#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 – 11/21/13

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Agenda

- Background
- Objectives
- Mechanical Design
- Electrical Design
- Procurement
- Potential Challenges / Safety
- Future Plans
- Summary

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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 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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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 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

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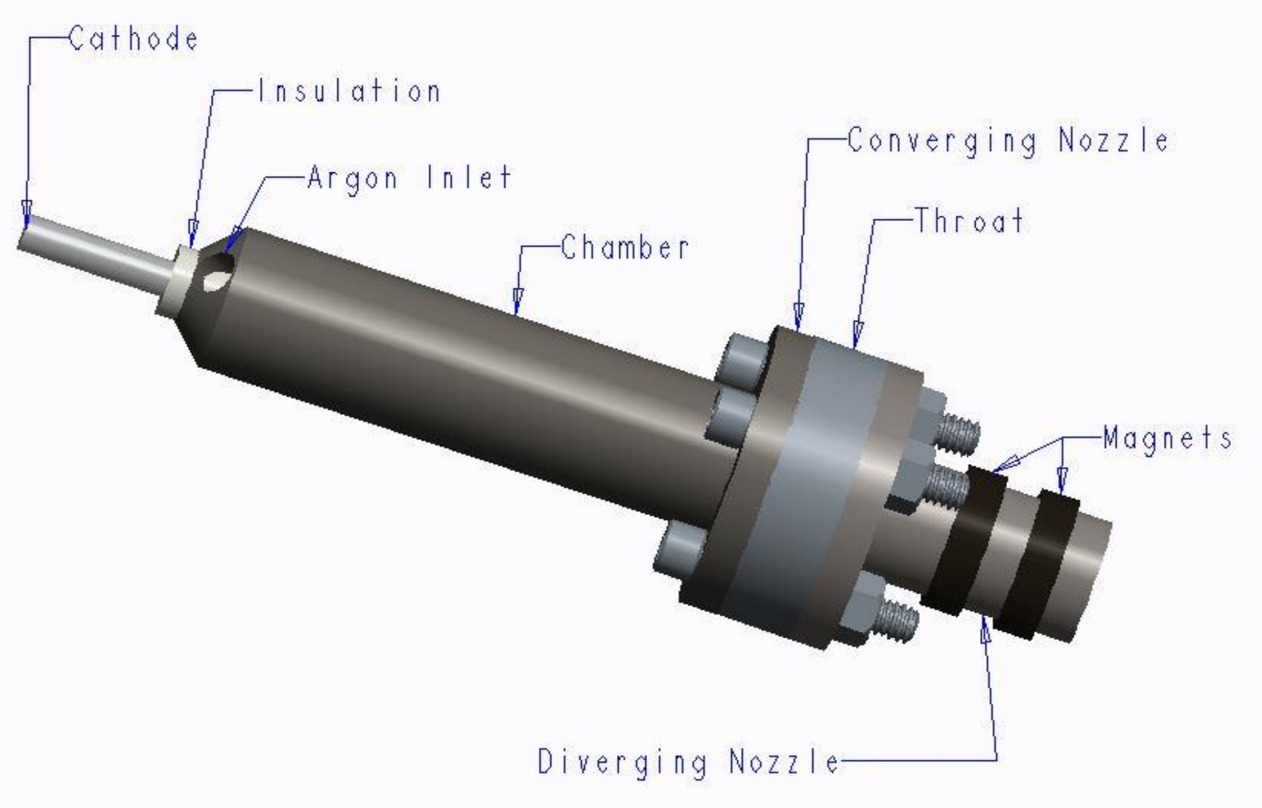
Thruster Design



Characteristics

- Gas injected at angle
- Annular anode insulated from rest of nozzle
- Magnets more evenly spaced over nozzle
- Nozzle designed for Mach 2
  - Area ratio = 1.531
- Stagnation pressure - 550 Pa
- Static Pressure at throat – 267 Pa
- Anode/Cathode Spacing – 0.15”
- Easy to manufacture

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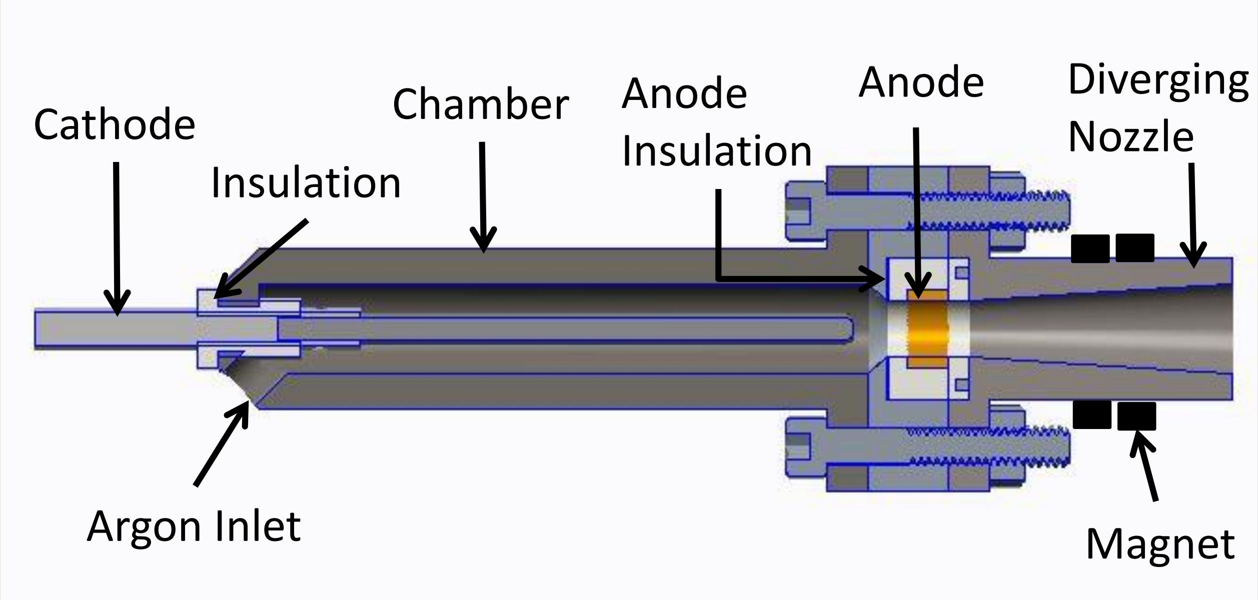
Thruster Design



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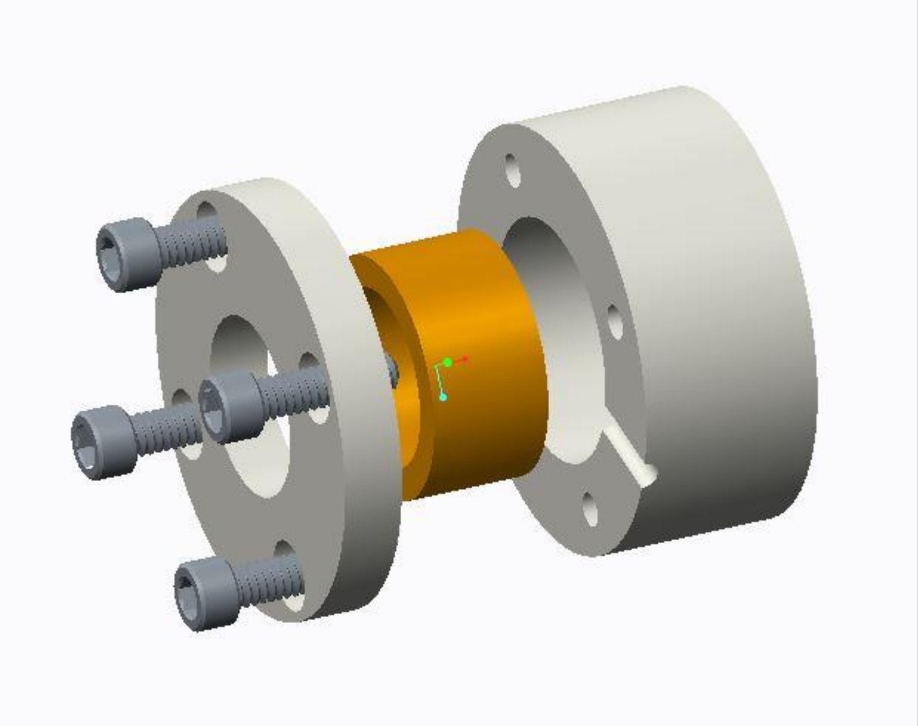
Machining Considerations

- Anode Assembly
  - Allows anode to be insulated yet easily accessible



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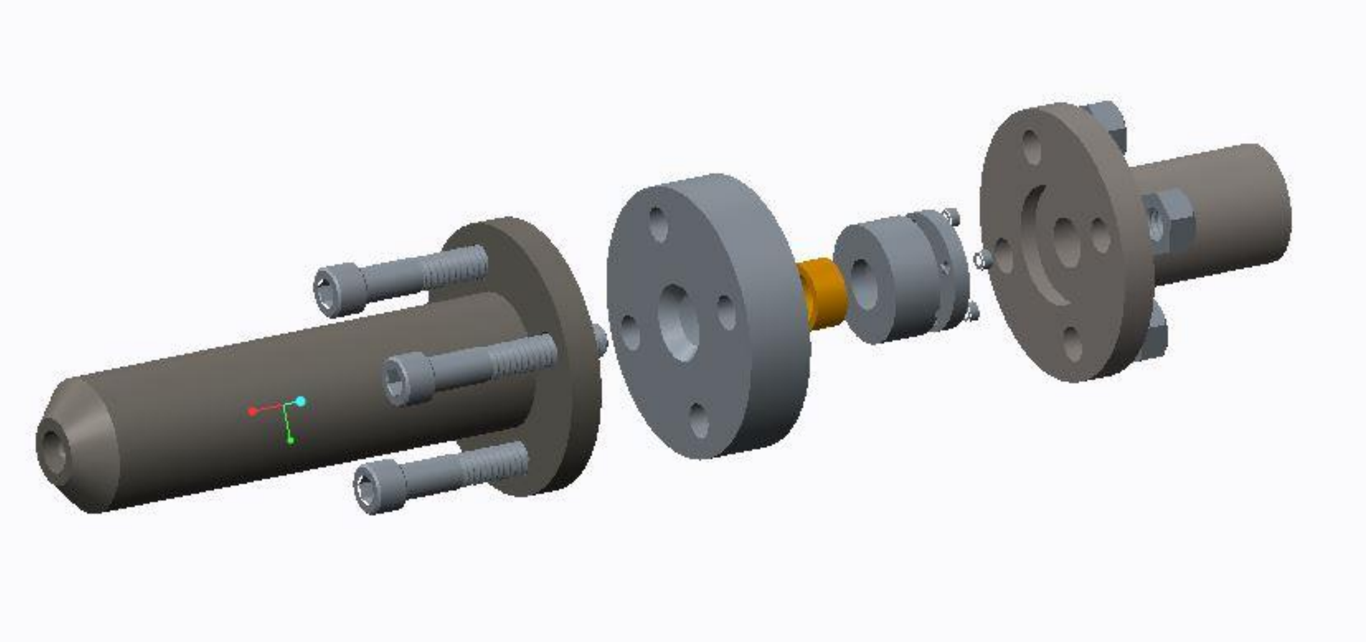
Machining Considerations

- Nozzle Construction
    - Three main components
        - Converging
        - Throat
        - Diverging



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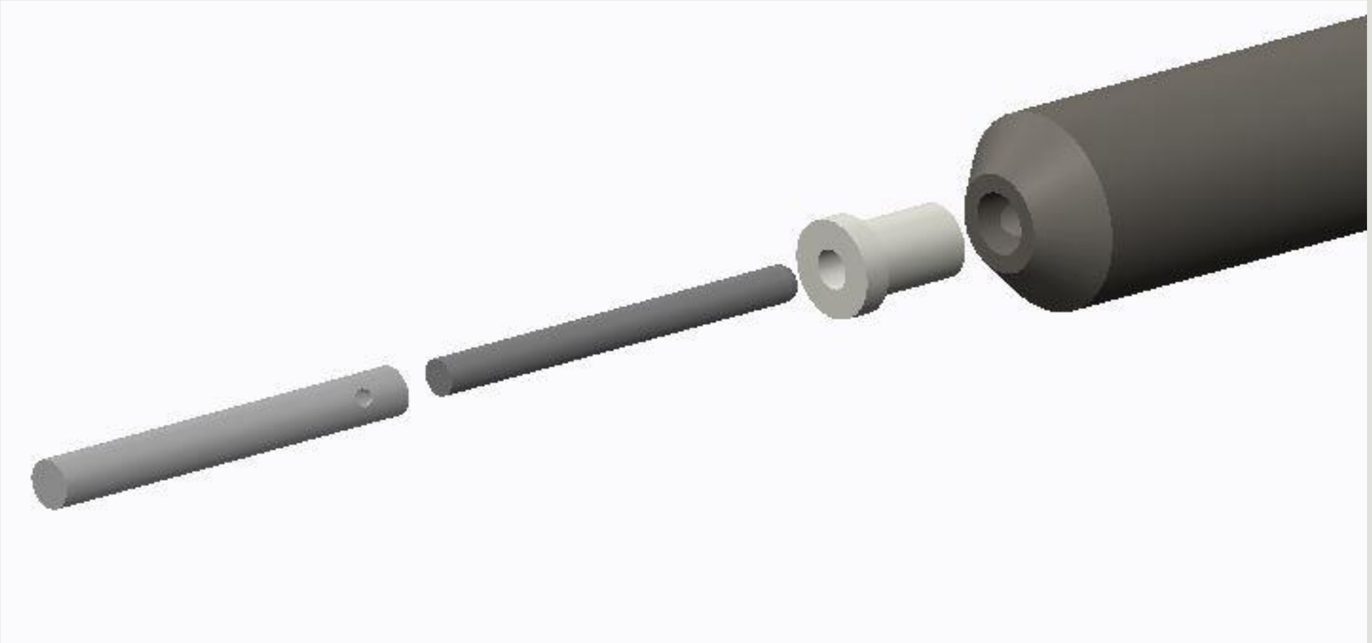
Machining Considerations



- Cathode Placement
    - Adjustable with threads
- Cathode Holster
    - Avoid machining tungsten

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Mechanical Design

Component	Material
Cathode	Tungsten
Anode	Stainless Steel
Fuel Supply	Argon Gas
Heating Chamber	Stainless Steel
Insulation	Macor (Glass Ceramic)
Nozzle	Stainless Steel
Vacuum Chamber	Glass Bell Jar

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Testing Apparatus

Vacuum Chamber

- Bell Jar
- Borrowed from Dr. Weatherspoon
- Chamber will be evacuated to 0.5 torr
- Argon and electrical connection input through baseplate

Vacuum Pump

- Dekker RVL020H
- Vacuum to 0.5 torr
  - Pb = 66 Pa

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Electrical Designs

2 Major Designs Needed

1.) Design a circuit that uses the four Aleko 100 W solar panels to first generate a voltage spike across the anode-cathode region high enough to achieve breakdown of the gas, and then produces a high enough current to maintain the plasma field

2.) Design a magnet configuration that focuses the positive ions in order to both increase thrust and also protect the thruster from the heat

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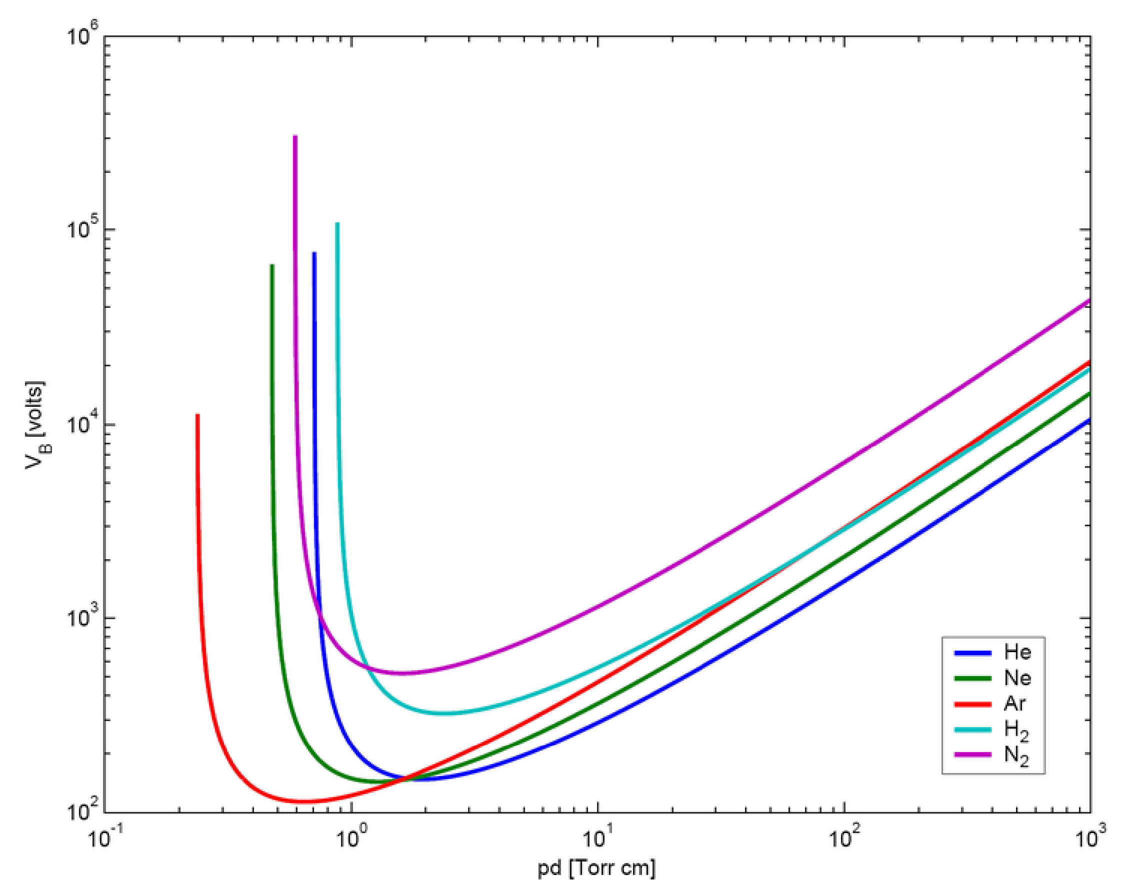
Paschen’s Law



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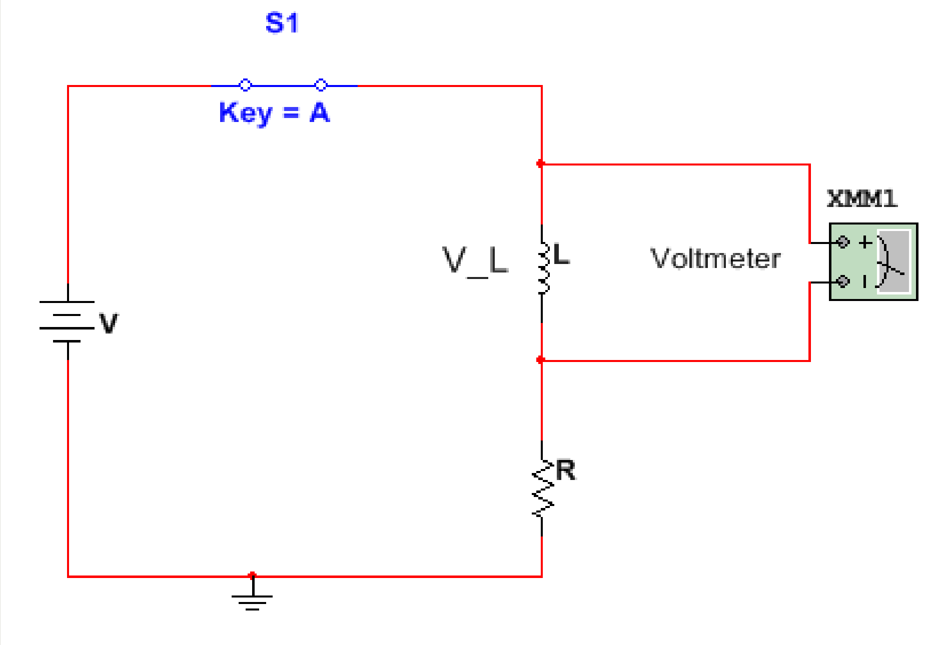
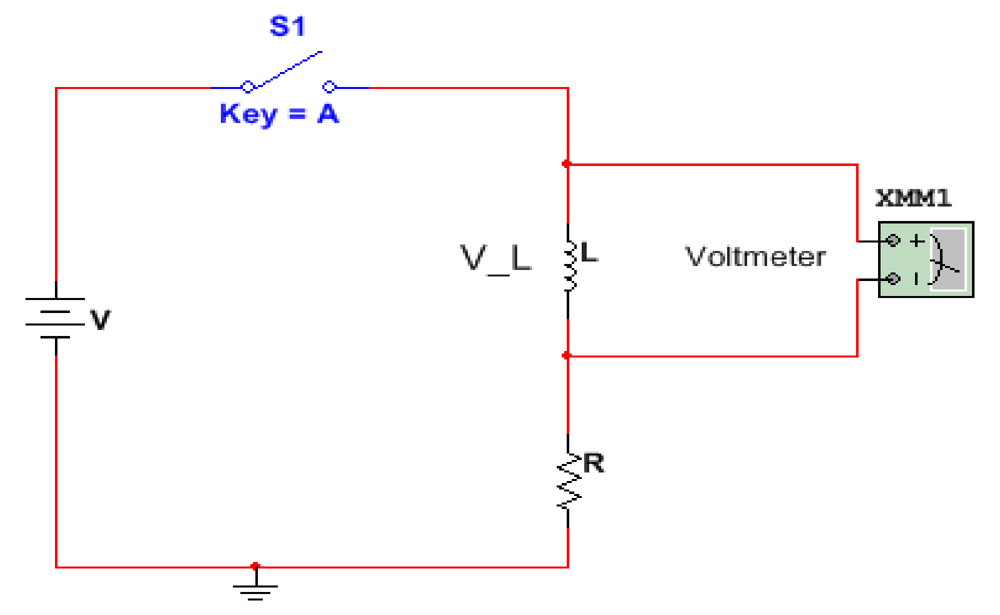
Inductor Properties





Once in steady state: I = $\frac{V}{R}$

When the switch opens: $V\_L = L\frac{di}{dt} = L\frac{I-0}{dt}$

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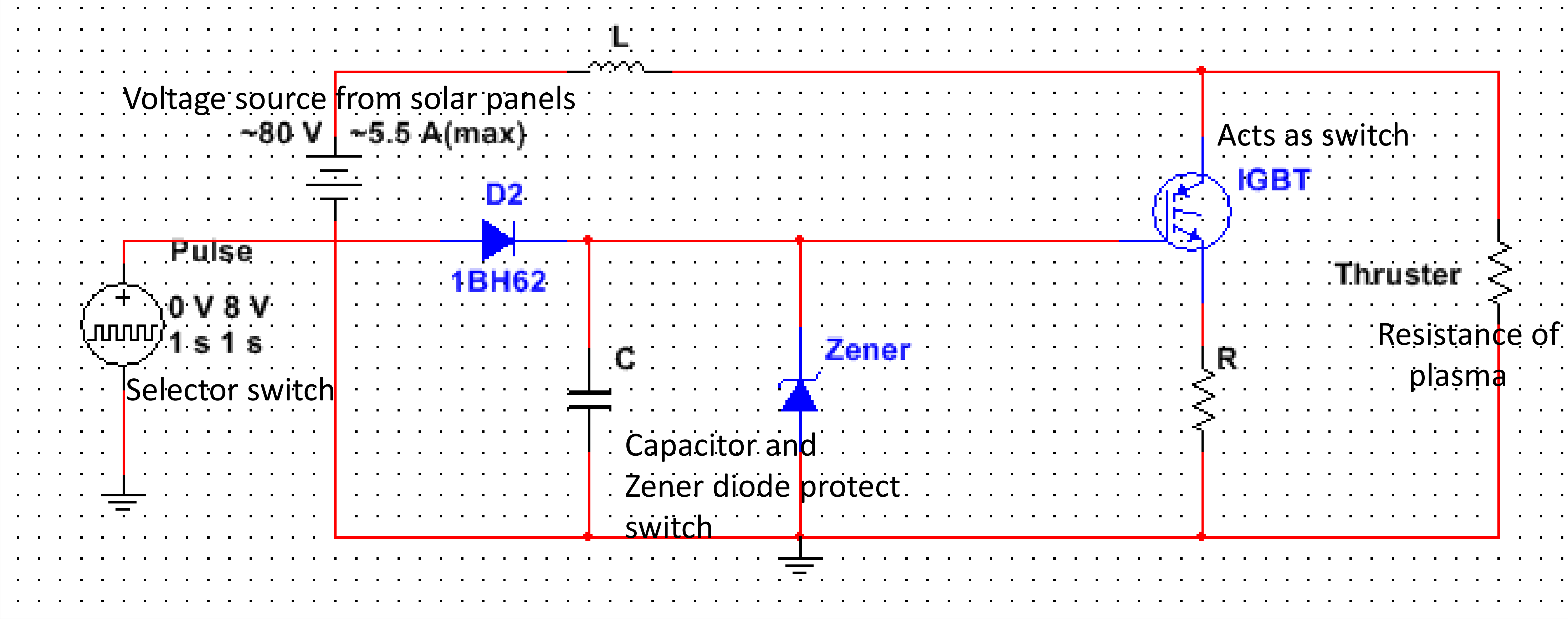
Final Circuit Design



Voltage source from solar panels

Acts as switch

Selector switch

Capacitor and Zener diode protect switch

Resistance of plasma

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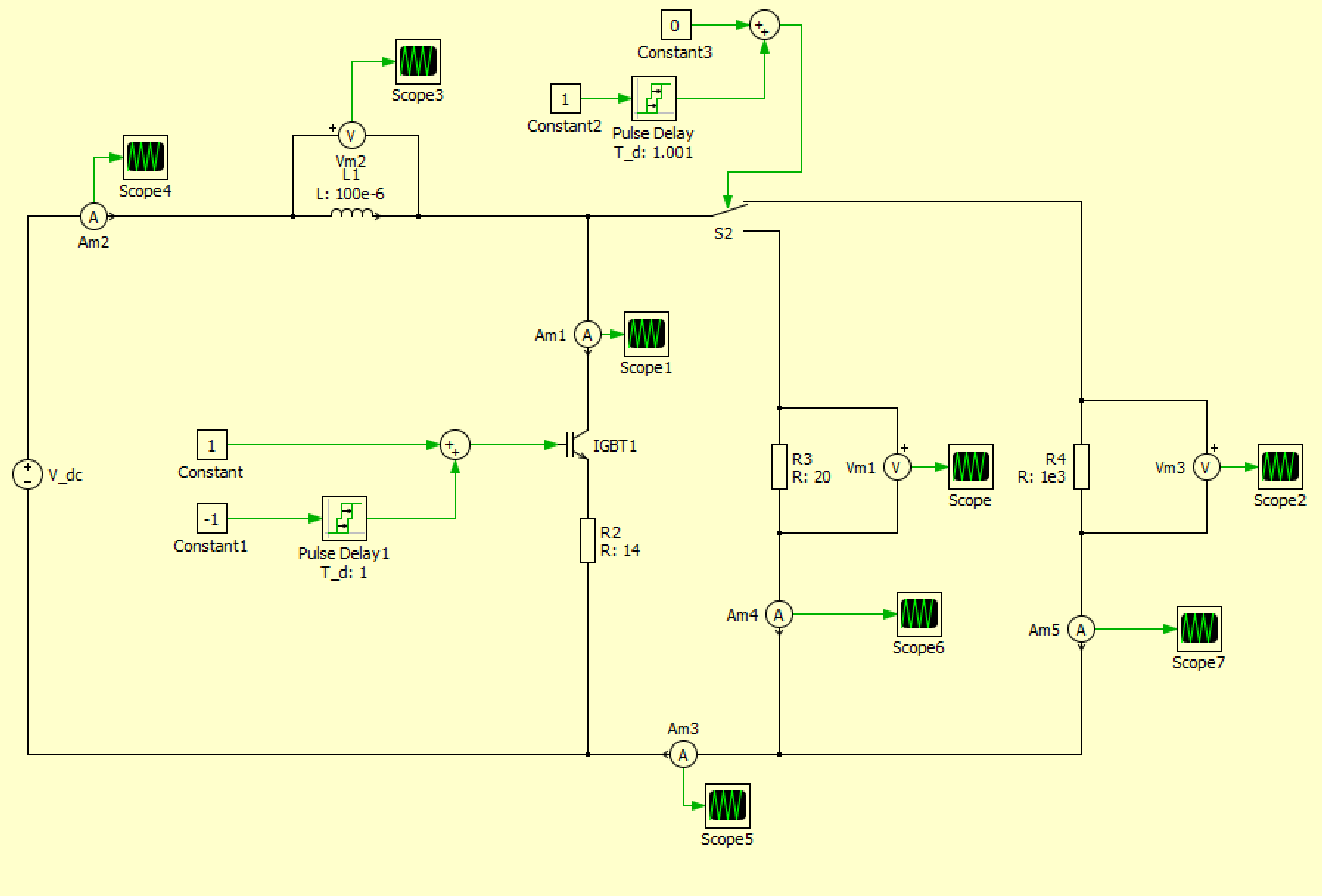
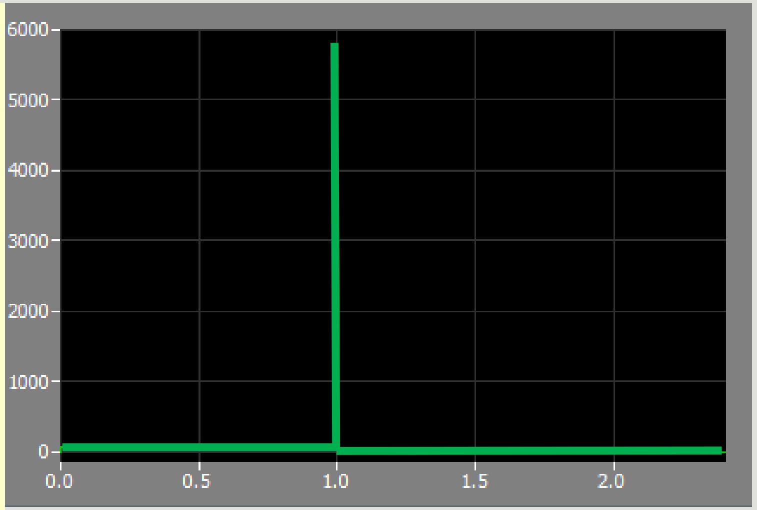
Circuit Simulation using MATLAB





Voltage spike of 5.9kV in MATLAB

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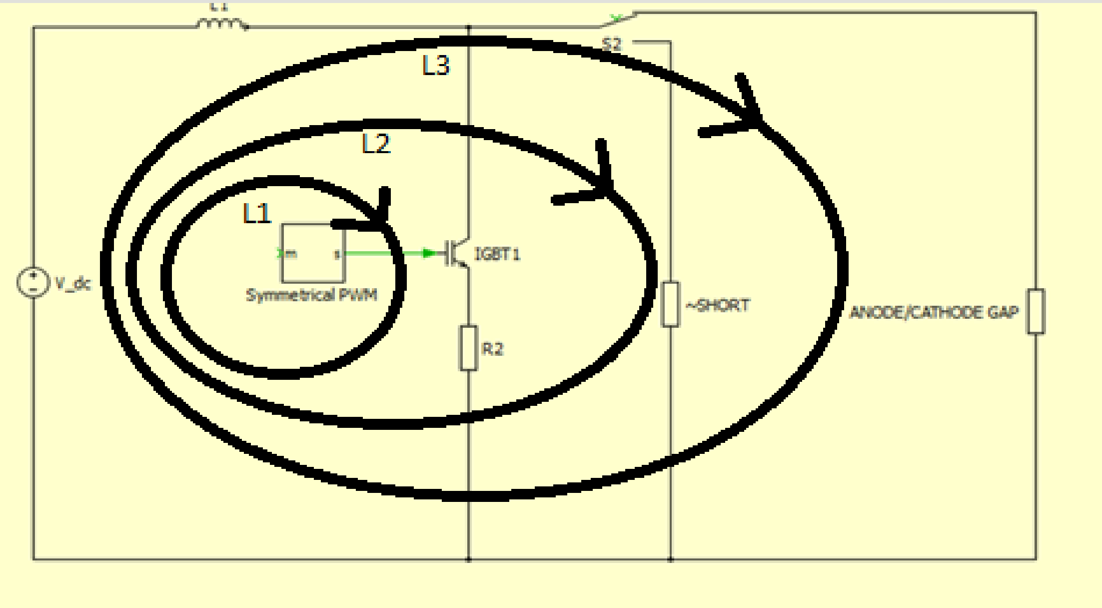
Circuit Analysis

- The magnitude of the voltage spike is incorrect.
- Can be calculated using KVL in loop L3 as:
- V_breakdown = V_dc + L$\frac{di}{dt}$
- V_breakdown ≅ V_dc + L$\frac{V_{dc}}{R_2 * dt}$
- V_breakdown = 80V + 100µH$\frac{80V}{R_2 * 130ns}$
- When R2 = 1.1kΩ, V_breakdown = 136V
- When R2 = 65Ω, V_breakdown = 1.0kV



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Component Values Output Range

L = 100 uH

R = 15 to 400 Ω

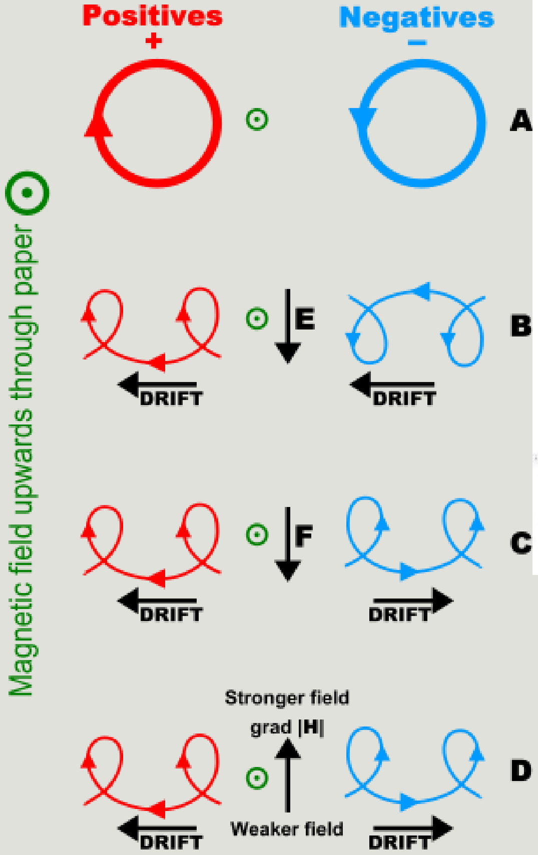
di = 0.2 to 5.5 A

dt = 130 ns (max)

Vmax = 4230 V

Vmin = 153.8 V

Magnet Design



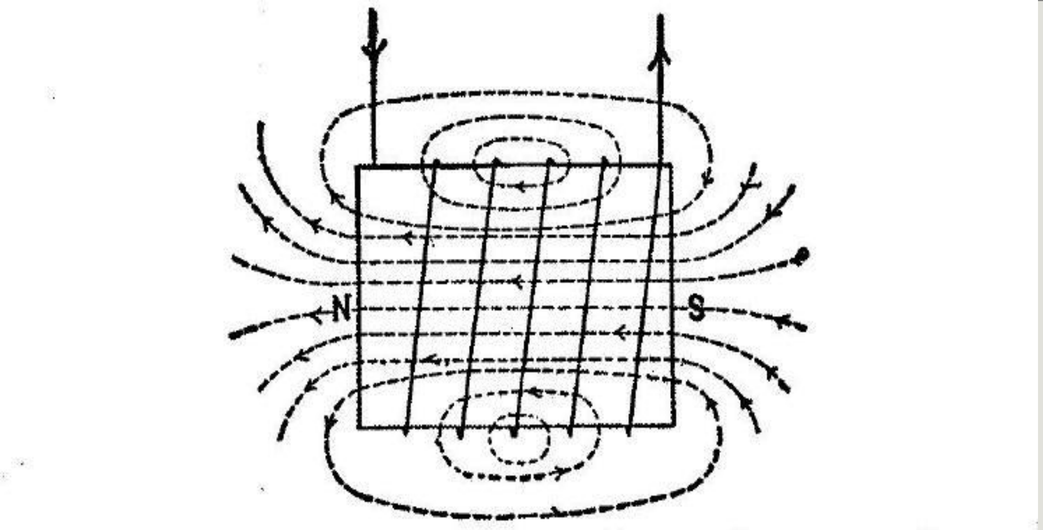


Fig. 145. DIAGRAM OF AN ELECTRO-MAGNET SHOWING RELATION OF CURRENT AND WINDING TO ITS POLARITY AND LINES OF FORCE.

The 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 = 3/r mT.

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Procurement

Component	Description	Quantity	Cost	Manufacturer
Cathode	Tungsten Rod, 3/16" x 6"	2	$ 33.24	McMaster Carr
	Stainless Steel 304, 3/16" x 6'	1	$ 9.36	McMaster Carr
Anode	SS Steel Tube 1/2 OD, 0.37 ID 3' P# 9220K461	1	$ 8.79	McMaster Carr
Argon Gas Cylinder	20 CF, Welding Cylinder	1	$ 77.00	Welding Supplies from IOC
Argon Gas	20 CF Fill	1	TBD	TBD
Hose	High/Pressure Vacuum Hose	1	$ 29.17	McMaster Carr
Hose Fitting	Outlet Fitting, Right Hand Thread, Brass	1	$ 1.23	McMaster Carr
Housing/Nozzle	Stainless Steel 304, 2' Diameter, Stock	1	$ 56.50	McMaster Carr
O-Ring	High Temp Buna-N O-Rings, 1" OD, 3/32" Width	2	$ 18.24	McMaster Carr
Bolts (Anode)	P# 92185A078	1	$ 3.23	McMaster Carr
Bolts	Stainless Steel 316, Fully Threaded, 7/8" Long, 1/4"-20 Thrad	1	$ 5.23	McMaster Carr
Nuts	Stainless Steel 18-8, Easy-On Flange Hex Locknuts, 1/4"-20 Thread	1	$ 7.78	McMaster Carr
Insulation	Macor Rod P#8489K131	1	$ 71.34	McMaster Carr
IGBT	Part# IRG7PH30K10DPBF	1	$ 8.73	Digi-Key
Inductor	100.0 µH, 6 A PART#1410460C	1	$ 2.62	Digi-Key
Switch	PART# C3900BA	2	$ 8.92	Digi-Key
Potentiometer	Part# AVT20020E200R0KE	2	$ 31.24	Digi-Key
Magnet	Ceramic Ring Magnet, ID 2"	3	$ 11.25	American Science & Surplus
		TOTAL	**$ 383.87**	

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Potential Challenges/ Safety

Safety

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

Challenges

- Lots of assumptions
- Multiple tests needed

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Future Plans

- Order materials
- Test voltage spike of circuit
- Measure resistance of plasma
  - Determine whether to insert additional resistor or transconductance amplifier
- Design mounting and thrust measurement apparatus
- Create test plan

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Questions?

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