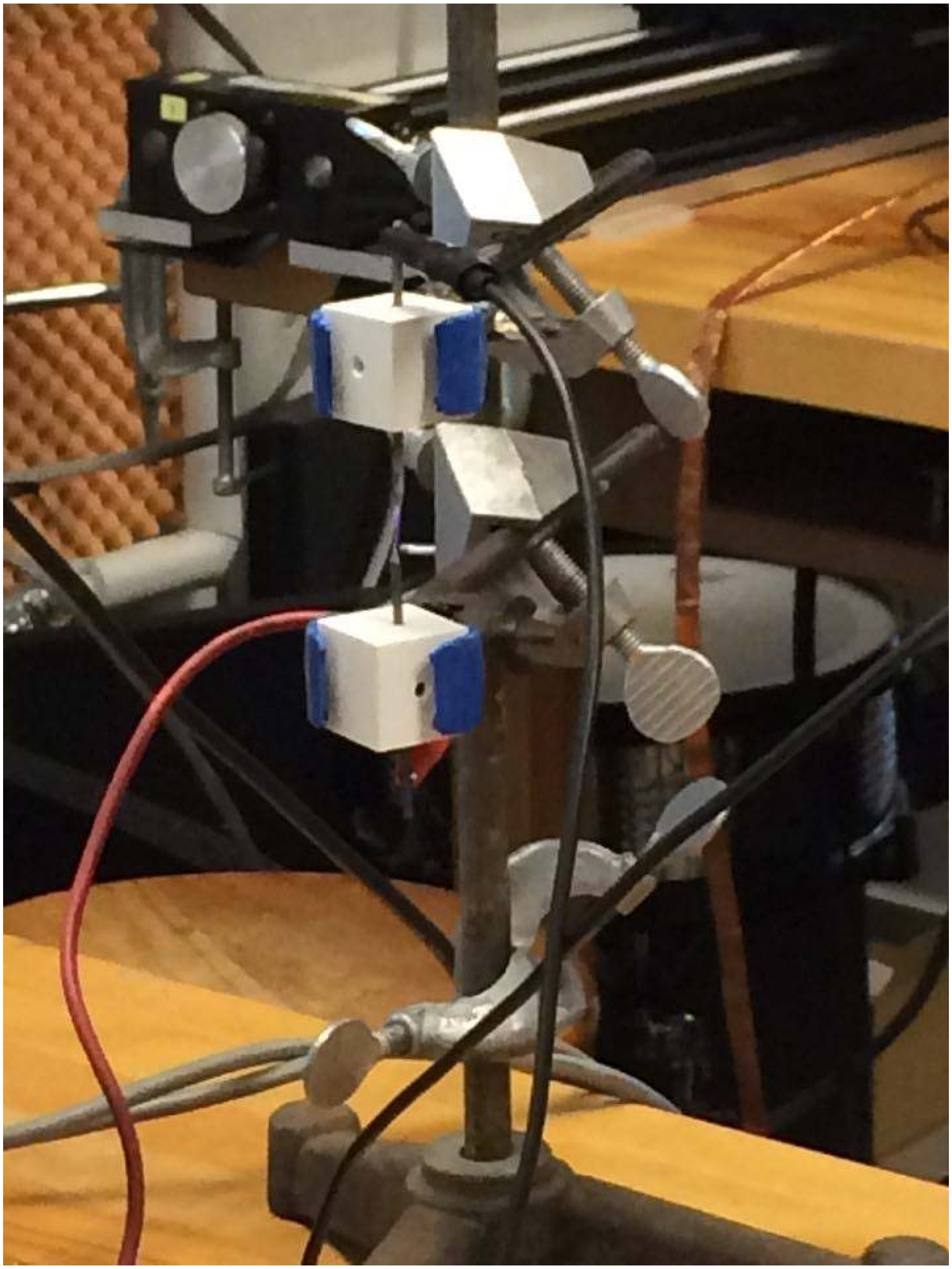

Figure 9

CONCLUSION

The circuit design shown in this report has been demonstrated that it works to produce the signal necessary for plasma speakers. The main problem we encountered was with the transformers, all of which were liberated from very old CRT monitors and none of which were the exact same. They all worked to up a voltage when testing the transformers alone, but only some of them worked to increase the voltage enough to ionize the air between the electrodes. If the project were to be continued, we would have liked to test the frequency output of the speakers.