#20 - Direct Drive Solar Powered Arcjet Thruster

SPONSOR – NASA, MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE AL

ADVISORS – DR. GUO, DR. KWAN, DR. ANDREI

SENIOR DESIGN COORDINATORS – DR. AMIN, DR. FRANK

Team Members

Date – 3/18/14

Chris Brolin - ME
Cory Gainus - ME
Gerard Melanson - ECE
Tara Newton - ME
Griffin Valentich - ME
Shane Warner - ECE

Griffin Valentich

Agenda

- Background
- Sponsor Requirements/Objectives
- Final Design
  - Mechanical
  - Electrical
- Testing Overview
- Procurement
- Future Plans
- Gantt Chart

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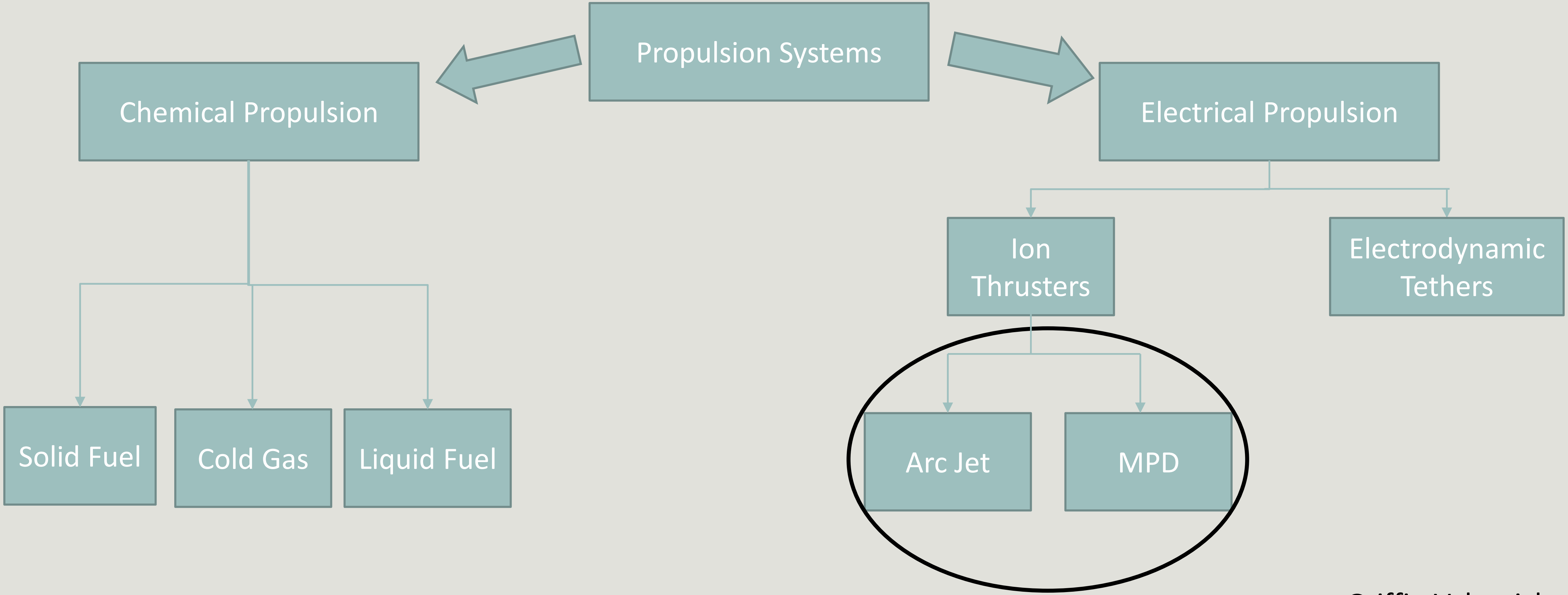
Background



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Background

- Electrical Propulsion Systems
    - High specific impulse – low thrust
  - Electro-thermal thruster– arcjet
    - Produce thrust by heating gas propellant (Ar) and expelling through C-D Nozzle
  - Electromagnetic thruster – MPD
    - Accelerates particles with applied magnetic force
- Purpose of Electric Propulsion Systems
  - Station keeping – lower overall lifetime costs
  - Satellite altitude and attitude adjustment
  - Potential for deep space applications
- Power Processing Unit (PPU)
  - Expensive and complex
  - Largest prohibitive component to electronic propulsion systems
  - Converts input power to correct current and voltage

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Sponsor Requirements / Objectives

- **Eliminate the PPU**
  - Enable thruster to operate in Direct-Drive Mode
  - Obtain power directly from solar panels
- Design, manufacture, and test an arcjet thruster
  - Utilize permanent magnets to confine focus ion stream to increase thrust
  - Independently control propellant flow
  - Design mounting apparatus and a workable vacuum chamber
  - Measure thrust produced
- Quantify the range of operating conditions over which thruster is effective at operating continuously

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Paschen’s Law

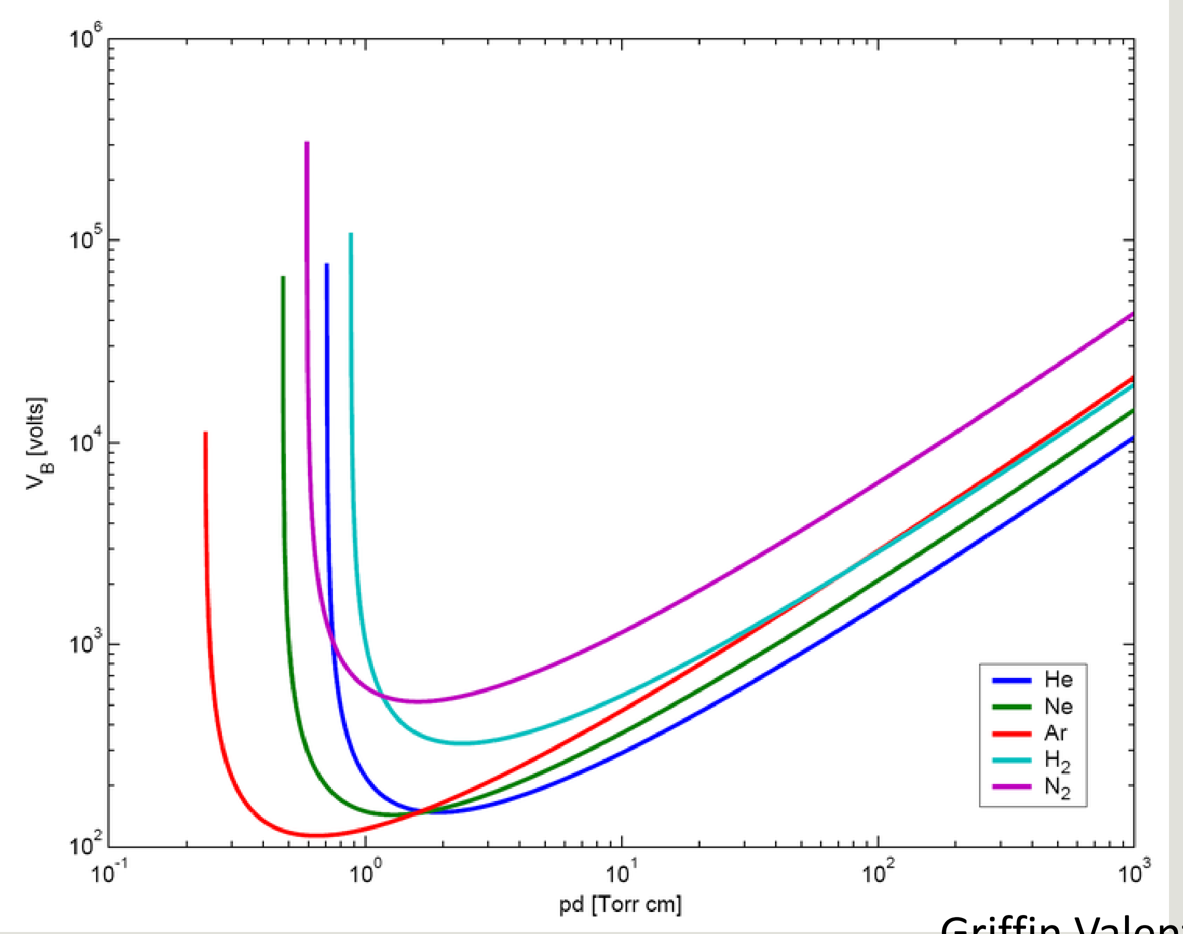
- Relates the product of pressure and distance between anode and cathode to the voltage necessary to initiate breakdown

$$V_{Breakdown} = f(P * d)$$

- Argon had lowest breakdown voltage

$$\sim 137\ V$$

- Good starting point, but values will be different due to complex geometry



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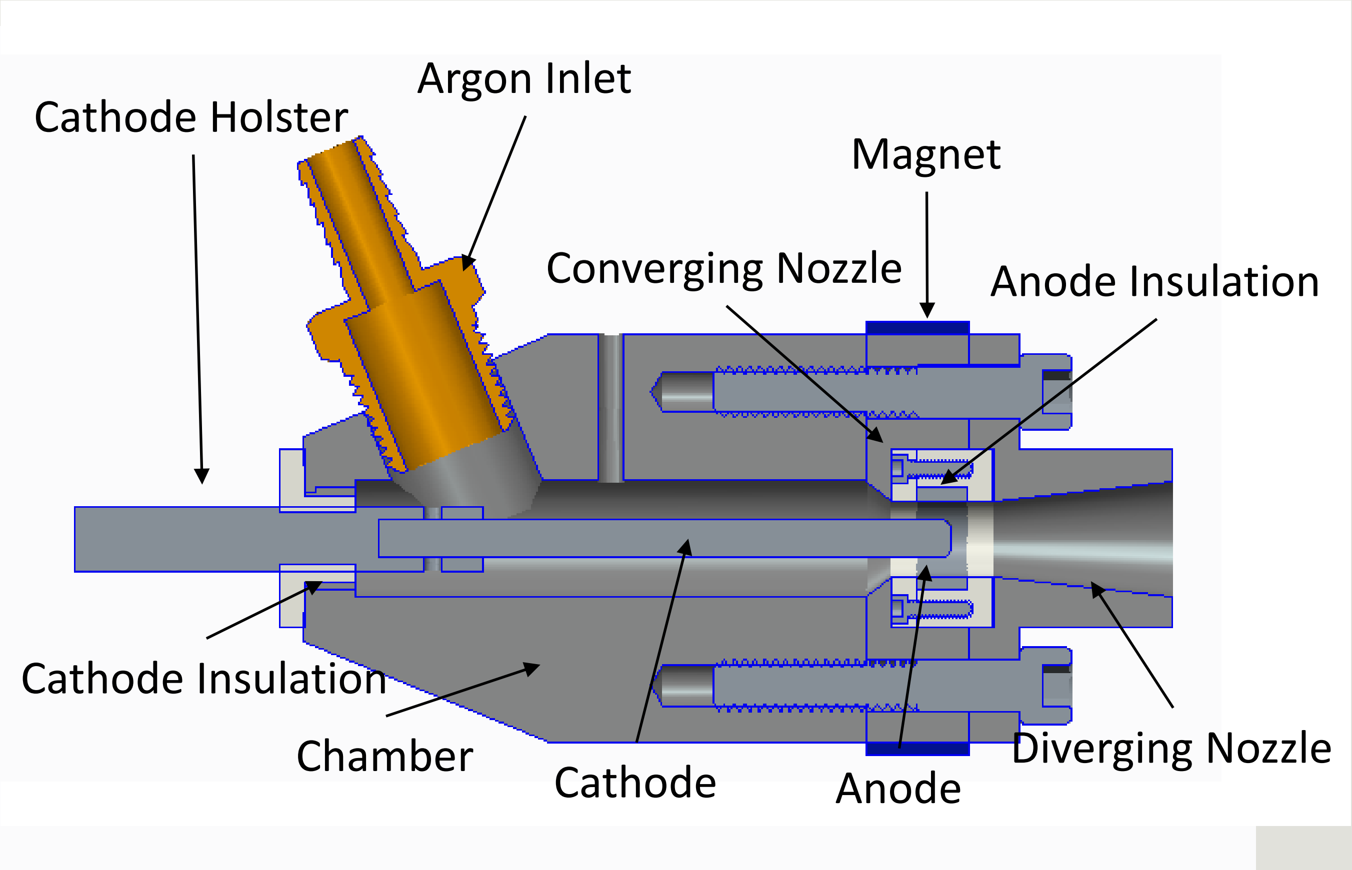
Final Thruster Design

Characteristics

- 3 part nozzle construction
    - Easier machinability
    - Designed for Mach 2.65 - $A/A^* = 3.15$
- Magnet placed at throat of nozzle to protect nozzle walls
- Stagnation Pressure – 550 Pa
- Static Pressure at throat – 267 Pa
    - Pressures from Bernoulli's Eq with const. mass flow rate
    - $P/P_0 = 0.4867$, at throat $M = 1$
- Anode/Cathode Spacing – 0.15"
- Product of pressure and distance gives breakdown voltage of 137 V
    - Well within circuit's capabilities



Cory Gainus

Testing Apparatus

Vacuum Pump

- Welch 1400
- Vacuum to $1x10^{-4}$ Torr

Baseplate

- Borrowed from Dr. Weatherspoon
- Argon and electrical connection input through baseplate

Vacuum Chamber

- Bell Jar
- Borrowed from Dr. Weatherspoon
- Chamber will be evacuated to $1x10^{-4}$ Torr

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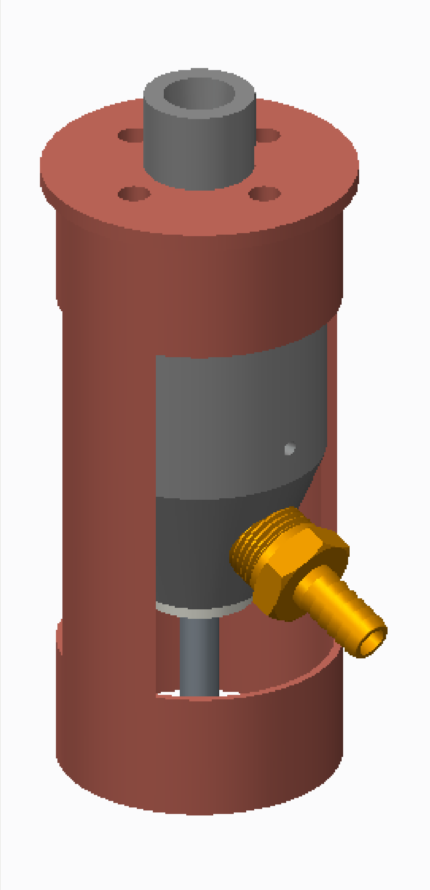
Test Stand

- Standard Pipe with cap
  - Separate Pieces
- Easy to machine
- Easily attached to thruster and detached for any required adjustments
- Lightweight
- Easy to access argon and pressure ports
- Adaptable for whatever force measurement equipment is used



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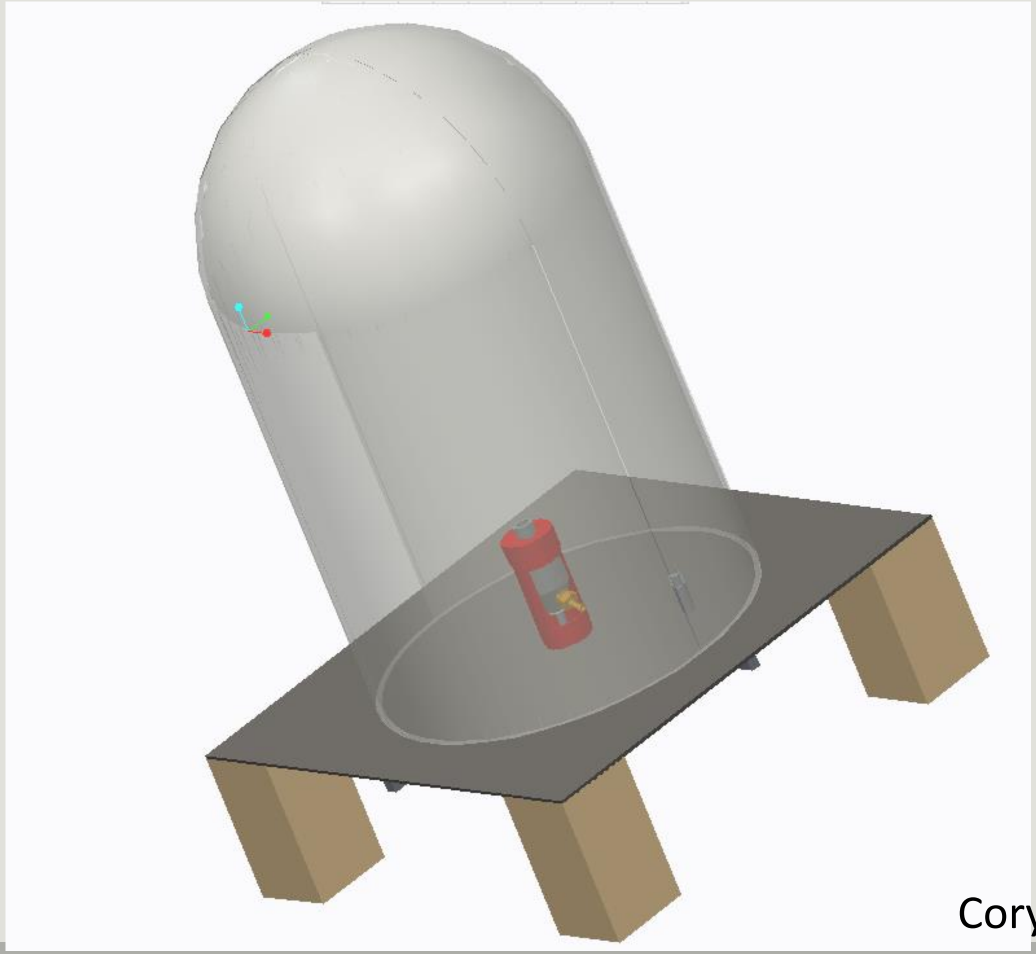
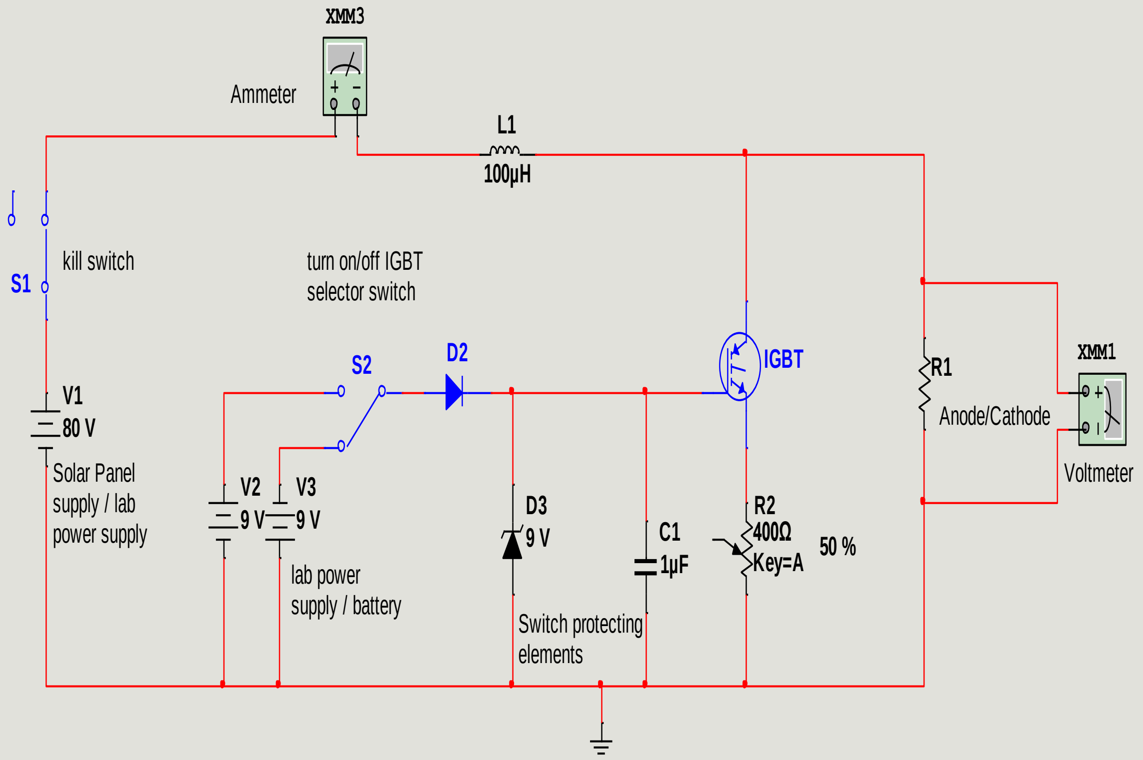
Final Testing Set Up

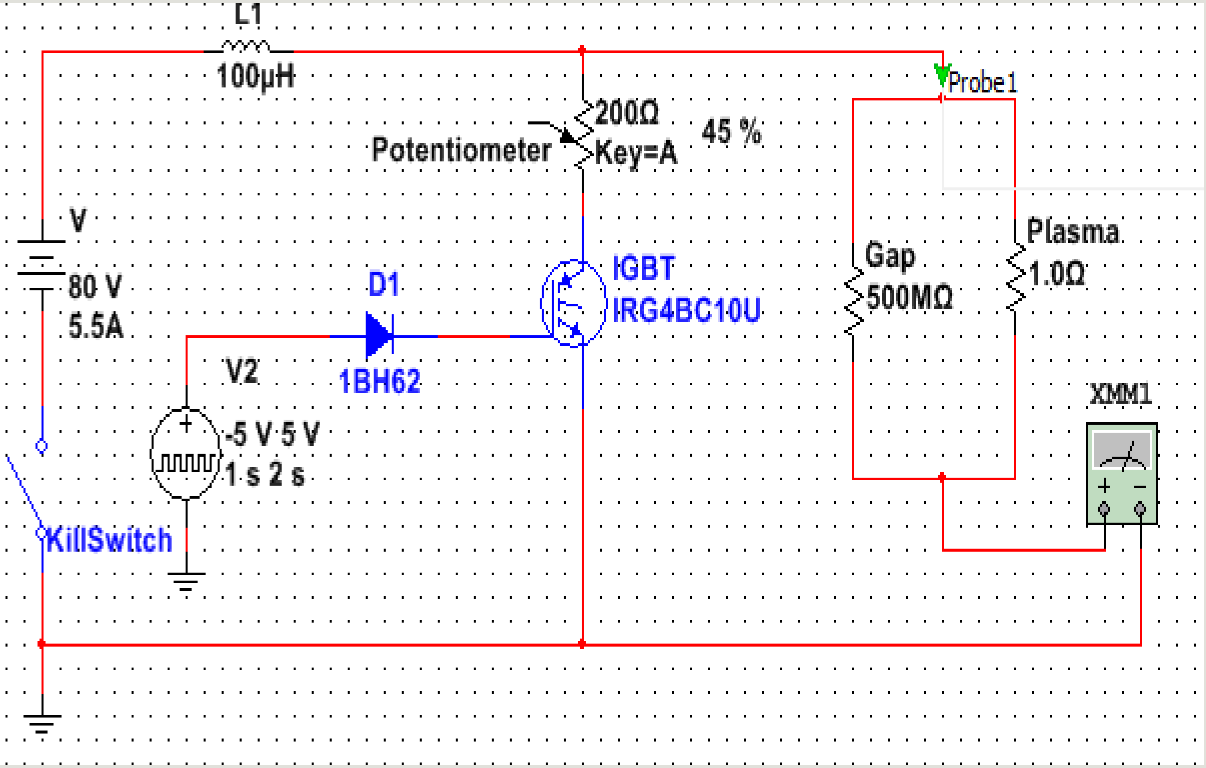
- Square steel tubing reinforced baseplate
- Pipes welded for
  - Vacuum hose
  - Vacuum gauge
  - Argon inlet
- Wires throughput with stycast epoxy
  - Supplied by Dr. Guo
- Edges of chamber sealed with vacuum grease



Cory Gainus

Circuit Alterations





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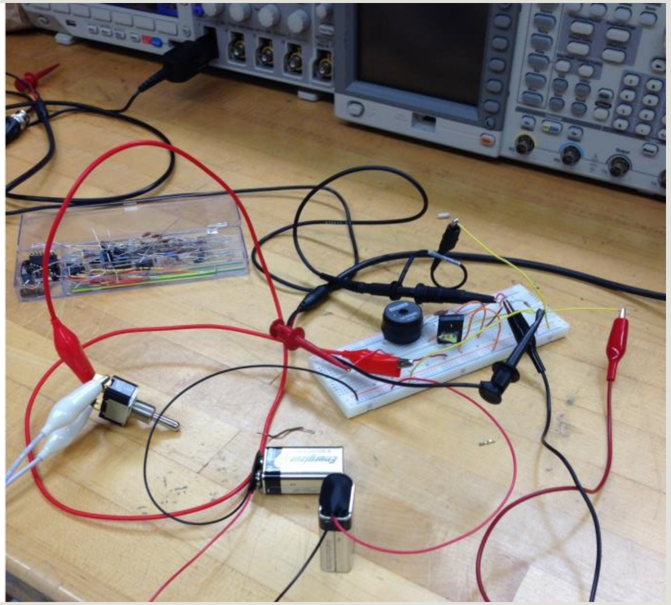
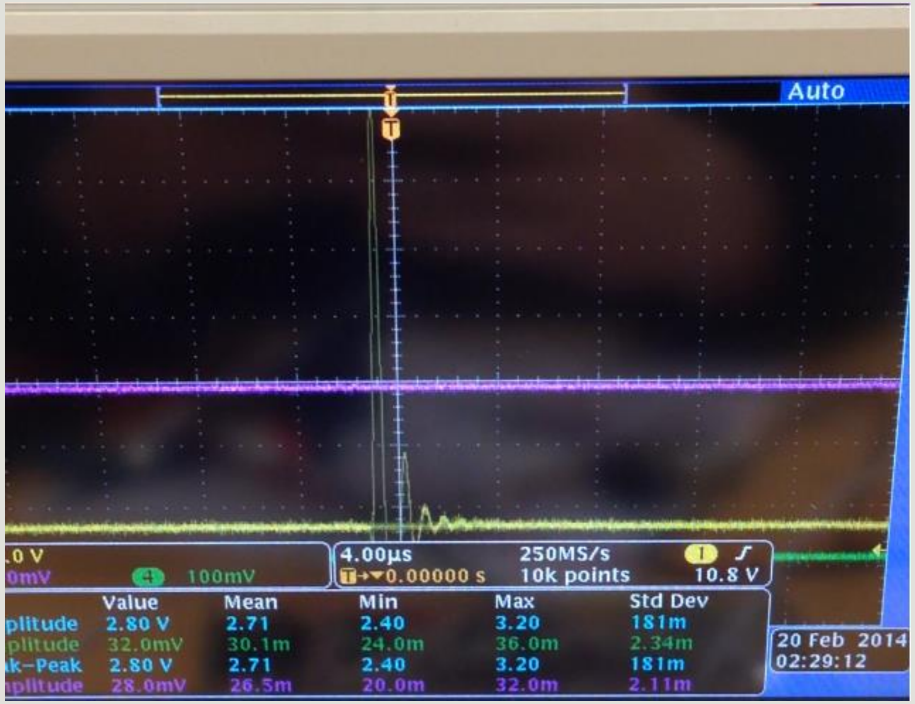
Testing and Results



Full Circuit Testing

Approximately
150 V spike at
Vsource = 20 V
and
Rtop = 50 ohm



Theoretical max spike
2 kV

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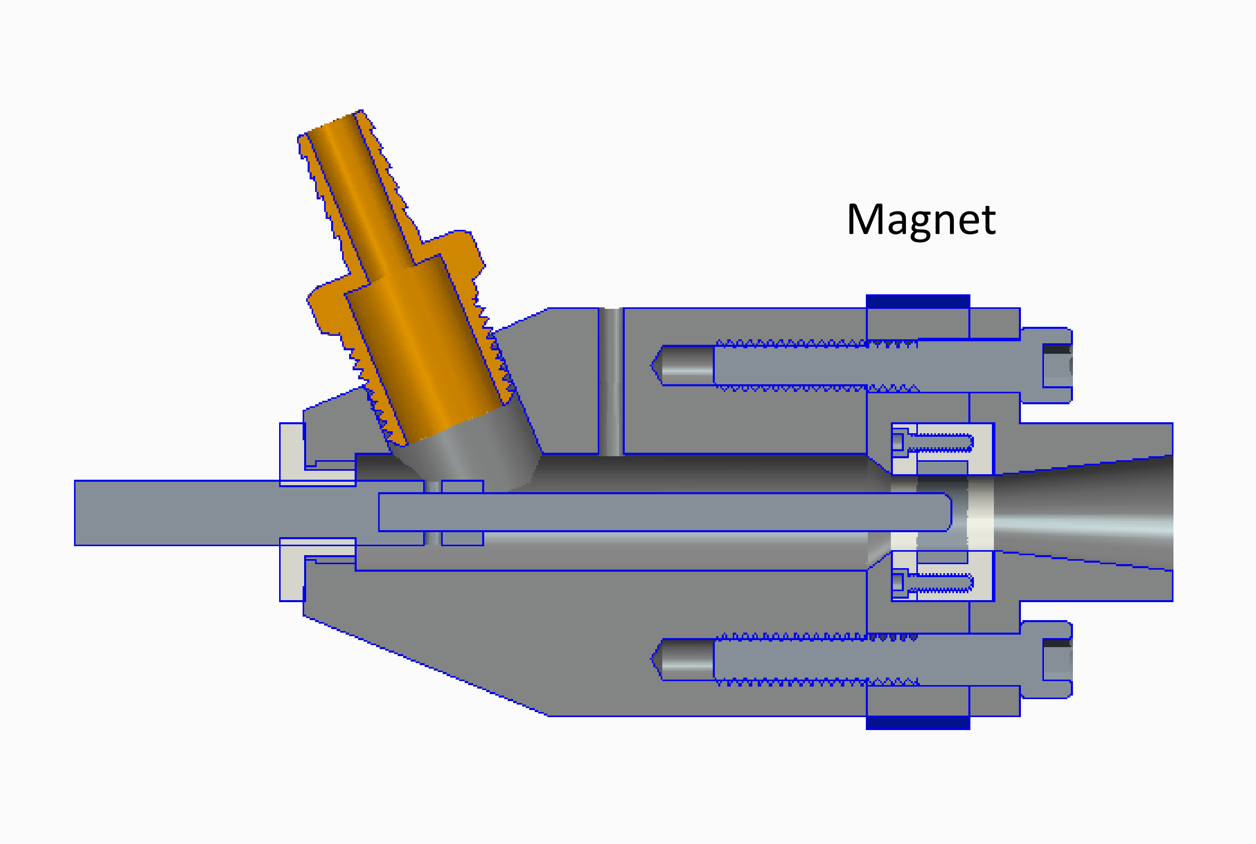
Final Magnet Design



$$B = \mu_r \mu_0 \frac{N}{L} I$$

B = Magnetic field strength

μ_r = relative permeability

μ_0 = free space permeability

N = number of turns

L = Length of electromagnet

I = Current

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Maximum Magnetic Field

The desired magnetic field is given by B = $\frac{mv}{qr}$, $v = \sqrt{\frac{20eV}{3m}}$, where m is mass, v is velocity, q is charge, r is radius, eV is an electron-voltage, and B is the magnetic field. These equations simplify to give us

$$B = 0.316\,T$$

Now the current and number of turns we need is given by:

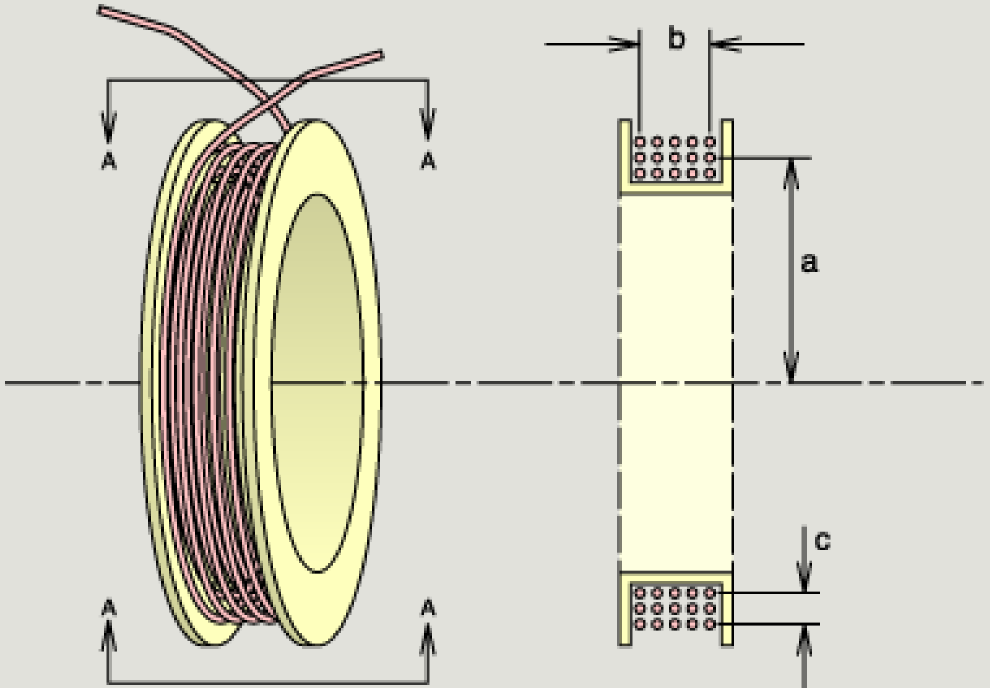
$$NI = \frac{LB}{\mu_r\mu_0} = 4790 \ \ (A - turns)$$

Gerard Melanson

Magnet Design

Max Current = 5 A
Length = 0.01905 m
Diameter of 22 gauge wire =0.0017 m
Number of loops per layer = 11
Absolute max field = 0.316 T = 4790 A-turns
Typical ideal field = 0.050 T = 758 A- turns
At least 14 layers needed
Coat with layer of insulation between wire layers

Fig. 1 Dimensions of a multi-layer coil of rectangular cross section



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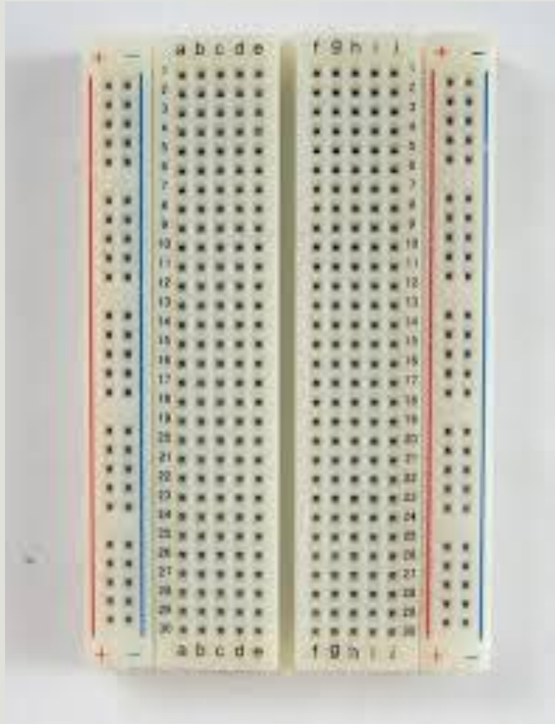
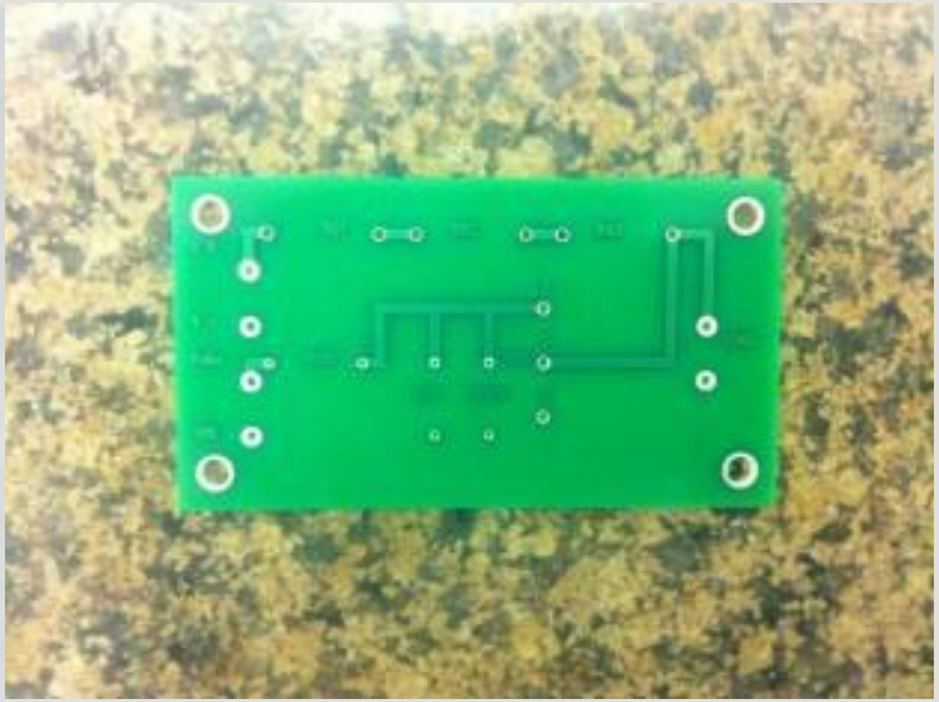
Circuit Testing and Finalization

- We are currently designing the PCB on Eagle now that the design has been finalized





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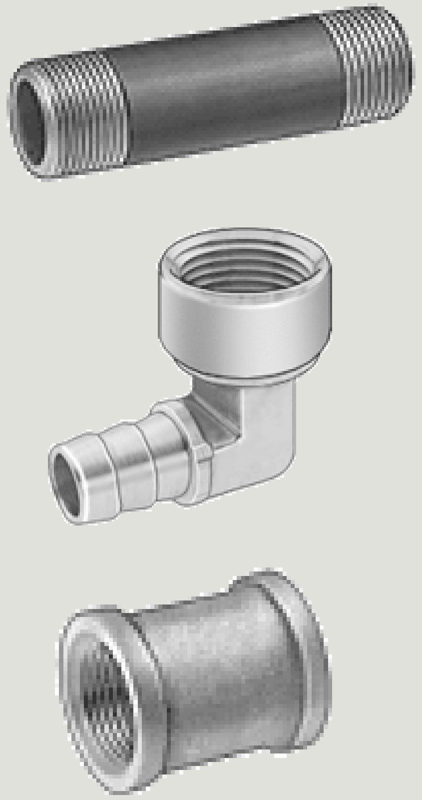
Procurement

Through baseplate hardware

Component	Part #	Quantity	Cost
Threaded Pipe Nipple	44615K462	2	$3.24
Vacuum Hose Fitting 90 deg	5346K125	1	$10.20
Coupling for Vacuum Gauge	4429K111	1	$5.70
		Total	$19.14



- Remaining hose fitting and poly flow hose will be supplied by sponsor
- **Remaining Budget – $130.74**

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Future Plans

- Machining baseplate
  - Mounting apparatus completed
  - Weld tubes and attach appropriate fittings
- Test vacuum chamber and leak proof connections and through holes
- Measure resistance of plasma
  - Determine whether to insert additional resistor or transconductance amplifier
- Determine thrust output and range of operating conditions
- Acquire Printed Circuit Board

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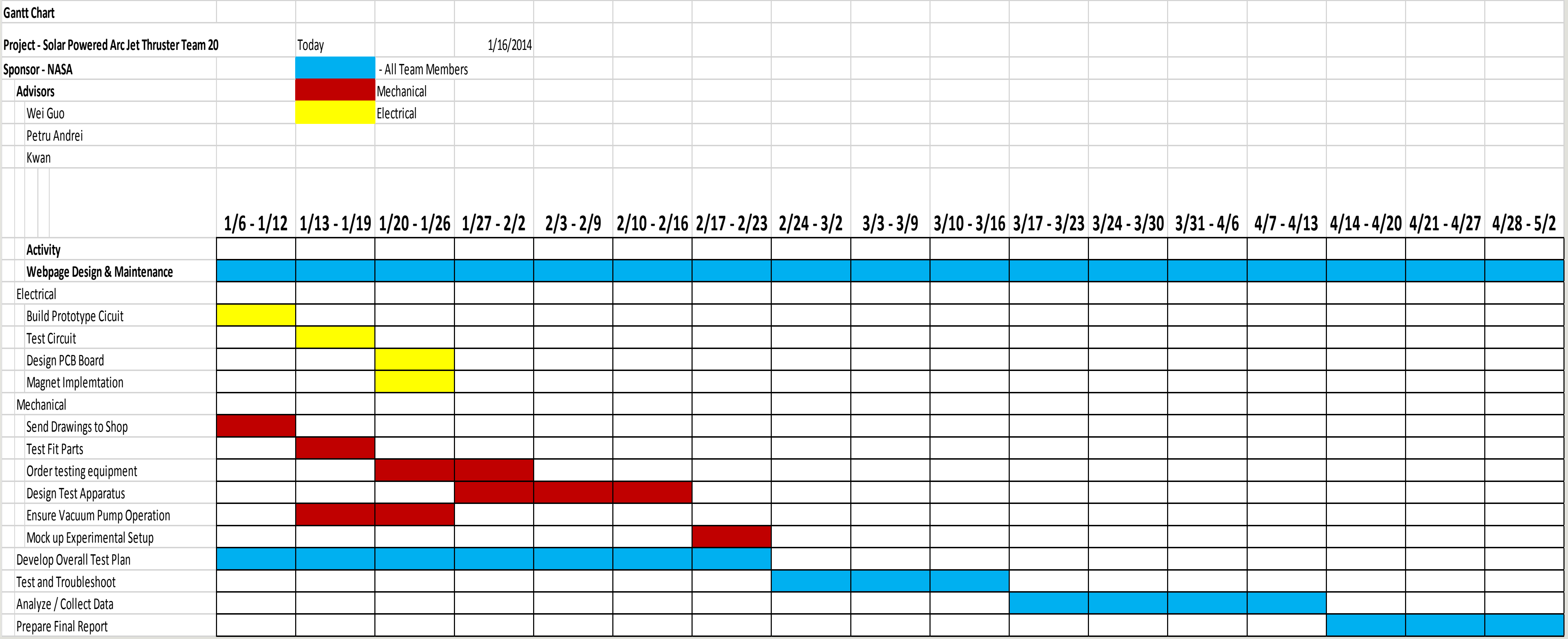
Gantt Chart


Gantt Chart
Project - Solar Powered Arc Jet Thruster Team 20
Today
1/16/2014
Sponsor - NASA
- All Team Members
Advisors
Mechanical
Wei Guo
Electrical
Petru Andrei
Kwan
1/6 - 1/12
1/13 - 1/19
1/20 - 1/26
1/27 - 2/2
2/3 - 2/9
2/10 - 2/16
2/17 - 2/23
2/24 - 3/2
3/3 - 3/9
3/10 - 3/16
3/17 - 3/23
3/24 - 3/30
3/31 - 4/6
4/7 - 4/13
4/14 - 4/20
4/21 - 4/27
4/28 - 5/2
Activity
Webpage Design & Maintenance
Electrical
Build Prototype Cicuit
Test Circuit
Design PCB Board
Magnet Implemtation
Mechanical
Send Drawings to Shop
Test Fit Parts
Order testing equipment
Design Test Apparatus
Ensure Vacuum Pump Operation
Mock up Experimental Setup
Develop Overall Test Plan
Test and Troubleshoot
Analyze / Collect Data
Prepare Final Report

Questions?