Three Methods of Wireless Power Transfer For a Fixed-Wing Drone

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Introduction

❖ Purpose of Research

The purpose of this research is to compare three modern methodologies of wireless power transfer (WPT) to power unmanned aerial vehicles (UAV) for firewatch and extraterrestrial exploration.

❖ Research Objectives

Design and compare inductive power transfer (IPT), microwave power transfer, and infrared (IR) power transfer.
Secondary objective is to design a UAV fixed-wing drone for use with these power transfer systems.

❖ Why Wireless Power?

UAVs have a limited flight time, especially fixed-wing UAVs. Wireless power allows these systems to fly for near infinite amounts of time even when sources such as wired or solar power are not available.

❖ Drone Design

- ➢ The secondary objective of this research was to design a fixed-wing UAV system that works practically with the wireless power transfer systems being tested.
- ➢ Built with the help of the UNR Aerospace Club/AIAA.
- ➢ Design Aspects:

Design Aspect	Specification	Reason
Wingspan	3 Feet Long	Good glide characteristics while remaining small
Configuration	Low-wing, cargo style	Stability, bring wing closer to power transmitters
Airfoil	Clark Y-18 airfoil	Stability, high lift for reduced battery use
Motor	2400 kV DC Brushless	Chargeable, low drag, low loss
Batteries	3-cell Lithium Polymer	11.1 V, 1300 mAh, high output, low enough to charge
Skin material	Carbon Fiber, PETG	Resistant against environmental factors, good with RF

Figure1: First UAV Design

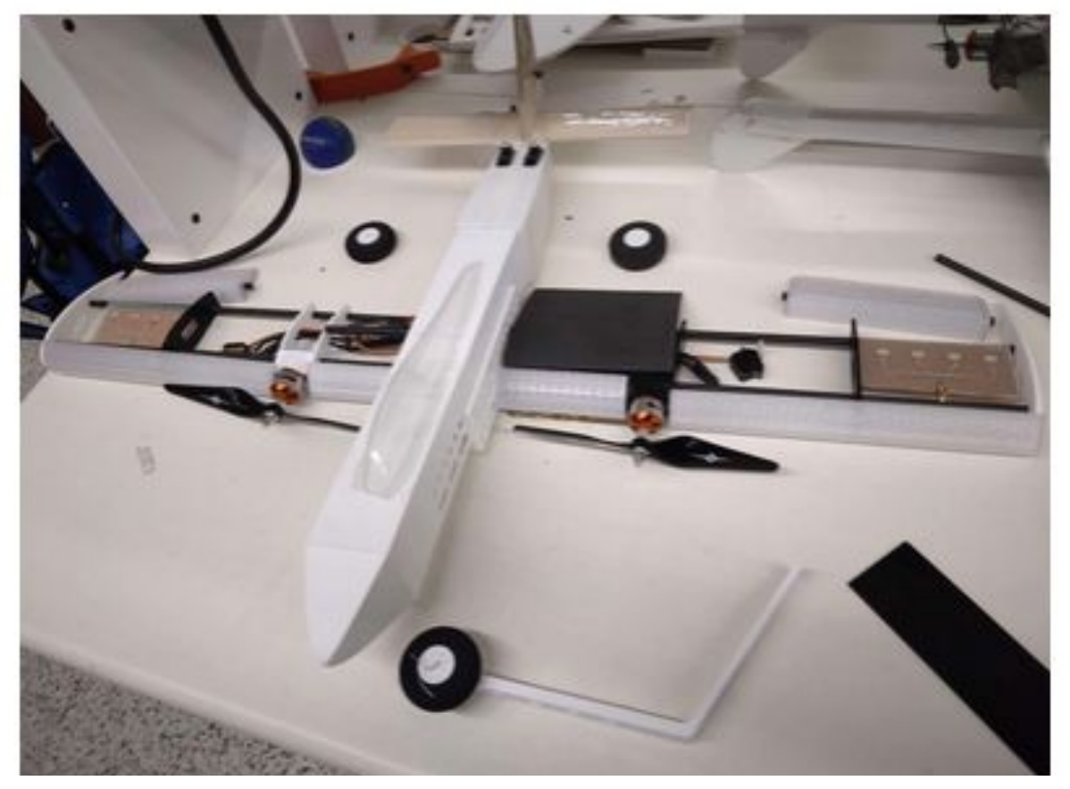

Figure 2: New Design Progress

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Methods and Processes

❖ Initial Research

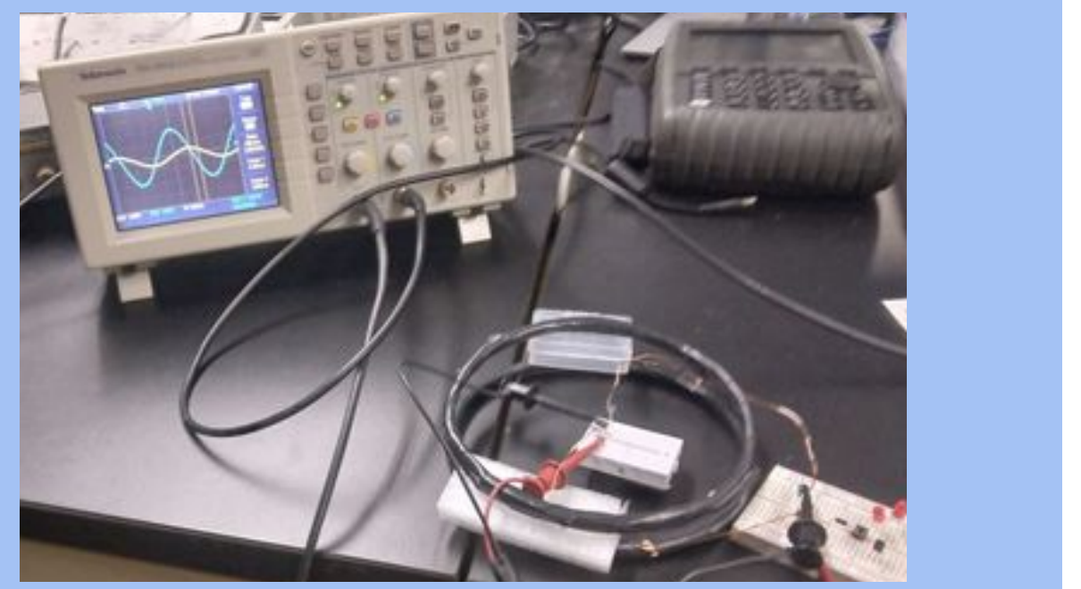
Initial research showed that wireless power transfer is for the most part much less efficient than wired power transfer. This puts it at a disadvantage to begin with. This is why such systems need to be highly optimized - to make them practical.

Of the three types of wireless power transfer I studied, inductive power transfer was the most heavily researched, with exact formulas. Microwave power transfer had some work done, but still had the most room for improvement, and infrared devices had some research but the market on infrared power transfer is still closed off, so was more difficult.

❖ Inductive Power Transfer

➢ Fabrication:

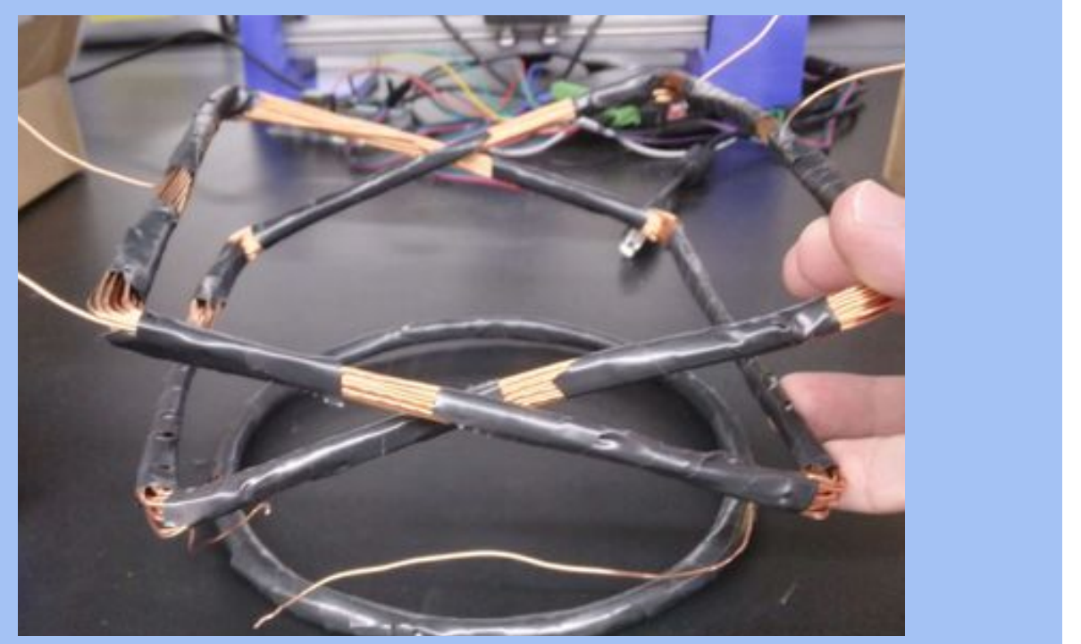
Parameter	Specification	Reason
Coil Diameter	6 inches	Length of test drone wing chord to wrap around
Wire Gauge	20 AWG / 0.0315"	Not too heavy, not to small to cause large surface currents
Number of Turns	32	Cell voltage 3.3 V / 100 mA current draw from battery
Max distance	6 inches	Clearance of the propeller from the ground
Frequency	10 kHz	Lower frequencies more efficient in mutual induction



➢ Equations:

$$Number\ of\ turns = \frac{Cell\ voltage}{Current\ draw}$$

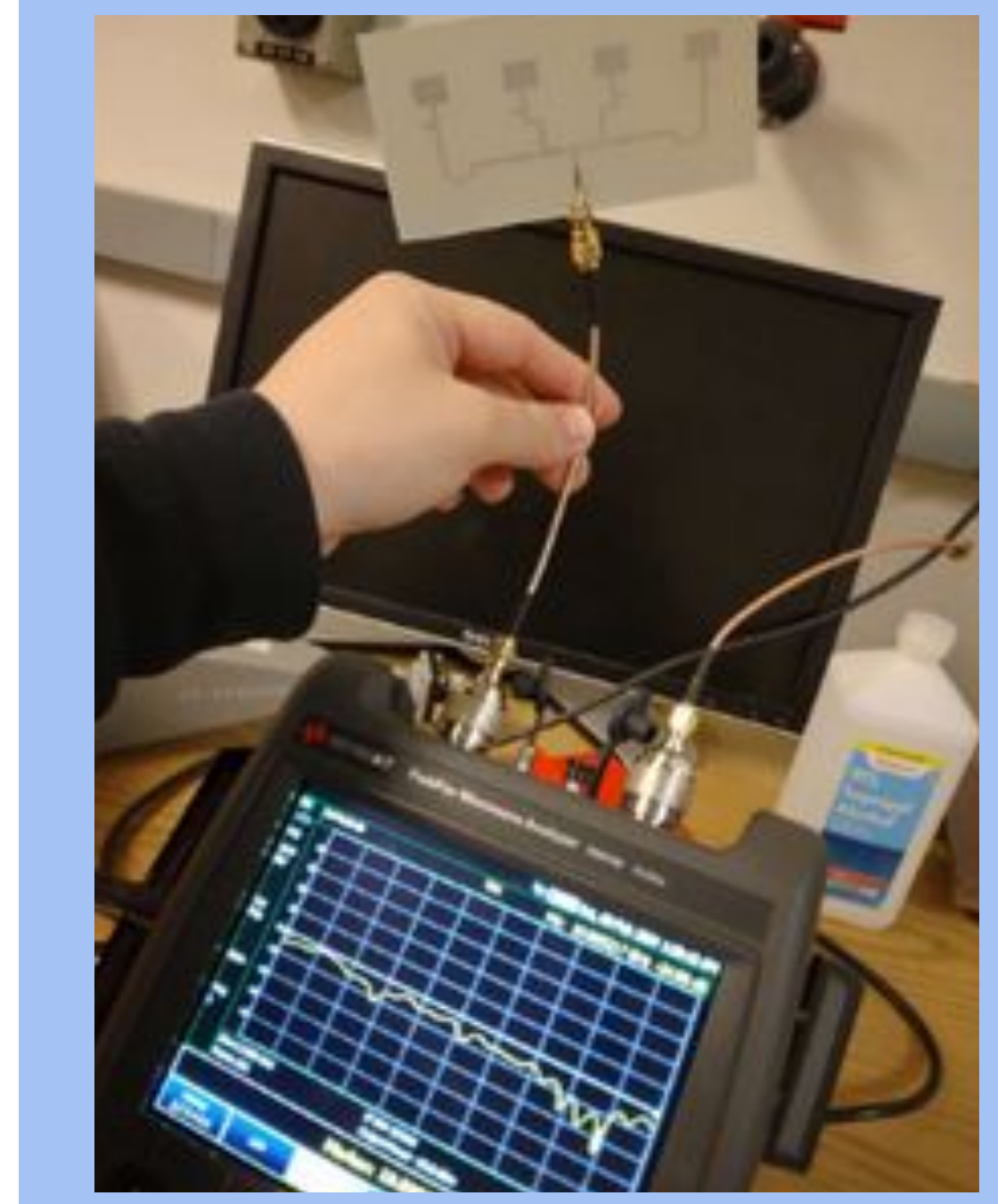
$$C = \frac{1}{L}\left(\frac{1}{2\pi f}\right)$$

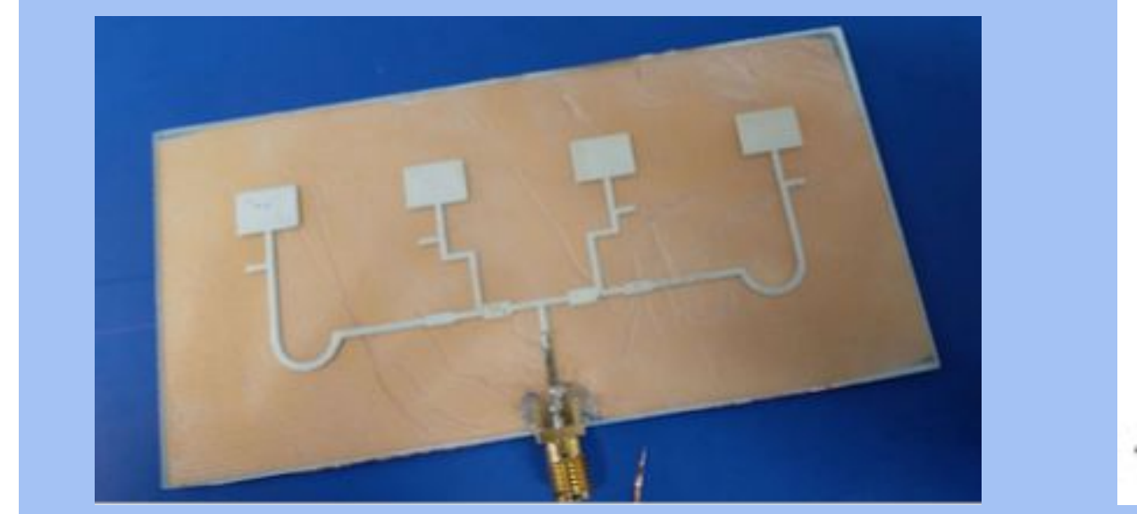


➢ Testing:

A full bridge rectifier was built out of four 1N4007 diodes to convert the AC signal into DC. This DC voltage was then compared against the peak of the input signal voltage. Testing was done between coils initially at no distance, then at increasing distances up to 6 inches. This distance was chosen due to the length of the propellers to determine needed clearance from the ground. Once these tests were done, the coils were cross-connected to compensate for misalignment.

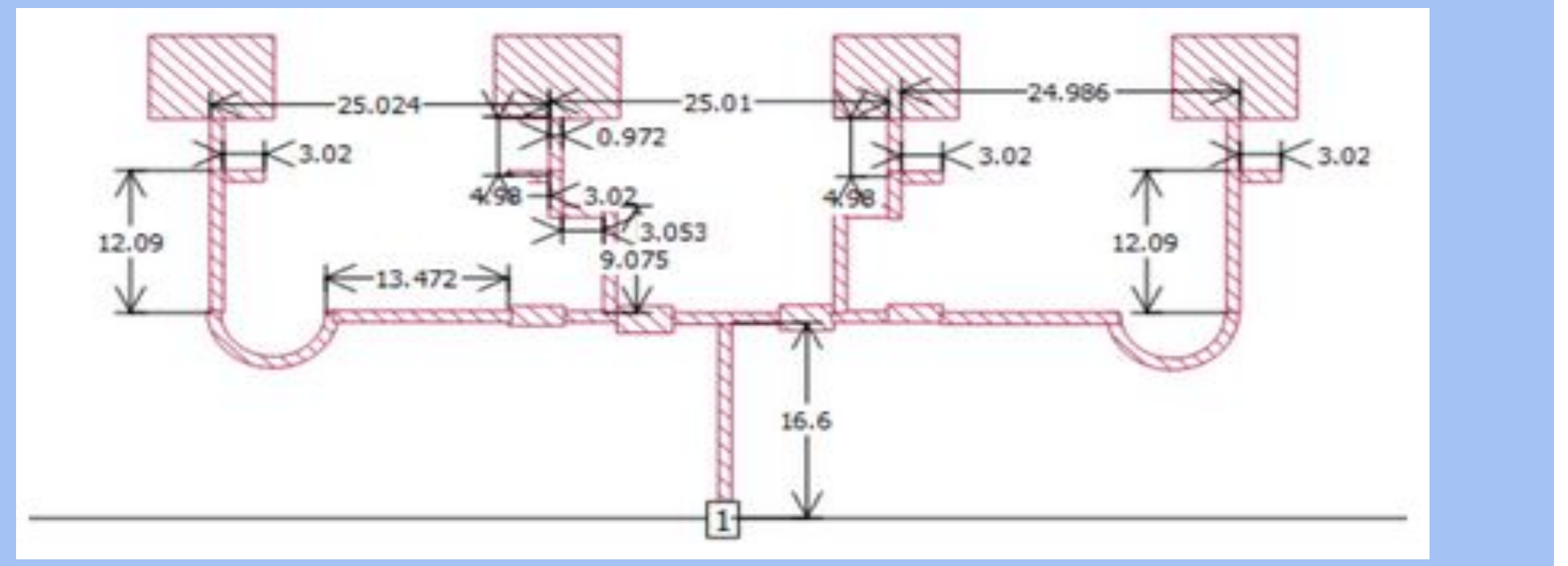
❖ Microwave Power Transfer





➢ Design and Fabrication:
A 10 GHz microstrip patch array was designed using Sonnet, with stub matching done in SmithChart. CST was used to simulate the Design. A Voltera V-one PCB printer printed the antenna.

➢ Testing:
Fieldfox Vector Network Analyzer (VNA) was used to characterize the array design. A second reference antenna was compared against the new design to get the S12 value, with the new design showing a notable improvement over the reference. Simulations were run in Sonnet and CST.

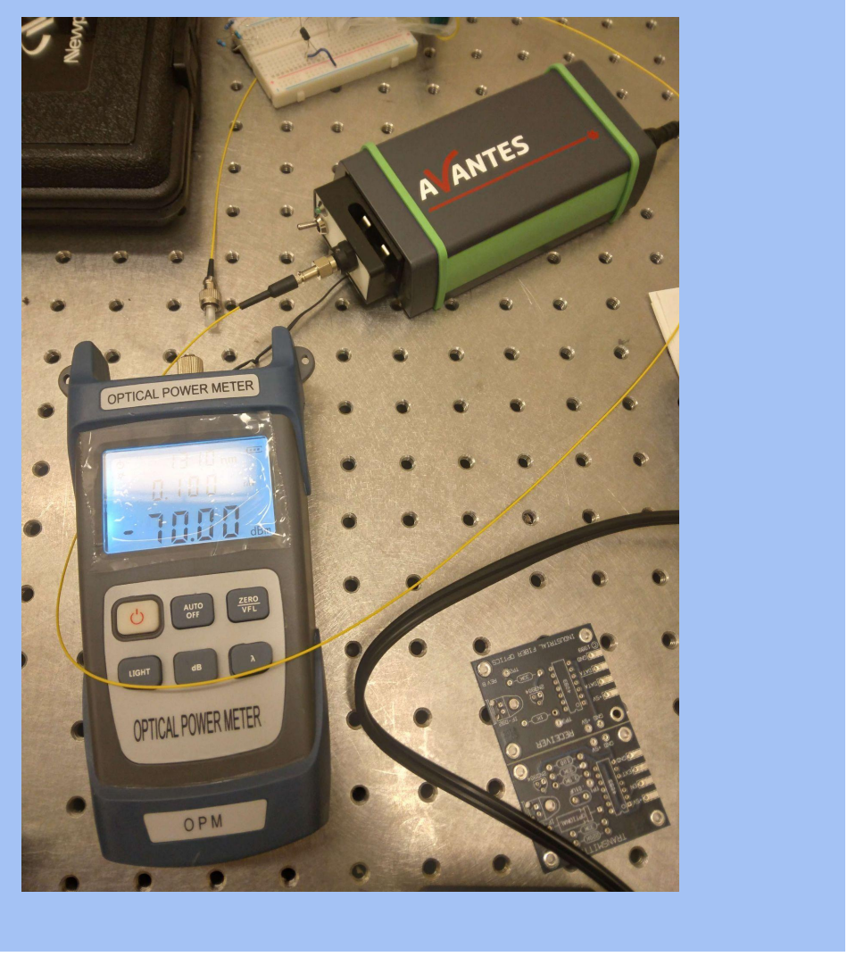


$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)}\right)$$

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}};\ \varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12(\frac{h}{W})}}\right]$$

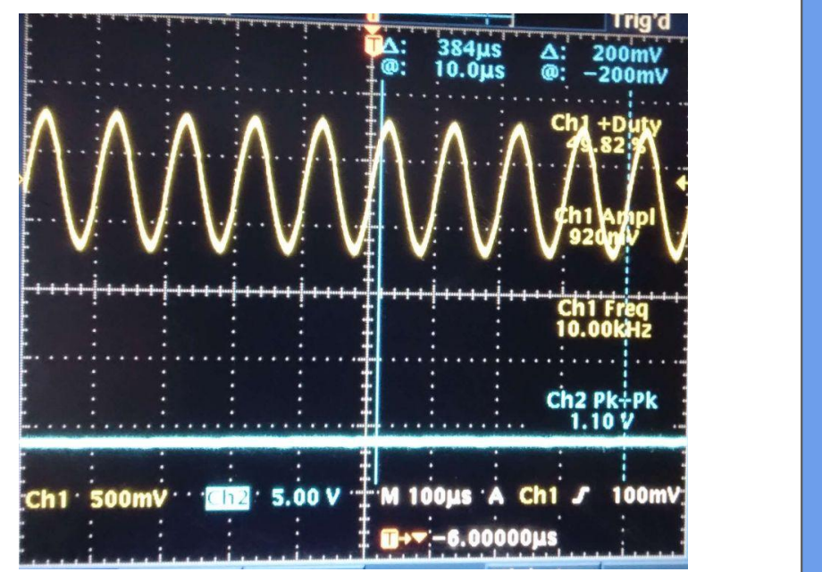
❖ Infrared Power Transfer

➢ Current Research:
Research reports that IR transfer is one of the most promising forms of power Transfer. As this form of transfer is dangerous and expensive, little testing was done. An Avalight Hal S Mini variable wavelength laser source was tested with an optical power meter. This was the extent of the testing with the remainder of the results relying on external research sources.



Results

❖ Results of testing



➢ Inductive Power transfer

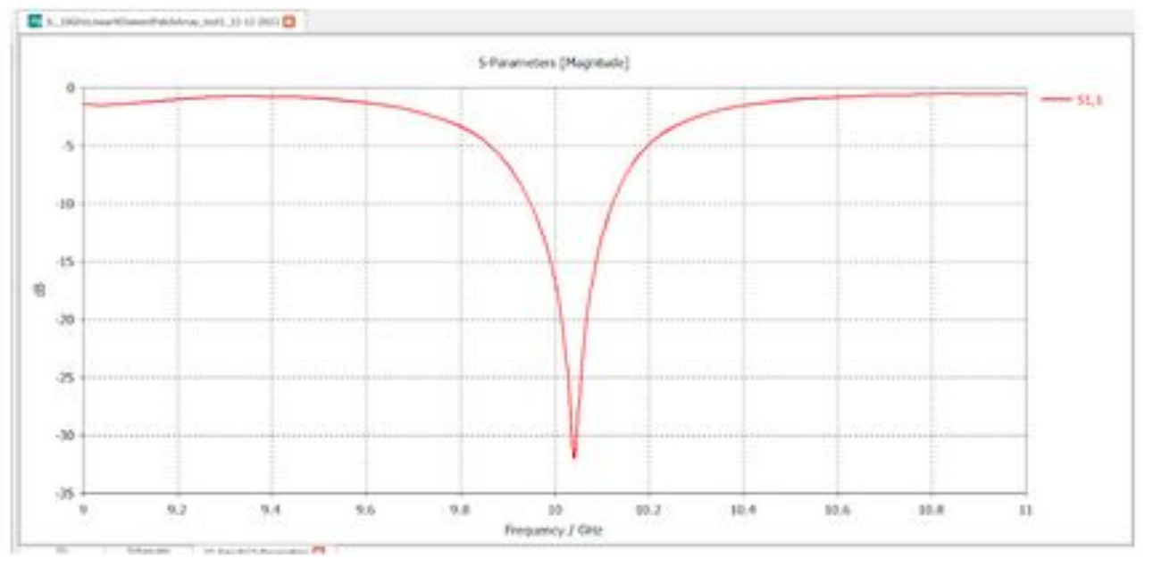
During testing of the final square coils, the input voltage was 2.9 V and the output voltage was 1.14 V. This produced an efficiency of 39.3%.

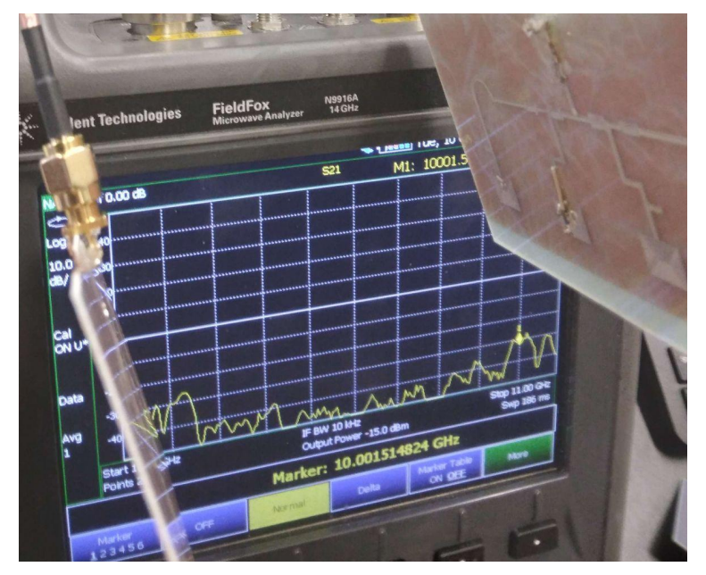
$$\eta = \frac{P_{out}}{P_{in}} = \frac{1.14(0.1)}{2.9(0.1)} * 100\% = 39.3\%$$

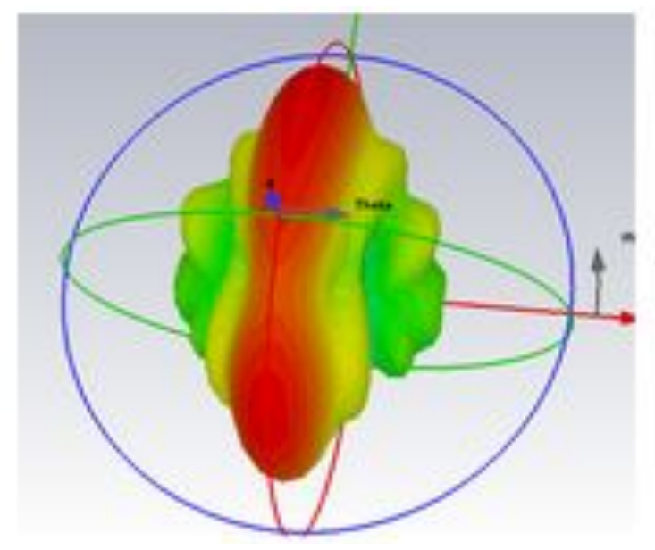
$$Q = \frac{ResonanceFrequency}{Bandwidth}$$

➢ Microwave Power Transfer

S11 value showed a -30 dB reflection coefficient. S12 to a similar antenna showed -37 dB, which is about 0.001 mW of power transferred on the VNA alone. To transfer sufficient power, an inverter circuit needs to be made. For now, this simple metric was sufficient for comparison. The VNA puts out -15 dB of power so efficiency is a mere 2.2% with the unoptimized system.







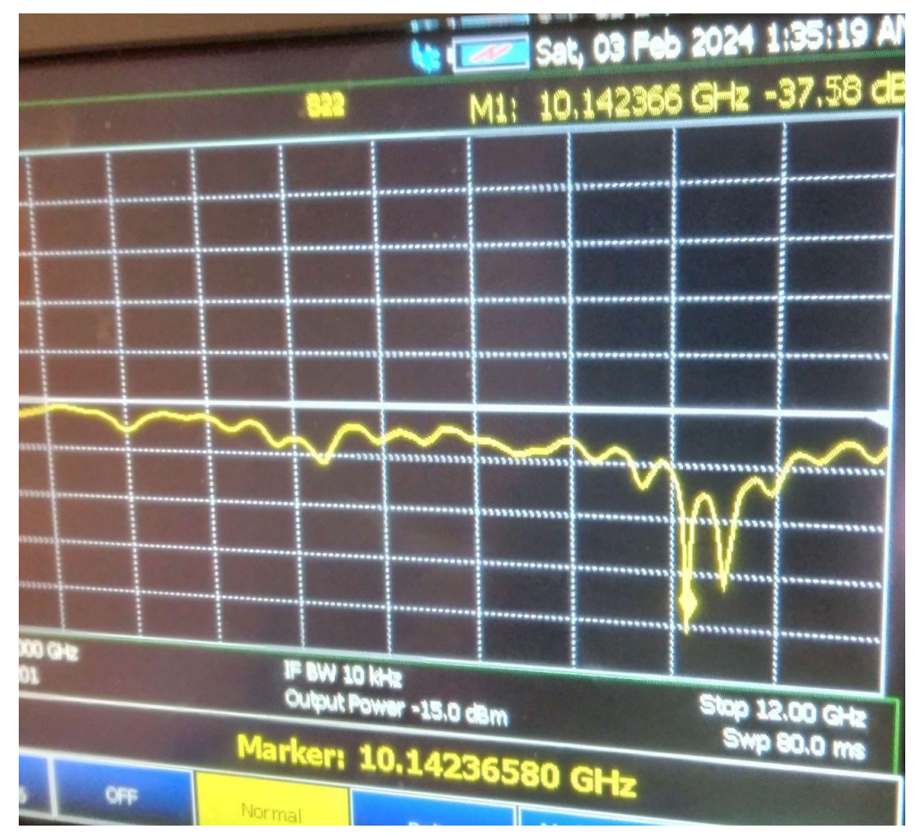
➢ Infrared Power Transfer

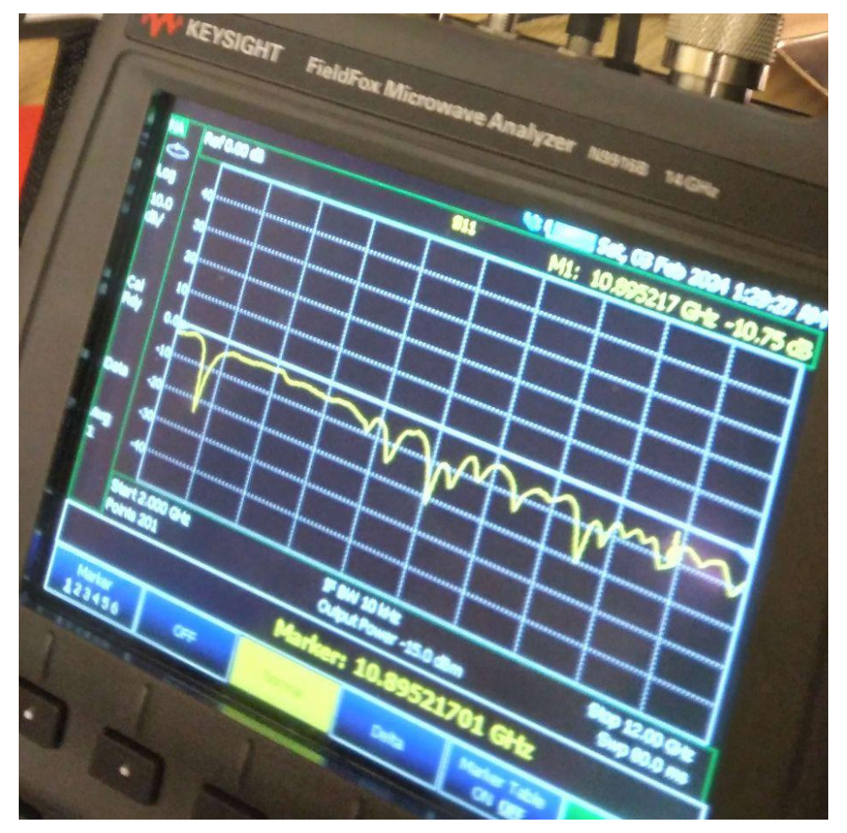
Currently the last component that is being tested. Results from IR are to follow in the week to come.

❖ Comparisons

- ➢ Of the three antenna designs, the inductive power transfer system was the most efficient by far, however, the microwave transfer system is completely unoptimized and not professionally printed yet. With extra linear arrays, better materials, more efficient rectification diodes, and a reflector or metamaterial, the microwave antenna has the potential to be superior to the coil, if still more dangerous. The IR system was based solely off of readings at this stage with low efficiency.

➢ S11 of my microstrip array as seen in the left image versus the S11 of the professional reference antenna also for 10 GHz.
S11 (left) = -37 dB
S11 (right) = -10.75 dB
This means my antenna has much less reflections blocking the transmitted signal.





Further Discussion

❖ Regulatory Considerations

Wireless Power Transfer systems to UAV falls under the FCC and FAA on Earth.

❖ Infrastructure of Wireless Power Transfer Systems

Solar-powered charging towers would create a hefty up-front cost, but would require low recurring costs.

❖ Interference by air particulates

Microwave Power Transfer is the most heavily affected by this interference, with IPT and IR mostly unaffected.

❖ Future Research

More efficient rectification via design of MIG diode, more optimized antenna systems, and experimental gain improvement additions such as metamaterials.