Multistage Coilgun Part 2

ECE 445 SPRING 2017

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Introduction

- Uses current through a coil of wire to launch a metal projectile.
- A demonstration tool for Engineering Open House.
- Project was originally devised by a senior design group in 2013.
- Two teams working on the project this semester

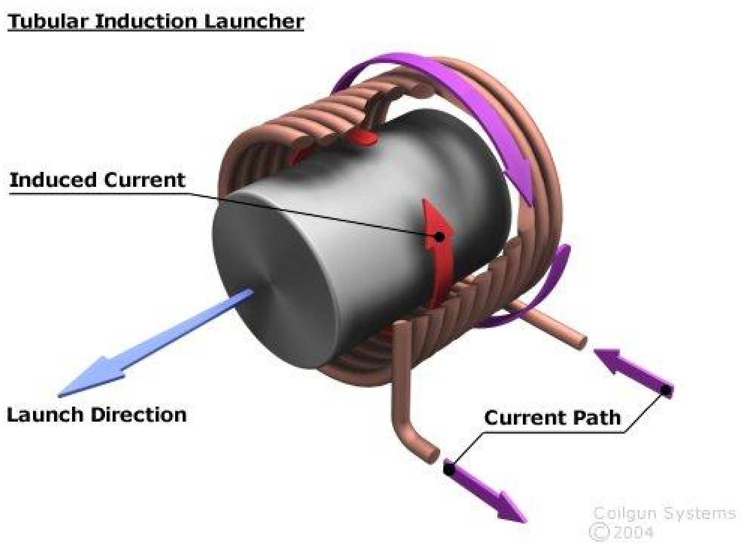
Objectives

Improve and finish the work done by the team from 2013:

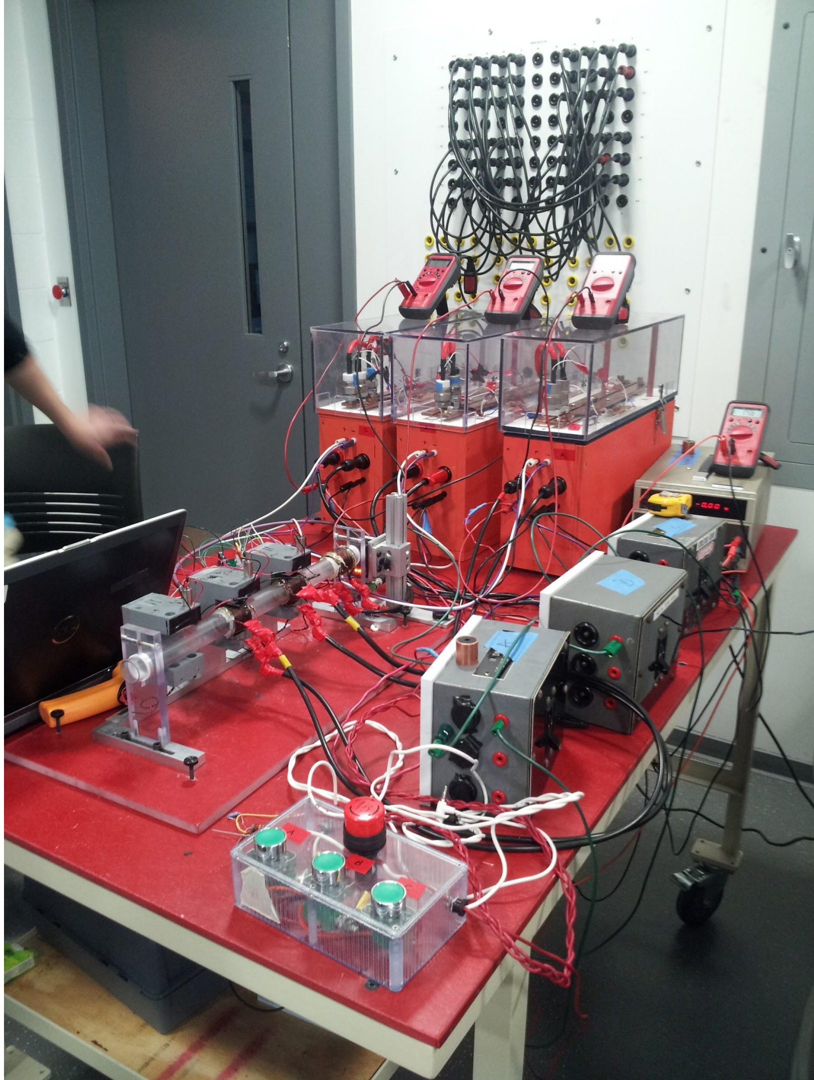
- Improve the longevity of the components
- Redesign the charge controller to protect from user error
- Add various safety features

Operating principle

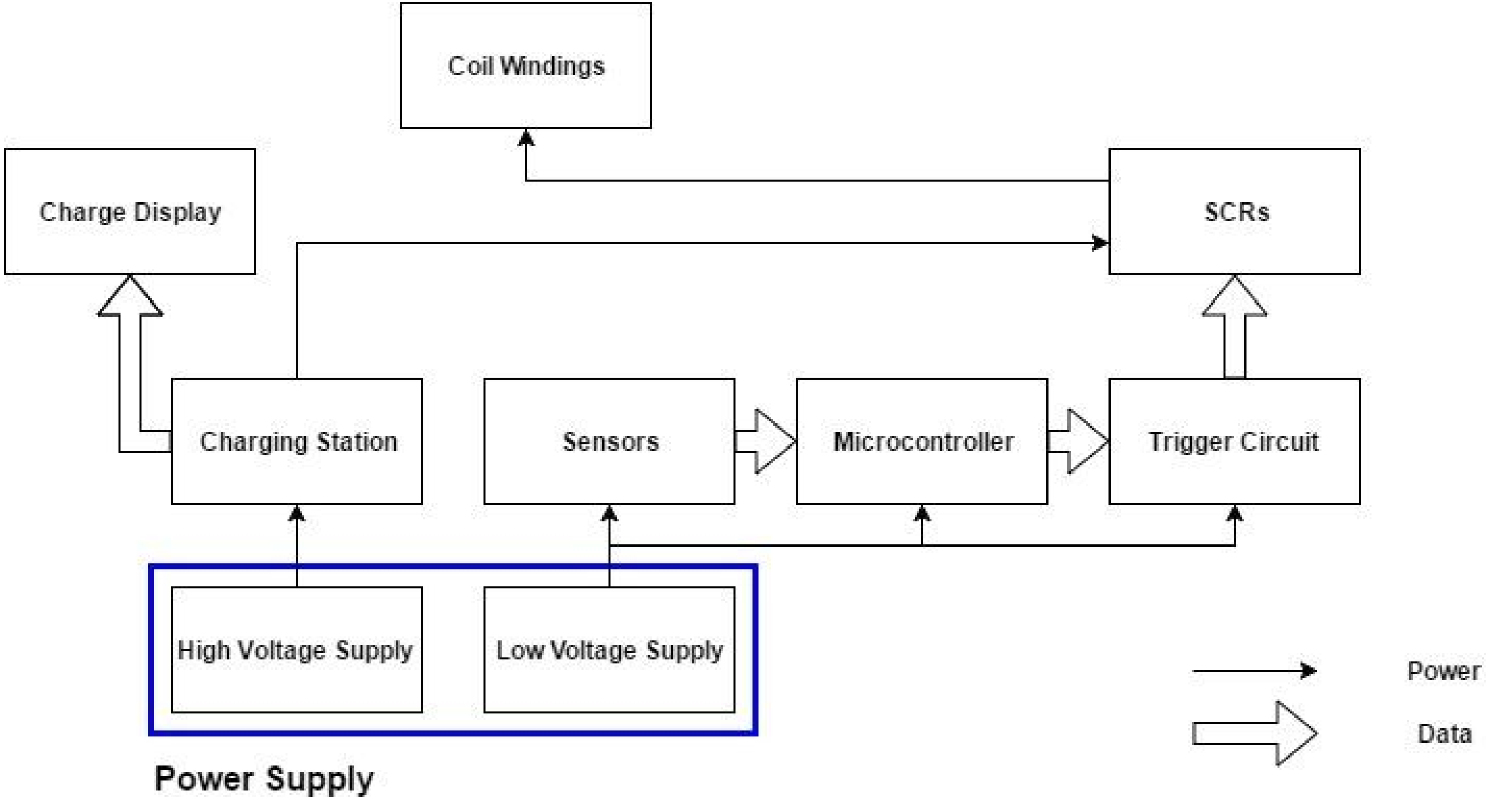
- Current through a coil of wire induces current in conductive projectile
- Opposing currents create repulsive force



The coilgun



Block Diagram

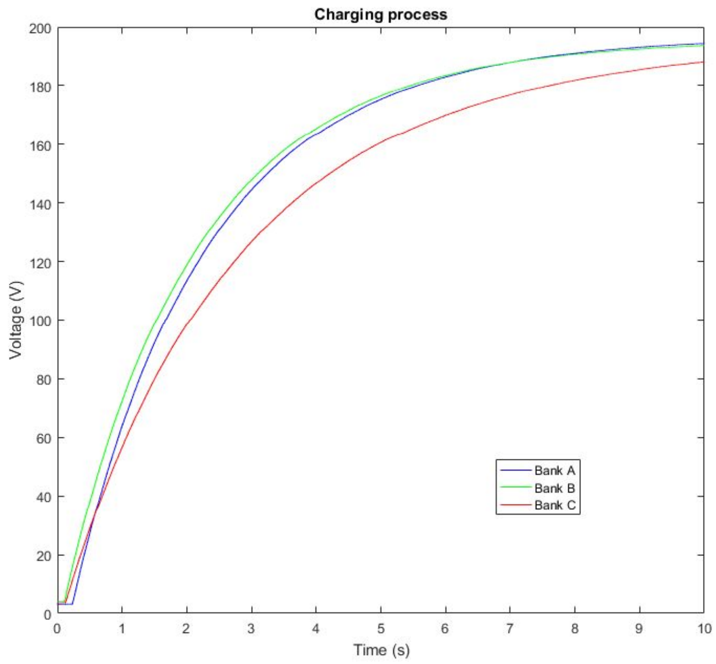


System overview

- Our Team's Work
  - High Voltage Power Supply, Charging Station, Triggering Circuit, SCRs, Charge Displays, Charge Controller, and Coil Windings
- Other Team's Work
  - Low Voltage Power Supply, Microcontroller, and Sensors

High Voltage Power Supply

- Supplies 200 V to charging station
- Maximum current during charging is 2.65 A
- Charges one bank of capacitors in less than 10 seconds

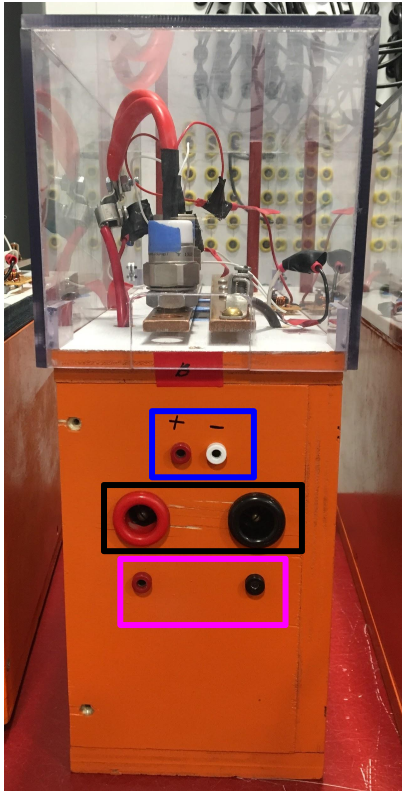


Charging Station

- Three banks of capacitors to store energy for firing
- Capacitors rated up to 450 V, we are charging to 200 V
- First bank has four 10,000 μF capacitors in parallel, the other two banks have three
- Holds 95% of charge for at least 30 seconds

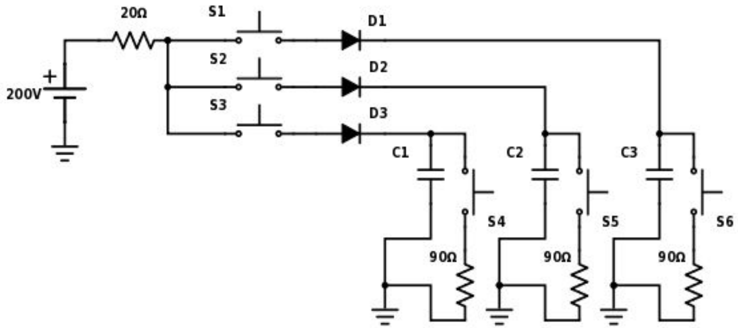
Capacitor Bank Enclosure

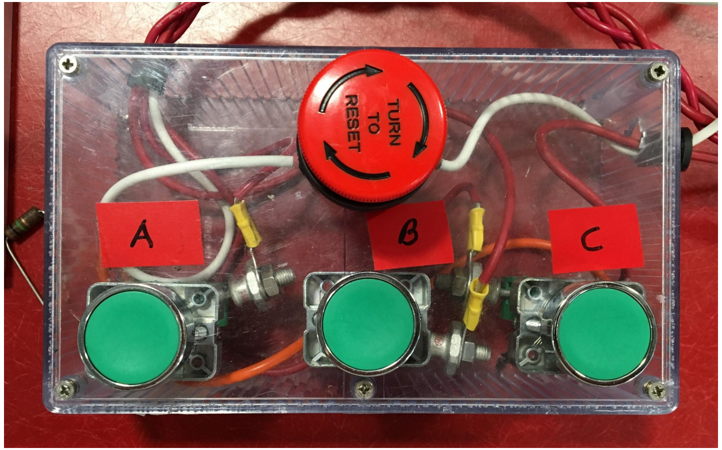
- Separates user from high voltage components
- Shorts capacitors when cover is removed
- Blue: SCR gate driving circuit
- Black: to coils
- Purple: to charge



Charge Controller

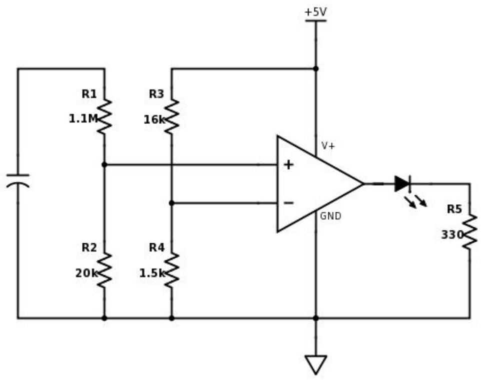
- Has buttons for charging each of the three capacitor banks
- Added diodes so that multiple banks can be charged at once without breaking controller
- Independent discharge resistor for each bank





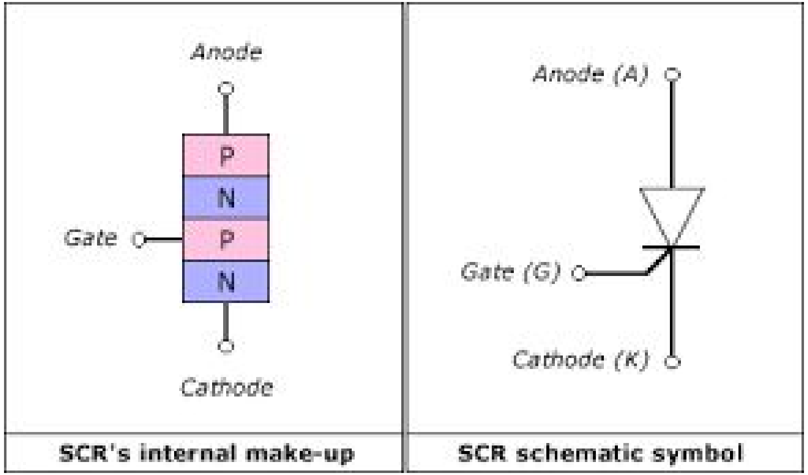
Charge Display

- Lights an LED when capacitor voltage exceeds 25 V
- A safety feature to warn of potentially dangerous voltage
- Issues with connections between comparator and board prevented integration into the capacitor banks



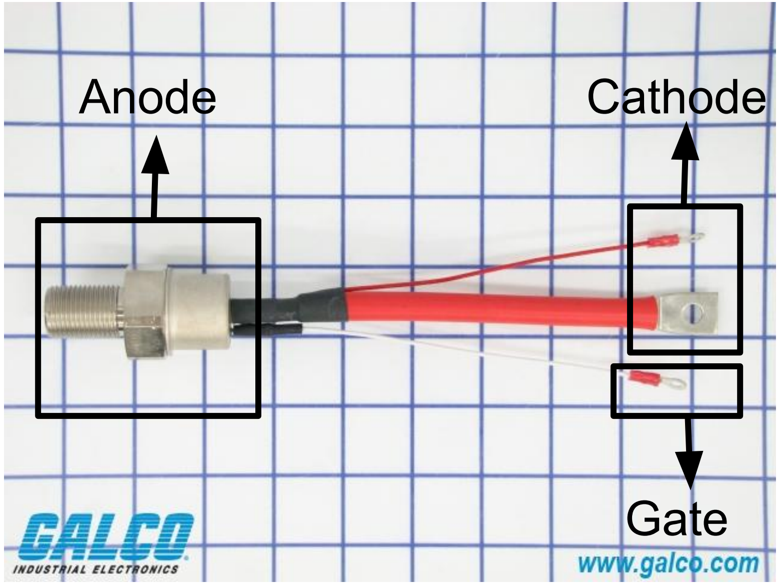
Silicon Controlled Rectifier (SCR)

- Also known as a thyristor
- Multilayer semiconductor device
- Voltage controlled switch
- Unidirectional current flow
- Modes of operation
  - Reverse blocking mode
  - Forward blocking mode
  - Forward conducting mode

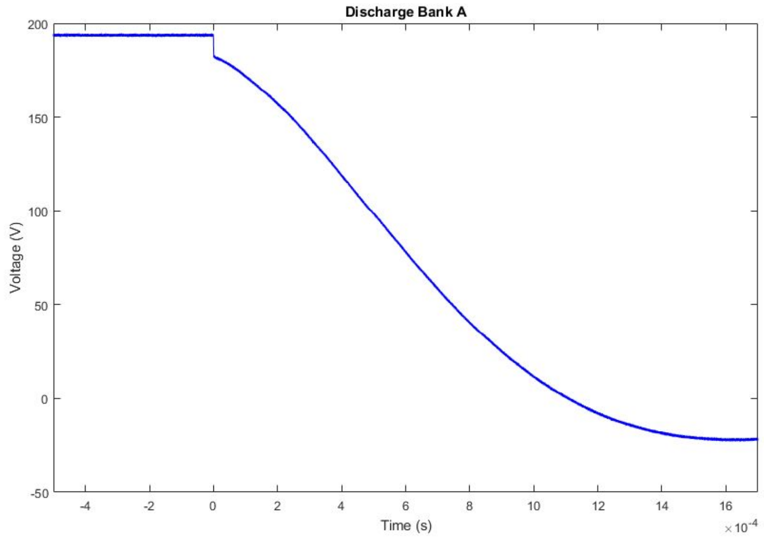


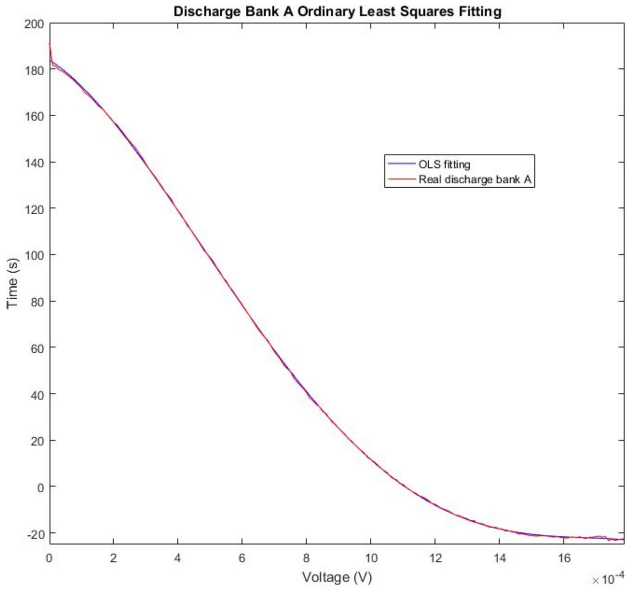
SCR

- Gate requires 3 V and 150 mA to switch on
- Peak gate current rated to 4 A
- T_{on} is 2µs
- Peak On-state Current is 5.5kA



SCR stress analysis I





SCR stress analysis II

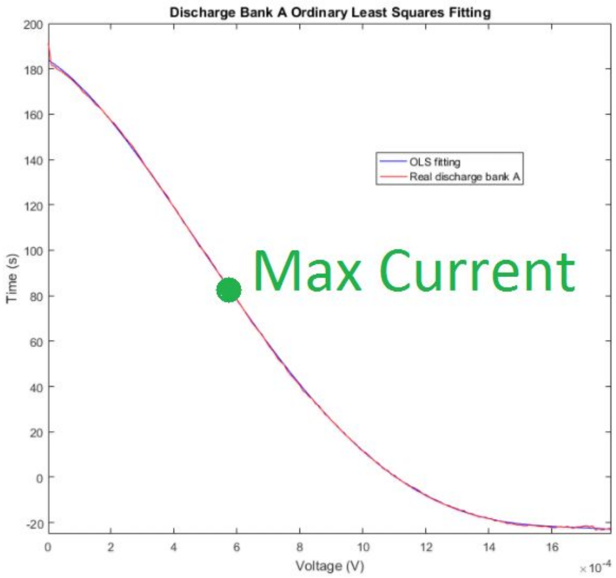
$$\frac{dV_c}{dt}_{max} = 2.06 * 10^5\ V/s$$

$$Capacitor's\ equation: i_C = C\frac{dv_c}{dt}$$

$$I_{C\ max} = C\frac{dV_c}{dt}_{max} = 0.03 * 2.06 * 10^5 = 6.18 * 10^3 = 6.18kA$$

$$number\ of\ SCRs\ in\ parallel = n = 2$$

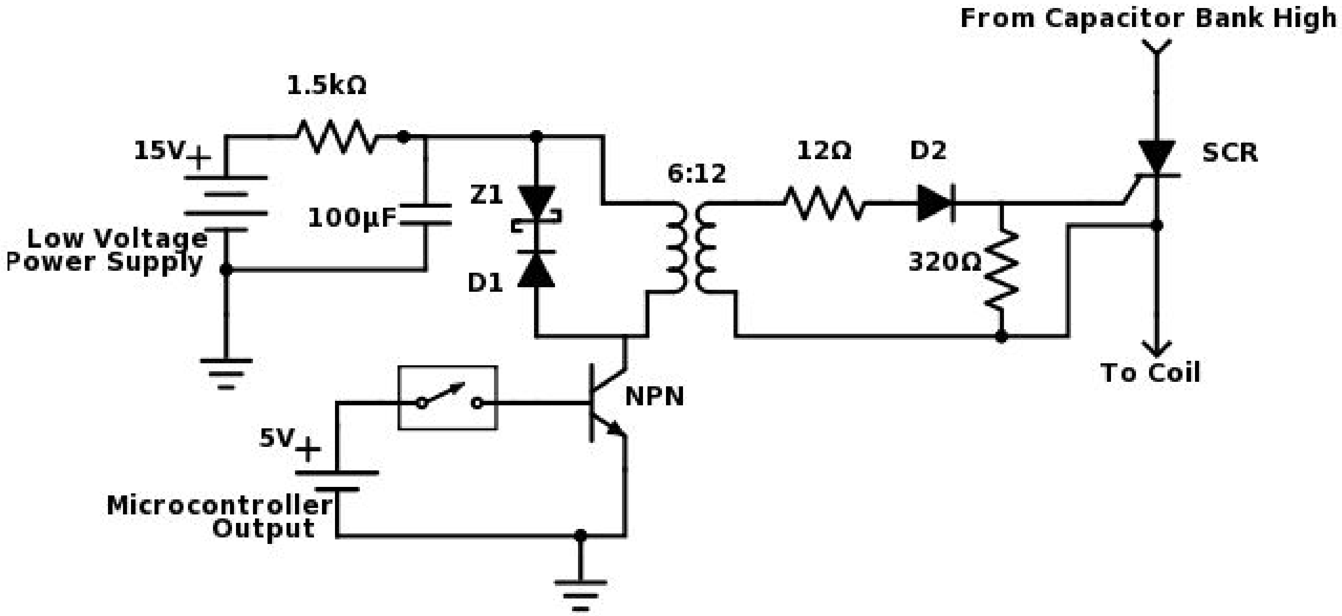
$$I_{max} = n * I_{pk} = 2 * 5.5kA = 11kA > 6.18\ kA$$



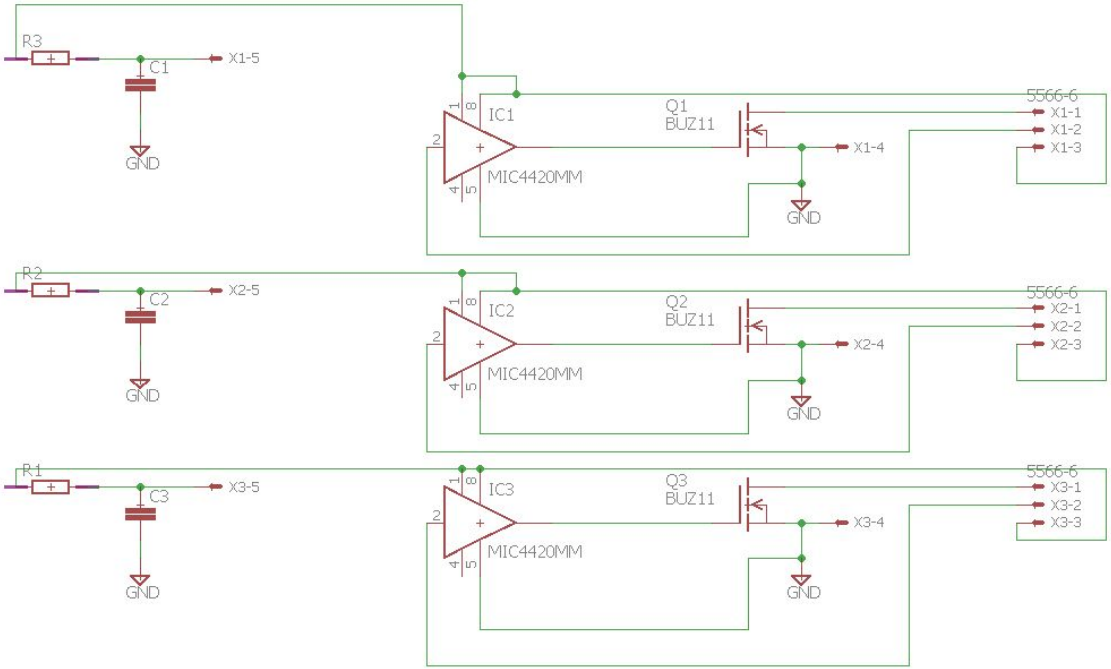
Triggering Circuit

- Input: 5 V, low-current signal from microcontroller
- Output: Signal to turn on SCR gate
- Pulse transformer isolates microcontroller from high voltage components

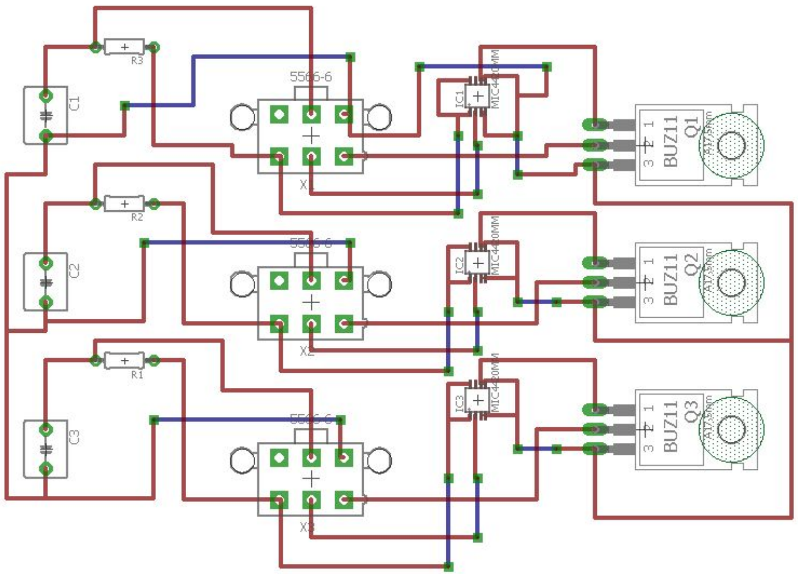
Triggering Circuit Schematic

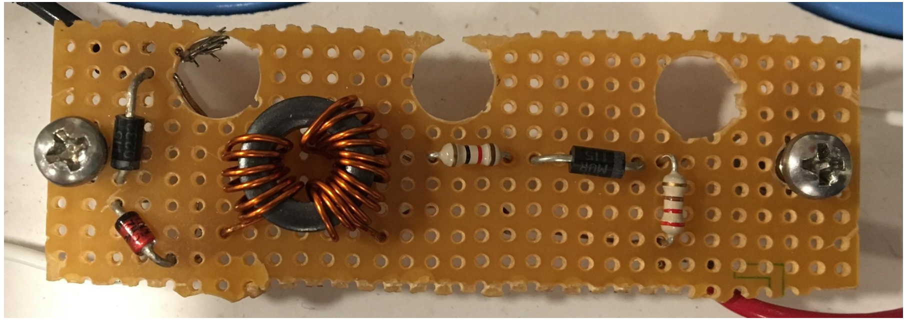


Trigger Circuit layout (1)



Trigger Circuit layout (2)





Trigger circuit calculations

$$\int vdt < NB_{sat}A_{core}$$

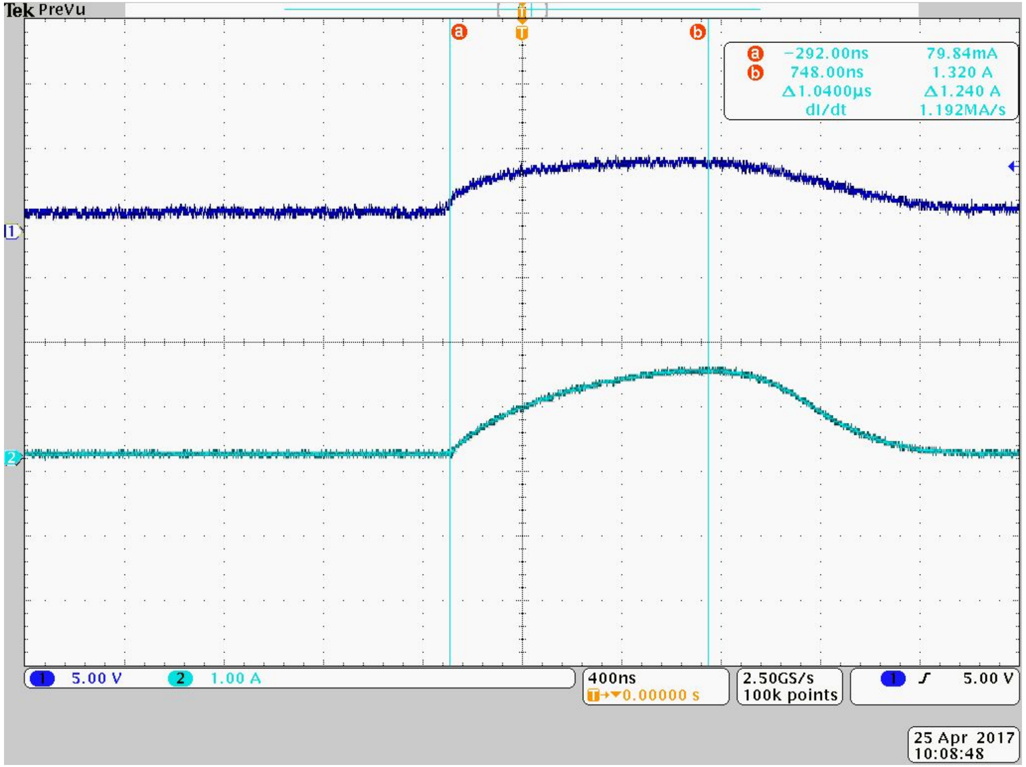
$$15V * 1 * 10^{-6}s < N * 0.250 * 13.6 * 10^{-6}$$

$$N > 4.41\ turns;\ N_{low} = 6$$

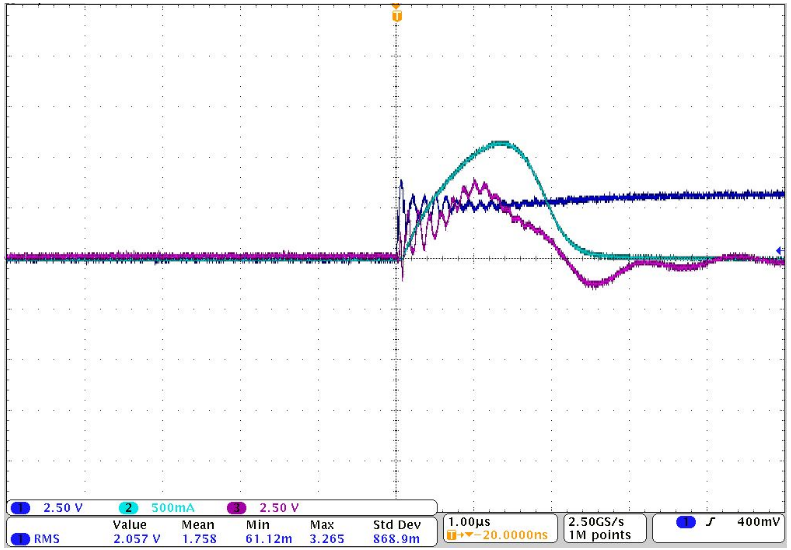
- Pulse transformer can operate adequately when saturation is avoided
- Transformation ratio 1:2 to provide adequate voltage at the gate

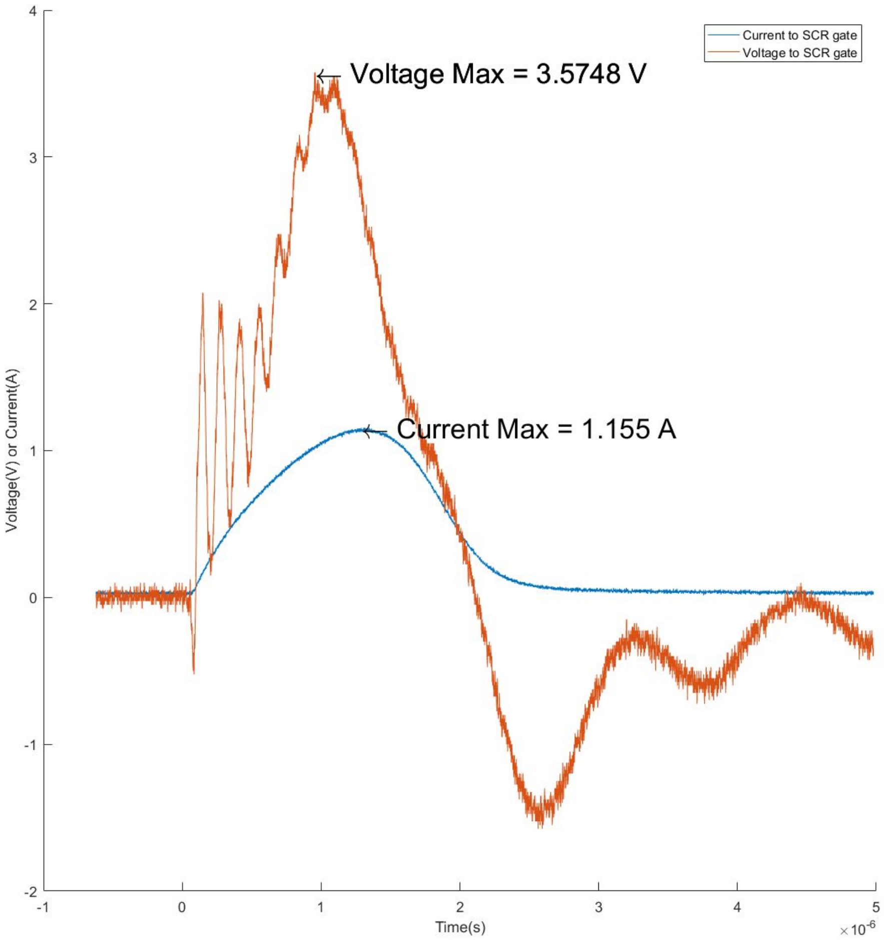
Current into SCR Gate

- $\Delta T = 1.04\ \mu s$
- $\Delta V = 3.00\ V$
- $\Delta I = 1.24\ A$



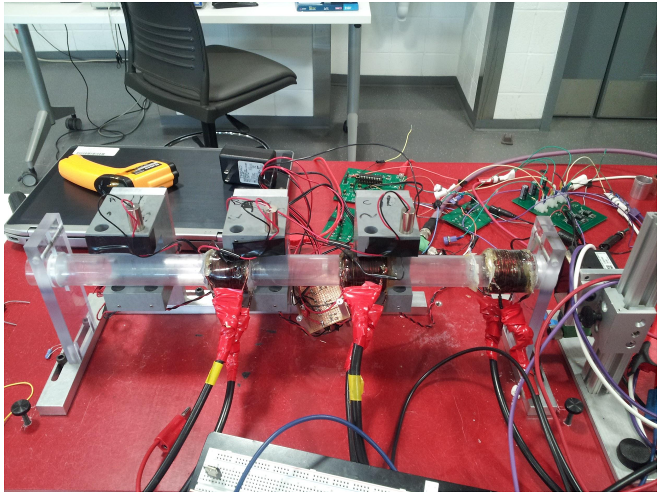
Trigger Signal





Coil Windings

- Resistance must be enough to avoid an underdamped system
- Must be able to withstand the pulse of current



Damping coefficient analysis

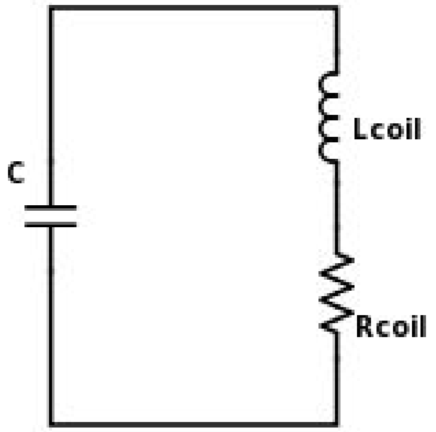
- Differential equation of the system:

$$L_{coil}\ddot{Q} + R_{coil}\dot{Q} + \frac{1}{C}Q = 0$$

- Critical value for the resistor value:

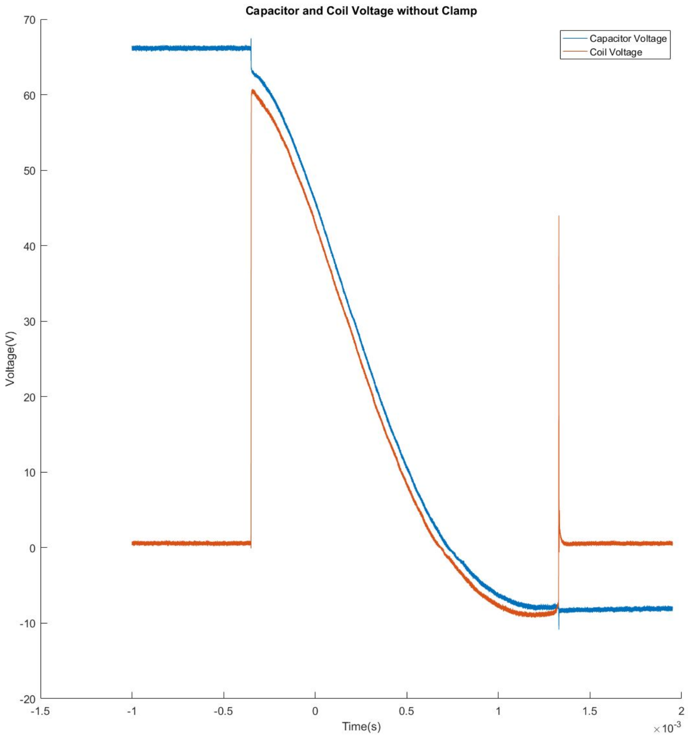
$$R_{crit} = 2\left(\frac{L_{coil}}{C}\right)^{1/2} = 2L\left(\frac{8 * 10^{-6}}{0.03}\right)^{1/2} = 0.03\Omega$$

- In our system we have 2 coils in parallel sharing the magnetic flux

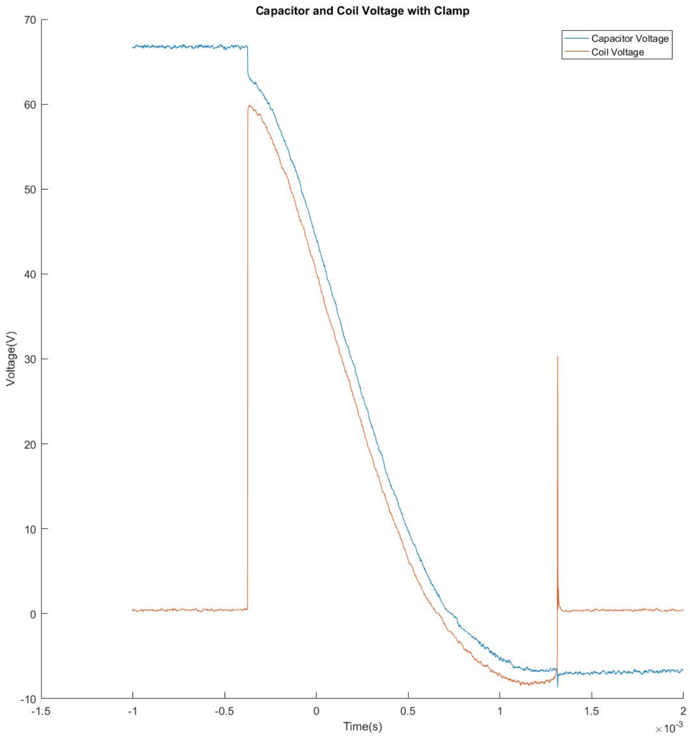


Coils' Results

Without Clamp



With Clamp



Coils' Results

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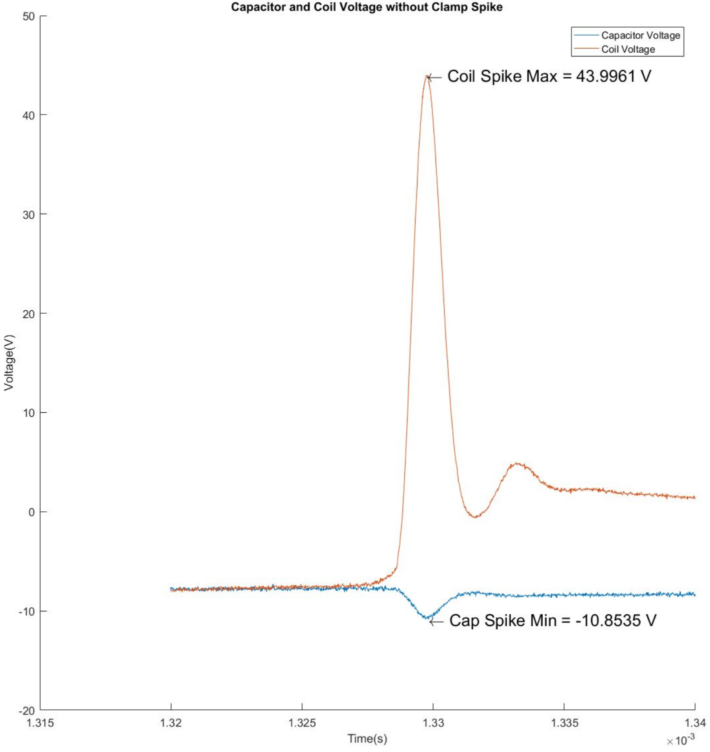
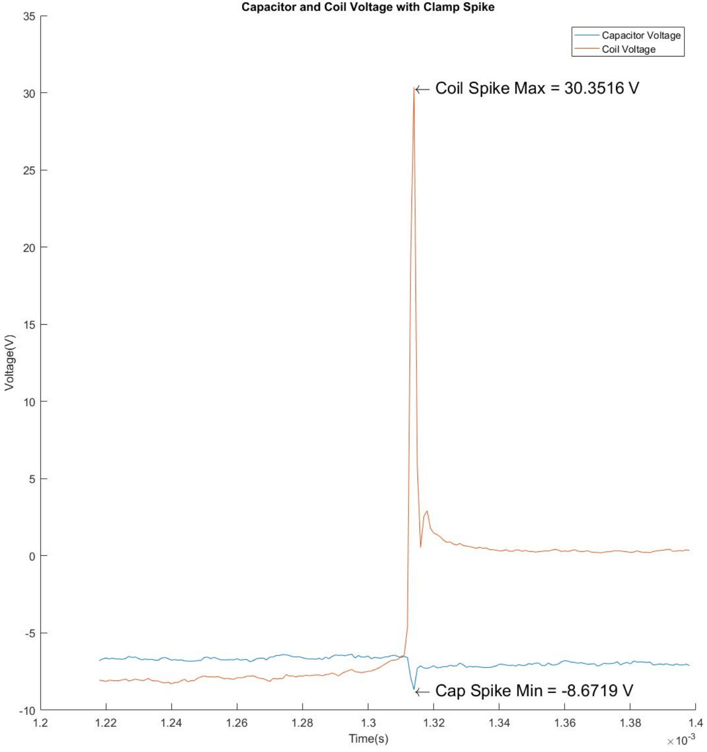


With Clamp



Firing Results

- Two Stage Fire during Demo: 12.5 m/s
- One of the coils needs to be repaired, will collect more data when it is

Ethical Considerations

- We have gone to great lengths to protect the user from high voltage components
- We took care never to fire the coilgun at people or breakable objects
- Our documentation instructs future users to take the same precautions

Future Work

- Enclose PCBs and resistors to make the coilgun into a permanent fixture for EOH
- Test the coilgun at higher voltages
- Experiment with including an RD clamp in parallel with each coil to improve efficiency

Thanks to

- Professor Karl Reinhard
- Christopher Barth
- Jackson Lenz
- Kevin Colravy
- 2013 Team - Jon Dagdagan, Yohan Ko, and Shashvat Nanavati
- Sensor Team - Adwaita Dani, Felipe Fregoso, and Bryan Mbanefo