MINIATURE HIGH VOLTAGE IMPULSE GENERATOR

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Abstract: This paper describes the design and construction of a high voltage impulse generator. The design consists of a PSpice circuit model, functional breadboard prototype, and circuit board layout following certain specifications. The main design objectives, which were met, include functionality and size.

Key words: High Voltage, Stun Gun, Miniature

I. INTRODUCTION

A. Background

This design project was completed during the summer 2002 academic term for EE-490, Senior Electrical Engineering Design Project, at Kettering University. The project is intended to challenge students using their knowledge gained from engineering courses and their experiences from co-op employment. The following formal program educational objectives were defined by the electrical engineering faculty:

1. Ability to design, analyze, construct, and test basic electrical and electronic systems
2. Necessary interpersonal and communications skills to be productive members in a team work environment
3. Experience and self-confidence to be technical and/or managerial leaders
4. Awareness of the ethical and professional responsibilities

B. Goals

The goal of this project is to design and build a miniature handheld high voltage impulse generator, powered by a single 3 V Duracell CR2032 battery. The main design objectives for functionality stipulate that the device must be able to generate a minimum of 1 kV peak across a given load without using a mechanical generator, include an ON/OFF switch for activation, and a LED to indicate when the device is ready for discharge. Design objectives for the chassis include that all components required for the device must be contained within 100 cm^3 or less and that quick access for battery changing be provided. The circuit board objectives require that no surface mount parts be used, and a logo be present on the board.

II. DISCUSSION

A. Milestones

1. Battery Characteristics and PSpice Modeling

This first portion of the project involved testing the Duracell CR2032 battery for characteristics such as its open circuit voltage, Thevenin resistance, maximum current, and total energy. The proposed design was then modeled on the circuit simulation program, PSpice. The battery characteristics were:

- Open Circuit Voltage = 3.3 V
- Thevenin Resistance = 12 Ω
- Maximum Current = 0.28 A
- Energy = 270J

Figure 1 is the PSpice schematic used to simulate the desired voltage response. A sinusoidal input was used as an oscillator in the transient analysis. The 0.001 Ω resistor seen in the figure is used as a by PSpice as a current calculator. Without the resistor, the simulation will not work correctly.

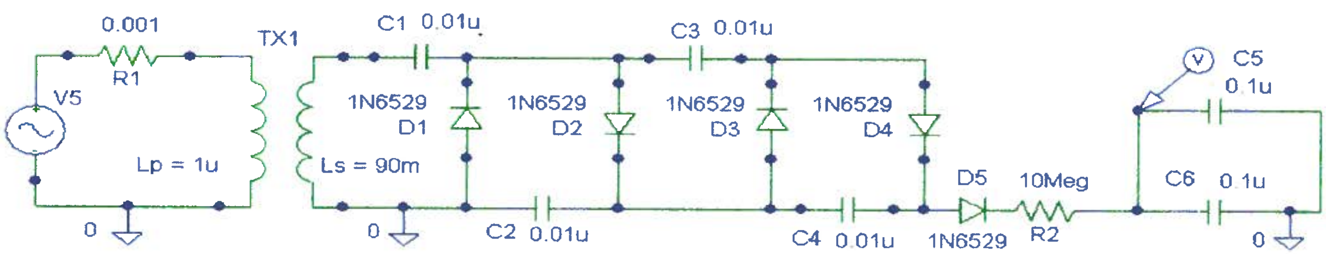

Figure 1. PSpice Schematic

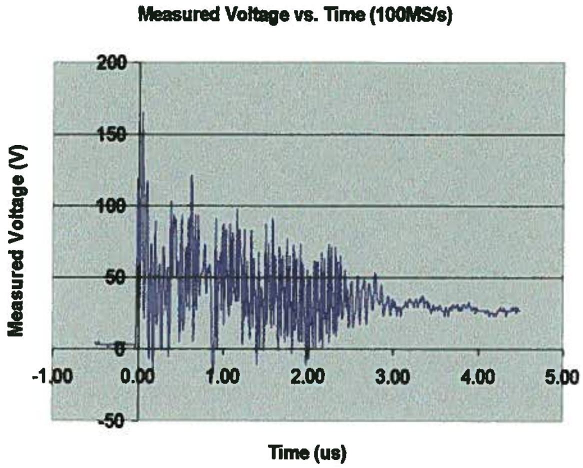

Figure 7. Voltage Dishcarge Through the 20 Ω Resistor (100 MS/s)

III. CONCLUSIONS

The preceding discussion touched on the major topics related to the students' senior electrical engineering design project. The information presented in this paper is the authors' design approach to meeting the desired specifications. The end product was successful in meeting all of the requirements mentioned in the Goals section of this paper.

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HIGH VOLTAGE IMPULSE GENERATOR

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Abstract: This paper describes the design and construction of a high voltage impulse generator circuit using a 3 V CR2032 Lithium button cell battery. The design consists of an oscillator circuit, step-up transformer, and an output stage. The main design objectives of the project were functionality, size, safety, and cost.

Key words: High Voltage, Impulse Generator, Taser

I. INTRODUCTION

A. Background

The high voltage impulse generator circuit design project was completed during the Summer 2002 academic term for EE-490, Electrical Engineering Senior Design Project, at Kettering University. The project was very unique because it not only required the use of hands-on engineering, but also utilized real-world design constraints. This project is intended to challenge students to meet the following formal program educational objectives defined by the electrical engineering faculty:

1. Analyze and design basic electrical and electronic systems.
2. Develop the necessary interpersonal and communication skills to function in a team environment.
3. Gain more experience and self-confidence to become technical and/or managerial leaders.
4. Develop the necessary organizational skills to become more aware of ethical and professional responsibilities.

B. Goals

The goal of this project is to design and build a high voltage impulse generator circuit. A group of three students were given specifications that were agreed on by the class and the professor. The main design objectives were functionality, size, safety, and cost. The team did extensive research on existing high voltage systems, which included stun guns, tasers, camera flash circuitry, and bug zappers. After analyzing the circuitry required, the project design was divided into three major categories for each group member to further investigate. The first stage of the project was to analyze and design a dc-ac converter using discrete components. The next stage involved the use of a step-up transformer to boost the signal from the oscillatory circuit. The last stage for the project was to analyze and design the output stage of the circuit, which would include studying the effects of implementing voltage multiplier stages and a spark gap.

II. DISCUSSION

During the analysis and design of the project, the following design specifications were required to be met in the final product:

1. Output voltage must reach 1 kV across a 500 Ω resistor, Ohmite Model 47824, in series with a 20 Ω resistor, Biddle Model 411K85CS.
2. Charge up time must not exceed 1 minute.
3. Battery holder must be easily accessible for quick replacement.
4. Host volume must not exceed 100 cubic centimeters.
5. Status light must indicate when the circuit is ready to trigger.

A. Safety Precautions

Throughout the design and construction of this project, the teams' number one priority was to work safely when dealing with high voltages. During the design, construction, and testing of this project, certain safety precautions were taken into consideration. The precautions included avoiding contact of the charged components and the proper discharging of all the capacitors in the circuit.

B. Oscillator Circuit

After researching and analyzing the available components, it was decided that an RL BJT oscillator circuit (see Figure 1) would be the most efficient configuration. The BJT that was used was an NTE 128P NPN general-purpose amplifier. This configuration has a small space requirement and is easily configurable to any desired frequency. Another reason this configuration was chosen was because the inductor used in the oscillator circuit was contained in the transformer. Using these components minimized the number of discrete components required for the oscillator stage. Using a network analyzer, the optimal frequency range for the transformer was determined to be between 22 kHz and 32 kHz. Designing the oscillator circuit to operate at 27 kHz would give the most efficient response. The frequency of oscillation for the RL circuit [1] is given by $(R_1/L_3) = f$, where R_1 is the resistor value, and L_3 is the inductor value was included in the transformer configuration and had a value of 2.53 mH. It was calculated that a 68.31 Ω resistor would be needed; however, a 68 Ω resistor was used because the value was readily available.

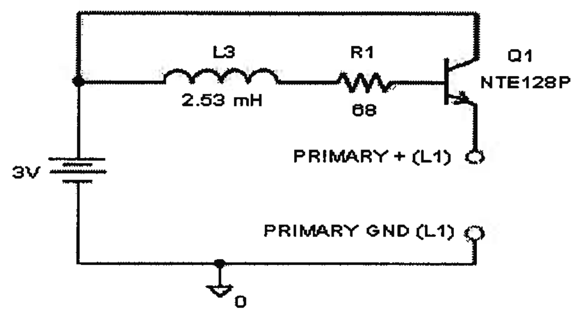

Figure 1. RL BJT Oscillator Circuit

C. Step-up Transformer

The transformer used in the circuit design was taken from a bug zapper circuit. This transformer was chosen because it would perform well for this application. Using an inductance meter, the values for the primary and secondary windings were measured to be 11 μH and 430 mH, respectively. The inductance ratio (L_2/L_1) of the transformer was calculated to be 39,090. Using the equation for calculating the coefficient of coupling [2], *k*, is roughly listed below

$$k = \left[\frac{\left(\frac{V}{\Delta I} \right)}{\sqrt{L_1 * L_2}} \right] \quad (1)$$

where *Vs* is equal to the primary voltage of 3 V, ΔI is equal to the current of 150 mA over .1 s, and L_1 and L_2 are the primary and secondary inductances, respectively. The coefficient of coupling value was calculated to be 0.919. Using the measured primary and secondary voltages, the turns ration was determined to be 1:400. This value was determined by using the turns' ratio [3] equation, $(V_s/V_p) = (N_s/N_p)$, where V_S is equal to the primary voltage, V_P is equal to the secondary voltage of 1200 V, N_P is equal to the number of turns on the primary side, and N_S is equal to the number of turns on the secondary side. This transformer had a six-pin configuration that included the primary winding (L_1), secondary winding (L_2), and an extra inductor (L_3) for the oscillator circuit.

D. Output Stage

1. Voltage Multiplier Stages

The voltage multiplier stages were used to achieve a final output of over 1 kV. The UL listed safety requirements [4] (*to prevent ventricular fibrillation*) were taken into account in determining the correct capacitance values. These values would help to achieve maximum efficiency while still being considered safe. The capacitor value for the desired circuit was limited to the range of 3.28 nF to 2.67 μF in order to achieve an output between 368 V and 39,999 V. The capacitor value used to achieve the best efficiency from the multiplier stage was 33 nF due to its size and the metal/polyester film composition, which has a quick discharge time. Using the UL maximum voltage equation [4] $V = (0.046/C^{0.7})$, where C is the capacitance and V is the output voltage, the circuit was calculated to safely reach a peak voltage of 7,940 V. Three half-wave rectified voltage multipliers (see Figure 2) were used because this configuration is very versatile and has uniform stress on all of the diodes and capacitors. The diodes in the circuit have to withstand the high voltages that the circuit will generate, so 1N4007 high voltage diodes were used.

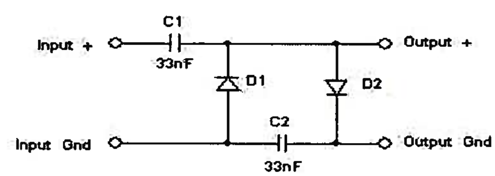

Figure 2. Circuit of One Half-Wave Rectified Voltage Multiplier

2. Spark Gap

During the load testing of the circuit, it was observed that there was a problem with the circuit design (refer to Section IV C). After extensive research, it was concluded that in order to measure a transient signal across the load, the circuit output would have to be a time-varying signal. To accomplish this, a momentary switch or a spark gap must be implemented. The final decision was to add a spark gap into the output stage of the circuit because it would allow many pulses to occur with no human interaction, and it has a small footprint. The spark gap was created by bending two metal leads toward each other. Seeing that a spark gap is variable in nature, the gap separation to achieve the most efficient response had to be calculated. The spark gap separation distance [5] is roughly given by $D = (V/E)$, where E is equal to 3000 V/mm, V is the DC output voltage from the circuit, and D is the calculated separation distance in mm. It was calculated that the distance of the gap should be 0.40 mm.

III. PSPICE SIMULATION

After the initial design, the circuit (see Figure 3) was modeled in PSpice to verify that the high voltage impulse generator would meet the 1 kV requirements. In the simulation, the circuit was modeled according to the calculations that were done during the design of the three stages in the circuit. The oscillator stage was modeled using a voltage source, while the transformer and the multipliers were modeled exactly the way they were in the circuit design. The simulation showed that the output voltage met the 1 kV requirement (see Figure 4).

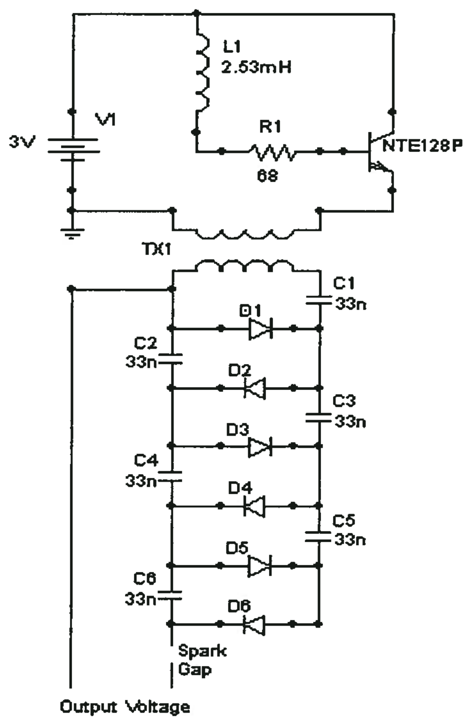

Figure 3. Circuit Schematic

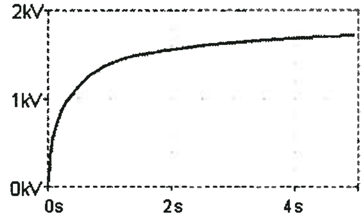

Figure 4. PSpice Simulation Output

IV. TESTING

A. Battery Load Test

Before the team began any circuit design, several tests had to be run on the battery to help determine its characteristics. The battery load test setup used a 1 kΩ resistor in series with the battery. Using the values from the test, the battery load curves, one example being the Voltage vs. Time curve (see Figure 5), were determined. From these curves, the battery's operating parameters were taken into consideration when designing the final circuit.

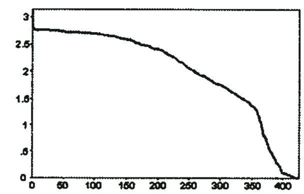

Figure 5. Battery Load - Voltage vs. Time Curve

B. No-Load Testing

Once the circuit was built, the output was tested to verify the circuit operated as designed. The output of the circuit was tested using an oscilloscope with a Tektronix P6138A 10X probe, to allow the signal to be viewed on the oscilloscope. We observed a 1.2 kV output signal that resembled a step signal (see Figure 6).

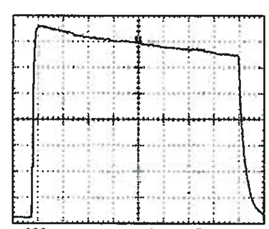

Figure 6. Oscilloscope Waveform of DC Output

C. Load Testing

The load testing for the circuit was done using a 500 Ω resistor in series with a 20 Ω resistor. The output from the circuit was loaded by the series combination of these resistors. The input waveform for the oscilloscope was measured across the 20 Ω resistor. This allowed the output waveform to be viewed on the oscilloscope without the use of special high voltage probe by creating a voltage divider with a ratio equal to 1:26. This voltage divider ratio was accomplished by taken the series combination of the resistors and dividing by the 20 Ω resistor. The circuit was originally designed to accomplish a 1 kV DC output across no load. However, when the circuit was tested using the load, it was discovered that the DC output was insufficient because the output was unfavorably affected by the load. The output signal from the circuit had to be changed because the voltage was not visible across the load. After implementing the spark gap, the transient response across the load could be measured without any problems. The final output waveform that was observed showed that the circuit met the specifications of reaching a 1 kV output Signal (see Figure 7). It is important to realize, however, that a portion of this load voltage is due to the finite, parasitic inductance of the load. Using Excel, the energy of the output was calculated to be 16.3 mJ. This low energy value resulted from the fact that the circuit was designed to deliver several high voltage impulses instead of one impulse.

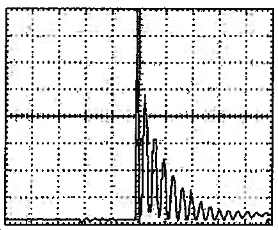
Figure 7. Output across Load

V. HOST

Another goal of the project was to embed the circuit into a host so the circuitry was hidden. To fit within the 100 cm^3 maximum space requirements, and because of the constraint of the transformer size, it was decided that an MP3 player could be used to house the circuit (see Figure 8). This would allow the circuit to be hidden so the user would be safe from the high voltage impulses, and to help disguise the functionality of the circuit. After acquiring an MP3 Player (RCA K@ZOO Model RD1000), the PCB was designed to fit into the host. The PCB design took into account the hosts existing internal support structures, so no extra mounting hardware was necessary.

Figure 8. MP3 Player Host

VI. CONCLUSION

The preceding discussion touched on the major topics related to the design and analysis of a high voltage impulse generator. The circuit discussed was only one of the many designs that could have been used for this project. Selecting the best circuit involved a thorough understanding of the design specifications that were assigned for this project.

The information presented in this paper is, by necessity, very generalized. The reader is strongly encouraged to seek additional information related to the design of high voltage impulse generators.

VII. REFERENCES

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HIGH VOLTAGE IMPULSE GENERATOR

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Abstract: This paper outlines the design, prototyping, and testing of a high voltage impulse generator for Kettering University's Electrical Engineering Senior Design Project. The project revolves around the team concept in the production of a hand-held impulse generator. The design was to be easy to use, small and effective. This team was successful in meeting the design requirements and was awarded a bonus for the design's ease of use.

Key words: High Voltage, Impulse, Amplification, Transformer

I. INTRODUCTION

A. Background

This design project was completed in the summer 2002 academic term for EE-490, Senior Design Project, at Kettering University. The project is intended to challenge students to meet the following formal program objectives defined by the electrical engineering faculty.

1. Ability to analyze and design basic electrical, electronic, and digital systems.

2. Demonstration of interpersonal and communicational skills necessary to be productive members in a team environment.

3. Demonstration of experience gained and self-confidence in performing as a technical and/or managerial leader.

4. Awareness of the ethical and professional responsibilities of an engineer.

B. Goals

The goal of this project was to design and build a high voltage impulse generator with a minimum output of 1 kV using a single 3 V lithium coin battery (the Duracell® CR2032). The main design objectives were functionality, size, cost, reliability, safety, and aesthetics. The team did extensive research on high voltage impulse generators, transformers, oscillators, and capacitors to familiarize themselves with the components and workings of these devices.

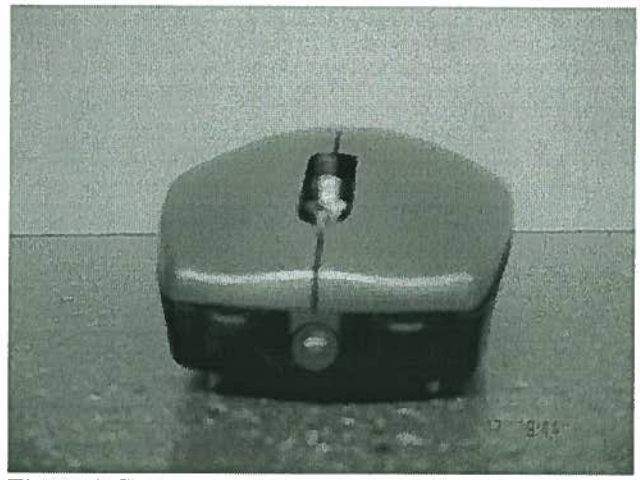

Figure 1: The Mighty Mouse - Finished Product

The team then performed simulations on OrCAD's PSpice v9.1® for a series of designs to determine which design was to be prototyped. The chosen design was then prototyped and tested by the team. When satisfied with the results, the team determined the desired size and layout for the printed circuit board, and chose a chassis to encase the circuit. The final product was then built, tested, and presented to the competing teams from the rest of the class. Care was taken to not exceed an output voltage that would lead to ventricular fibrillation. For this application the voltage (V_{vf}) is represented by the following equation [2]:

$$V_{vf} = \frac{.046}{C^{.7}} \text{ V}$$

II. DISCUSSION

A. Product Specifications

The specifications for this design project required that the team design and build a high voltage impulse generator. This device was to be powered by a single 3 V lithium battery, and it was to create a minimum output of 1 kV. Size was certainly an issue, so a size restriction of 100 cm^3 was put in place. This restriction however was later adjusted as it was found difficult to house the device in this little space.

Ease of use, including firing and reloading, was an important concern as it was initially expected that a single shot might drain the battery. The device was to contain an indicator informing the user that it was ready to fire and fire at the "flip of a switch" within easy access of the user.

B. Battery Characteristics

As mentioned, the power source was a single Duracell CR2032, 3 V, 220 mA·hr coin style battery.

The open circuit voltage was obtained by placing a voltmeter across the battery and was found to be 3.2 V. To drain the battery, a voltmeter was placed in parallel with the battery which was loaded with a 10 Ω, 1 W resistor and an ammeter. The voltage and amperage were recorded every minute for the first hour and periodically for the next 16 hours.

To calculate R_{TH}, a 10 Ω, 1 W resistor was placed across the battery with a voltmeter across the resistor to measure V_R. The current through the resistor is found by dividing the V_R, by the value of the resistor. The current, I_R, was calculated as 190 mA. R_{TH} was found by subtracting V_R from V_{OC} and then dividing by I_R. R_{TH} was equal to 6.3 Ω.

The energy from the battery was estimated from the voltage vs. current plot using the trapezoid method to find the area under the curve. The total energy the battery could provide was estimated as 550 mJ.

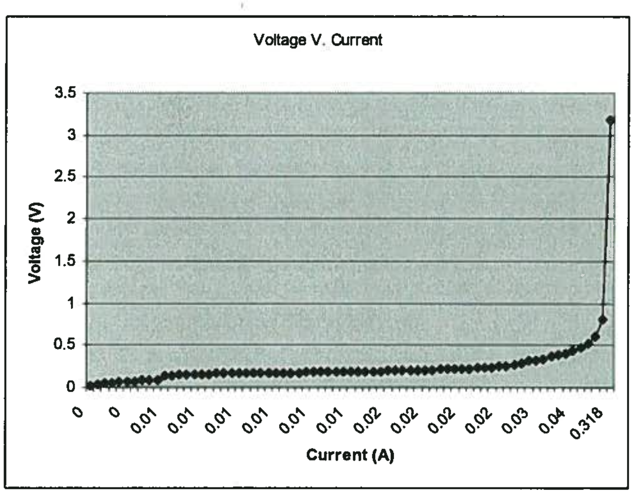

Figure 2: A plot of the voltage vs. current.

C. Schematic

The electrical schematic is shown in Figure 4. The oscillating circuit is located to the left, and the voltage rectifier/multiplier is located to the right.

D. Oscillator/Current Amplifier

The first stage of the voltage generator is a regenerative amplifier/oscillator coupled to an energy multiplier section. The two transistors NTE-184 (Q1) and NTE-185 (Q2) form a regenerative amplifier and act as a power oscillator. When Q1 turns on, Q2 turns on and the power supply is shorted across the primary side of the transformer (T1). The current pulses through the primary of T1 induce a high voltage in the secondary side of T1. As C1 charges, Q1 turns on again and the cycle repeats itself. The cycle time is determined by the resistor and capacitor in the circuit.

E. Transformer

The key to obtaining 1 kV across the output is the step-up transformer used in the circuit. This transformer is an Ultra-Mini Power Audio Transformer with a 1:150 turn ratio. The core type/size is EI-14. The frequency response is ±3 dB, 300 Hz - 3.4 KHz at 1 KHz 0 dB. The primary impedance is 8 Ω and the secondary impedance is 1.2 KΩ.

F. Output Stage

A rapid series of pulses is generated by the oscillator and stepped up by the transformer. The voltage output of the transformer is rectified and increased by the voltage multiplier section consisting of C2 to C9, and D1 to D8. This voltage multiplier stage is based on the basic voltage doubler and voltage quadrupler circuits shown in Figure 3.

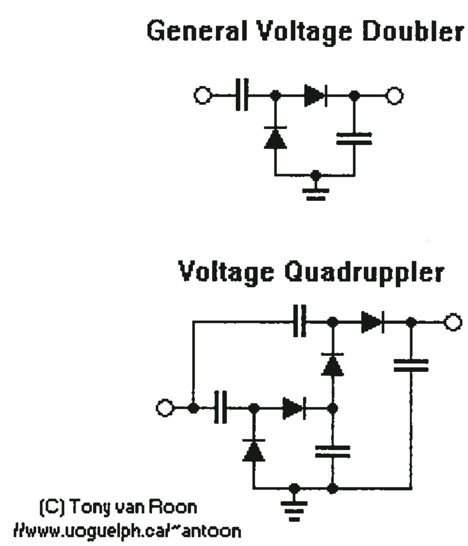

Figure 3: Basic voltage divider and quadruppler circuits used in the second stage of the Mighty Mouse. [1]

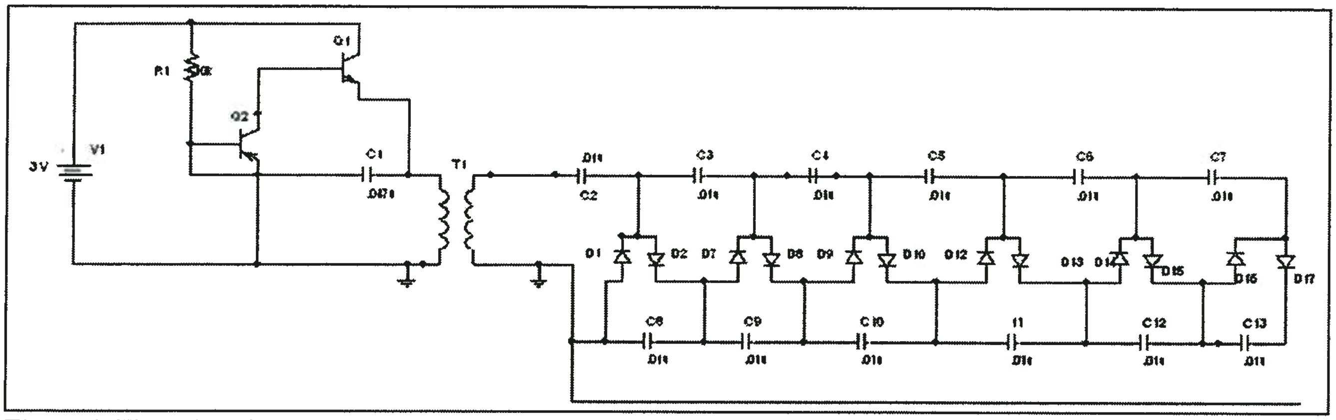

Figure 4: Final electrical schematic

In order to provide the oscilloscope with a signal within its range, a voltage divider was required. The divider consisted of a 500 Ω, 500 W resistor in series with a 20 Ω, 500 W resistor to create a ratio of 24:1. The oscilloscope could then read the voltage across the 20 Ω resistor. It was also necessary to use the triggering feature of the scope to capture the waveform, as the duration was so short. Figure 5 shows the output signal as captured by the oscilloscope.

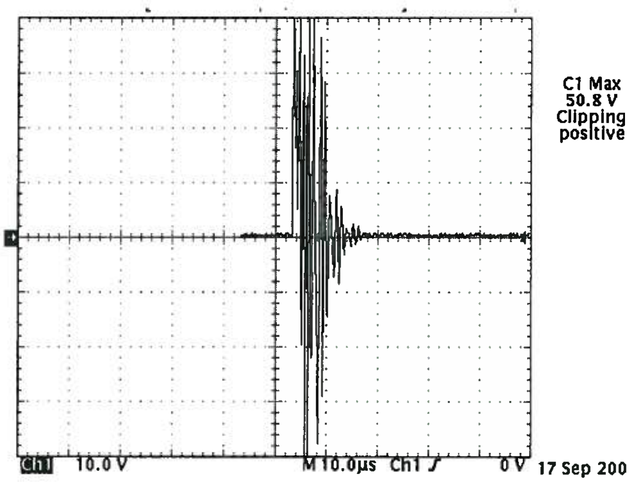

Figure 5: The output waveform across the 20 Ω resistor as seen on the oscilloscope.

The load had inductive qualities. This may have caused the output voltage to appear higher than it really was. It also led to the oscillations seen in the waveform. Although tested with a weakened battery, an output voltage of 1.2 kV (24.25 x 50.8 V = 1.23 kV) was measured across the 20 Ω resistor of the divider.

G. PCB Layout

The layout of the printed circuit board was a very important portion of this design process as space was of utmost concern. Many steps were taken to minimize the required space on this layout.

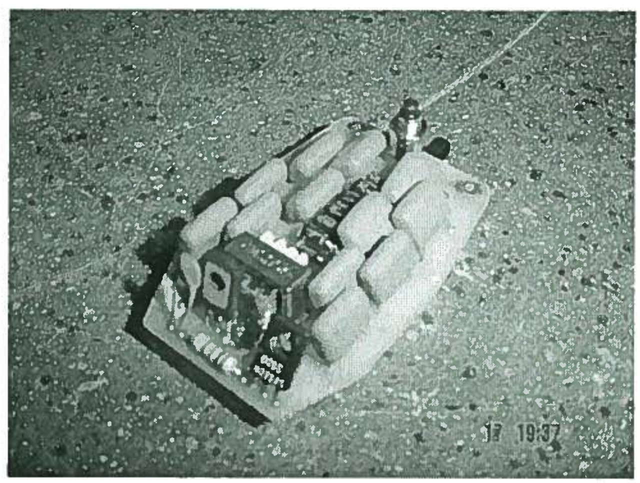

Figure 6: The assembled printed circuit board.

Observe that the diodes are packed very densely in the center of the board while the storage bank capacitors outline that arrangement. This allowed the capacitors to be staggered and minimize the lost space between them. Notice also that this design takes advantage of the capacitors sitting higher than the diodes. By staggering the diode lead length, the pads were able to be located even closer together.

The oscillating circuit is positioned at the rear of the board while the probes occupy the front real estate next to the firing switch. All the devices were mounted such that they could be tilted inward to account for the curvature of the selected chassis. This design worked very well and fits very snugly into the chassis.

H. Chassis

The chassis chosen for the Mighty Mouse is the body of a mouse found on a standard notebook style computer. The mouse used in this project is the Kensington Pocket Mouse® measuring 8.89 cm x 3.81 cm x 5.7 cm and occupying a volume of 193 cm^3. The body was modified slightly to house the printed circuit board and provide easy access to the battery holder making the device's operation simple.

Figure 7: The underside of Mighty Mouse provides access to the battery holder for simplistic operation.

III. CONCLUSIONS

It is the opinion of this team that this design project was a success. While the team found it challenging, it was completed successfully, and the final product meets the required specifications. While this is acceptable, the team is slightly disappointed that one miscalculation was overlooked until the final days of development on this device. The final device is capable of firing many times in the 1.3 kV range, which may be a desirable characteristic to some. However, simply increasing the capacitance of the storage bank would allow a more powerful shot. While the discharges may be fewer from a single battery, this situation would have been more desirable to this project especially since great care was taken to make the device easy to reload.

IV. REFERENCES

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HIGH VOLTAGE IMPULSE GENERATOR

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Abstract: This paper describes the design and construction of a high voltage impulse generator. The design consists of battery specifications, output voltage, size limitations, safety precautions, and electrical connections to integrate the system and implement a safe and reliable High Voltage Impulse Generator. The main design objectives were functionality, safety, reliability, durability, efficiency, ergonomics, aesthetics, and cost.

Key words: High voltage, Impulse Generator

I. INTRODUCTION

A. Background

This design project was completed during the summer 2002 academic term for EE-490, Senior Electrical Engineering Design Project, at Kettering University. This is the first time this project has been completed to fulfill the requirements of this core course. The project is intended to challenge graduating students to meet the following formal program educational objectives defined by the electrical engineering faculty:

1. Ability to analyze and design basic electrical and electronic systems.
2. Necessary interpersonal and communications skills to be productive members in a team work environment.
3. An insight into contemporary issues and their implications to engineering practice.
4. Experience and self-confidence to be technical and/or managerial leaders.

B. Goals

The goal of this project is to design and build a high voltage impulse generator, powered by a 3 volt battery. A group of four electrical engineering students were given a set of specifications and assigned the task to design a high voltage impulse generator. The main design objectives were functionality, safety, reliability, durability, efficiency, ergonomics, aesthetics, and cost. The team performed extensive research on high voltage impulse generator designs, and tackled the designated milestones. The research and design had to encompass all safety precautions when dealing with high voltage. Appropriate voltage levels and safety precautions for different types of high voltage environments were accounted for using electronic industry standards. The first milestone investigated the characteristics of the Duracell CR2032 model 3 volt battery, the load data, and performed computer simulation using PSPICE. For the next milestone, the team designed a battery operated working prototype. The third milestone was to have a professional PCB board fabricated, and to have a chassis designed and built. At project completion, the circuit was built on the professional PCB board, and installed in the chassis creating a complete working device.

II. DISCUSSION

A. Battery Characteristics

1. Voltage, Resistance, and Current Characteristics

This portion of the project involved experimentally determining *Voc, Rth, Imax*, and *total energy.*

- The open circuit battery voltage was measured across the battery using a digital multimeter.
- The battery was then placed in series with the resistor.
- The voltage was measured over the resistor.
- The current was calculated using the voltage drop across the resistive load and dividing by the resistive load.
- The voltage drop across the battery was then determined by subtracting the voltage drop across the resistor from the open circuit voltage.
- The voltage drop across the battery was then divided by the current previously calculated.
- This process was repeated for a variety of resistive load values.
- From this data the maximum and average Thevenin resistance, as well as the maximum current were determined.

Figure 1. DC current vs. resistance

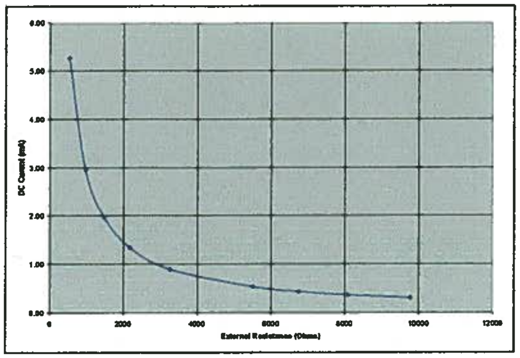


Table I. Experimental battery characteristics

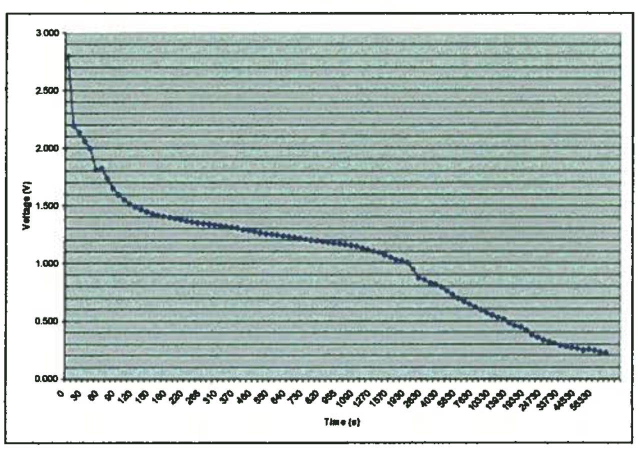
Voc (V)	2.90
Rth avg (Ω)	16.79
Rth max (Ω)	22.58
I max (mA)	5.27

2. Energy Characteristics

The total available energy was needed to continue in the design process.

- The battery was placed in series with a 50 Ω resistor.
- The energy was experimentally achieved by taking voltage readings over designated time intervals.
- Once the battery voltage fell below 0.2 volts the experiment was completed.
- The data points were integrated over time to determine the total available energy.

Figure 2. Battery voltage vs. time



Energy (Joules)	248.34

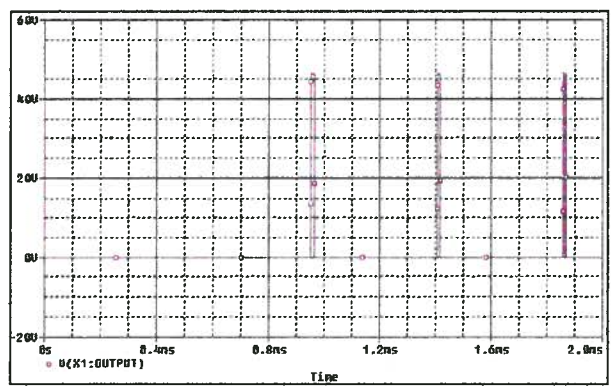
B. Circuit Design and Prototype

1. Design

The preliminary concept for this circuit began with an oscillator leading into a transformer to potential voltage multiplier stages. The team's first step was to research different circuit ideas for low voltage oscillators and high voltage multipliers in the library and on the internet. The research yielded many different design options.

The next step was to simulate the possible circuits in PSPICE. After modeling the designs in PSPICE, different outputs were compared to determine the best circuit design to pursue in the lab. The design that was decided upon incorporated an oscillator with two power transistors connected to the voltage source, an audio step-up transformer, and 6 output multiplier stages consisting of two diodes and two capacitors each. The circuit was tested on a resistor divider consisting of a 500 Ω and a 20 Ω. The output is measured across the 20 Ω resistor. The output energy is 1 mJ, this allows for multiple uses. The output voltage across the load will be multiplied by 26.

Figure 3. PSPICE output voltage across 20 Ω resistor



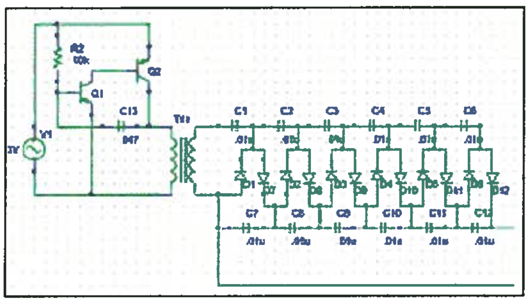
2. Prototype

After ordering and acquiring the needed components, the first prototype circuit was assembled on a breadboard. The physical circuit was then tested. Using the experimental outputs, adjustments were made to the circuit to improve the output, satisfying the desired specifications. Some changes were additional stages to the multiplier and changes in the model of the components, which resulted in the final circuit.

Power transistors, NPN model NTE184 and PNP model NTE185, were used in the final design of the oscillator circuit because of their durability and high power rating.

The final transformer was chosen by testing multiple available transformers and looking at their output characteristics. The transformers tested included: an 8:1000 Ω transformer from Radio Shack, a transformer from the flash circuit of a Kodak Max disposable camera, a transformer from a 9 volt stun gun, and an 8:1200 Ω audio transformer produced by Hammond Manufacturing. The transformer with the optimal response was the 8:1200 Ω transformer, model 141P by Hammond Manufacturing. This transformer has a resonant response from 200 Hz – 500 KHz, with a turns ratio of 1:12.

Figure 4. Circuit schematic

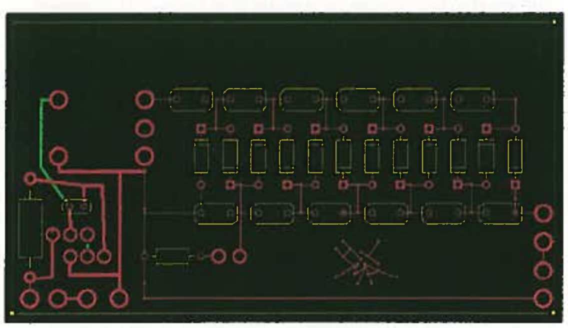


C. Final Product

1. PCB Board

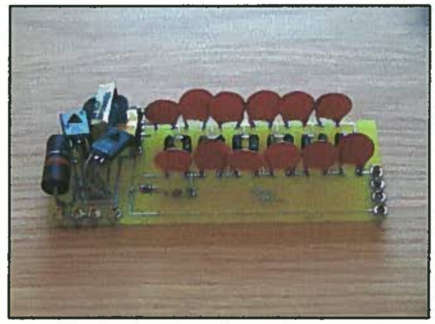
The final product required a PCB board that was professionally fabricated. The board was designed using Express PCB software. The board included a team logo that was drawn with additional circuit traces.

Figure 5. PCB board layout in Express PCB software



Once the board was designed and the traces were placed, sockets were soldered to the board for the transistors, probes, on/off switch, trigger button, battery, and the transformer. With all of the sockets attached, the individual components were soldered to the board or plugged in. It was very important that the soldering be precise on both sides of the PCB board.

Figure 6. Assembled PCB board



2. Chassis

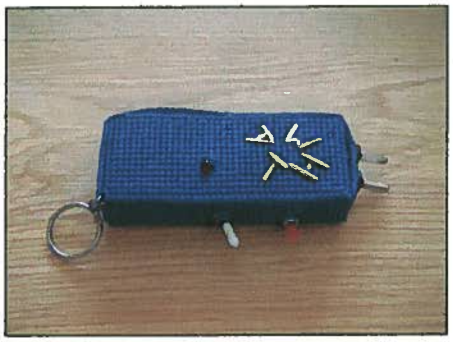
The chassis was designed to be a maximum volume of 100 cm^3 to fulfill design requirements. A rectangular keychain made of plastic canvas was chosen. The team logo was stitched on the top of the keychain opening panel. A static bag was stitched inside the keychain to prevent static damage to the board and components, and also to prevent fire to the chassis from high voltages in the circuit. Holes for the probes, indicators, and switching mechanisms were implemented into the design.

3. Assembly

After the PCB board was assembled, soldered, and tested, it was installed into the chassis. Two banana jack probes were fitted into one end. The LED indicator was fitted into the opening lid. The on-off switch and trigger button on a side panel. All components requiring the use of wires were attached to the board. After the final fitting of all components into the chassis and troubleshooting, the device was tested and met all functional requirements.

Figure 7. PCB board in chassis

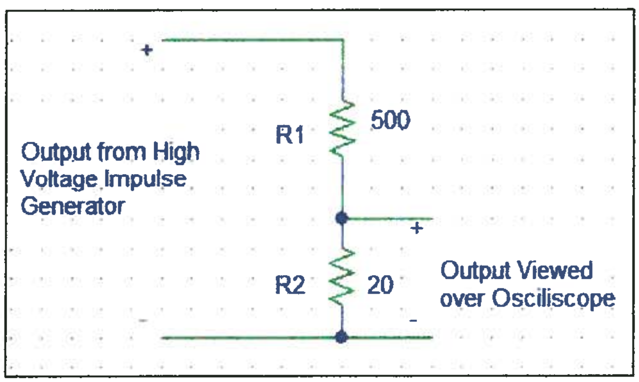
Figure 8. Completed product



4. Validation Testing

The high voltage impulse generator was tested over a resistor divider consisting of two 500 watt power resistors in series, a 500 Ω manufactured by Ohmite and a 20 Ω manufactured by Biddle. This load made it possible to measure the output over the oscilloscope.

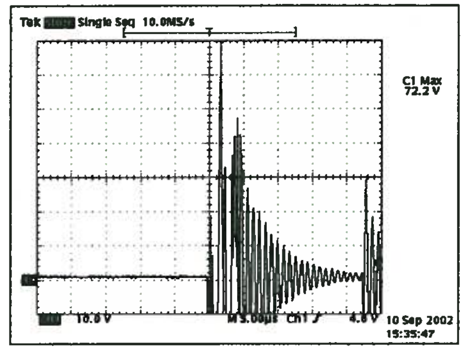
Figure 9. Load schematic



The final output signal was 72 V over the 20 Ω resistor; therefore the total output of the impulse generator is 1.8 kV. Although the inductive capacity of the load created an addition insignificant amount of voltage to the output of the impulse generator, in result we rounded down in our final calculation of the output.

The circuit design satisfied the UL guidelines to prevent ventricular fibrillation. The capacitor on the primary side could withstand a maximum of 6.2 kV; the circuit provided approximately 6 V. The capacitors on the secondary side of the circuit could have a maximum of 18.3 kV; the circuit provided approximately 1.8 kV.

Figure 10. Output over load



III. CONCLUSIONS

The preceding discussion described how the concept design of the impulse generator progressed to the final product. Through careful experimentation of the 3 volt battery and utilizing its characteristics an oscillator design was implemented to best complement a low voltage source. The components were tested and chosen to produce the final schematic. A six stage voltage multiplier coupled with the high frequency oscillator produced well over 1,000 volts across the output probes. The result was a working high voltage impulse generator that incorporated voltage oscillation, voltage step-up, and voltage output multiplication into the final design.

IV. REFERENCES

[1] Reilly, Patrick J., *Electrical Stimulation and Electropathology,* Cambridge University Press [New York City], 1992, p.445.

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