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Underwater Wireless Power Transfer

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EECE 401 Senior Design II
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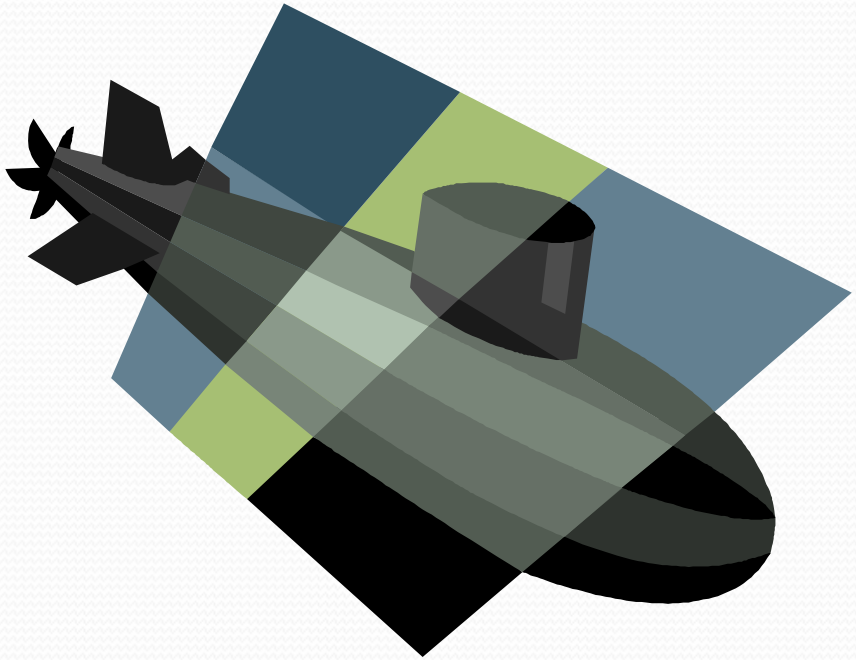
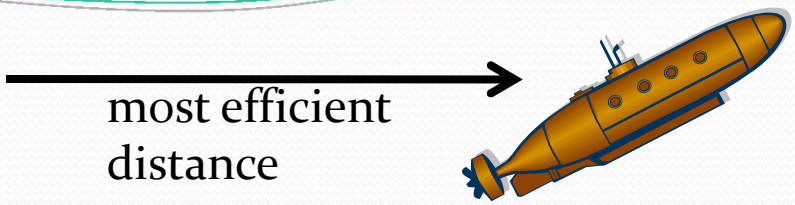
April 20, 2009

Overview

- Introduction
- Top Solution Selection
- Design and Implementation
- Evaluation
- Recommendations
- Conclusion
- Acknowledgements
- Questions



Introduction



Objective:

- Wirelessly connect to an unmanned underwater vehicle (UUV) through inductive power transfer
- Transfer the most power over the greatest distance possible

What is that?

- Contactless between source and object through magnetic induction
  - Same Resonant Frequency
  - Mutual Induction

Why?

- Sponsor : Northrop Grumman
  - Base station
  - Without Resurfacing

Design Requirements

Requirements	Descriptions
Overall Function	To recharge an unmanned underwater vehicle remotely and without use of wires or cables.
Performance	Operable in fresh and sea water Transfer – 100VDC , 10A Depth – 300feet
Cost	Budget - $1000
Safety and Compliance	IEEE Standard C95.1-2005
Energy, Power, and Environment	Most power over greatest distance Radius of Operation – 3feet Safe to biological organisms
Lifespan	25 years
Size, Weight, Maintenance	Between 25-30 lbs, 10in x 10in x 10 in (Rough estimate)

Current Status of Art

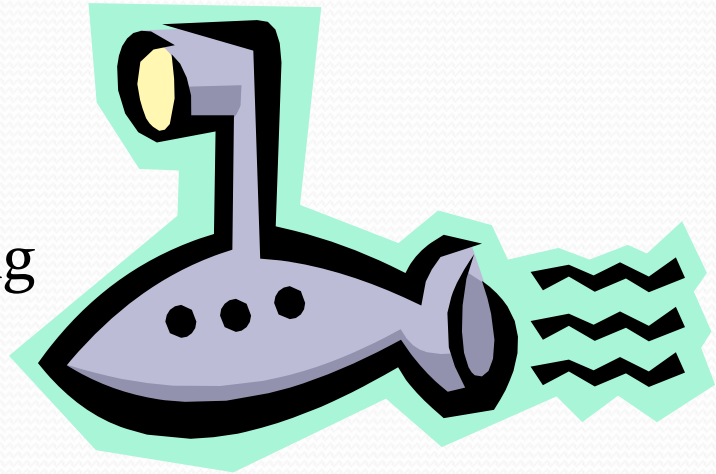
An idea that's been approached in a wide variety of ways…

- Laser Wireless Power Transmission
- Powercast
- eCoupled Technology
- US Patent 6489745 (Contactless Power Supply)
- MIT Inductive Power Transfer Experiment
- US Patent 5301096 (Submersible Contactless Power Delivery System)

Deliverables

Approved Project Proposal	In-Air and underwater research	Design and Simulate Schematics	Order Materials	Build and Test Model	Write Technical Report
Oct '08 – Dec '08	Oct '08 – Jan '09	Dec '08 – Feb '09	Feb '09	Feb '09 – Apr '09	Mar '09 – Apr '09

Overall Scope



- Expand range of travel of UUV
- Recharge battery without resurfacing
- System Goals:
  - Transfer 100 V dc with 10 amps
  - Transmit in a radial range of at least 1 meter
  - Should have a minimum of 80% efficiency
- Finish Date: April 15, 2009 and Budget: $1000

Solution Generation

- Air Tube- Laser Power Transmission
  - Air tube would extend from the base station and connect to the UUV creating an “in-air” medium.
- UUV Turbine Powered – Self Powered UUV
  - Utilizes ocean currents while in motion to recharge
- Radio Wave Power Transmission
  - Radio waves can transmit at low frequencies underwater
  - Dependent on environmental conditions
- Magnetic Inductive Coupling
  - Uses inductive coupling between primary and secondary coil that have the same resonant frequency

Decision Matrix

S.A.A.M.ay 09		Underwater Wireless Electrical Connector Decision Matrix							
		Laser		Turbine		Radio Wave		Inductive Coupling	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Performance	40%	4	1.6	5	2	6	2.4	8	3.2
Price	30%	8	1.6	1	0.2	5	1	9	1.8
Power Generation	20%	3	0.6	7	1.4	5	1	5	1
Durability	10%	7	0.7	8	0.8	9	0.9	5	0.5
Total Score			4.5		4.4		5.3		6.5
Rank			3		4		2		1

Principle & Theory

$$f = \frac{1}{2\pi\sqrt{LC}}$$ *resulting resonant frequency*

$$R_0 = \sqrt{\frac{\mu_0\omega}{2\sigma}}\frac{l}{4\pi a}$$ *ohmic resistance, σ = conductivity of material*

$$R_r = \sqrt{\frac{\mu_0}{\varepsilon_0}}\left[\frac{\pi}{12}n^2\left(\frac{\omega r}{c}\right)^2 + \frac{2}{3\pi^3}\left(\frac{\omega h}{c}\right)^2\right]$$ *radiative resistance, c = speed of light*

$$\Gamma = \frac{(R_0 + R_r)}{2L}$$ *couple − mode theory decay*

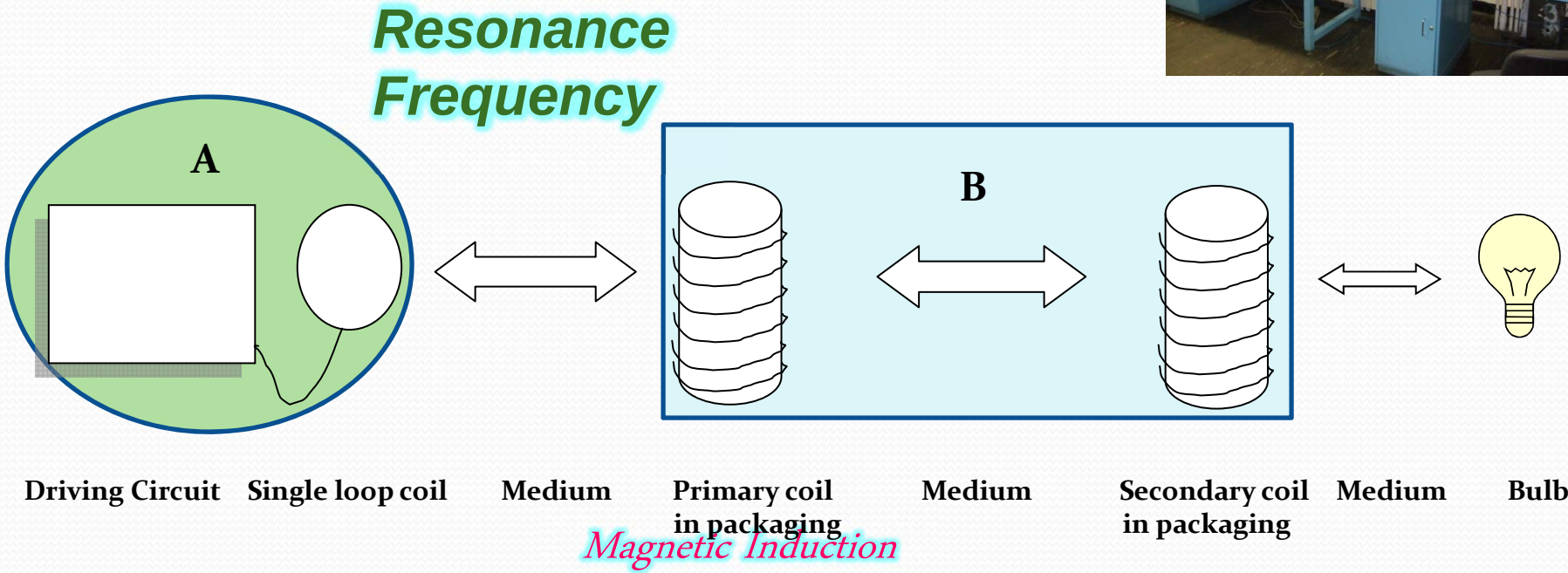
$$P_{s,p} = \Gamma L\left|I_{s,p}\right|^2$$ *calculated power transfer*

$$\kappa_{sp} = \kappa_{ps} = \kappa = \frac{\omega M}{2\sqrt{L_s L_p}}$$ *standard coupled − mode theory*

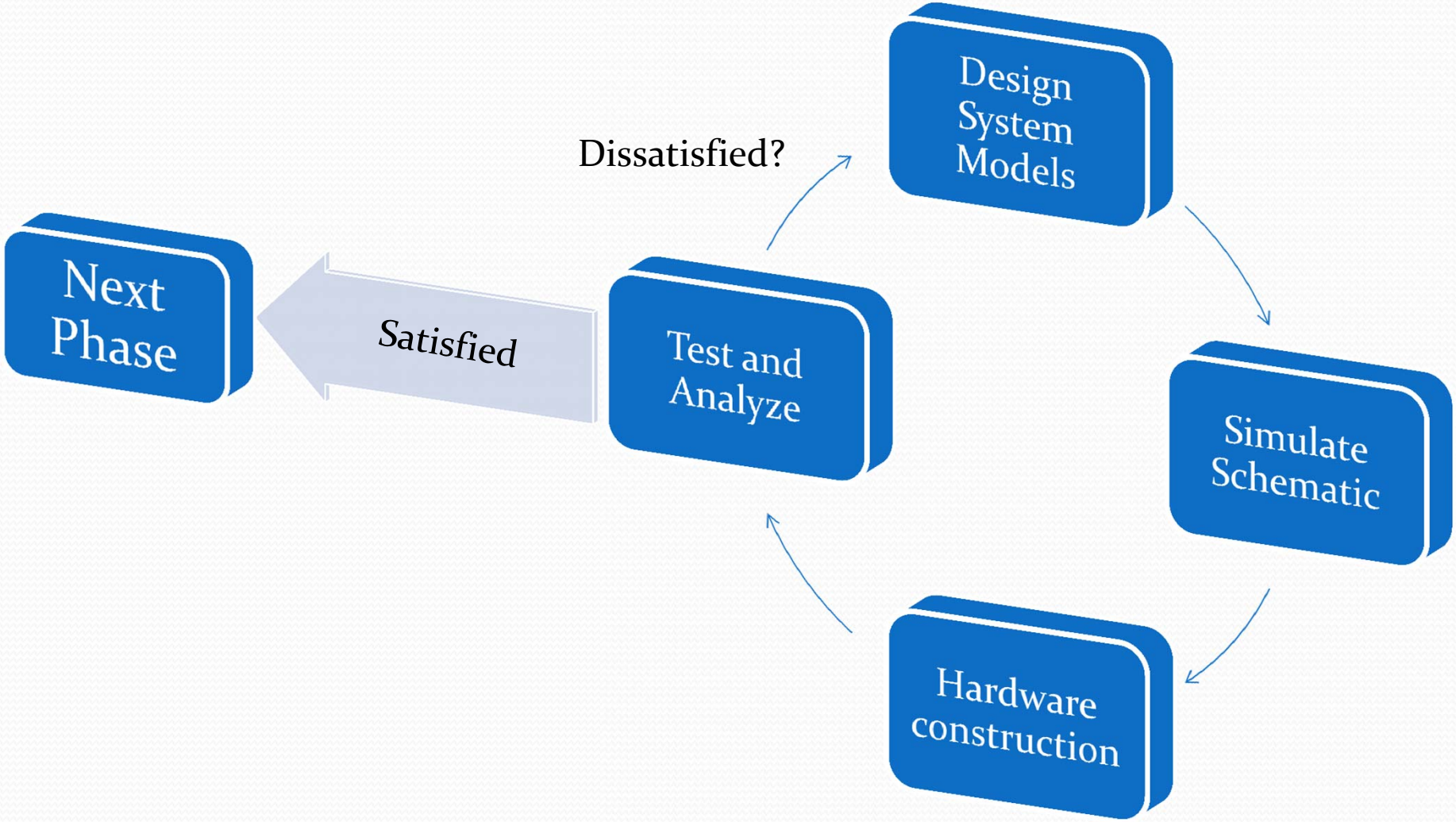
$$\eta = \frac{P_W}{(P_s + P_p + P_W)}$$ *calculated efficiency*

$$\frac{\kappa}{\sqrt{L_s L_p}} = \frac{\kappa}{\Gamma}$$ *for maximum efficiency*

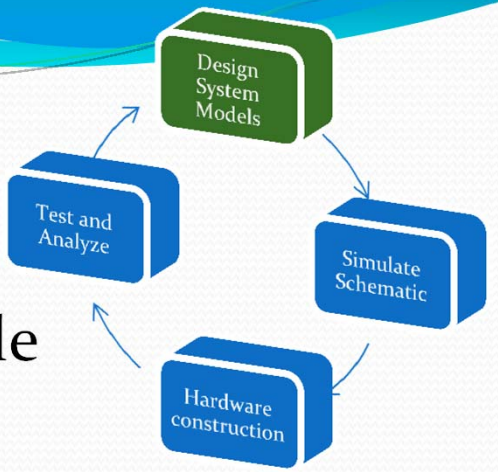
System Design



Design Process

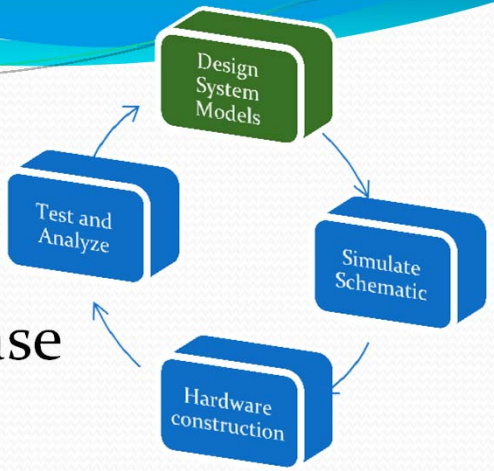


Circuit Design



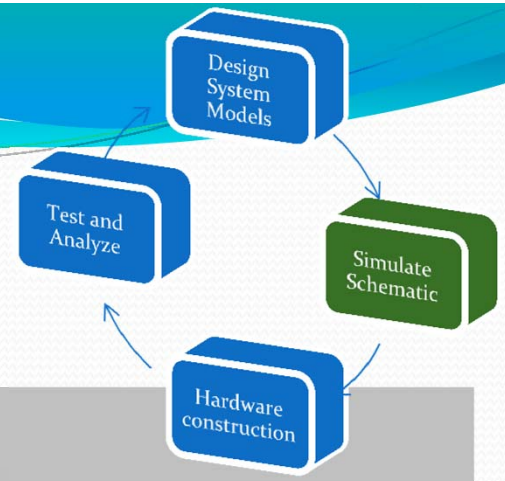
- Used Colpitt's Oscillator – resulted in unstable waveform
- Increased efficiency with square wave – designed "logic oscillator"
- Stable transmission from oscillator across system
- Creates the magnetic coupling within the system
- Originally constructed on March 7th

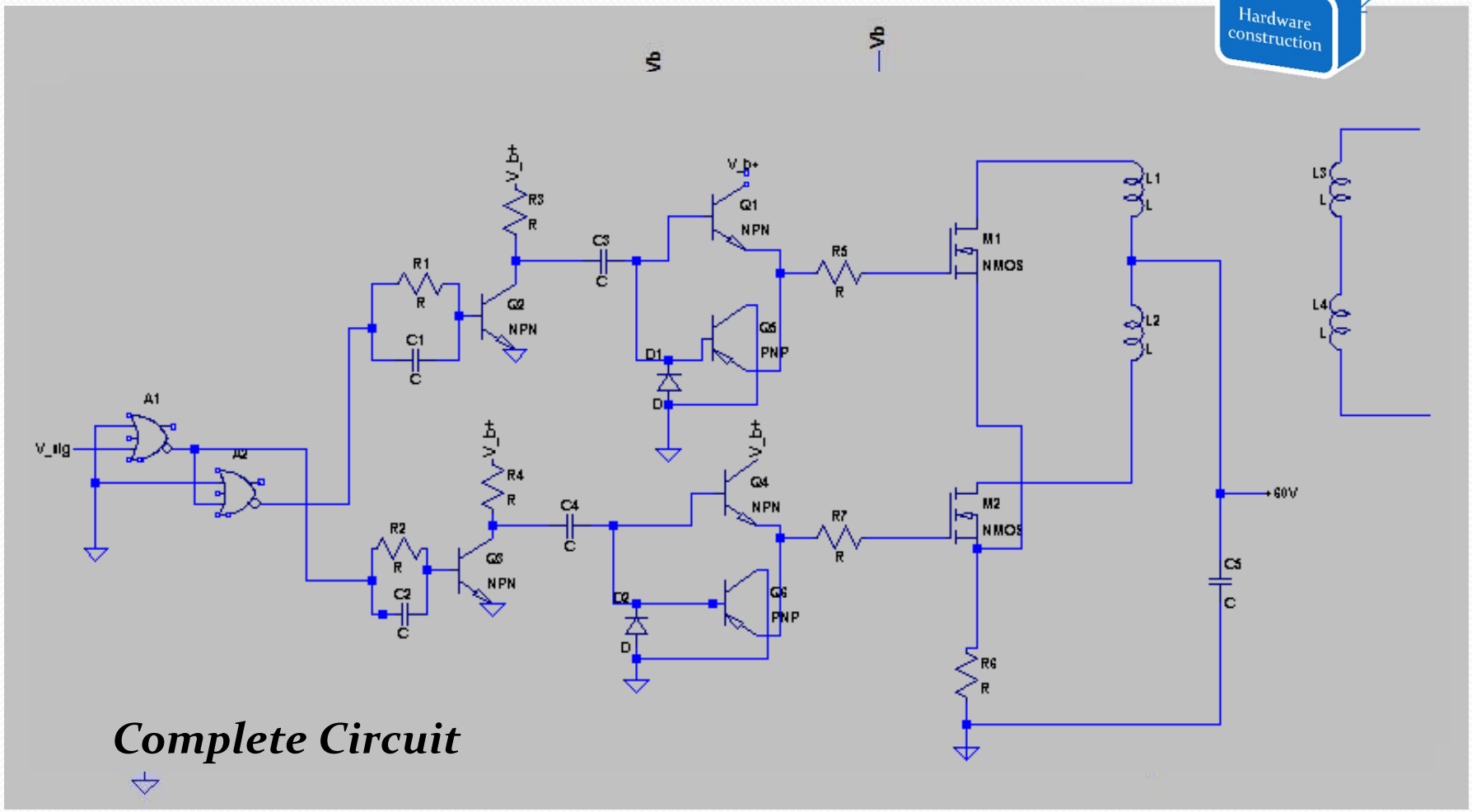
Circuit Design Cont'd



- Push –Pull Converter could potentially increase power transfer across the system
- Use a step-up and step-down transformer
- Connect oscillator, driving circuit, and transformer
- Added a 220μF capacitor in addition to another +60 V input to induce the DC to DC conversion

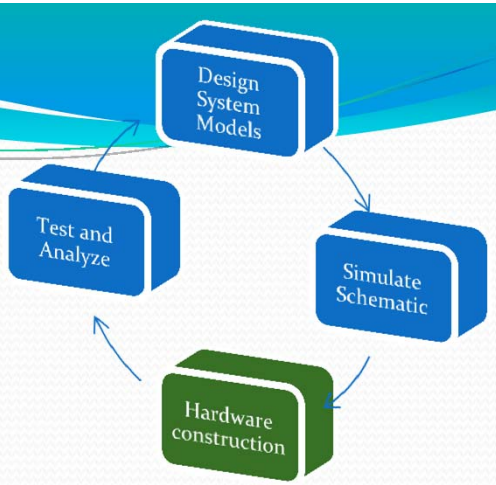
Circuit Schematic

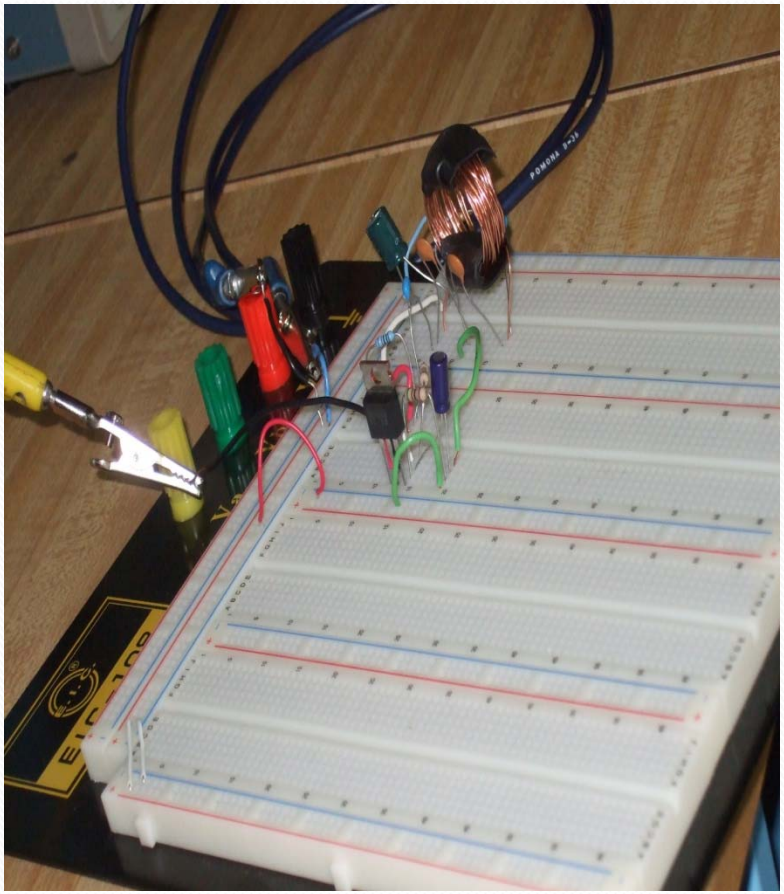




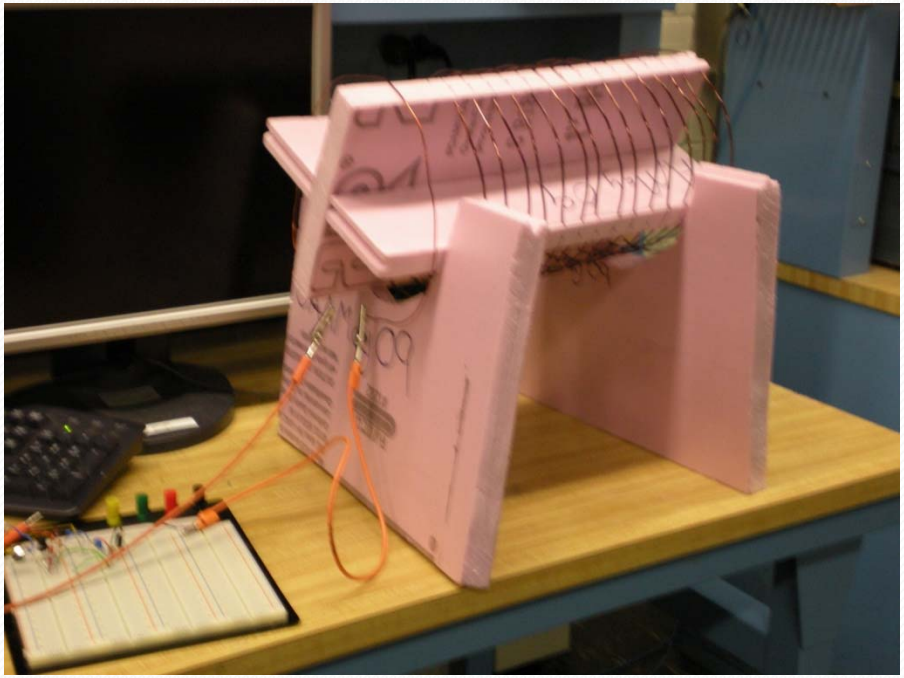
Complete Circuit

Hardware



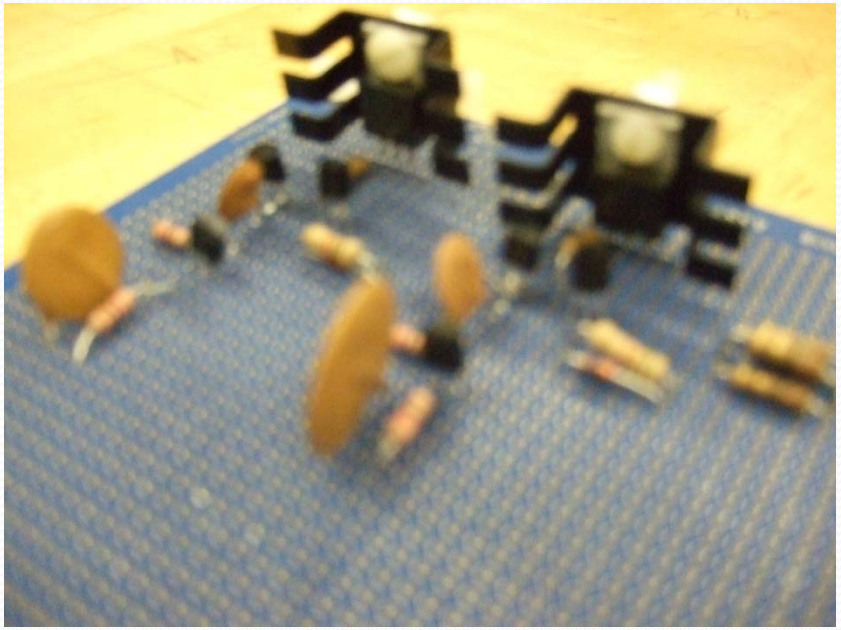


Colpitts Oscillator

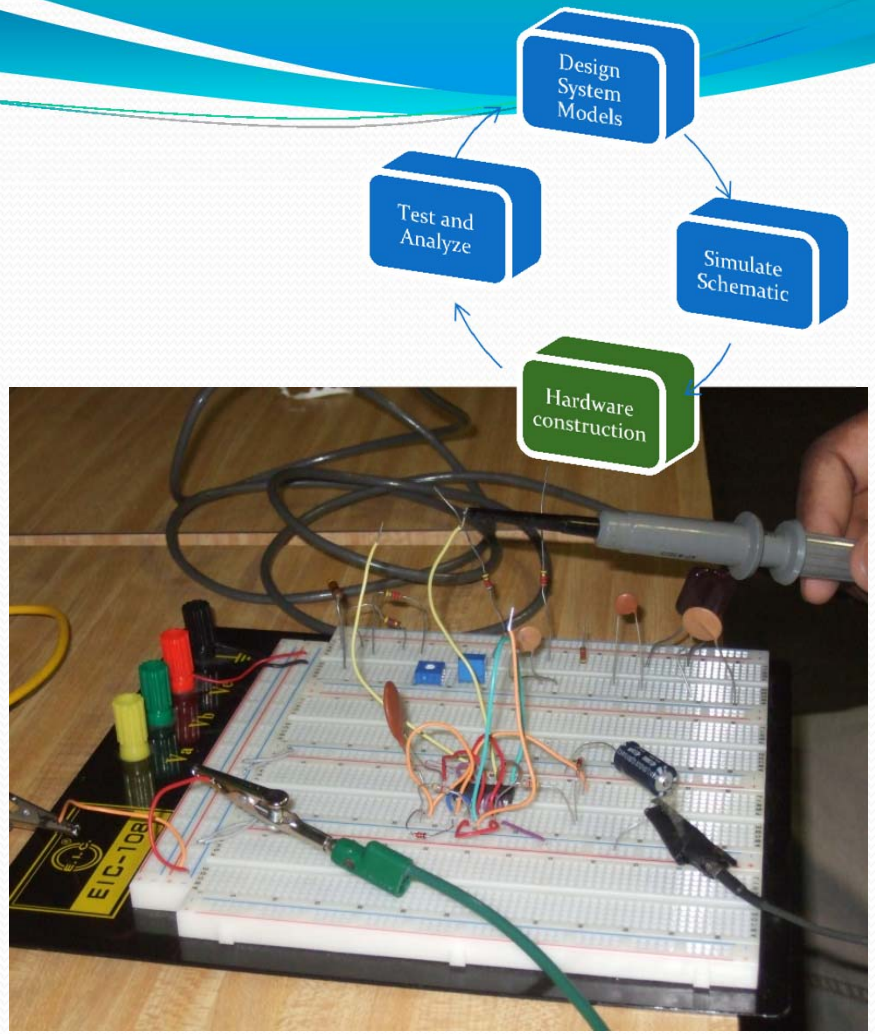


In-Air Coils

Hardware

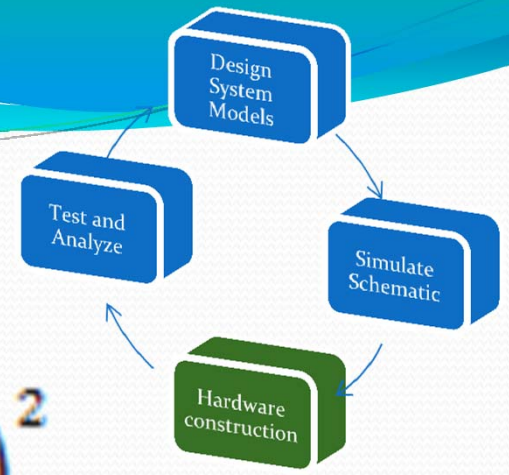


Driving Circuit



Logic Oscillator

Tuning In-Air Coils



$$f = \frac{1}{2\pi\sqrt{LC}}$$

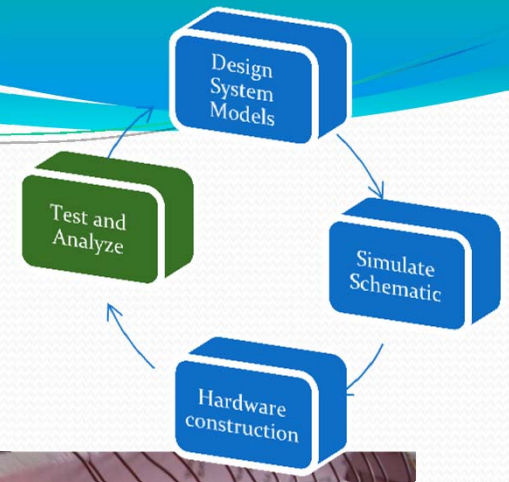
Resonance Frequency Equation

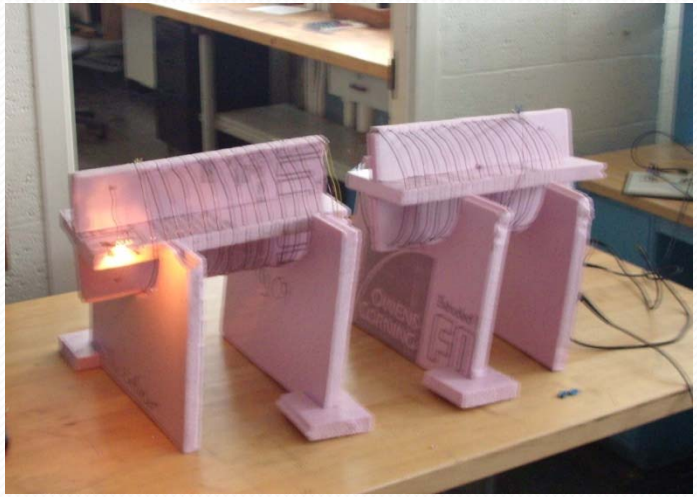
$$C = \frac{\left(\frac{1}{2\pi f}\right)^2}{L}$$

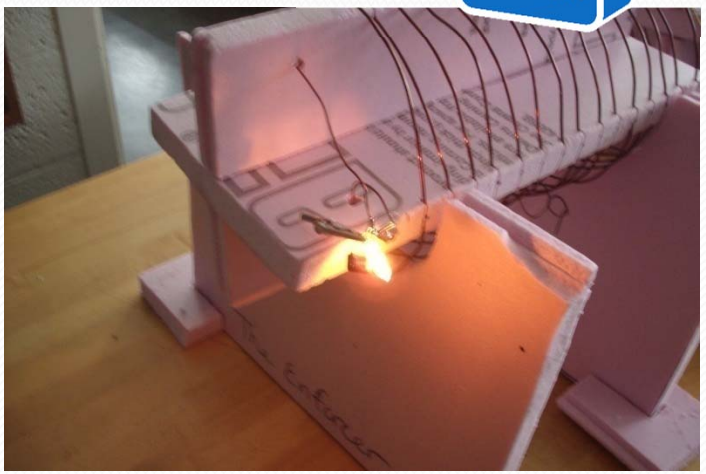
Needed Capacitance Equation

- Calculated needed capacitance on each coil
- Placed capacitor as added turn on coils

Power Transfer

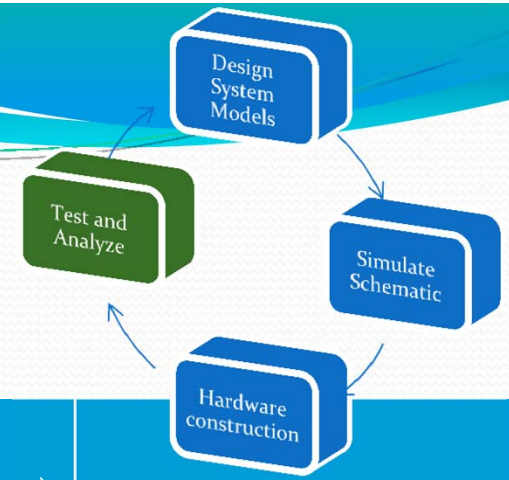






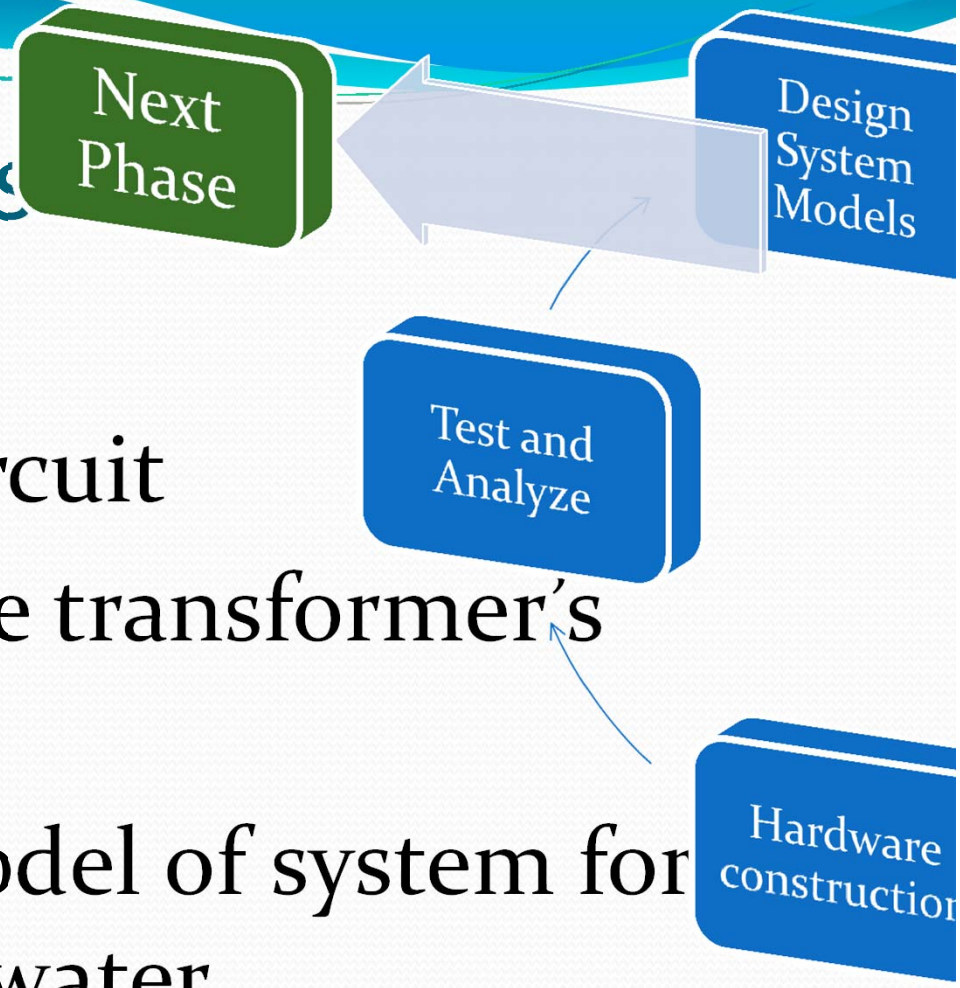
- Tested for resonance frequency using function generator and oscilloscope
- Experimented with the resonance frequency of the inductive coils using RF generator

Contingency Studies



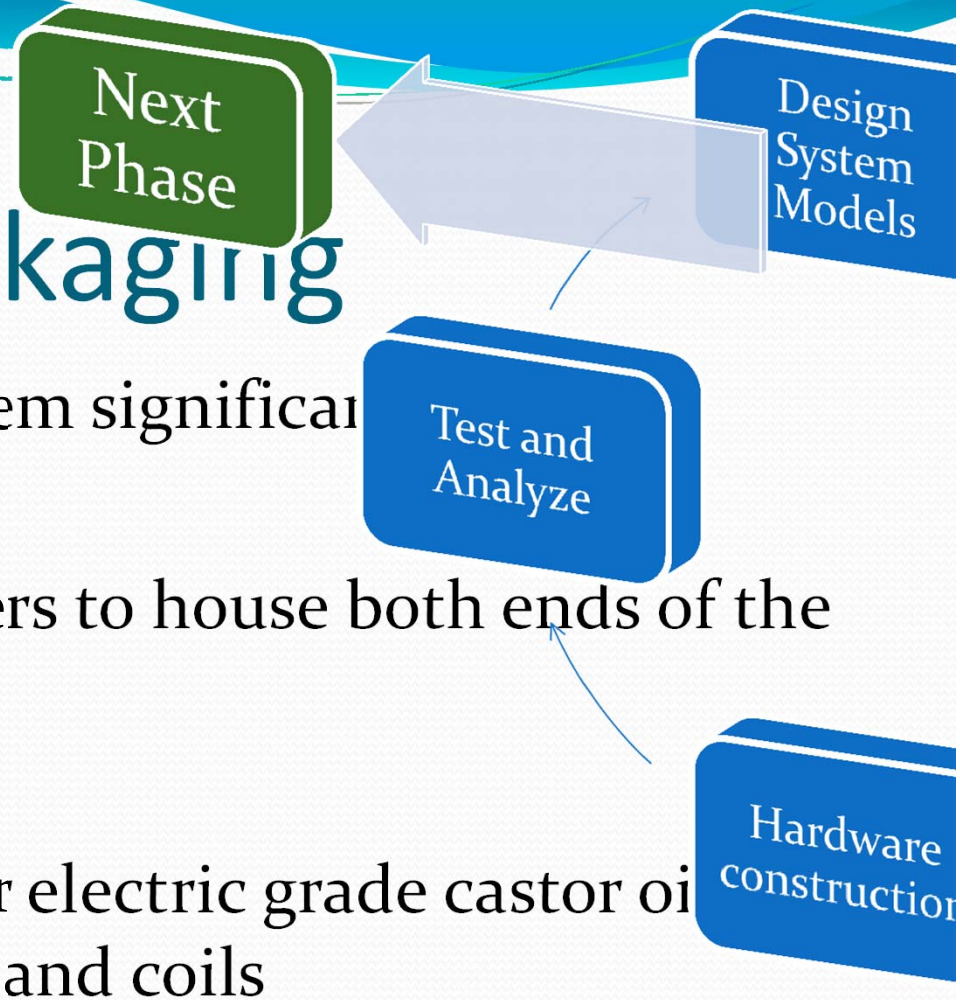
Distance (inches)	Frequency (MHz)	Output Voltage (V)	Output Current (A)	Power Transfer (W)	Orientation
3	1.033	170	2.83	15.15	Series (horizontal)
6	1.016	180	3.00	17.02	Series (horizontal)
12	1.009	50	0.833	1.13	Series (horizontal)
3.5	1.013	100	1.67	5.27	45° Angle
6	1.010	100	1.67	5.27	45° Angle
9	0.990	100	1.67	5.27	45° Angle
10.5	0.992	95	1.58	4.72	Parallel (horizontal)
3.5	0.985	250	4.16	32.72	Parallel (vertical)

Steps to Move Sys Underwater



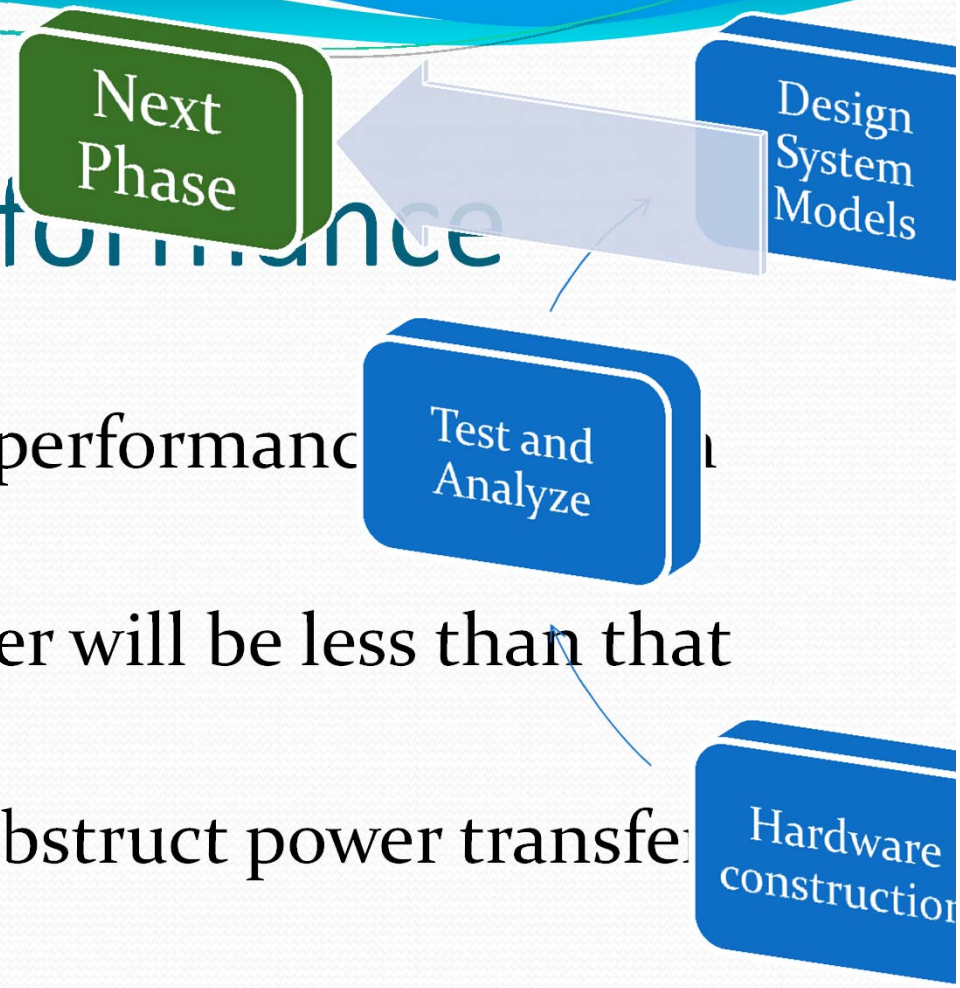
- Stabilize driving circuit
- Successfully test the transformer's capabilities
- Design working model of system for effective use underwater

Underwater Packaging



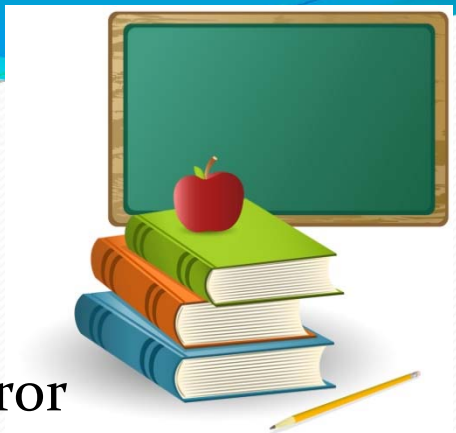
- Reduce the size of the system significan
- Use plastic sealed containers to house both ends of the system
- Possible use of vegetable or electric grade castor oi dielectric buffer for circuit and coils

Underwater Performance



- Possible that underwater performance would suffer underwater
  - Permeability of sea water will be less than that of air ($4\pi_E$-7 H/M)
  - Water molecules may obstruct power transfer between coils

Lessons Learned



- Technically
  - Building circuits required extensive trial and error
  - Team was dependent on electronic components' performance
- Managerially
  - Use time wisely in conjunction with other courses
  - Focus on attainable goals in order to make significant progress
  - Project required a lot time to completely cover the scope of work
- Socially
  - Team work
  - Effective communication

Conclusion

- Made significant progress but a lot more can be made
- Adhere to design requirements
- Great learning process

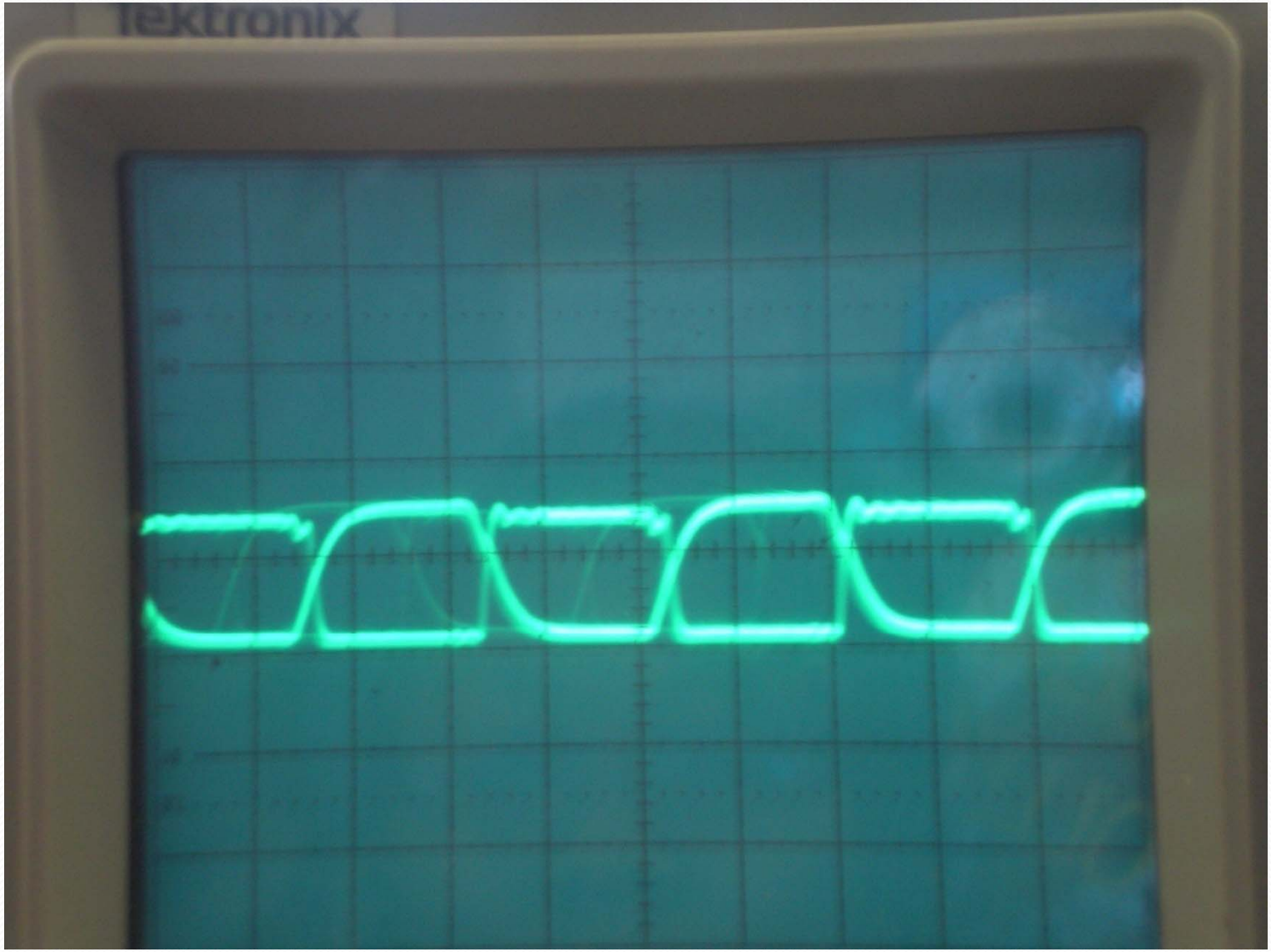
Conclusion / Recap

- Proposed Project
- Top Solution Selection
- Implementation
- Evaluation
- Future Work
- Conclusions
- Questions

Acknowledgements

- Mr. Allen Kelly — Northrop Grumman
- Mr. Gregory West — Northrop Grumman
- Dr. Charles Kim — Howard University
- Dr. Mihai Dimian — Howard University
- Mr. Iverson Bell — Howard University

Questions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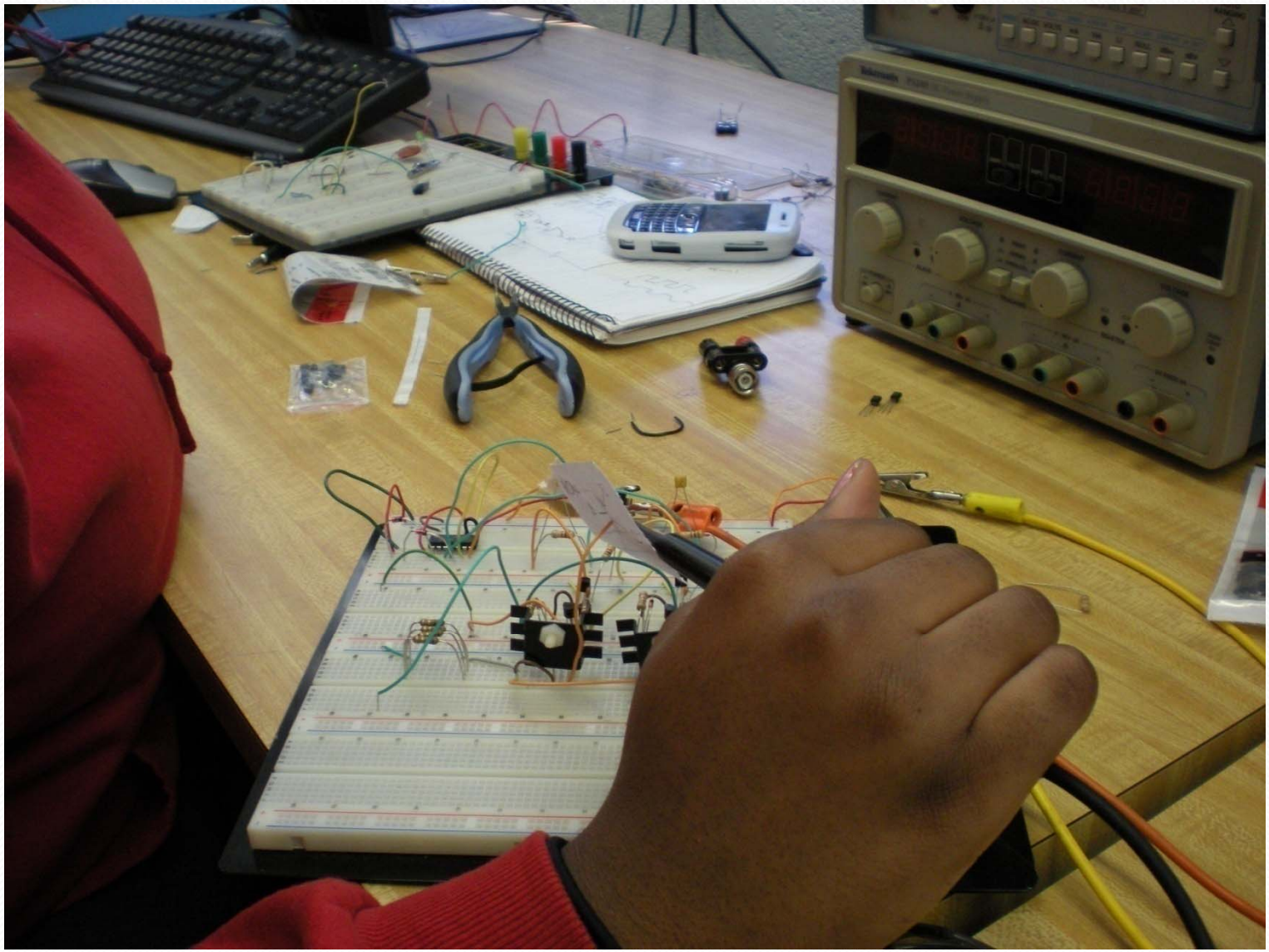

SAAMay09
Polystyrene Insulation
Amular
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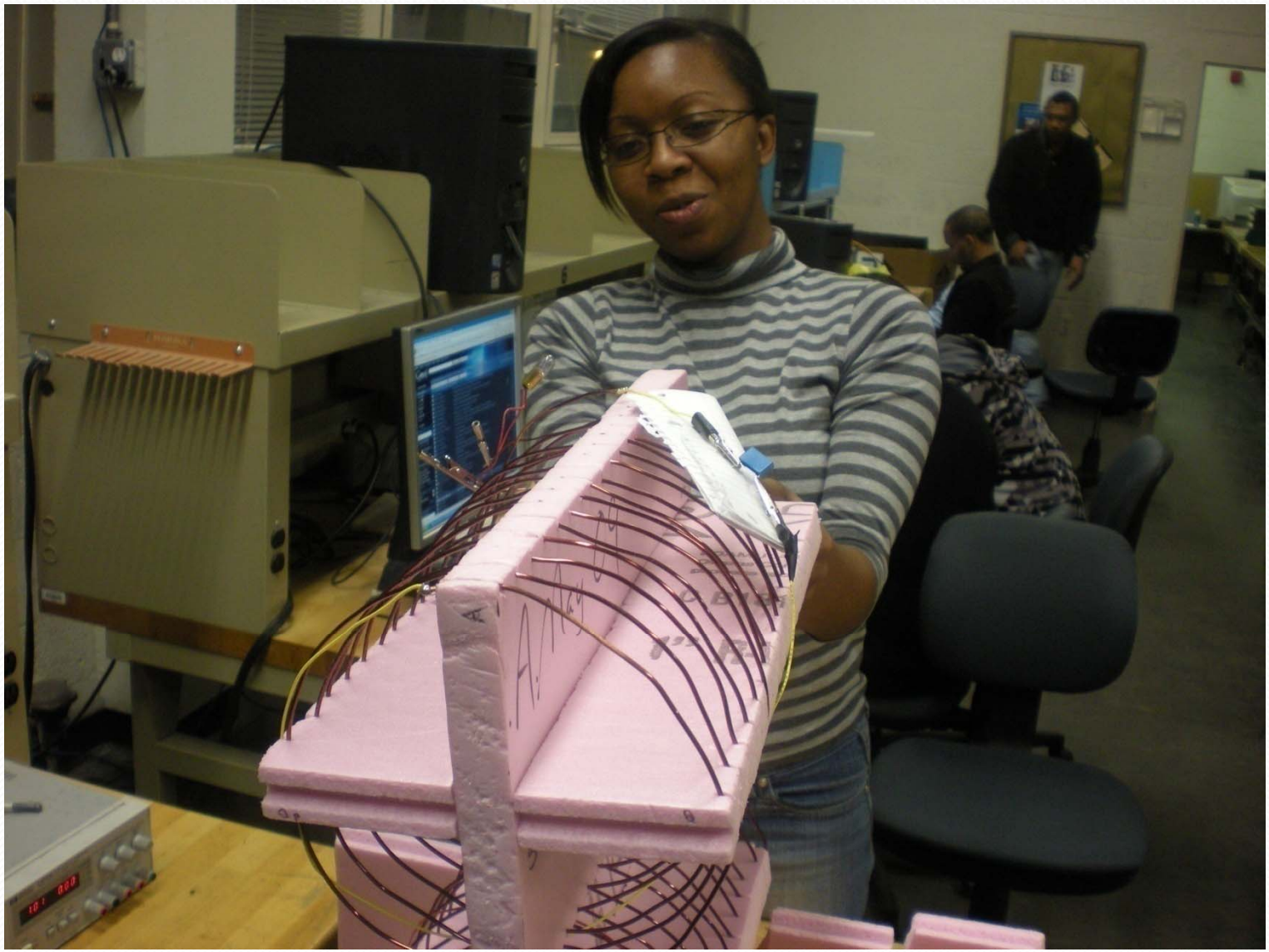

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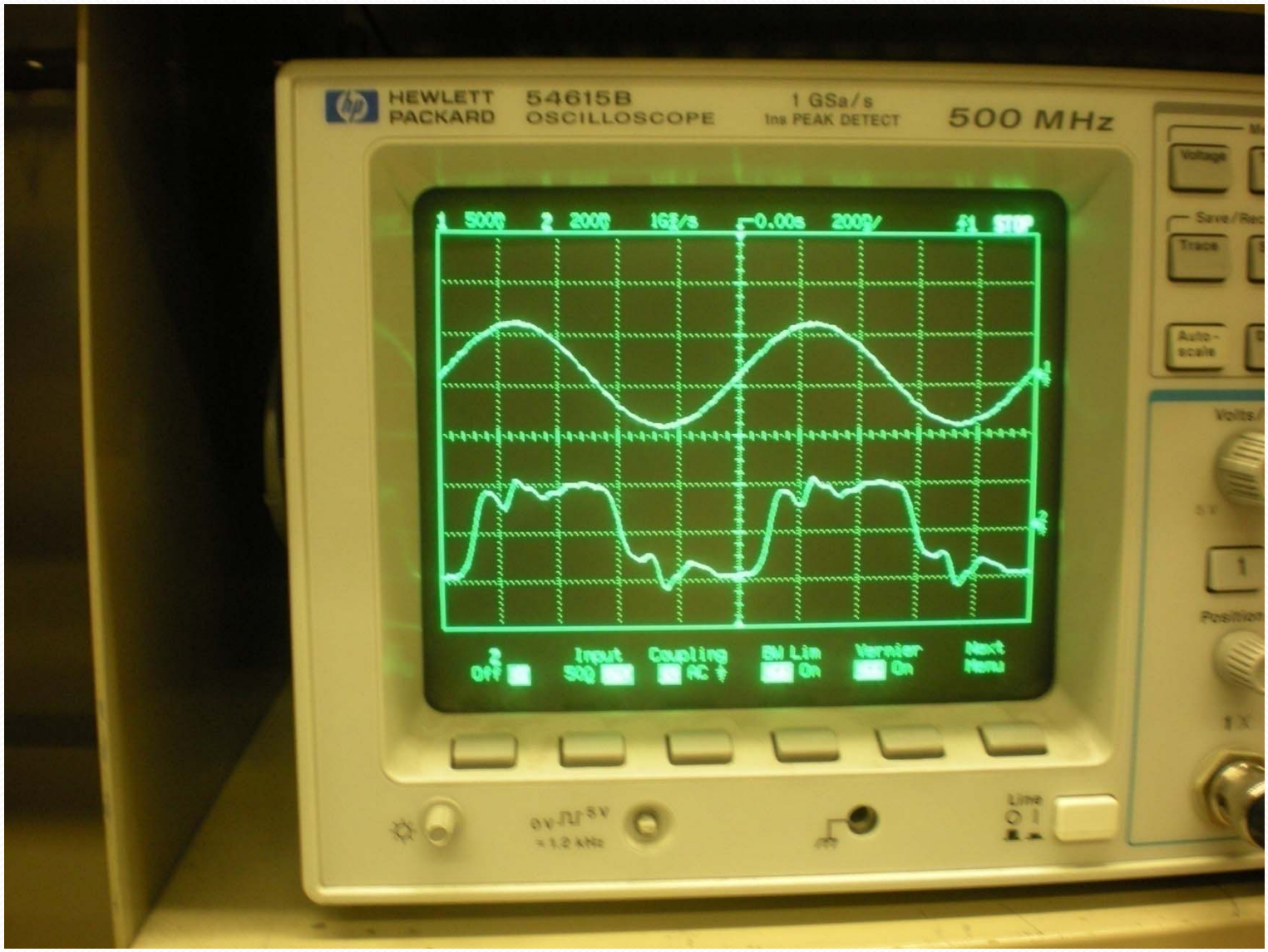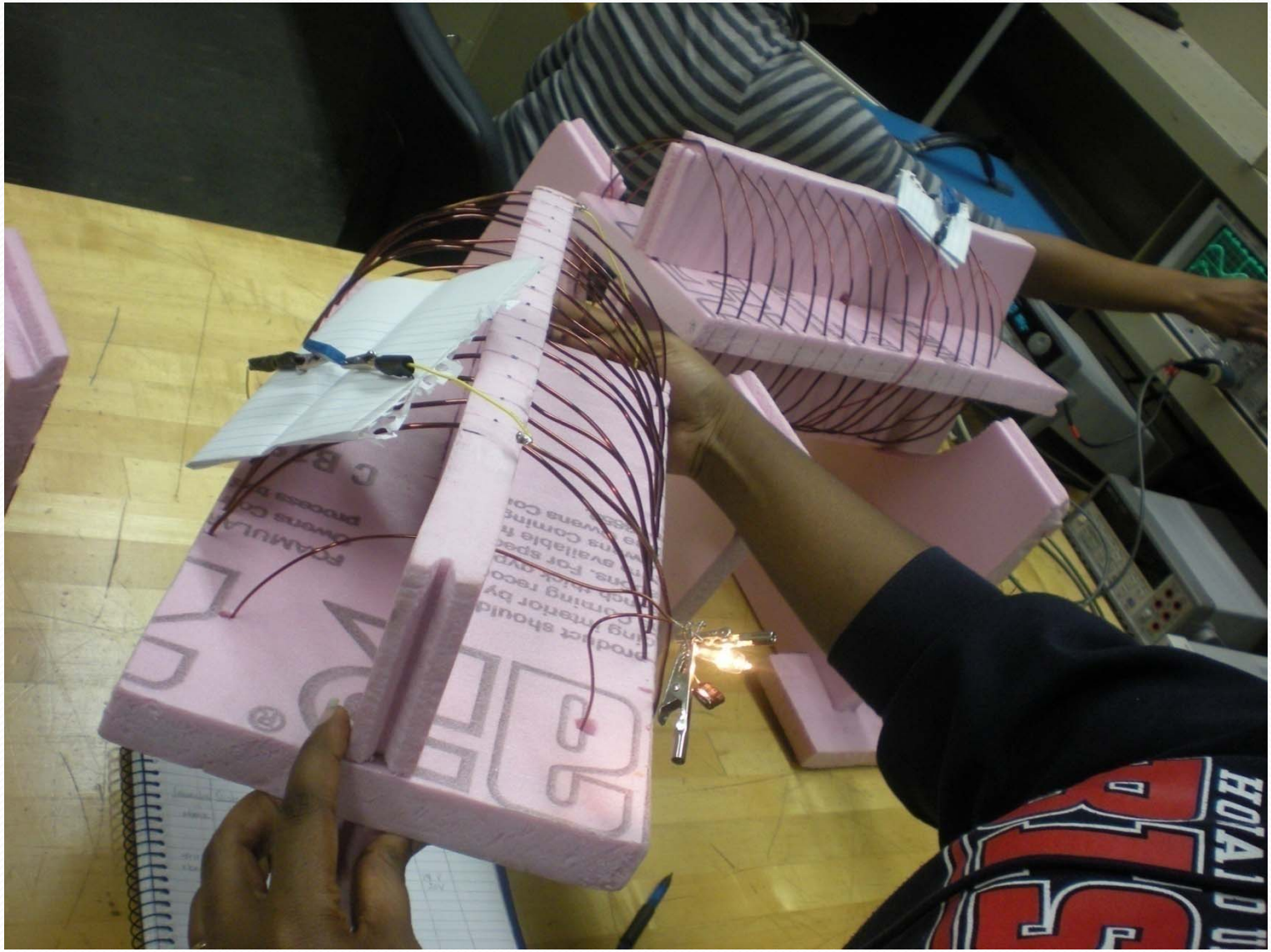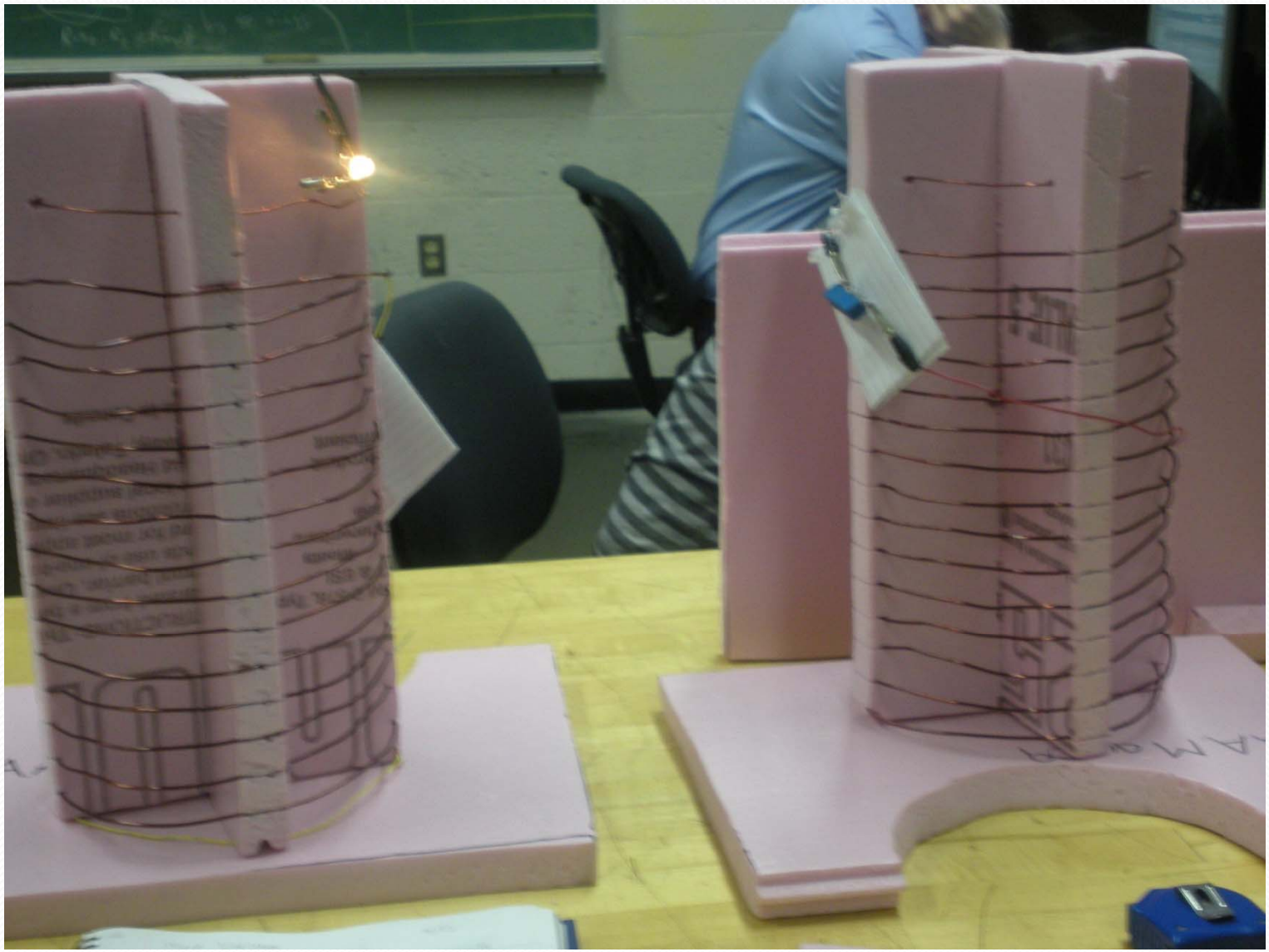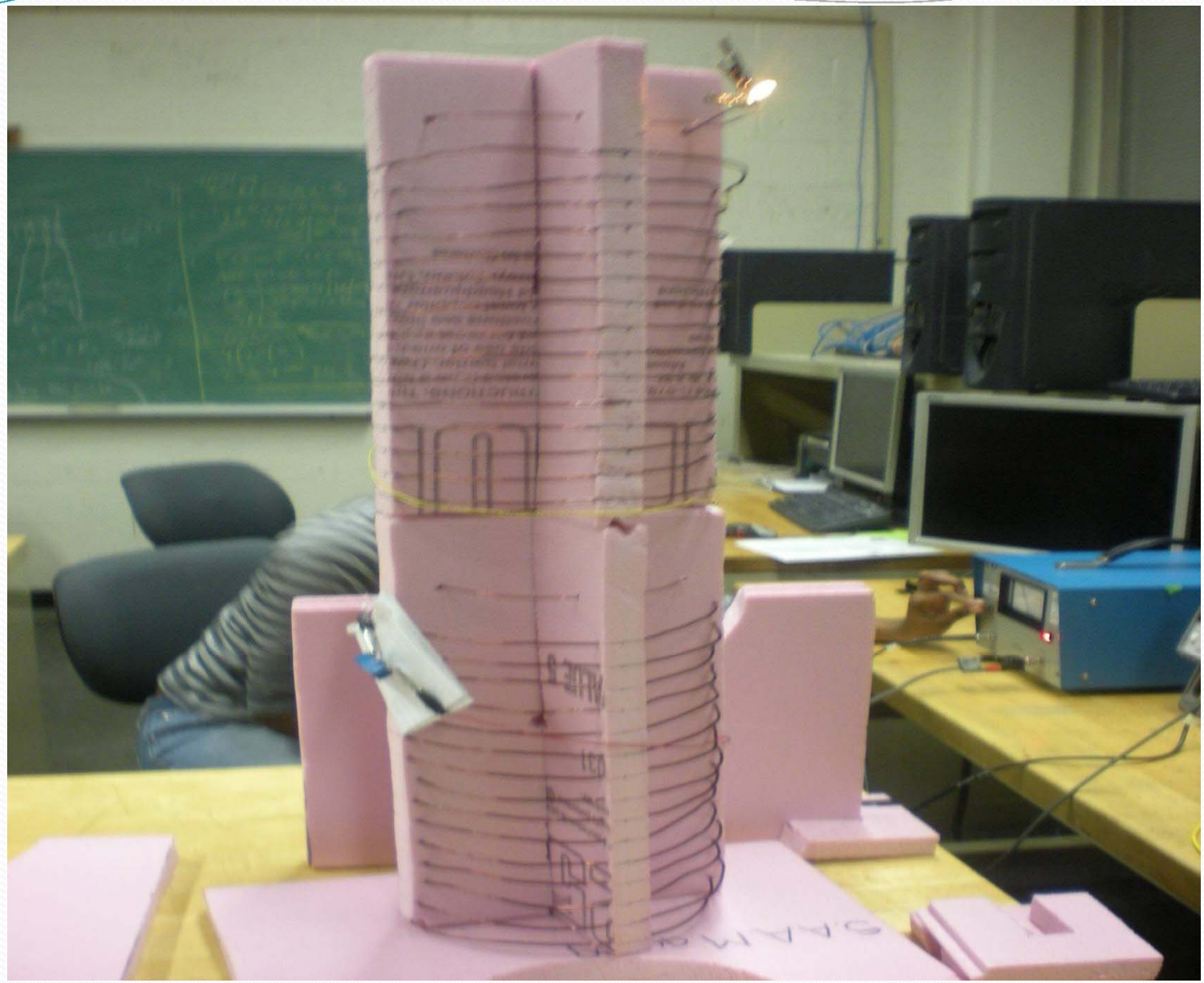
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