A High Voltage DC Power Supply to Excite a Laser Tube: A Capstone Design Project

Jeng-Nan Juang[1] and R. Radharamanan[2]

Abstract – This paper describes the course of action taken in the development of a power supply capable of driving a Helium-Neon Laser. The power supply will produce a triggering voltage of 8,000 volts DC and an operating voltage of 1,100 volts DC from an input voltage of 10 volts DC. The power supply will also produce an operating current between 0.004 and 0.0055 ampere while drawing approximately 0.750 ampere of current. The enclosure for the power supply was constructed of Plexiglas to insulate the operator from the high-voltage output of the power supply, and to allow the user to observe and/or demonstrate the operation of a laser (Figure 1). Three different designs were considered and the design with minimum components as well as cost was chosen for fabrication. The power supply operates the laser within the operational specifications without overheating [Mcpherson, 6].

Keywords: High voltage DC power supply, multiplier, inverter, Helium-Neon laser, and capstone design project.

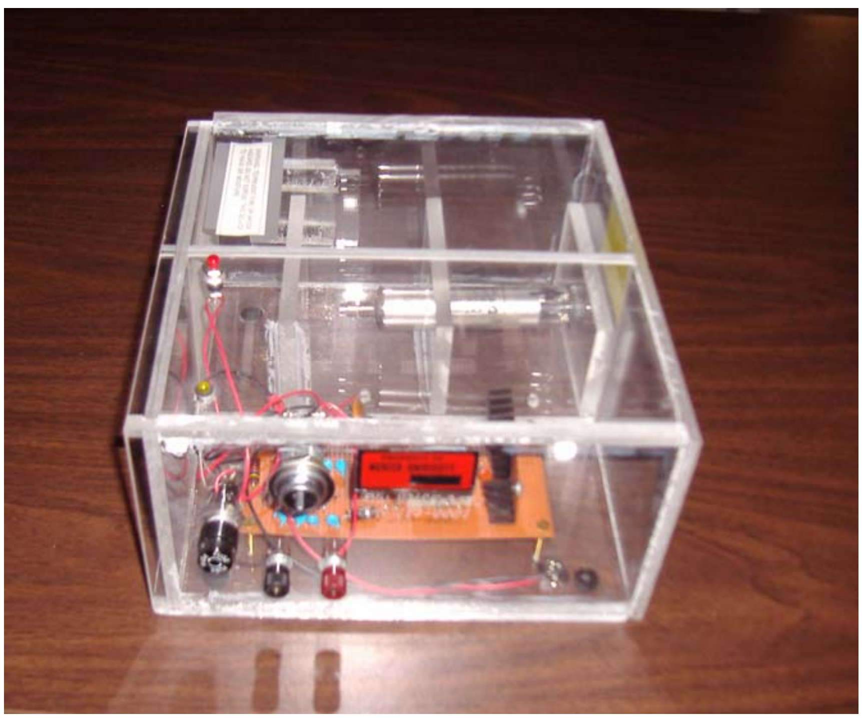

Figure 1: The laser power supply

---

[1] Mercer University School of Engineering, 1400 Colman Ave., Macon, GA 31207, juang_jn@mercer.edu

[2] Mercer University School of Engineering, 1400 Coleman Ave., Macon, GA 31207, radharaman_r@mercer.edu

INTRODUCTION

The helium-neon tube is the staple of the laser experimenter. They emit a bright, deep-red glow that can be seen for miles around [Seigman, 7; Willetts, 9]. Although the power output of He-Ne tubes is relatively small compared to other laser systems, it is perfectly suited for many homebrew and school experiments in diffraction, reflection, etc.

The helium-neon laser is a glass vessel filled with 10 parts helium and one part neon, pressurized to about 1 mm Hg (The exact gas pressure and ratios vary between laser manufactures). Electrodes placed at the ends of the tube provide a means to ionize the gas, thereby exciting the helium and neon atom. Mirrors mounted at either end form an optical resonator, or Fabry-Perot resonator. In most of laser tubes, one mirror is totally reflective and the other is partially reflective. The partially reflective mirror is the output of the tube [Csele, 2].

Helium-neon lasers are actually composed of two tubes: an outer plasma tube that contains the gas and a shorter and smaller inner bore or capillary, where the lasing action takes place. The bore is attached to only one end of the tube. The loose end is the output and faces the partially reflective output mirror. The bore is held concentric by a metal element called the spider. The inner diameter of the bore largely determines the diameter of the laser beam. The ends, where the mirrors are mounted, typically serve as the anode (positive) and cathode (negative) terminals. On some lasers, the terminals are mounted on the same end. A strip of metal or wire extends to the cathode on the other end. The output mirror can be on either the anode or cathode end, but on most tubes, it is the cathode. Many manufacturers prefer that arrangement, claiming it is safer and more flexible [Webb, 8].

Most laser power supplies use high-voltage capacitors at the output stage. Like all capacitors, they can retain a charge even after the power supply has been turned off. So when working with a laser, make sure the power supply is off and disconnected from its power source, then temporarily short the output leads of the power supply together, or simply touch the supply's positive output connection to ground [McComb, 5].

PROJECT GOAL

The project goal is to design, build, and test a high voltage (DC) power supply for a 1 mW Helium-Neon laser. The laser's specifications are given below. The input to the power should be about 10 VDC and 0.004 Amps of current. The laser will be operated in 30 second intervals.

Triggering Voltage (V_{tr})	8,000 Volts
Operating Voltage (V_{op})	1,100 Volts
Operating Current (I_{op})	0.004 Amperes

Feasibility Criteria

The design was determined to be feasible by meeting the criteria listed in Table 1.

Table 1: Feasibility Criteria

The components must be obtainable on time.
Its cost must not exceed $80.
The weight of the power supply unit must be less than 10 pounds.
Its length, width, and height should be less than a foot.
The hazards to the operator must be minimal.
The design must be reliable.

Merit Analysis

The design was then evaluated using the merit criteria listed in Table 2.

Table 2: Merit Criteria

Availability of the components.
Total cost of the power supply unit
Weight of the power supply unit
Reliability of the power supply unit

WORK ACCOMPLISHED

Three designs were presented in the preliminary design review. The application of the feasibility criteria resulted in the elimination of the Alternative 1 (see Figure 2) because of excessive component costs. Alternative 2 (see Figure 3) was eliminated upon the application of the merit criteria. The merit analysis showed that Alternative 3 (see Figure 4) has the highest total merit points and therefore it is the best design [Grossblatt, 4].

To reduce the chance of the operator coming in contact with the high voltages produced by the power supply, the power supply was encased in a Plexiglas enclosure. Plexiglas was chosen because it is an insulator and it allows the operation of the laser to be observed. The Plexiglas enclosure has the following dimensions: 5"H x 9.25"D x 10"W. The rear panel of the enclosure is removable, to allow access to the circuitry and the laser tube. The removable panel is secured by a pad-lock and locking tee. A locking switch is used to limit the number of operators to those who possess a key. A lamp fuse was used between the input voltage and the locking switch to protect the circuit from excessive current draw (see Figure 4).

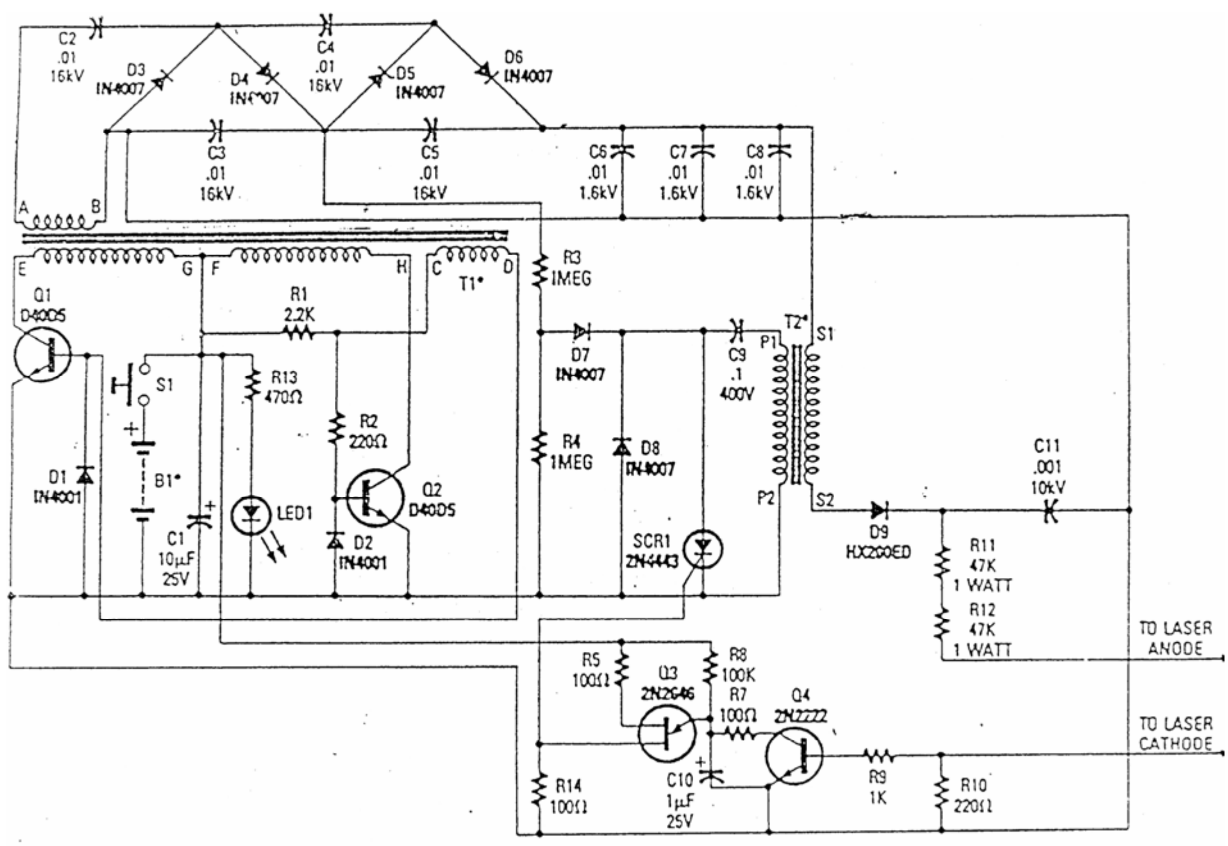

Figure 2: Alternative 1

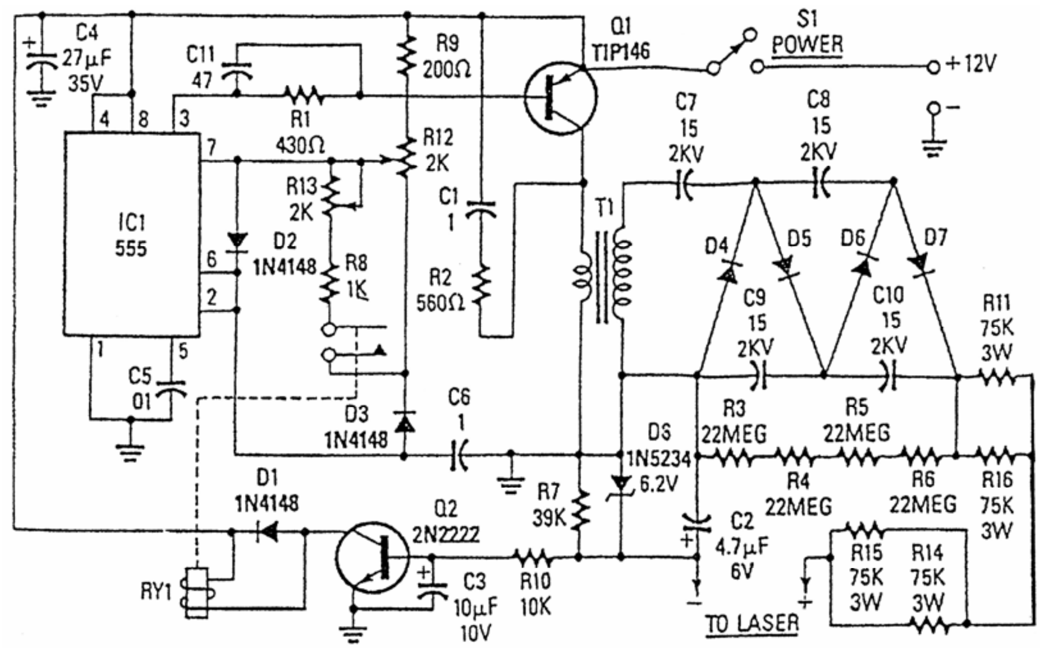

Figure 3: Alternative 2

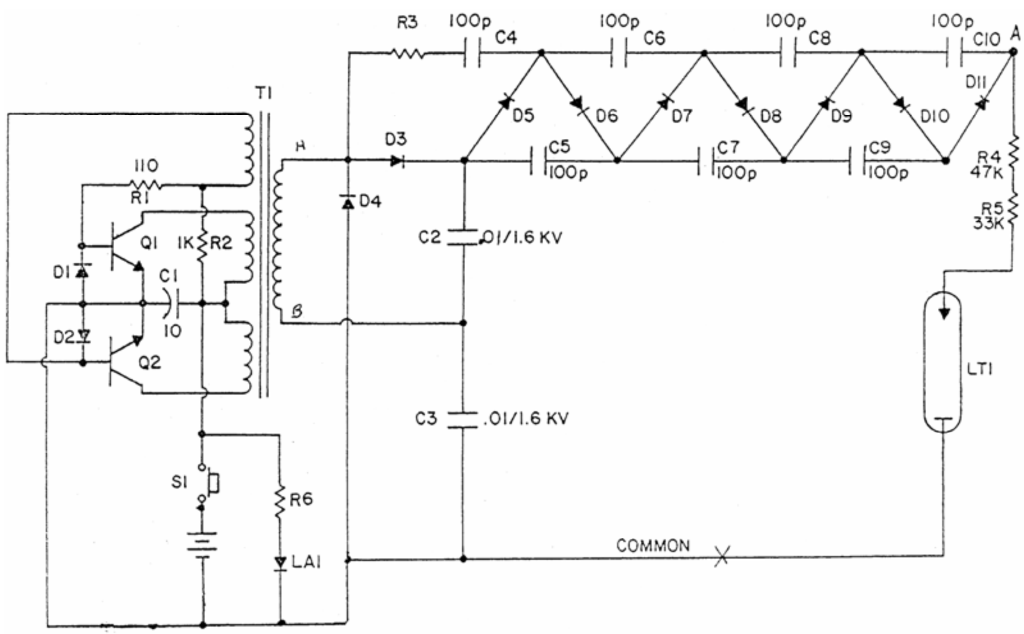

Figure 4: Alternative 3

TEST PLAN

The design team has comprised the following test plan to aid in the realization of the design goal. The goal of this project is to design, build, and test a power supply capable of powering a 1 maw Helium-Neon laser. The power supply will produce at least 8,000 volts DC, the voltage needed to trigger the laser into operation. After the laser is triggered, the power supply will output the operating voltage of the laser, 1,100 volts DC. The DC current provided by the power supply will meet the operational requirements of the laser, 0.004 to 0.005 amps. The input required by the power supply will be a DC source capable of providing approximately 12 volts and 0.750 amps. The power supply should be capable of operating the laser for a minimum of 30 seconds. The results from the tests are presented in "Tests Results" [Alberson, 1].

INITIAL TESTING

Upon arrival of the components needed to construct the circuit show in Figure 5, each component was tested to insure that they are in working order. The circuit consists of several capacitors, diodes, resistors, a transformer, two switches, and two transistors. These components were checked in the Electromagnetic Laboratory at Mercer University School of Engineering.

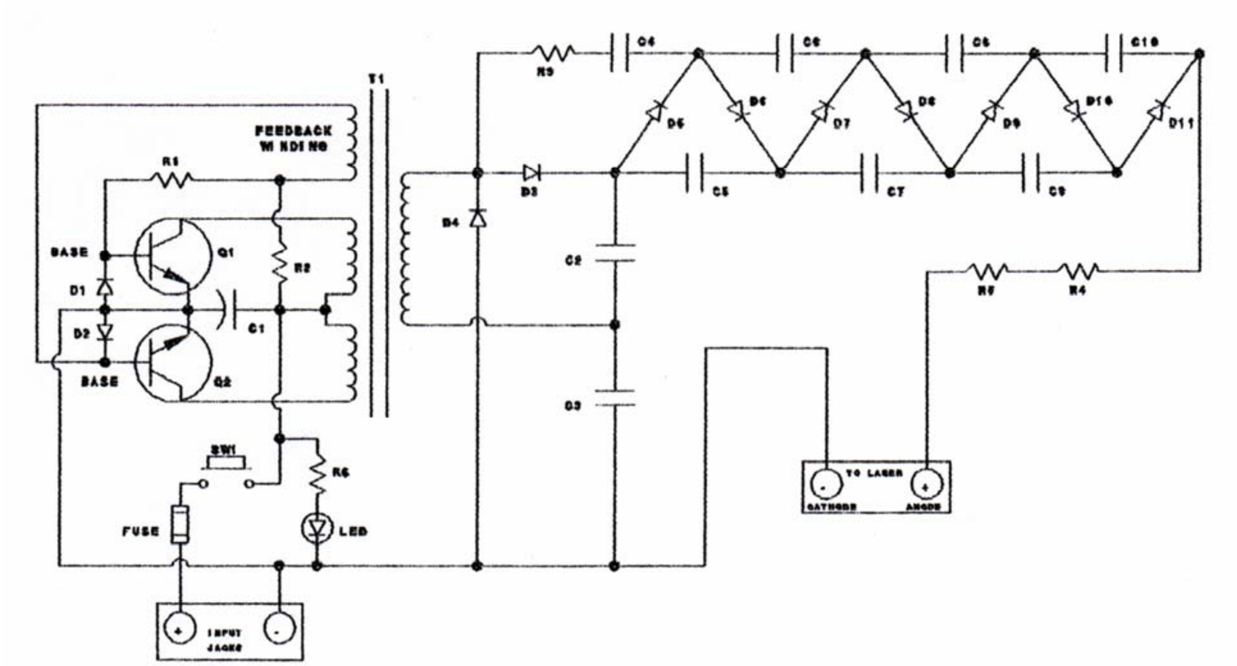

Figure 5: Laser power supply circuitry

TEST RESULTS

Quality Assurance Tests

Each component was tested individually to be sure that they were in working order and within the tolerance limits specified in the test plan.

The resistors and diodes were tested with a digital multi-meter (DMM). By connecting the resistors to the test leads of the DMM in the resistance mode, the accurate values of the resistance can be obtained. The resistances must be within ± 10 % of those given in the parts list so the design will perform as expected. If the resistances are too high, the output voltage may not meet the design requirements. If they are too low, the output voltage may exceed the requirements and possibly damage the laser.

Similarly, the diodes were tested by connecting them to the test leads of the DMM. The resistance of a diode should be off-scale when its anode is connected to the positive terminal, and the cathode is connected to the negative terminal of the DMM. The resistance should be measurable when the polarity of the test leads is switched. If this is not the case, the diode is not functioning properly. Should one diode fail to function properly, the circuit would not produce the voltage needed to trigger the laser.

The capacitances of the capacitors were measured with a heath-Bridge. The capacitances should be within $\pm 10\,\%$ of those specified in the parts list. The output of the power supply is provided by discharging the capacitors in the circuit. The length of time needed to discharge a capacitor is dependent on the capacitance of the capacitor. If the capacitance is too large, the capacitor would not be able to discharge quickly enough to produce the DC voltage needed to meet the design requirements. If their capacitances are not large enough, they would not store the voltage needed to trigger and operate the laser.

To check the transformer, an AC power source was connected to one of its primary windings, and a DMM to the secondary winding. With the AC source providing a 1 volt (root mean square or RMS) input, the transformer should output about 94 volts (the output to input ratio should be approximately 94 to 1). If the output of the transformer is less than 94 volts, the input voltage required by the laser power supply will be more than 12 volts. If the output is more than 94 volts, the input voltage required will be less than 12 volts.

There are two switches utilized by the power supply. One is a normally-open momentary switch, and the other is a locking switch. The normally-open momentary switch must be pressed and held for the switch to be considered closed. The locking switch can not be closed without a key, thus the power supply can only be operated by someone has a key.

By connecting each switch to the test leads of the DMM in the resistance mode, one can determine if they work properly. When each switch is open, their resistance will be very high (ideally infinite), so the DMM should give an off-scale reading when set on its highest scale (20 mega ohms). When a switch is closed its resistance should drop below 10 ohms.

If the switch has measurable resistance when open, the power supply could begin operating when the input source is initially connected (although the laser tube would not be operating). This would not be a problem unless the operator is using batteries for input. If the batteries were to remain connected to the power supply for an extended period, this resistance would cause them lose their charge (go dead). If the resistance of the switch, when it is closed, is higher than 10 ohms, the input voltage required for the power supply would be higher than 12 volts.

Each transistor was tested by connecting the test leads of the DMM to their collector and emitter. Then the ground lead of a DC power supply will connect to the emitter and the positive lead to the base. As the voltage applied to the base of the transistor is increased, the resistance between the emitter and collector should decrease. Should the resistance fail to decrease, the transistor is not working properly. The laser power supply will not work if the transistors do not function properly.

Testing the Multiplier and Inverter

With the multiplier on breadboard, an AC voltage source was connected to its input. If the multiplier is functioning properly, its output should be eight times its input. The inverter’s output was then connected to the multiplier’s input. The DC source connected to the inverter’s input was adjusted until the output of the multiplier was 8,000 volts [Gottlieb, 3].

When all components have passed the initial testing, the circuit will be constructed on a breadboard. The first section to be bread-boarded will be the multiple-section voltage multiplier (the capacitors, diodes, and resistors connected to the secondary winding of the transformer in Figure 5). A function generator was used to supply 1 volt AC (maximum or peak to peak) input to the multiplier while a DMM will measure its output.

The output should be 8 volts DC. If the multiplier’s output is less than 8 volts, more capacitors and diodes can be added to increase its output. Since the multiplier is a linear circuit, the output will increase by the same factor that the input is increased. For example, if the input voltage is increased to 10 volts, the output will be 80 volts DC.

The transistor inverter was the next section to be bread-boarded. It consists of the transistors, the transformer, and the other components shown in Figure 6. A DC power supply was connected to the inverter’s input, and an oscilloscope to its output. With an input of approximately 12 volts DC, the inverters output should be a square wave that peaks at about 1,100 volts or a peak-to-peak output of 2,200 volts. If the inverter does not function properly, there is either a faulty component or incorrect connection.

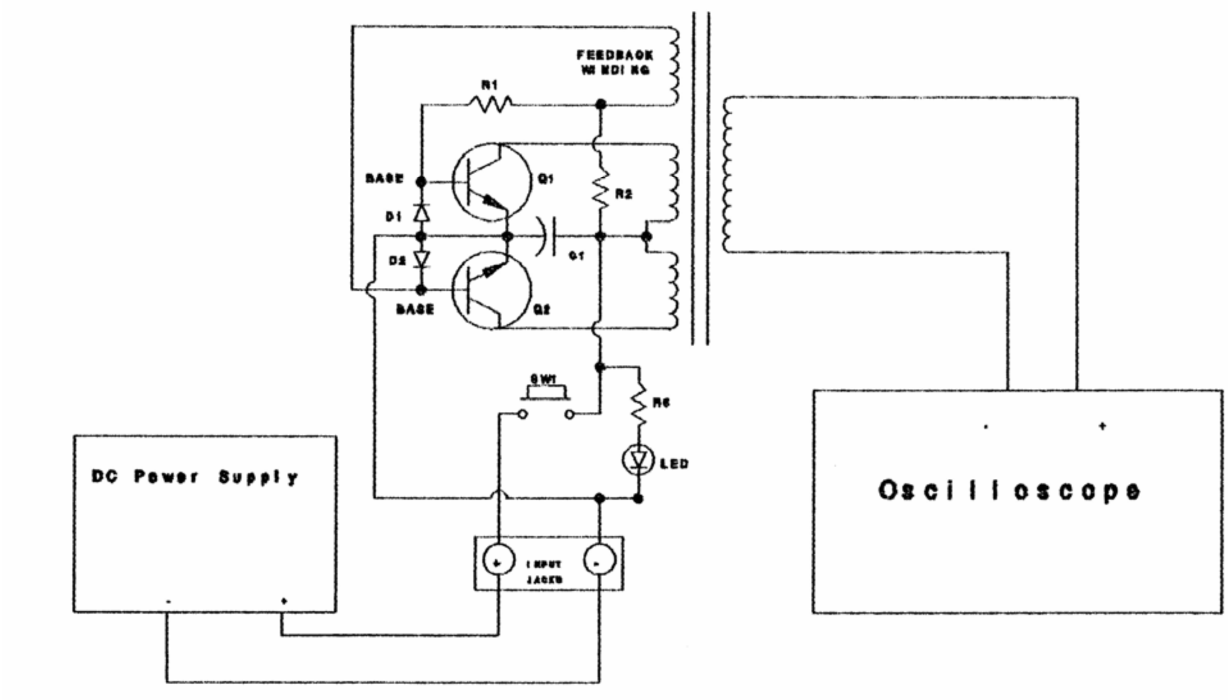

Figure 6: Connections to test transistor inverter

Next, connect the inverter's output to the multiplier. Using a DC power supply as input, monitor the output of the multiplier with a DMM. The input voltage was increased until the triggering voltage is produced. This voltage was noted as the required input voltage.

A 220 kilo-ohm resistor was connected to the output of the laser power supply. A DMM, used as an ammeter, was connected in series and another DMM was connected in parallel with the test resistor to measure its voltage. The input voltage will be slowly increased to the required voltage previously determined. When this voltage is reached, the voltage across the test resistor should be about 1,100 volts DC and the current should be between 4 to 5 milliamps. If the voltage and current are not those previously mentioned, resistors R4 and R5 (see Figure 5) can be varied to obtain the desired values.

TESTING FINAL ASSEMBLY

The circuit was removed from the breadboard and assembled on the PC board. The inverter and multiplier were tested individually before their final connection. The results from these tests were the same as when the circuit was on breadboard.

Testing the Enclosure

The scrap piece of Plexiglas was heated in water to 98 degrees Celsius. At 98 degrees, the scrap began to deform. To avoid deformation of the enclosure and possibly burning the user, the temperature must be limited so that the enclosure would be allowed to reach to about 55 degrees Celsius.

Testing the Prototype

The power supply was operated five times in intervals of 30 seconds to examine the effects of heating in the enclosure. The room temperature was 24.5 degrees Celsius.

Safety Tests

With a metal plate placed on the left side of the power supply (the laser's side), no arcing was observed during the operation of the power supply. Since arcing did not occur, the operator will be fully insulated from the high-voltages of the circuit, as long as the supply is operated with the enclosure sealed (closed).

CONCLUSIONS

Of the three designs originally considered, Alternative 3 was determined to meet the design criteria. The application of the feasibility criteria eliminated Alternative 1. Alternative 2 was eliminated by the application of the merit criteria.

After receiving the components needed to build the power supply, each section (the multiplier and the inverter) was tested separately as they were constructed. The sections were then connected and tested as a system. Meanwhile, the Plexiglas (needed for the construction of the enclosure) was tested for resistance of deformation when exposed to heat. System tests were performed to ensure that the circuitry and the laser would perform as expected without overheating. The power supply operates the laser within the operational specifications without overheating.

The Plexiglas enclosure gives a clear view of the laser tube, making it very easy to demonstrate how a laser works. The power supply's size and weight, as well as its ability to be operated with batteries (DC), make it possible to demonstrate the operation of a laser at any place.

REFERENCES

[1] Alberson, K., G. Le and H. Ng, *A High-Voltage DC Power Supply to Power a Helium-Neon Laser Tube*, Senior Design Report, Mercer University, Macon, GA, 1991.

[2] Csele, M., *Fundamentals of Light Sources and Lasers*, John Wiley & Sons, 2004.

[3] Gottlieb, I. M., *Principles and Applications of Inverters and Converters*, Howard W. Sams & Co., Inc., 1977.

[4] Grossblatt, R., and R. Iannini, "Helium-Neon Laser," *Radio-Electronics*, June 1986, pp. 42-46.

[5] McComb G., "Universal Laser Power Supply," *Radio-Electronics,* March 1989, pp. 33-42.

[6] Mcpherson, G., and R. Laramore, *An Introduction to Electrical Machines and Transformers,* Second Edition, John Wiley & Sons, 1990.

[7] Siegman, A. E., *An Introduction to Lasers and Masers*, McGraw-Hill, New York, 1974.

[8] Webb, C. E., and J. D. C. Jones, *Handbook of Laser Technology and Applications – Volume II: Laser Design and Laser Systems*, Institute of Physics Publishing, Bristol & Philadelphia, 2004.

[9] Willetts, C. S., *Introduction to Gas Laser,* Pergamon Press Inc., Fairview Park, Elmford, NY, 1974.

JENG-NAN JUANG

Dr. Juang received the B.S. degree in Electrical Engineering from National Taiwan Ocean University, Keelung, Taiwan and the M.S. and Ph.D. degrees from Tennessee Technological University, Tennessee. He has been a faculty member of the Electrical and Computer Engineering at Mercer University since 1987. He organized and chaired the "International Workshop on Future Aerospace Maintenance & Technology" at Taipei in Taiwan. He also served as a prime consultant for Fiber Optic Rate Gyroscope Development Program (A grant from Wright-Patterson Air Force Base, Ohio, USA). He has received one teaching award, and two research fellow awards from NASA Langley Research Center, Virginia, USA. His professional affiliations include: ASEE, IEEE, AIAA, NATPA, NSPE, CAPASUS, and AAUP.

R. RADHARAMANAN

Dr. R. Radharamanan is a Professor of Industrial and Systems Engineering in the Department of Mechanical and Industrial Engineering at Mercer University in Macon, Georgia. He has twenty-eight years of teaching, research, and consulting experiences. His previous administrative experiences include: President of International Society for Productivity Enhancement (ISPE), Acting Director of Industrial Engineering as well as Director of Advanced

Manufacturing Center at Marquette University, and Research Director of CAM and Robotics Center at San Diego State University. His primary research and teaching interests are in the areas of manufacturing systems, quality engineering, and product and process development. He has organized and chaired three international conferences, co-chaired two, and organized and chaired one regional seminar. He has received two teaching awards, several research and service awards in the United States and in Brazil. His professional affiliations include ASEE, IIE, ASQ, SME, ASME, and ISPE.