# Nail Coil Gun

## Design Review Fall 2012

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*TA: Ryan May*

*Project 20*

# 1. *Introduction*

## *1.1 Purpose*

Traditional nail guns use compressed air, explosive gases or charge, or an electric motor. The disadvantage of the pneumatic nail gun is the hose and extra equipment, like a pump, that has to be on site at all times. The explosive gas nail guns get rid of the need of the hose, but must be regularly cleaned, and require a battery. The electric nail gun solves the problem of having to clean the gun, but is generally heavy due to the motor.

Our solution to these problems is the coil nail gun. The nail is shot out of the gun by a series of electromagnetic coils which are powered by batteries. It solves many of the problems listed above, filling a void in the nail gun market. Our goal is to build a nail gun that is safe, enjoyable, and easy to use.

## *1.2 Objectives*

The goal of this project is shoot a nail with enough force to make it into a piece of wood. According to our calculations below, with a bank of 10 alkaline C batteries in series, we should be able to fire 412 nails.

## *1.3 Features and Benefits*

### *1.3.1 Benefits*

- Limited moving parts, which increases the life of the gun
- No hose, power cords, or extra equipment besides the batteries making it conveniently handheld
- No cleaning or maintenance required, making this gun easy to use.

### *1.3.2 Features*

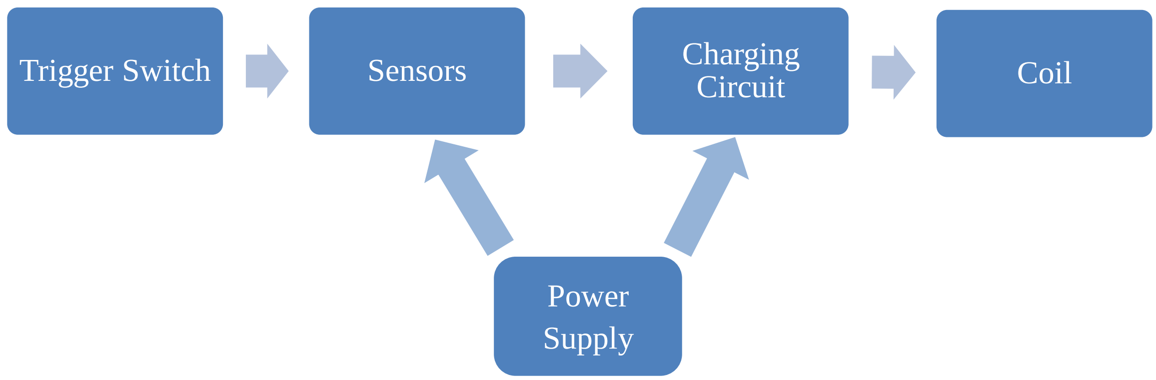
- Infrared LED switches to trigger coils, for simpler cheaper circuits
- Self contained charging circuit

## 2. Design

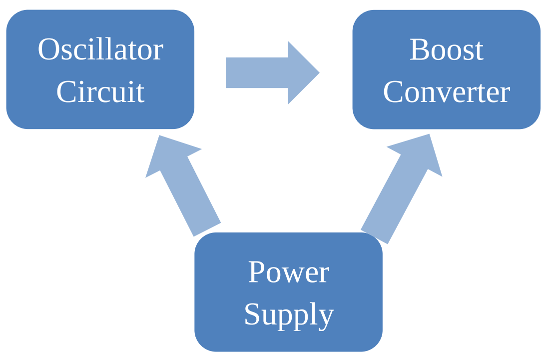
### 2.1 Block Diagram

This is a block diagram for one stage in the coil gun. There will be two stages, which one stage is shown in orange below, and includes the coil, charging circuit, and the power supply.

*High Level Block Diagram*




*Charging Circuit*




### 2.2 Block Descriptions:

*2.2.1 Overall Description*

Our coil gun is meant to shoot a nail through wood, and in order to do so it must be moving fast enough to pierce the wood. The nail needs to be traveling at least 200m/s, which is a conservative estimate according to our research. From this speed we can determine the corresponding gun statistics:

A nail with a mass of 2 grams would need: $KE = .5mv^2 = .5(.002)(200)^2 = 40 joules$

The corresponding capacitance can be found from the equation for the energy in capacitor. Using 350 volts we get the following: $W = .5CV^2 => C = {}^{2W}/_{V^2} = {}^{80}/_{350^2} = 653uF$

The reason we used 350 volts, is because the voltage is squared, requiring less capacitance. We want the capacitor to discharge as quickly as possible, so lowering the capacitance, by increasing the voltage, decreases the time constant $\tau$=RC. We will use a 680uF capacitor rated at 350 volts, due to availability, which is 41.65 joules.

We will design the gun so each stage has a capacitor that matches this specification. This means that 83.3 joules will be needed per shot. Since an alkaline C battery has 34,398 joules, we should be able to fire 412 nails.[1]

The power is the important parameter that now must be considered. For the following calculations we will assume the initial speed of the nail going into stage one from the ignition coil is zero. This is because the initial speed of the nail will be so small it can be neglected. If we assume an effective length of acceleration as 4.4 inches, we can calculate the acceleration of the nail. This distance is chosen as an estimate of the distance that the nail will experience acceleration. If we estimate the length that the nail experiences a force as 2.2 inches for each stage, then we get a distance of 4.4 inches or 11.1cm. Using the using the following kinematic equations we get our values:

$$v_f^2 = v_i^2 + 2ad => (200)^2 = 0 + 2a(.111) => a = 180{,}180 m/s^2$$

Using this acceleration, estimating to 180,000m/s^2 for ease of calculations we find the following:

$$v_f = v_i + at => 200 = 0 + (180{,}000)t => t = .00111s$$

Therefore, our capacitors must discharge in half of the 1.11ms calculated above. This is equal to about 5 time constants of the RLC circuit. Therefore using the equation for the time constant above, it can be seen that the equivalent resistance seen by the capacitor discharging into the coil must equal approximately .342Ω. The power can now be found using the following equations:

$$Power = Fv = \frac{mad}{t} = \frac{(200)(180{,}000)(.111)}{.00111} = 36{,}000\ watts$$

This means that about 18,000 watts will be discharged into each inductor in each stage of the coil gun. The corresponding current can be found as follows:

$$I = C\frac{dv}{dt} = (650 * 10^{-6})\left(\frac{350}{.00111}\right) = 205\ Amps$$

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*2.2.2 Individual Block Descriptions*

*2.2.2.1 Trigger switch*

This is simply a mechanical trigger that launches the nail into the first stage.

*2.2.2.2 Sensors*

These are infrared sensors. Their purpose is to throw the switch between the capacitor bank and the coil, allowing the capacitors to discharge into the coil. They will get power from two alkaline batteries. They are connected to the charging circuit via an inverter. When the nail passes through the sensor, the output will change from high to low and then going through the inverter the signal will go from low to high. This final high signal will be sent to the SCR and trigger it, connecting the capacitor to the inductor. Once the capacitor has discharged, the SCR will turn back off and be ready for the next signal.

We will test the infrared sensors using a motor with a plate on the shaft with slots in it. We can then hook up the output of the sensor to an oscilloscope and view the rise and fall delays, and therefore figure out the total delay. We can also determine the exact voltages involved with the sensor. Next we will connect the sensor to the inverter and observe the output waveform produced by the inverter. Our final test will be to hook up the SCR and find the total delay from the sensor to the SCR triggering. This delay will affect the placement of the infrared sensor.

*2.2.2.3 Power Supply*

The power supply will provide 15V to the charging circuit. The power supply will be 10, 1.5V alkaline batteries for the charging circuit, 2 batteries for the oscillator circuit, and 1 battery for the sensor.

*2.2.2.4 Coil*

The two coils are the main component of the gun, and are what supplies the magnetic field to pull/push the nail through the barrel. They will be made of 22 gauge copper wire. Each inductor will have an inductance .02mH, which is the value needed to allow the capacitor to discharge all of its energy within 1.11ms without ringing. A resistance of less than .342 ohms must also be realized in the inductors, a value which is explained below. The length of the coil should be approximately the length of the nail.[2]

The capacitor discharging into the coil it shown below, with an initial voltage of 350 volts on the capacitor:

[2] From discussion with Karl Reinhard

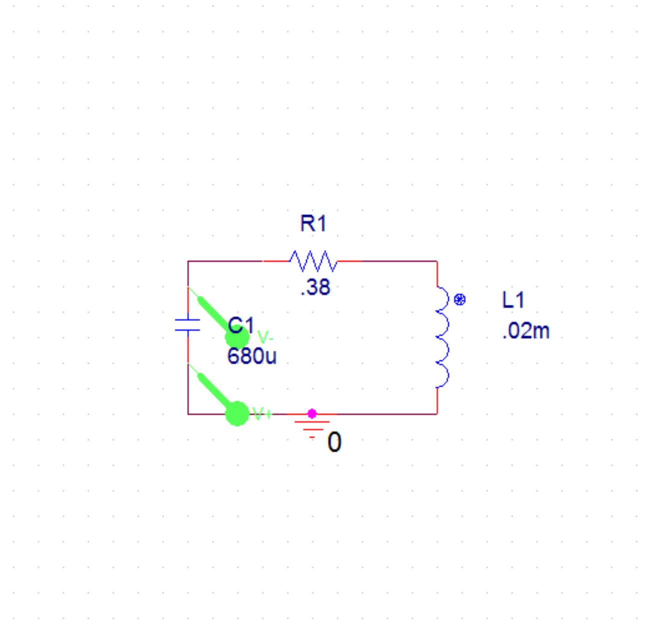


Figure 1: Schematic of coil circuit

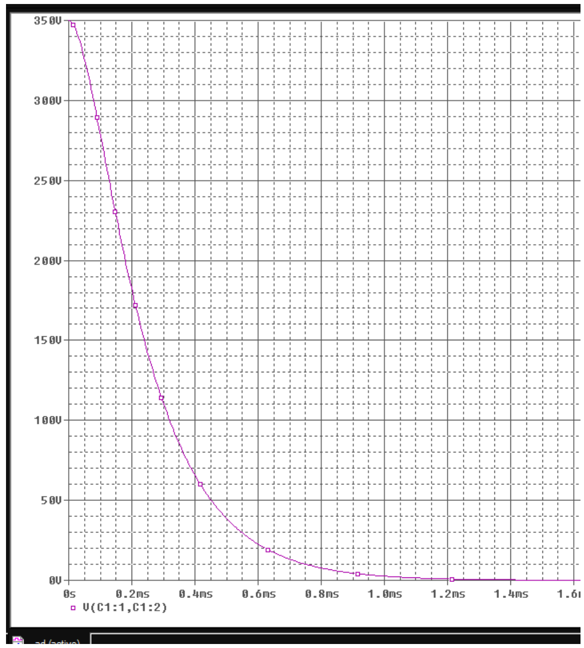


Figure 2: Discharge Curve

*2.2.2.5 Charging Circuit*

The charging circuit is composed of two parts: the oscillating circuit and the step up circuit. It gets power from the 15V battery. The purpose of this circuit is to charge the capacitor that provides the energy for the coil.

The oscillating circuit will provide a pulse with a maximum at to the step up circuit a high frequency oscillator will be implemented with a NE555 chip.

The waveform generator will use the 555 timer circuit to generate the required waveforms, which is a 0 to 3V, 2kHz pulse. The frequency we used is somewhat arbitrary but explained below in the step up circuit. The calculations below are based on the schematic for the astable operation in the NE555 datasheet. For the actual circuit we would use the LM555, because it is available in the part shop.

For a 2000Hz waveform $C = .25uF$

Period = $t_H + t_L$ = 1/2000Hz

$t_H = .693(Ra + Rb)C$

$t_L = .693(Rb)C$

$Ra + 2Rb = 1k\Omega$

The final result is therefore:

Ra = 900Ω

Rb = 50Ω

C = .25uF

The oscillation circuit is shown below with its simulation:

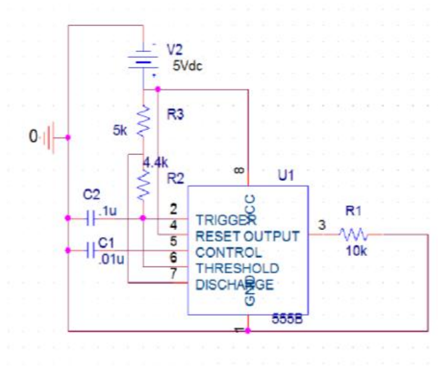


Figure 3: Schematic of Oscillator

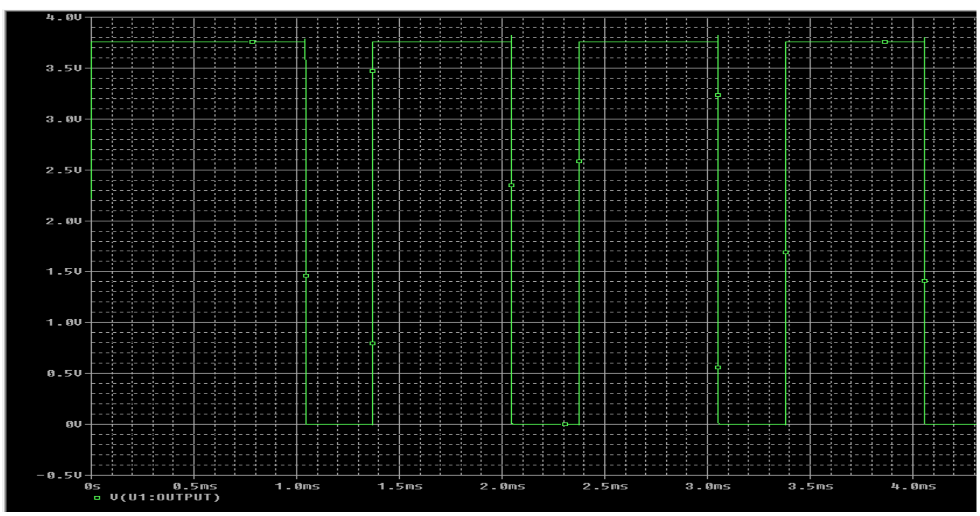


Figure 4: Simulation of Oscillator

The step up circuit is a simple boost converter. High powered diodes will be used. These diodes can withstand the 1000V output. We used a simple boost converter to step up the voltage from 15 volts to 350 volts. The equation for a boost converter is:

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D}$$

The relationship between the inductance needed and the frequency can be obtained from the voltage across an inductor:

$$V_i - V_o = L\frac{di}{dt} = L * di * f$$

If we want to use a smaller inductance in the boost converter, we use a higher frequency.  Once we set the frequency, we varied the inductance to achieve an output voltage of 350 volts from an input voltage of 15 volts.  Therefore the inductance required was .21 mH.  We did this instead of varying the duty cycle, which is harder to control with a the 555 timer.

The boost circuit and oscillator is shown below with its schematic:

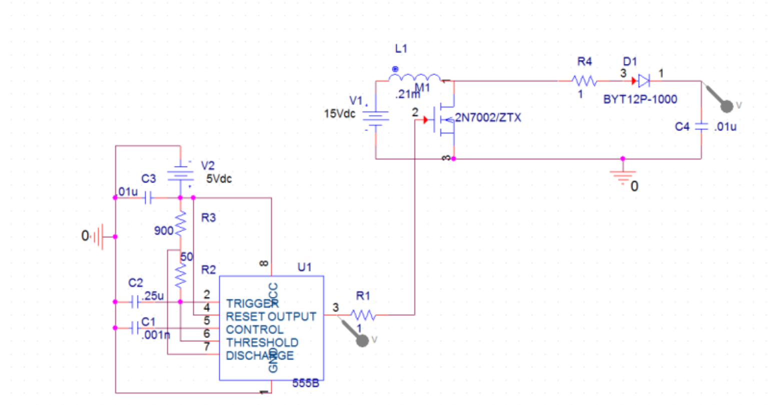


Figure 5: Schematic of Boost and Oscillating Circuit

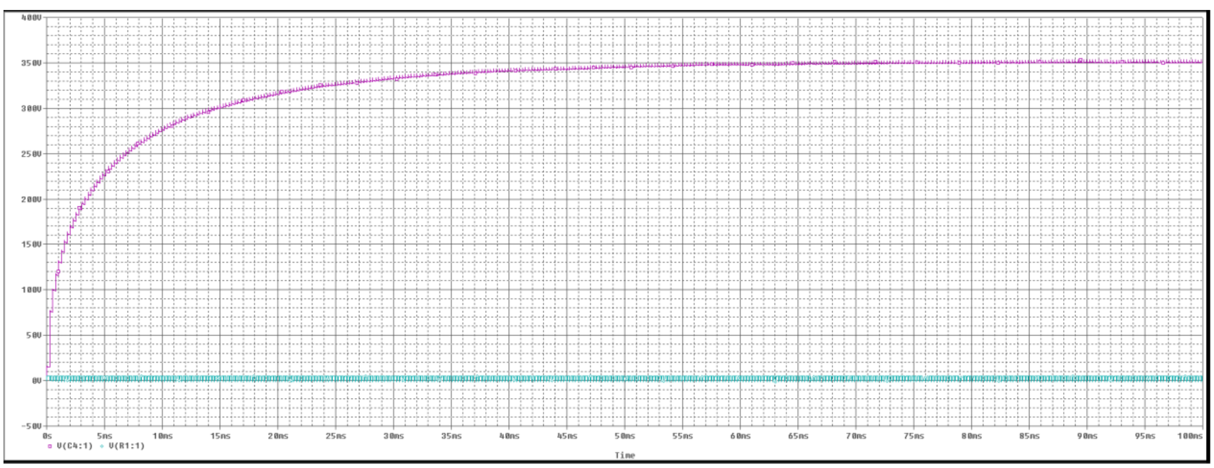

Figure 6: Simulation of Boost and Oscillating Circuit

Below is the total charging circuit.  The switch U2 in the boost converter is turned on in order to charge the circuit.  It is then turned off at 49ms, and at 50 ms U3 is turned on, which simulates the sensor and inverter, and the SCR is turned on.  The simulation shows the output below.  The red curve shows the voltage on the capacitor and the green curve shows the voltage on the inductor.  The other curve shows the inductor voltage on its own:

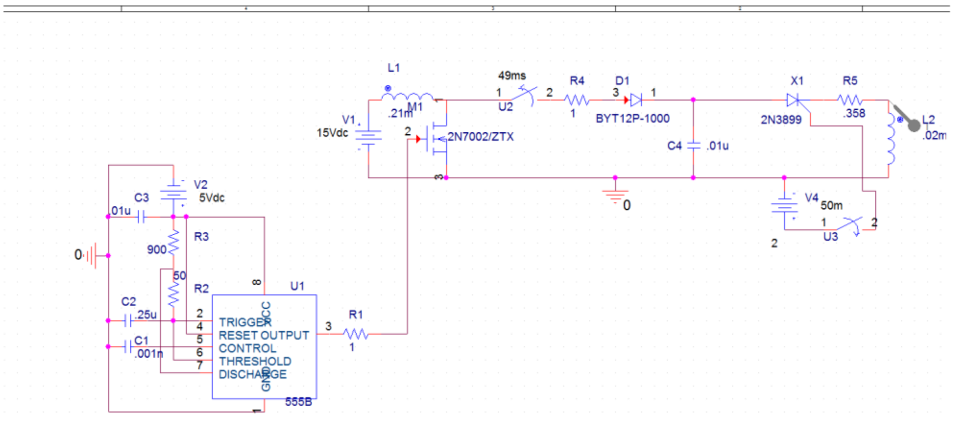



Figure 7: Schematic of Charging Circuit

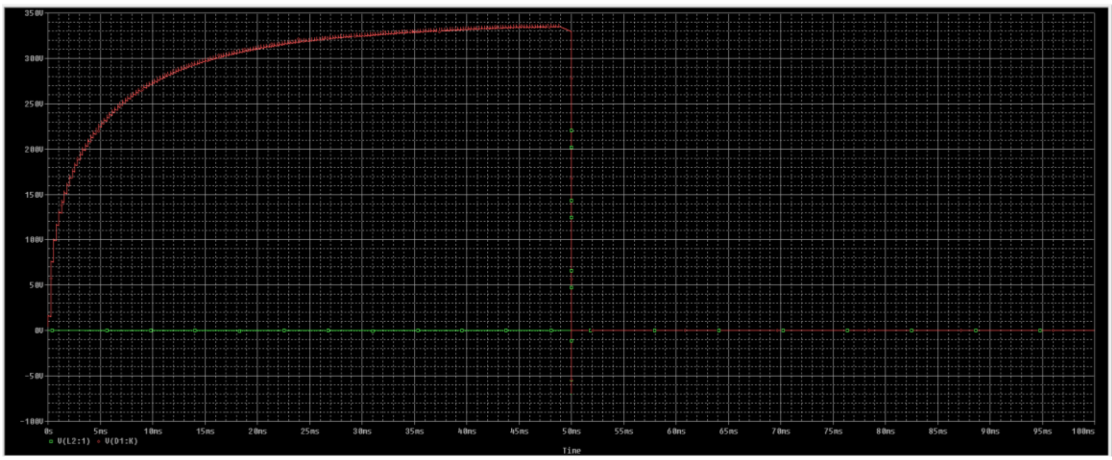

Figure 8: Simulation of the Coil and the Capacitor

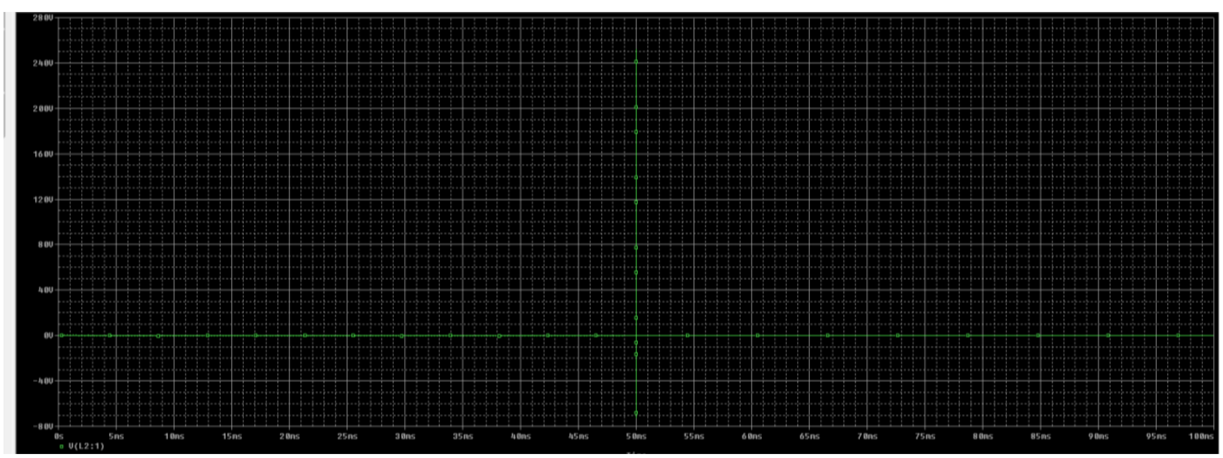

Figure 9: Simulations of Inductor

*2.2.3 Inefficiencies*

We have figured in massive losses by doubling the power we would need to fire a nail. While talking to Mr. Reinhard, he mentioned that we double our power requirements in order to account for losses. So we followed his advice actually more than doubled the requirements. The energy calculated for the capacitor was 40joules. We are using 83.3 joules. This allows our values to vary some without affecting our final output. We have chosen to limit our error to ten percent in order to keep our circuit within the ranges we have tested for, while allowing some variation in the real world components.

# *3. Requirements and Verification*

## *3.1 Testing Procedures*

| Requirements | Verifications |
|---|---|
| 1. Trigger Switch | 1. Must be able to mechanically launch nail into first stage. |
| 2. Sensors<br>a.) Must detect the nail and trigger the SCR in the charging circuit.<br>b.) Must be placed at correct distance for the correct timing of triggering the SCR. | 2. a.) Connect the sensor to power. Put it in parallel with a voltmeter. Move the nail through the sensor and make sure the sensor switches from high to low, and that the inverter switches from low to high. Verify SCR is triggered by the sensor and inverter in less than 1ms, by applying a voltage across the SCR and observing the time delay to turn on.<br>b.) Make sure that when nail passes through sensor, it is propelled through the next stage completely. If it gets stuck or doesn't pass through then realign sensor. |
| 3. Power Supply<br>a.) The power supply must provide 15VDC to the charging circuit. | 3.<br>a.) Use voltmeter to measure the voltage across the batteries in series to verify 15 volt charge for boost converter, and 3 volt charge for the timer circuit.<br>b.) We'll use DC power supply for testing purposes that follows the guidelines listed in part (a). |
| 4. Coil | 4. |

| | |
|---|---|
| | a.) Must have resistance less than .358 ohms, and have an inductance equal to .02mH, within 10% of these values. The meter in the power lab can be used to test these values.<br>b.) Must have length within ten percent of the length of the nail being used. |
| 5. Charging Circuit<br>a.) Boost converter - must charge the output capacitor to 350V.<br>b.) Oscillating Circuit – The oscillating circuit should produce a pulse with a frequency of at least 500Hz with a pulse width of 1.9ms. | 5. Boost Converter<br>a.) Check that the output is providing 350V using the oscilloscope, within 10% of that value using a pulse from the function generator. If the output is within the desired range, connect the oscillator circuit to the boost converter.<br>b.) Check that the capacitor is charging to required voltage in less than 30 seconds . If the capacitor takes longer to charge add 10uF capacitor in series until the desired charge time is reached.<br><br>Oscillating Circuit<br>a.) Check the output of the oscillating circuit using the oscilloscope to verify the frequency requirement to within 10% of the desired value.<br>b.) Check the output of the oscillating circuit using the oscilloscope to verify the pulse width requirement to within 10% of the desired value. |

### *3.2 Tolerance Analysis*

The limiting factor of the design is the charging circuit. It has to charge the capacitor fast enough so that when the nail is detected the capacitor would be completely charged and therefore able to discharge into the coil. If the capacitor can't discharge in 1.11ms then it will not get passed through the coil. Also if the charging circuit can't charge the capacitor up to the 350VDC there will not be enough energy in the capacitor to force the nail out of the gun and into the piece of wood.

## *4. Cost and Schedule*

### *4.1 Labor*

| Team Member | Hourly Wage | Total Hours* | Total Cost | Total × 2.5 |
|---|---|---|---|---|
| Andria Young | $35 | 180 | $6300 | $15750 |
| Seth Hartman | $35 | 180 | $6300 | $15750 |
| | | | **Total** | $31500 |

*Total hours include 12 weeks of work at 15 hours/week.

### *4.2 Parts*

| Parts Acquired | Cost | Total |
|---|---|---|
| Copper Wire | 0 | 0 |
| Infrared Sensors | 0 | 0 |

| Parts Needed | Cost | Multiplier | Total |
|---|---|---|---|
| 680uF @ 350V Capacitor Part#: 565-2994-ND | $7.00 | 2 | $14.00 |
| 1.2 mH Inductor | $0.42 | 2 | $0.84 |
| 10pk C Rayovac Alkaline Batteries | $10.00 | 1 | $10.00 |
| BJT – BC848b | $0.16 | 2 | $0.32 |
| High power diode BYT 12P-1000 | $13.31 | 2 | $26.62 |
| Clear Acrylic Tube | $9.00 | 1 | $9.00 |
| LM555CN Part#: 90137500 | $0.25 | 2 | $0.50 |
| Trigger Switch | 0 | 0 | 0 |
| Thyristor – C228 | $15.73 | 1 | $15.73 |

Total Cost = Parts + Labor = $77.01 + $31,500 = $31,577.01

Schedule:

| Week of | Project |
|---|---|
| 9/16 | Project Proposal (COMPLETED) – Seth and Andria |
| 9/23 | Design and Simulate Charging Circuit (COMPLETED) – Seth<br>Design and Simulate Oscillating Circuit (COMPLETED) – Andria |
| 9/30 | Design Review – Seth and Andria |
| 10/7 | Test the Tolerance of the Capacitor Bank – Andria<br>Test Switch and Inductors Tolerances – Seth |
| 10/14 | Build Charging Circuit – Seth<br>Build Oscillating Circuit – Andria |
| 10/21 | Test Oscillating circuit frequency and pulse width – Andria<br>Test Charging Circuit Output voltage requirement – Seth |
| 10/28 | Test Charging Circuit requirements with Capacitor Bank – Andria<br>Test discharge of Capacitor Bank into coil with sensor – Seth |
| 11/4 | Mock-Up Demo – Seth and Andria |

| | |
|---|---|
| 11/11 | Test stage 1 – Seth<br>Presentation – Andria |
| 11/18 | Test Stage 2 – Seth and Andria |
| 11/25 | Assemble and Test all parts – Seth and Andria |
| 12/2 | Demo – Seth<br>Final Paper – Andria |

## 5. Ethical Issues

Our project may encounter ethical issues since we are dealing with very high voltages. If at some point our project is unsafe for anyone to use we will stop and discuss other options with our TA. We will disclose any new findings in data and calculations they may change the course of our project.

## 6. References


1. Camera Flash Circuit: http://electronics.howstuffworks.com/camera-flash2.htm
2. LM555 Datasheet: http://www.utsource.net/pdf/pdf-LM555CN.html
3. Alkaline Battery Energy Table: http://www.allaboutbatteries.com/Energy-tables.html
4. http://news.consumerreports.org/home/2011/06/power-nailer-safety-injuries-on-the-rise.html
5. Nail Gun Safety: http://home.howstuffworks.com/nail-gun4.htm
6. Power Diode Datasheet: http://www.datasheetcatalog.org/datasheet/SGSThomsonMicroelectronics/mXuwtus.pdf
7. NE555 Datasheet: http://www.ti.com/lit/ds/symlink/ne555.pdf
8. SCR: http://pdf1.alldatasheet.com/datasheet-pdf/view/114263/MOTOROLA/C228B.html
9. Transistor Datasheet: http://www.nxp.com/documents/data_sheet/BC848_SER.pdf


Note: In the case that we are too ambitious with this project we will scale down the voltage therefore decreasing the speed of the nail. Then the nail would no longer be able to go into wood. Also if the batteries become too cumbersome we may use a power supply we plug into the wall that would provide 15V.