#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 – 2/11/14

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

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Agenda

- Background
- Sponsor Requirements/Objectives
- Fall Accomplishments
- Final Design
  - Mechanical
  - Electrical
- Testing Overview
- Potential Challenges / Safety
- Procurement
- Future Plans for Spring 2014
- Summary

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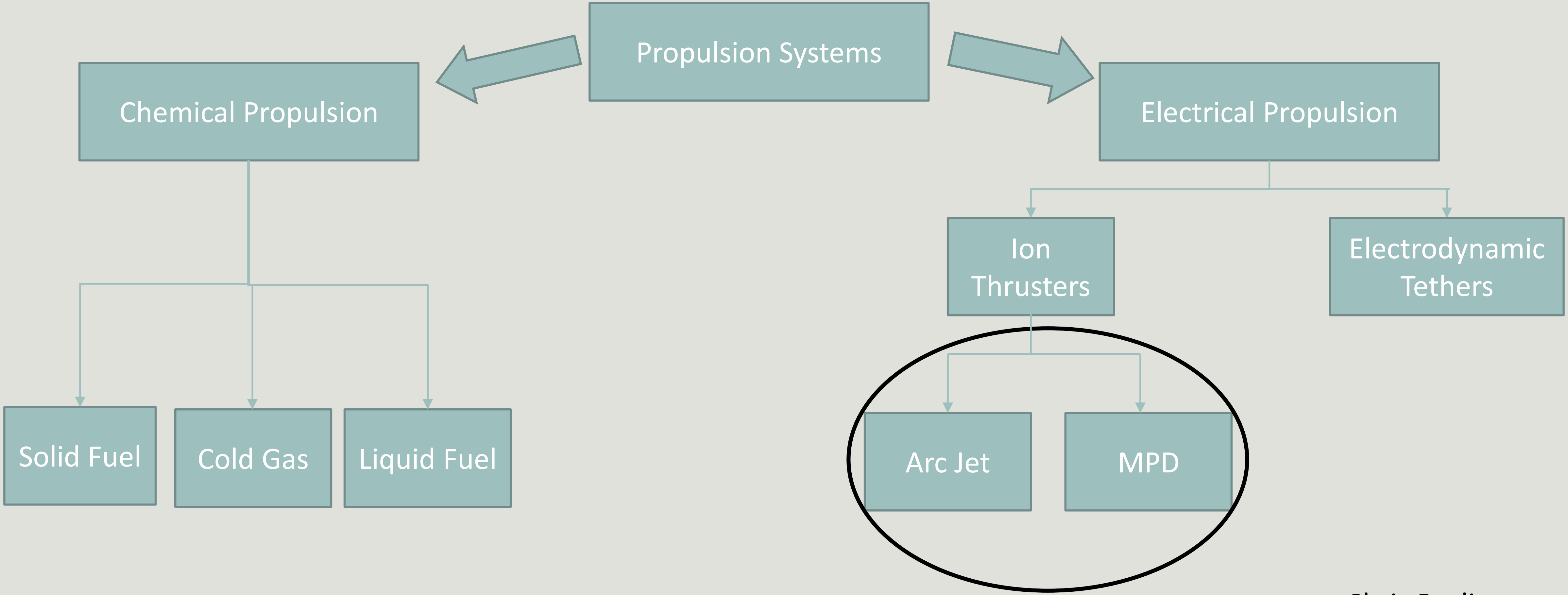
Background



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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
- 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 high temperature plasma
  - Independently control propellant flow
  - Design mounting apparatus for thruster inside 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

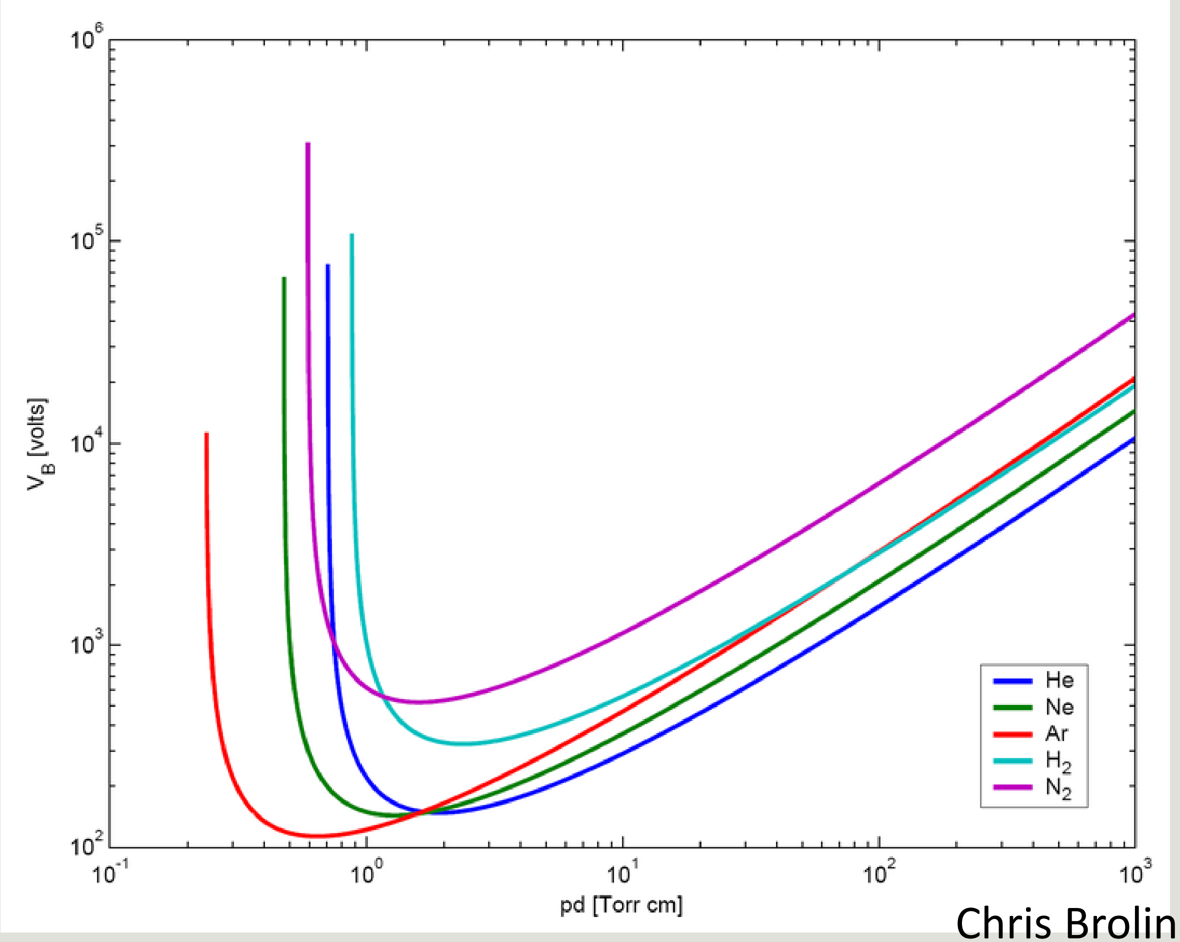
- Relates the product of pressure and distance between anode and cathode to the voltage necessary to initiate breakdown

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

- Argon had lowest breakdown voltage

$$\sim 137\ V$$

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



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Fall Accomplishments

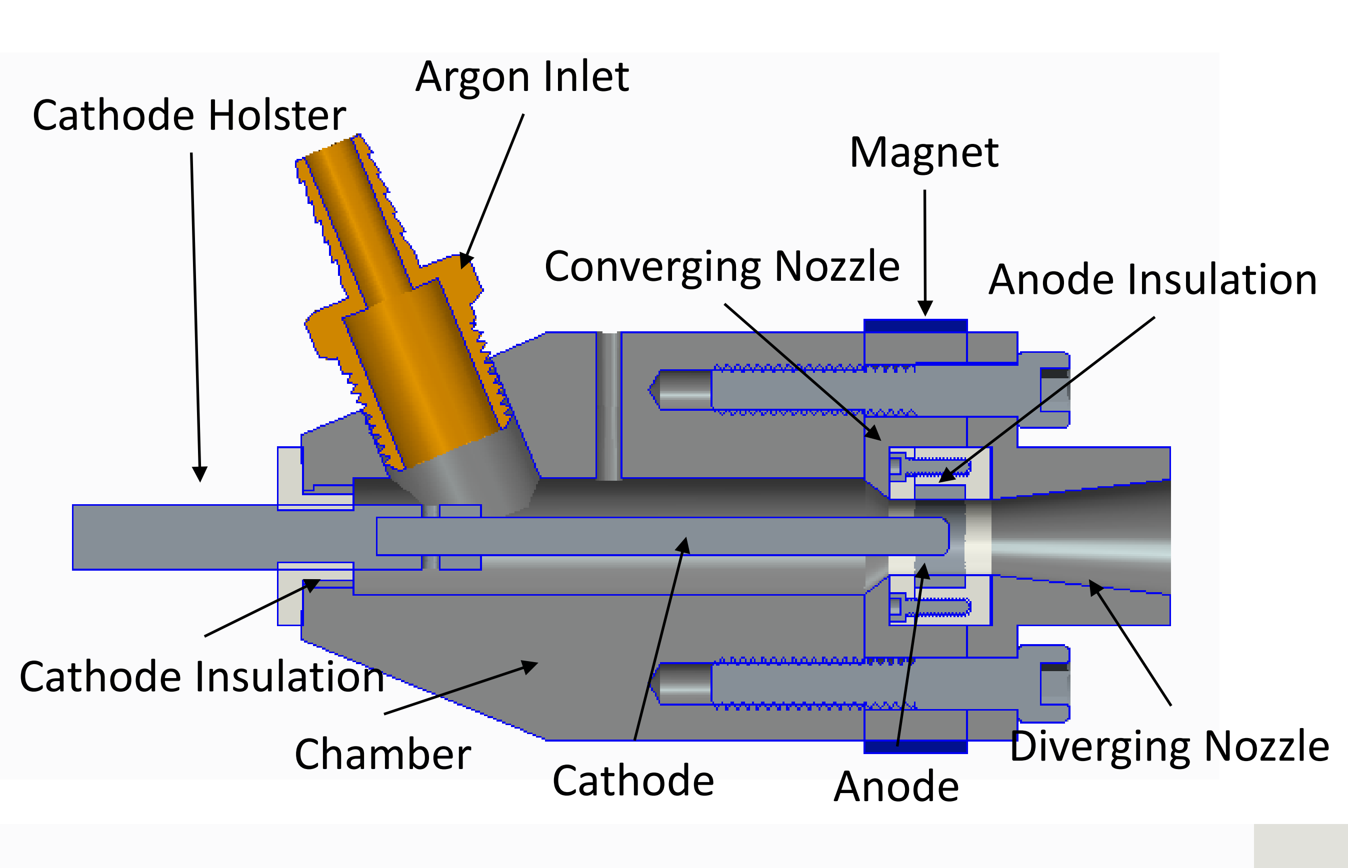
- Finalized design concept
- Ordered materials necessary to fabricate thruster
- Obtained all required circuit components
- Ran simulations on voltage spike and thruster nozzle
- Procured expensive resources from professors
  - Bell jar and baseplate – Dr. Weatherspoon
  - Vacuum pump – Keith Larson
  - Argon supply – Dr. Zheng

Tara Newton

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



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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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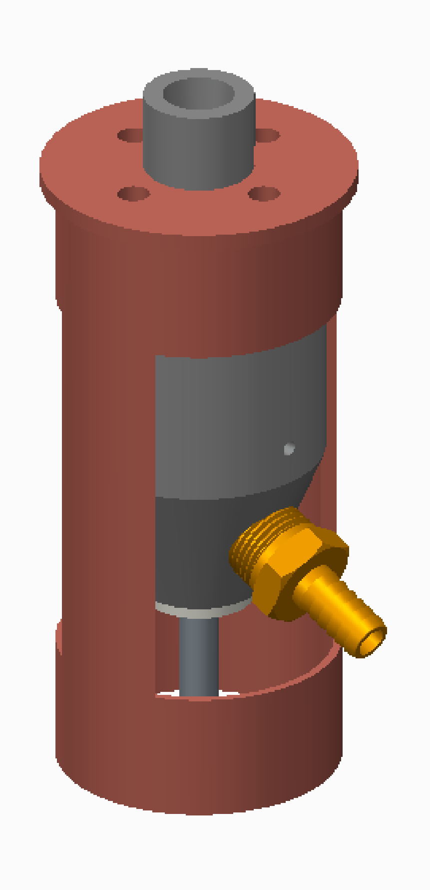
Test Stand

- Standard Pipe with welded flange
- Easy to machine
- Easily attached to thruster and detached for any required adjustments
- Lightweight
- Easy to access argon and pressure ports



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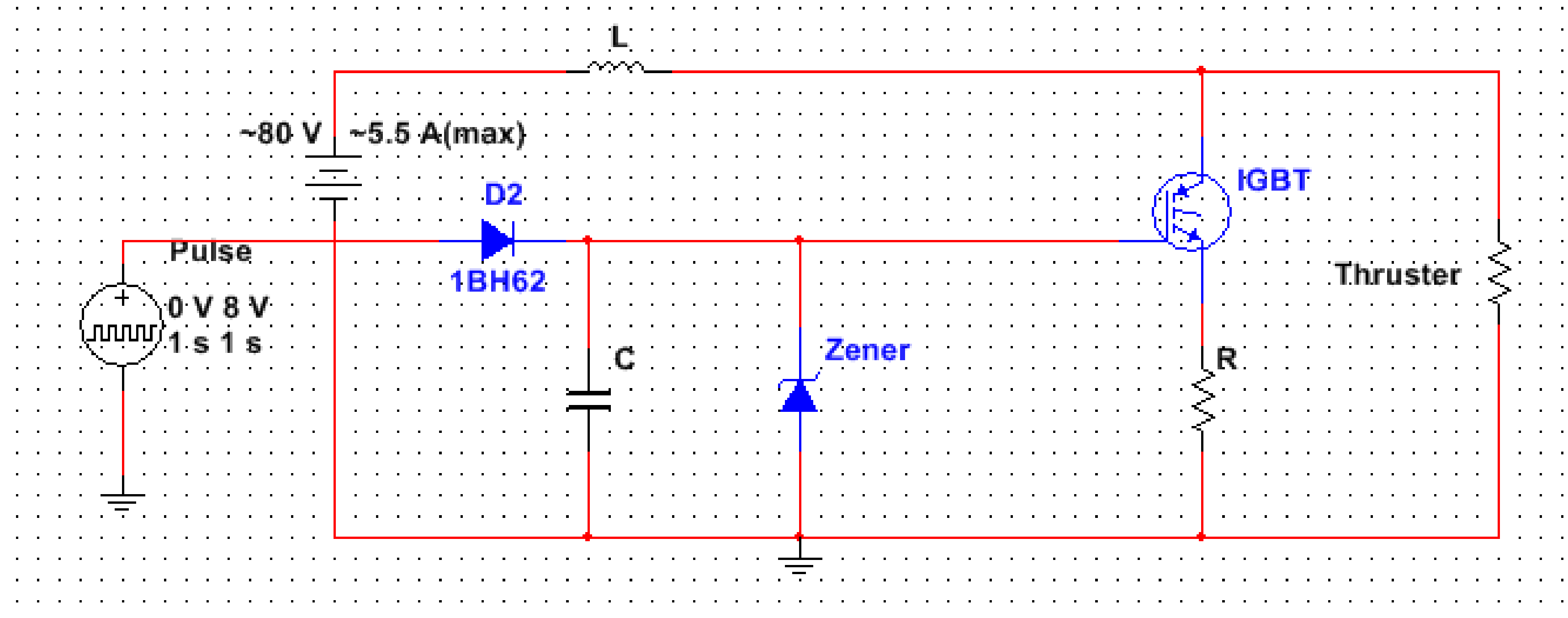
Electrical Designs and Testing



- A 20 volt source and 200 Ω resistance gives 0.1 A. V = $L\frac{di}{dt}$ = 100μH$\frac{0.1A}{130ns}$ = 77 V
- Tested this circuit and didn’t measure any voltage spike
- Researched IGBTs and found out we need a negative pulse to turn it off
- We may also need a different voltmeter than the Fluke 43b

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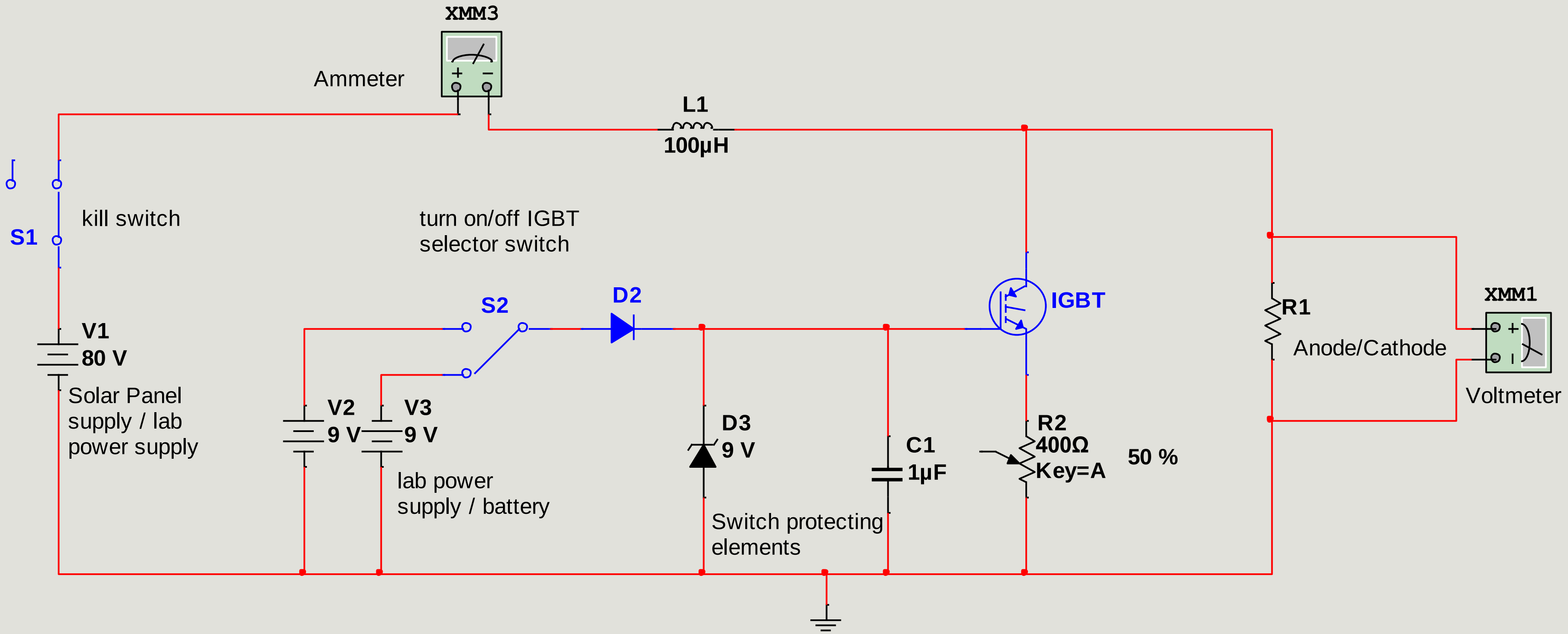
Final Circuit Design



- Tested this circuit in Multisim, but gave a small voltage spike (5 – 10 V) and runs inconsistently
- We plan to test this circuit in the lab Thursday 2/13/14

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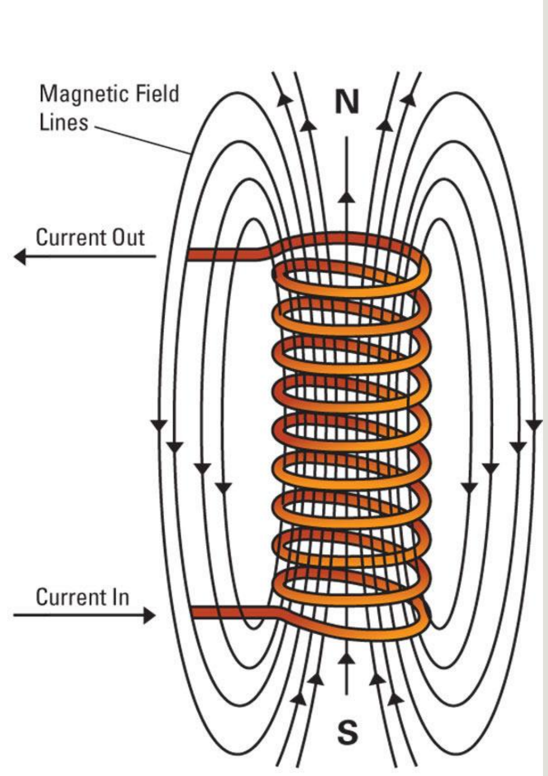
Magnet Testing and Finalization

- Electromagnets (Left) will be used in initial testing since it is easy to change their strength
- Final Design will feature permanent magnets (Right)



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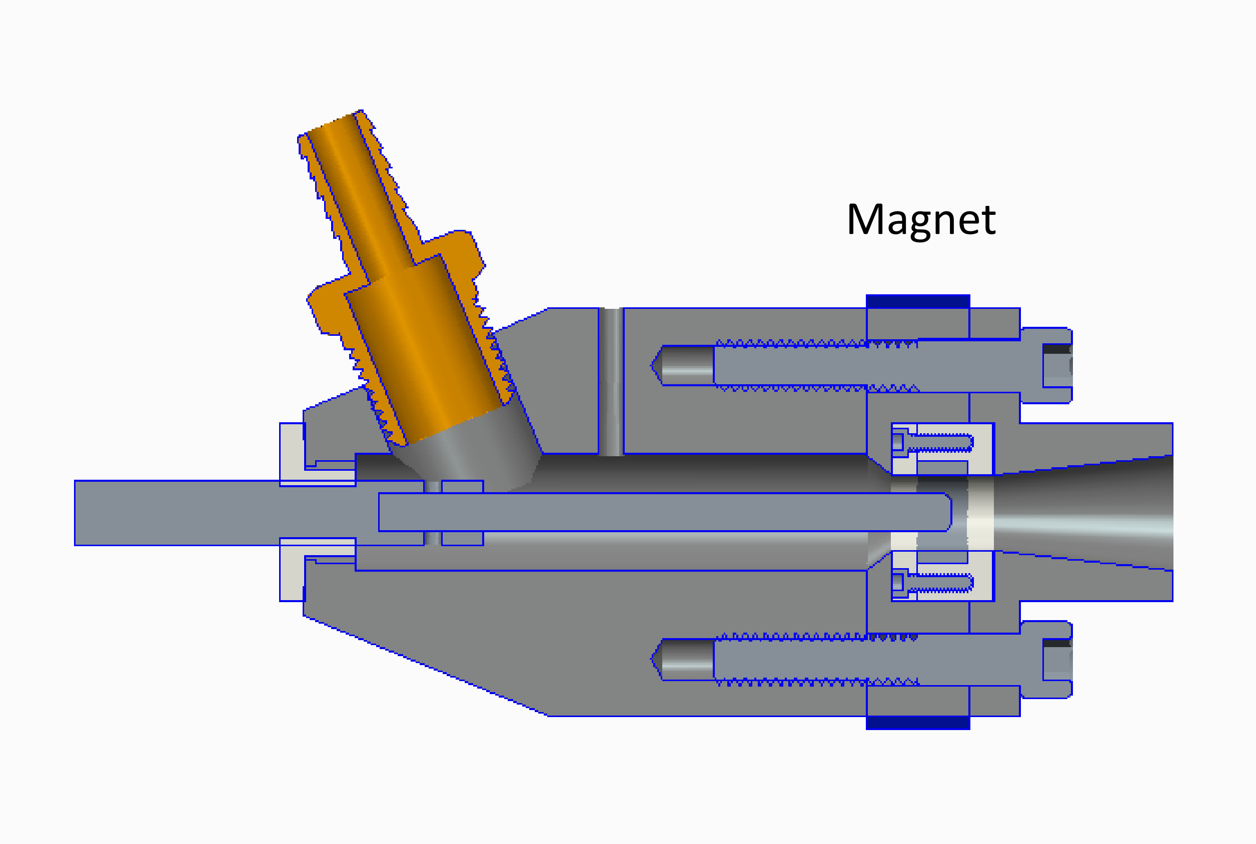
Final Magnet Design



We will use an electromagnet to vary the magnetic field and optimize the thruster performance, then order permanent magnet based on the tested magnetic field strength. The generated magnetic field at the center is:

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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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:

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

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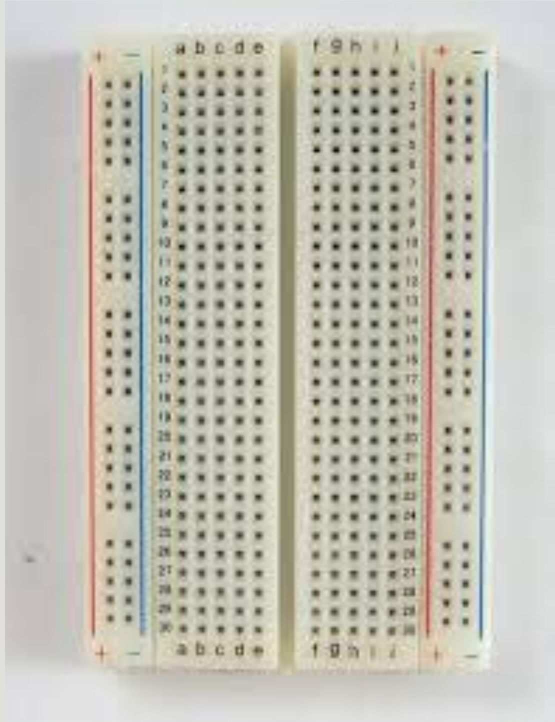
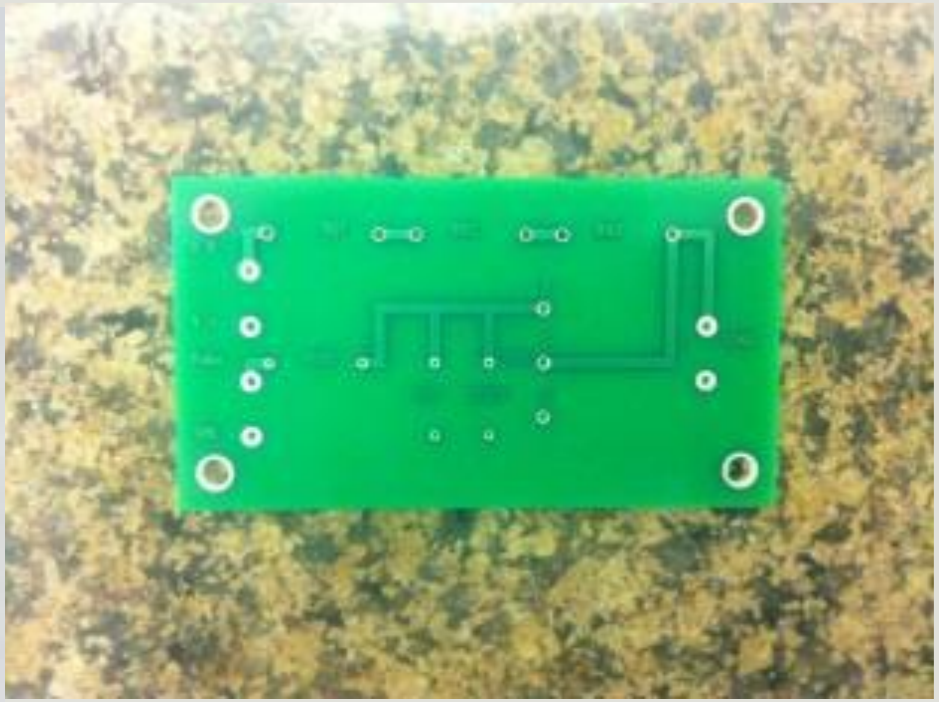
Circuit Testing and Finalization

- We will continue to use a breadboard (left) for testing, and design and fabricate a printed circuit board (right) for the final design





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Potential Challenges/ Safety

Safety

- High voltages/currents
- High temperatures
- Ar gas – asphyxiant

Challenges

- Multiple tests necessary
- More experience in testing procedures required
- Properly sealing vacuum chamber

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Procurement

Component	Description	Quantity	Cost	Manufacturer
Cathode	Tungsten Rod, 3/16" x 6" P#8788A153	2	$ 33.24	McMaster Carr
	Stainless Steel 303, 3/16" x 6' P#8984K93	1	$ 7.77	McMaster Carr
Anode	SS Steel Tube 1/2 OD, 0.37 ID 3' P# 9220K461	1	$ 8.79	McMaster Carr
Hose Fitting from Baseplate Fitting	3/8" Threaded Female Hose Fitting P# 5346K85	1	$ 11.00	McMaster Carr
Vacuum Gauge	Bottom Connection Vacuum Gauge P#4004K62	1	$ 10.61	McMaster Carr
Vacuum Grease	High-Vacuum Grease 5.3 oz. P#2966K52	1	$ 26.68	McMaster Carr
Argon Hose	3/8" ID x 5' Hose P#5304K24	1	$ 6.10	McMaster Carr
Mounting Pipe	2.375" OD, 2.157" ID X 12" P# 4561T611	1	$ 22.58	McMaster Carr

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Procurement Cont.

Housing/Nozzle	Stainless Steel 303, 2' Diameter, Stock P#8984K573	1	$ 79.64	McMaster Carr
Gasket	All Purpose Sheet Gasket 6"x6" P# 9470K26	2	$ 6.02	McMaster Carr
Bolts (Anode)	P# 92185A078	1	$ 3.23	McMaster Carr
Mating Bolts	P# 92185A546	1	$ 5.43	McMaster Carr
Nuts for Mating Bolts	P# 91845A029	1	$ 4.57	McMaster Carr
Insulation	Macor Rod P#8489K81	1	$ 72.95	McMaster Carr
IGBT	P#IRG7PH30K10DPBF	1	$ 8.73	Digi-Key
Inductor	100.0 µH, 6 A P#1410460C	1	$ 2.62	Digi-Key
Switch	P#C3900BA	2	$ 8.92	Digi-Key
Potentiometer	P#AVT20020E200R0KE	2	$ 31.24	Digi-Key
		TOTAL	**$ 350.12**	

Remaining Budget $ 149.88

Chris Brolin

Future Plans – Spring 2014

- Machining baseplate and mounting apparatus
- Create test and troubleshooting plan
  - Sponsor visit within next two weeks
- Measure resistance of plasma
  - Determine whether to insert additional resistor or transconductance amplifier
- Determine thrust output and range of operating conditions

Chris Brolin

Questions?