Wireless Energy Harvesting

DESIGN DOCUMENT

Team Number: sddec22-07
Client: Dr. Jiming Song
Advisers: Dr. Jiming Song
Team Members/Roles:
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Tanner Garity - EE, Head Researcher and PCB Designer
Jacob Walczak - EE, Physical Antenna Builder/Designer
Benjamin Brown - EE, Record Keeper & Mediator/Conflict Solver
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Revised: Date/Version: 05/02/2022

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Executive Summary

Development Standards & Practices Used

List all standard circuit, hardware, software practices used in this project. List all the Engineering standards that apply to this project that were considered.

- IEEE 211-2018 - IEEE Standard Definitions of Terms for Radio Wave Propagation. Terms and definitions used in the context of electromagnetic wave propagation relating to the fields of telecommunications, remote sensing, radio astronomy, optical waves, plasma waves, the ionosphere, the magnetosphere, and magnetohydrodynamic, acoustic, and electrostatic waves are supplied. This applies to our project because it sets out a standard definition for all of the various vocabulary surrounding Radio Wave propagation. Because we are using Wi-Fi which is a radio frequency it is necessary that all the terms we are using are being used correctly.
- IEEE 149-2021 - IEEE Recommended Practice for Antenna Measurements. Provides standards and recommendations for measuring antennas properties such as their propagation fields, patterns, and testing facility setups. This applies to our project because a large part of our job is to design and test an antenna to meet the requirements set out by our client. With this standard we will have better guidelines for testing and the common practices used by antenna designers.
- IEEE 145-2013 - IEEE Standard for Definitions of Terms for Antennas. Definitions for antennas and for systems that incorporate an antenna as a component of the system are established in this standard. Terms and definitions used to describe systems using antennas, as well as that of any associated interfaces and components. This applies to our project because of the application of antennas in conjunction with some form of power conversion circuit. Knowing industry standards for antenna test ratings, interfaces and values is key to designing our solution effectively.

Summary of Requirements

List all requirements as bullet points in brief.

- The power requirement is 20 milliwatts
- Needs to convert a wireless radio frequencies between 2.4 GHz and 5 GHz
- Needs to work with minimal maintenance.

Applicable Courses from Iowa State University Curriculum

List all Iowa State University courses whose contents were applicable to your project.

EE 330 Integrated Electronics

EE 311 Electromagnetic Fields and Waves

EE 224 Signals and Systems I

EE 324 Signals and Systems II

EE 201 Electric Circuits

EE 230 Circuits and Systems

EE 414 Microwave Engineering

EE 417 Electromagnetic Radiation, Antennas, and Propagation

New Skills/Knowledge acquired that was not taught in courses

List all new skills/knowledge that your team acquired which was not part of your Iowa State curriculum in order to complete this project.

- Antenna Function
- Yagi-Uda Functionality
- Antenna Design
- Agile and Waterfall management style

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

Figure 1. Conceptual Overview

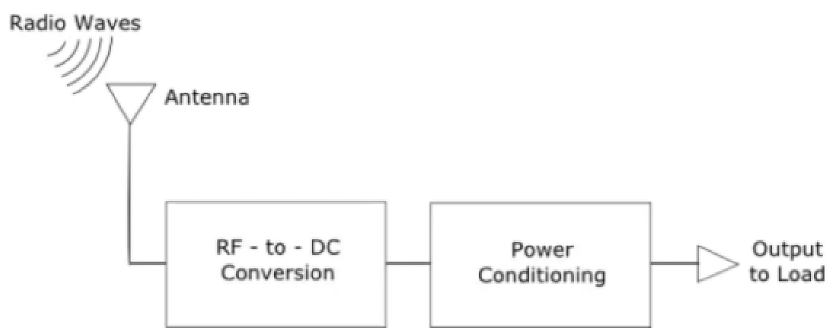


Figure 2. Systematic Objectives

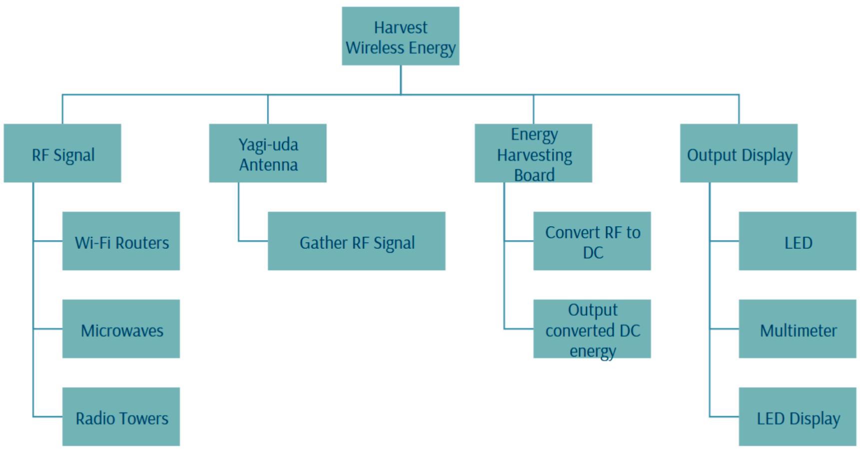


Figure 3. Five Unit Yagi-Uda Antenna Test Simulation

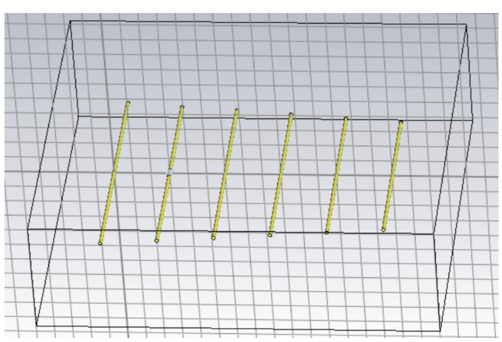


Figure 4. 2.35 GHz 5 Unit Yagi-Uda Antenna Gain Test Simulation

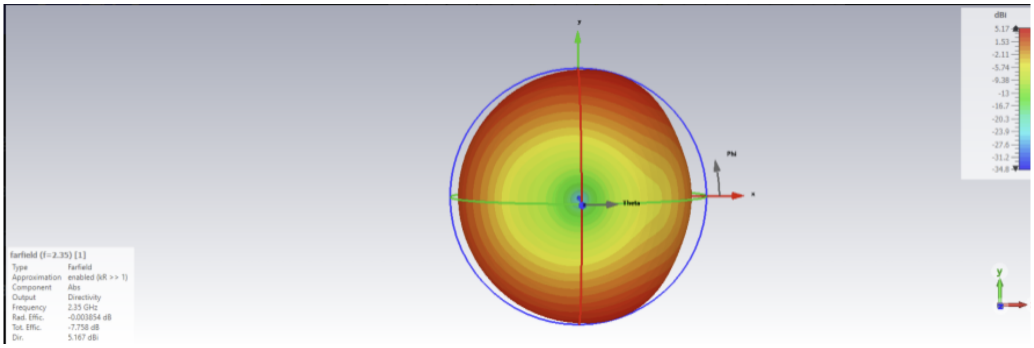


Figure 5. 11 Unit Yagi-Uda Antenna

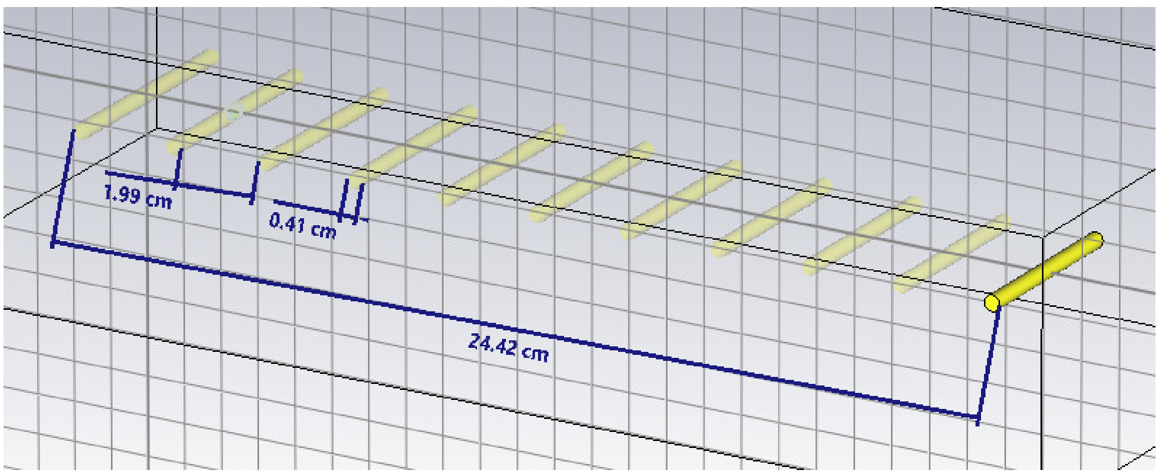


Figure 6. 2.4 GHz 11 Unit Yagi-Uda Antenna Gain Simulation: E Field Max 10.2 V/m

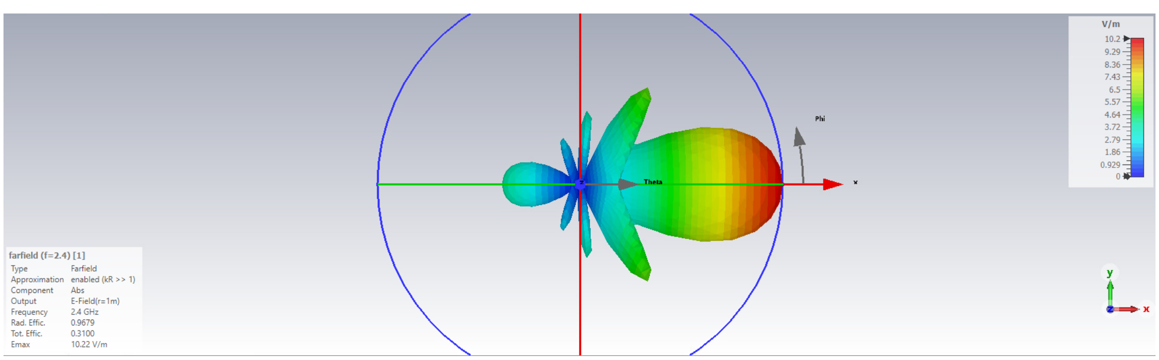
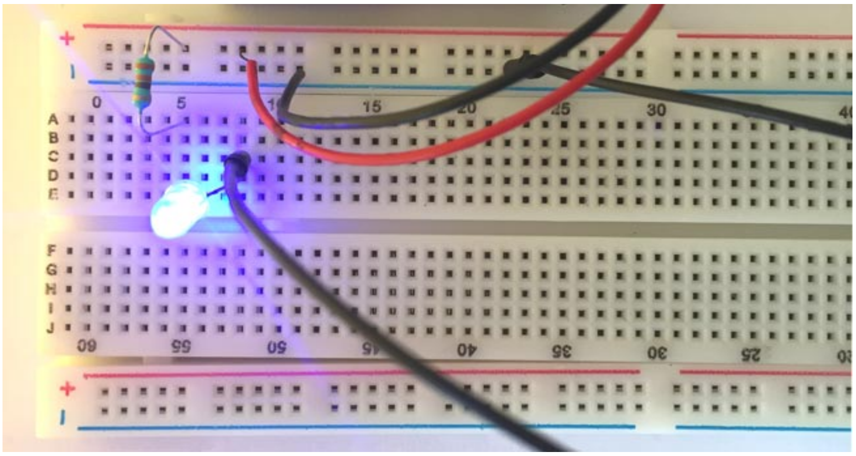


Figure 7. Test Board



1 Team

1.1 Team Members

Ben Brown, Tanner Garity, Chris Marting, Sam Runkel, Greg Schmitt, Jacob Walczak

1.2 Required Skill Sets for Your Project

- Antenna Design
- EM Knowledge
- AC Rectification
- Power Use and Measurement

1.3 Skill Sets covered by the Team

- Antenna Design
  - Chris Marting, Jacob Walczak
- EM Knowledge
  - Ben Brown, Tanner Garity, Chris Marting, Sam Runkel, Greg Schmitt, Jacob Walczak
- AC Rectification
  - Ben Brown, Tanner Garity, Chris Marting, Sam Runkel, Greg Schmitt, Jacob Walczak
- Power Use and Measurement
  - Ben Brown, Tanner Garity, Chris Marting, Sam Runkel, Greg Schmitt, Jacob Walczak

1.4 Project Management Style Adopted by the team

Agile Management Style

1.5 Initial Project Management Roles

- Sam - Team Leader, Coordinator, and advisor/client liaison
- Greg - Hardware Research, Product Testing
- Ben - Record Keeper, Mediator/Conflict Solver
- Chris - Antenna simulation/physical designer
- Jacob - Physical antenna builder/designer

- Tanner - Research, PCB testing and design

2 Introduction

2.1 Problem Statement

How can we harvest wireless energy produced by Wi-Fi routers to power small electronics such as LEDs or sensors?

2.2 Requirements & Constraints

List all requirements for your project . This includes functional requirements (specification), resource requirements, qualitative aesthetics requirements, economic/market requirements, environmental requirements, user interface requirements, and any others relevant to your project. When a requirement is also a quantitative constraint, either separate it into a list of constraints, or annotate at the end of requirement as "(constraint)". Other requirements can be a single list or can be broken out into multiple lists based on the category.

- Harvest EM waves with a frequency of 2.4 GHz
- Having a +/- 10 volts maximum on the RF input line
- 33 dBm(decibel[dB] milliwatts[m]) maximum RF input power on the RF input line
- 0.5 V/+40V maximum on the DC output line
- Maximum output current of 18 mA on the DC current output line
- Convert RF to AC
- Rectify AC to DC

2.3 Engineering Standards

What Engineering standards are likely to apply to your project? Some standards might be built into your requirements (Use 802.11 ac Wi-Fi standard) and many others might fall out of design. For each standard listed, also provide a brief justification.

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This applies to our project because of the application of antennas in conjunction with some form of power conversion circuit. Knowing industry standards for antenna test ratings, interfaces and values is key to designing our solution effectively.

2.4 Intended Users and Uses

Our intended users are anyone that wants to power small electronics or sensors. The use cas for our product would be a small sensor that requires very low power to run. Harvesting excess Wi-Fi energy would be ideal because it does not require light like a solar panel does and it also can penetrate through materials so sensors could be embedded into objects.

3 Project Plan

3.1 Project Management/Tracking Procedures

Which of agile, waterfall or waterfall+agile project management style are you adopting. Justify it with respect to the project goals.

We will be using a combination of both Agile and Waterfall methodologies but primarily leaning towards Agile development. We chose agile because of its focus on getting the bare minimum done first and then adding other features later. This will allow us to make sure that in the worst case scenario we can bring a working product even if it doesn't have all of the original features the customer wanted. Agile is also beneficial for us because it involves working very closely with the customer who also happens to be our advisor so we can make sure we are doing exactly what he would like along the way and can change things quickly if he wants a feature added or removed.

What will your group use to track progress throughout the course of this and the next semester. This could include Git, Github, Trello, Slack or any other tools helpful in project management.

We have been tracking our progress using Google docs and reviewing everyone's individual accomplishments throughout the weeks.

3.2 Task Decomposition

In order to solve the problem at hand, it helps to decompose it into multiple tasks and subtasks and to understand interdependence among tasks. This step might be useful even if you adopt agile methodology. If you are agile, you can also provide a linear progression of completed requirements aligned with your sprints for the entire project.

- Obtain market board and antenna for initial tests
- Design antenna with high gain
- Design AC to DC rectifier
- Design test procedures to determine load current and voltage
- Work on possible dual band antenna implementation
- Refine design into nice looking product for final presentation such as enclosure and screen

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

What are some key milestones in your proposed project? It may be helpful to develop these milestones for each task and subtask from 2.2. How do you measure progress on a given task? These metrics, preferably quantifiable, should be developed for each task. The milestones should be stated in terms of these metrics: Machine learning algorithm XYZ will classify with 80% accuracy; the pattern recognition logic on FPGA will recognize a pattern every 1 ms (at 1K patterns/sec throughput). ML accuracy target might go up to 90% from 80%.

In an agile development process, these milestones can be refined with successive iterations/sprints (perhaps a subset of your requirements applicable to those sprints).

1. Test board arrival
2. Board is tested with off the shelf antenna and shows that we can at least power an LED or show an open circuit voltage
3. AC to DC rectifier circuit can effectively convert an alternating current to a DC current efficiently
4. Antenna design is tested using software and shows that's it has a gain higher than 1
5. Antenna is built and tested with board to show it can power multiple LEDs or possible charge a battery

6. If time is permitting then we will try to design a dual band antenna that can give us an even higher gain and produce even more power without using much more space
7. Final product is able to power LEDs or power battery completely from harvest Wi-Fi signals and is in a compact, easy to use package

3.4 Project Timeline/Schedule

Week 1: Meet with the client to establish a working relationship and determine project goals.

Week 2: Determine team member roles and begin research into converter boards, antennas, and simulation software.

Weeks 3-4: Research and choose the test board to be ordered through ETG. Begin simulating antenna designs to confirm proof of concept and determine which design has the best gain.

Weeks 5-6: Order test board through ETG. Compile antenna simulation results and continue research/simulations for various antenna types. Research RF-AC filter circuits, as well as AC-DC converter circuits for our application.

Weeks 7-8: Meet with the client before and after spring break to discuss progress made. Waited for the test board to arrive.

Weeks 9-14: Assuming board is delivered within a timely manner, begin initial testing with baseline measurements of control tests, followed by extensive field tests of various conditions. There is no guarantee of when our hardware will arrive, so this phase is subject to variations of order, completion timeline, etc.

If the test board is not expected to arrive for a few weeks, then our next course of action will be to begin designing and creating our own energy harvesting board solution.

3.5 Risks And Risk Management/Mitigation

Consider for each task what risks exist (certain performance targets may not be met; certain tools may not work as expected) and assign an educated guess of probability for that risk. For any risk factor with a probability exceeding 0.5, develop a risk mitigation plan. Can you eliminate that task and add another task or set of tasks that might cost more? Can you buy something off-the-shelf from the market to achieve that functionality? Can you try an alternative tool, technology, algorithm, or board? Agile projects can associate risks and risk mitigation with each sprint.

We are uncertain the dual band dipole antenna will work properly with the test board when it arrives. We are uncertain how long it will take to build our own Yagi-Uda antenna and whether once we create it, it will work with our board. We are uncertain if the materials we are planning to use for our Yagi antenna will work properly together to get a good high quality signal. For a backup testing dipole antenna we can always go over to best buy and grab one. Materials for building the Yagi antenna will be a little harder to find quick replacements so that can end up being a little problematic. Also for the test board if that doesn't work we will be in a really bad stop because then we will have to order another one and have to wait a while until the new one arrives. Lastly, building the Yagi antenna in general shouldn't be too difficult even if we mess it up a little bit because Dr. Song has built plenty of Yagi antennas before so if we have questions or need help we have a great person to ask for help.

3.6 Personnel Effort Requirements

Include a detailed estimate in the form of a table accompanied by a textual reference and explanation. This estimate shall be done on a task-by-task basis and should be the projected effort in the total number of person-hours required to perform the task.

Antenna Design	• Antenna selection • Research into selected antenna • Software simulation familiarity • Simulation Design • Physical Design	25 Hrs
Circuit Design	• Circuit research • Designing some sort of antenna port • Circuit for RF to AC • Filter design • AC to DC rectifier circuit design • PCB modeling and ordering	10 Hrs.
Testing	• Initial dipole antenna testing • Determining testing parameters such as distance from WAP, and load to test on • Yagi-Uda antenna test • Test with different frequencies	40 Hrs
Cosmetic Design	• Designing Enclosure for final device • 3D modeling enclosure • 3D Printing	20 hrs

3.7 Other Resource Requirements

Identify the other resources aside from financial (such as parts and materials) required to complete the project.

Our project requires a lot of research to be done. Our wireless energy harvesting is not a mainstream technology and is in the research phase across the globe. This means we are required to do a lot of reading about various papers put out by universities. Our advisor is also a very good resource because he is an expert on antenna function and can provide a lot of help with general information. Other resources might include testing equipment which we can find in the labs in Coover.

4 Design

4.1 Design Context

4.1.1 Broader Context

Describe the broader context in which your design problem is situated. What communities are you designing for? What communities are affected by your design? What societal needs does your project address?

List relevant considerations related to your project in each of the following areas:

Area	Description	Examples
Public health, safety, and welfare	How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., solution is implemented in their communities)	Increasing/reducing exposure to pollutants and other harmful substances, increasing/reducing safety risks, increasing/reducing job opportunities
Global, cultural, and social	How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not limited to specific communities, nations, professions, workplaces, and ethnic cultures.	Development or operation of the solution would violate a profession's code of ethics, implementation of the solution would require an undesired change in community practices
Environmental	What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable practices related to materials manufacture or procurement.	Increasing/decreasing energy usage from nonrenewable sources, increasing/decreasing usage/production of non-recyclable materials
Economic	What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups.	Product needs to remain affordable for target users, product creates or diminishes opportunities for economic advancement, high development cost creates risk for organization

4.1.2 User Needs

List each of your user groups.

Dr. Song needs a way to test how much power can be pulled from Wi-Fi signals. Given different testing scenarios. For example, different wave frequencies and distances from source to antenna.

4.1.3 Prior Work/Solutions

Include relevant background/literature review for the project

– ***If similar products exist in the market, describe what has already been done***

There are currently Radio Frequency(RF) to Direct Current(DC) circuit boards that already exist that can take any radio waves in the air and harvest them with an antenna and converts it into an alternating current and then a direct current using a rectifier that is on the circuit board. We may plan on building one of these RF to DC circuits ourselves to further our testing process.

– ***If you are following previous work, cite that and discuss the advantages/shortcomings***

While we are using a circuit board that converts the radio waves into direct current we are not following any previous work. We have been told by our Advisor, Dr. Song, that a previous semester tackled this project as one of their senior design projects, however, we are not following their work. We are learning and accomplishing this project in our own way. An advantage to this would be a more unique end product and we get the opportunity to learn the topic more thoroughly.

– ***Note that while you are not expected to "compete" with other existing products / research groups, you should be able to differentiate your project from what is available. Thus, provide a list of pros and cons of your target solution compared to all other related products/systems.***

Our end result is more of a research based and testing based project. We are going to be testing several different things like different frequency radio waves(2.4 GHz & 5 GHz) as well, we will be testing the DC output depending on the range from the RF source and the antenna. This is what makes our project more unique compared to others that may have done a similar project.

– ***Detail any similar products or research done on this topic previously. Please cite your sources and include them in your references. All figures must be captioned and referenced in your text.***

The following article discusses RF energy harvesting and talks about the RF to DC conversion. The article also shows hardware applications of the system and how to apply them to the system. In addition, we can use the circuit diagrams to get a better understanding on how we could build our own RF to DC converter circuit.

[1]https://www.allaboutcircuits.com/technical-articles/wireless-rf-energy-harvesting-rf-to-dc-conversion-powe rcast-hardware/

4.1.4 Technical Complexity

Provide evidence that your project is of sufficient technical complexity. Use the following metric or argue for one of your own. Justify your statements (e.g., list the components/subsystems and describe the applicable scientific, mathematical, or engineering principles)

1. The design consists of multiple components/subsystems that each utilize distinct scientific, mathematical, or engineering principles –AND–
2. The problem scope contains multiple challenging requirements that match or exceed current solutions or industry standards.

Our project utilizes several different electrical components that serve several different functions. The first converts Wi-Fi wave signals into alternating current (AC), the next converts that alternating current (AC) to direct current (DC) using an AC-DC rectifier to provide power to small devices.

4.2 Design Exploration

4.2.1 Design Decisions

List key design decisions (at least three) that you have made or will need to make in relation to your proposed solution. These can include, but are not limited to, materials, subsystems, physical components, sensors/chips/devices, physical layout, features, etc.

- Operation Frequency. We decided to focus our efforts on 2.4 GHz. We made this decision because it's one of the primary frequencies used for Wi-Fi and has better material penetration than 5 GHz which is the other primary frequency used for Wi-Fi.
- Size. One major concern of ours is size. We could create an antenna that completely envelopes a Wi-Fi router therefore supplying us with all available power being produced by the router but this would not be cost effective, would render the router useless for other devices and would take up a lot of space. We plan on creating a device that is small enough to be handheld
- Build vs Buy antenna. We decided we are going to build our own antenna. This decision was made because it allows us to create a device that exactly meets our criteria. Initially we will test with a store bought antenna but the final product will use a homemade yagi-uda antenna which will allow us to get a much higher gain while also taking up much less space

4.2.2 Ideation

For one design decision, describe how you ideated or identified potential options (e.g., lotus blossom technique). List at least five options that you considered.

Annealed Copper vs. PEC vs. Brass vs. Aluminum vs. Silver vs. Iron. We decided on using Annealed Copper over the other ones for the following reason:

- PEC - Not a real material.
- Brass - Not as sturdy as Copper.

- Aluminum - Not as conductive as Copper.
- Silver - highly susceptible to rust, affecting long term performance.
- Iron - Poor conductor.

4.2.3 Decision-Making and Trade-Off

Demonstrate the process you used to identify the pros and cons or trade-offs between each of your ideated options. You may wish to include a weighted decision matrix or other relevant tool. Describe the option you chose and why you chose it.

We decided to use copper over the other materials by comparing the cons and pros of each one. Some of the cons outweigh the pros as stated above in section 3.2.2. For example, by comparing brass and aluminum directly to copper we can see that copper is the better choice.

4.3 Proposed Design

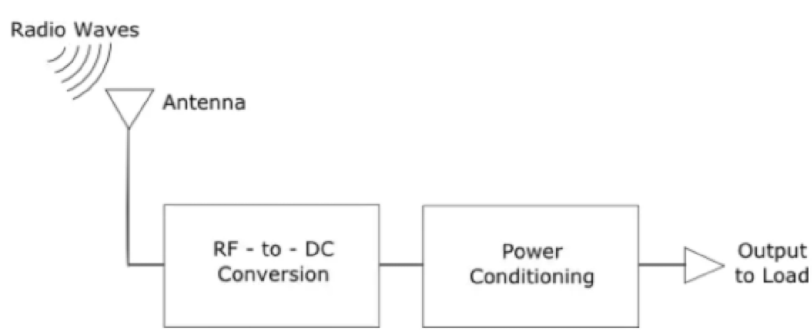
Discuss what you have done so far – what have you tried/implemented/tested?

So far much of our work has either been research or entirely simulation based. Chris and Jacob have produced a model of our proposed antenna using software. This also allowed them to mess around with different types of materials before we actually construct it. This lets us get a good idea of how we can get the largest gain with the lowest cost and weight. We also just obtained our test board. With the test board we have begun our initial testing to termine if our board and store bought antenna function. We plan to do more tests to flush out some good testing procedures before we construct our own homemade antenna.

4.3.1 Design Visual and Description

Include a visual depiction of your current design. Different visual types may be relevant to different types of projects. You may include: a block diagram of individual components or subsystems and their interconnections, a circuit diagram, a sketch of physical components and their operation, etc.

Describe your current design, referencing the visual. This design description should be in sufficient detail that another team of engineers can look through it and implement it.Wi-



Above is a very basic block diagram of our circuit design. We are currently building our own Yagi-Uda antenna to function at the 2.4 GHz band, the RF to DC component is currently being handled by our test board and the load we are testing with is just a simple LED.

4.3.2 Functionality

Describe how your design is intended to operate in its user and/or real-world context. This description can be supplemented by a visual, such as a timeline, storyboard, or sketch.

The end use of our project has a wide range of possible applications, primarily relating to electronic devices that require small amounts of power to operate, as well as applications that limit hardwiring from power sources to the device (caustic environments, space limitations, etc.)

How well does the current design satisfy functional and non-functional requirements?

The proof of concept has demonstrated potential to become viable in the real world eventually with further development, however the amount of power harvested and generated is negligible in its current state. Wi-Fi transmission power output, as well as antenna material technology are among the limiting factors holding this design back from becoming competitive in the world of power delivery.

4.3.3 Areas of Concern and Development

Based on your current design, what are your primary concerns for delivering a product/system that addresses requirements and meets user and client needs?

What are your immediate plans for developing the solution to address those concerns? What questions do you have for clients, TAs, and faculty advisers?

Based on our current design, our primary concern is building a RF-to-DC conversion board from scratch. We do not know much about building boards to begin with, and with the time and cost constraints, we may run into some trouble. Our immediate plans for this issue is to talk to Dr. Song about some of these concerns and potentially seeking outside help.

4.4 Technology Considerations

Highlight the strengths, weaknesses, and trade-offs made in technology available.

The strengths of the wireless energy harvesting technology are summarized as:

- small form factor, allows for various packaging and applications
- self-sustaining within operational environments
- mass produced units will be relatively inexpensive

Some major weaknesses holding the technology back include:

- individual part prices are much more expensive than bulk unit costs
- orientation of Yagi-Uda antenna massively affects performance with respect to power output
- produces far less electricity than is useful in large scale applications

- because of low power levels, line losses and conversion losses are much more significant to the operation of the final project

Discuss possible solutions and design alternatives

Alternatives to remedy some of the above problems are already being considered. Such alternatives include researching and experimenting with helical-style antennas that have properties more favorable to unidirectional EM field absorption, but the trade-off being a lower average gain of the signal harvested. Limitations in RF coaxial cable impedance values restrict power generation efficiency as a non-trivial amount of energy in the system is lost in the transmission lines.

4.5 Design Analysis

– ***Did your proposed design from 3.3 work? Why or why not?***

Yes and no, originally we designed our device to use a store bought dipole antenna to harvest the RF energy, we knew we would likely need to build a Yagi-Uda antenna to get the power we were looking for so we weren't very surprised once we started testing that that was the case.

– ***What are your observations, thoughts, and ideas to modify or iterate over the design?***

We have designed and plan to build a Yagi-Uda antenna that will greatly increase our gain over the original dipole antenna that we tested with.

4.6 Design Plan

Describe a design plan with respect to use-cases within the context of requirements, modules in your design (dependency/concurrency of modules through a module diagram, interfaces, architectural overview), module constraints tied to requirements.

We will build a device that utilizes a Yagi-Uda antenna to collect 2.4 GHz Wi-Fi frequency. That AC signal received by the antenna will then be rectified into a DC signal. Finally the DC signal will be used to power sensors or LEDs that could be implanted into objects or things such as concrete.

5 Testing

Testing is an extremely important component of most projects, whether it involves a circuit, a process, power system, or software.

The testing plan should connect the requirements and the design to the adopting test strategy and instruments. In this overarching introduction, given an overview of the testing strategy. Emphasize any unique challenges to testing for your system/design.

5.1 Unit Testing

What units are being tested? How? Tools?

We are testing the output voltage and current from the test board with the use of a multimeter. We are connecting the two output prongs on the test board to a breadboard and measuring the voltage over a closed and open circuit. We are expecting to have an output of 20 mW to power an LED. We will also be implementing the use of direction antennas like Yagi-Uda to increase the amount of gain.

5.2 Interface Testing

What are the interfaces in your design? Discuss how the composition of two or more units (interfaces) are being tested. Tools?

Interfaces that will be utilized during our testing phase include coaxial SMA (subminiature version A) connections for the test board and antenna. This interface is an industry standard with universal measurements and is compatible with any other SMA connector. Next we will be using handheld voltmeters with probe and clamp style connections extensively, as keeping a baseline control for measurement is key for such small tolerances. These probes will be connected either directly to the output pins on the test board, or across various load components on a breadboard.

5.3 Integration Testing

What are the critical integration paths in your design? Justification for criticality may come from your requirements. How will they be tested? Tools?

To ensure that multiple components of the system work as expected when they are combined to produce our final result we will be testing our output over an open and closed circuit. We plan to measure the direct value for the output with a multimeter for the open circuit and implement an LED for the closed circuit. With this testing plan we will be able to troubleshoot any errors in our system and identify any components that are not functioning the way we want them to.

5.4 System Testing

Describe system level testing strategy. What set of unit tests, interface tests, and integration tests suffice for system level testing? This should be closely tied to the requirements. Tools?

Generate as much DC power as possible using a RF to DC converter to see if we are capable of powering small scale devices. In order to do so we will be using a Yagi-Uda antenna since that has a high enough gain to be able to take in a lot of power. Additionally, until we are able to generate enough power to light up an LED we will be using a multimeter to get exact values on how much voltage we are getting. We will be testing the amount of power gained from a Wi-Fi router as our main source but also a microwave just in case the router doesn't output a high enough RF power to get the amount of power we want.

5.5 Regression Testing

How are you ensuring that any new additions do not break the old functionality? What implemented critical features do you need to ensure they do not break? Is it driven by requirements? Tools?

The only new addition that might break old functionality would be a new antenna. The new antenna could potentially burn out a resistor, but the odds of this happening is slim-to-none. This will be mitigated by impedance matching the board and the antenna to avoid any complications that might arise.

5.6 Acceptance Testing

How will you demonstrate that the design requirements, both functional and non-functional are being met? How would you involve your client in the acceptance testing?

Involvement of our client is very important to ensure that our device is doing exactly what they expect of it. Dr. Song has stated that this is more of a proof of concept device and isn't expected to work 100% perfectly or be extremely usable. Our first way to demonstrate that our device works is to turn on an LED with power obtained entirely from Wi-Fi. This should be very easy for us to show by lighting one up. This allows our advisor to see that we are indeed generating power wirelessly. We would like to try and attempt to use our device in other ways as well such as charging a battery which can be demonstrated by using that charged battery to power something. For non functional design aspects we will have to work with our advisor to get a general idea of the shape of the device he would like. We know it should be handheld in size and we will likely 3D print the housing and present it to our advisor for approval.

5.7 Security Testing (if applicable)

No security testing necessary

5.8 Results

What are the results of your testing? How do they ensure compliance with the requirements? Include figures and tables to explain your testing process better. A summary narrative concluding that your design is as intended is useful.

Our primary expected result is to receive power wireless through Wi-Fi. It is the entire goal of the project. We hope to best demonstrate this by simply powering an LED. This will require around 20 milliwatts of power. Our first initial round of testing using a store bought board and antenna allowed us to receive about 400 nanowatts. This means we are a number of orders of magnitude away from what we need. We have a lot of room for improvement which we hope to do by building our own directional antenna which should drastically increase our gain. Also we would like to create our own board that can work more efficiently by function only on 2.4 GHz instead of a range from 60 to 5 GHz.

6 Implementation

Describe any (preliminary) implementation plan for the next semester for your proposed design in 3.3. If your project has inseparable activities between design and implementation, you can list them either in the Design section or this section.

We have a few ideas of how this device can be implemented. One idea is to use this device to power sensors that could be implanted into objects such as cement. Another idea we had would be to use our device to charge a battery which could be later used to power devices.

7 Professionalism

This discussion is with respect to the paper titled “ Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment”, *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012

7.1 Areas of Responsibility

Pick one of IEEE, ACM, or SE code of ethics. Add a column to Table 1 from the paper corresponding to the society-specific code of ethics selected above. State how it addresses each of the areas of seven professional responsibilities in the table. Briefly describe each entry added to the table in your own words. How does the IEEE, ACM, or SE code of ethics differ from the NSPE version for each area?

Area of Responsibility	Definition	NSPE Canon	IEEE
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence.	Perform services only in areas of their competence; Avoid deceptive acts.	To continuously improve our technical competence and to take on technological tasks if qualified by training or experience
Financial Responsibility	Deliver products and services of realizable value and at reasonable costs.	Act for each employer or client as faithful agents or trustees.	To not accept any forms of bribery
Communication Honesty	Report work truthfully, without deception, and understandable to stakeholders.	Issue public statements only in an objective and truthful manner; Avoid deceptive acts.	To avoid any form of conflicts of interest whenever possible and to disclose them to affected parties when they do exist To be honest and realistic when providing claims or estimates based on available data
Health, Safety, Well-Being	Minimize risks to safety, health, and well-being of stakeholders.	Hold paramount the safety, health, and welfare of the public.	To avoid injuring others, their property, reputation, or employment by false or malicious action
Property Ownership	Respect property, ideas, and information of clients and others.	Act for each employer or client as faithful agents or trustees.	To treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disabilty, national orgin, sexaual orientation, gender identity, or gender expresssion

Sustainability	Protect environment and natural resources locally and globally.	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession	To accept responsibility in making decision consistent with the safety health and welfare of the public and to disclose promptly factors that might endanger the environment
Social Responsibility	Produce products and services that benefit society and communities.	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.	To accept responsibility in making decision consistent with the safety health and welfare of the public and to disclose promptly factors that might endanger the public

7.2 Project Specific Professional Responsibility Areas

For each of the professional responsibility area in Table 1, discuss whether it applies in your project's professional context. Why yes or why not? How well is your team performing (High, Medium, Low, N/A) in each of the seven areas of professional responsibility, again in the context of your project. Justify.

Work Competence

Work competence is an interesting concept when it comes to our senior design project. The majority of our group has little to no experience in antennas and wireless energy. This means that we are entering into this project incompetent to finish the task. However, our team is working diligently to research, learn and discover how these things work. We have a very accomplished advisor as well that is more than happy to help answer any questions we may have. By the end of the project, I believe we will all be competent in antenna and wireless energy technologies and confident in our final product's function and abilities.

Financial Responsibility

Financial Responsibility is extremely important when working towards a project goal. No project is going to have an infinite budget or infinite amount of time. For our project, we are trying to make a working prototype of a wireless energy harvesting device for the least amount of money. We are working to accomplish this by doing lots of research to find the cheapest components that will accomplish exactly what we are trying to do. The goal Team 7 is to create something that is worth more than the individual parts that make it up. Overall our team is doing a good job researching so we can be financially responsible.

Communication Honesty

Communication honesty is extremely important for a well functioning team to perform. So far our team has been doing a good job with it. We have had multiple meetings with our advisor and discussed how the project is coming along. We haven't run into any roadblocks thus far that we needed to communicate to our client but if we do in the future I believe we will be able to handle that professionally.

Health, Safety, and Well-being

Health and safety are important topics whether it comes to a school project or a fortune 500 company. We need to assure that while working that nobody becomes injured or harmed in the pursuit of our end product. Anytime you are working with EM radiation there are opportunities for someone to fall into harm's way. Luckily we are working with some of the least harmful of these waves. 2.4 GHz waves fall in the radio part of the EM spectrum. We are also harvesting these waves, not producing them. Any waves we are interacting with are already in the air at all times because of Wi-Fi routers. We are also working with extremely small amounts of power. We will still, however, need to be careful to properly insulate any circuits on final products to keep people safe. Our team has done a good job thus far with health and safety.

Property Ownership

Property ownership is important to companies large and small, whether it be physical or intellectual property. For our group, we have to be respectful of the physical properties of Iowa State University, since we might be using their equipment for our project. We also have to respect the intellectual property of each individual group member and make sure they get the credit they deserve.

Sustainability

Team 7 Sustainability is a fairly important part of our project. The main goal of this project is to take wireless energy and harvest it to see how much DC power we can get from it. If we are successful in getting enough energy we could be able to do away with lithium-ion batteries for certain items that do not require a lot of power to work. This would be great as lithium-ion batteries can cause harm to the environment if not disposed of correctly.

Social Responsibility

Social responsibility is an important part of every project. Projects should help the community and never put them in danger. Our project benefits the community by allowing them to harvest energy from Wi-Fi signals in the air. Our project can’t really cause harm to the user, but can be misused, like many tools.

7.3 Most Applicable Professional Responsibility Area

One professional responsibility that is both important to the project and we show a high level of proficiency in is ‘Work Competence.’ Even though we may not all have the same technical background and skills we have all individually shown high quality, integrity, and professional competence in learning, researching, and asking questions to better our technical skills where we may lack. For a specific example, the team does not have training or experience in wireless energy harvesting. However, we have shown ‘Work Competence’ by asking our advisor, Dr. Song, any question we may have and to use him as a resource to better enhance our technical skill and knowledge on the topic.

8 Closing Material

8.1 Discussion

Discuss the main results of your project – for a product, discuss if the requirements are met, for experiments oriented project – what are the results of the experiment, if you were validating a hypothesis – did it work?

We have made a great amount of progress developing the wireless harvesting technology, though much more work will need to be done before it can be considered a finished, working product. In its current state, our solution does not meet the requirements put on it, as we are still in the process of developing our custom antenna. The initial experiments using a consumer grade antenna showed proof of concept to our design, but revealed by how much current technology limits results.

8.2 Conclusion

Summarize the work you have done so far. Briefly reiterate your goals. Then, reiterate the best plan of action (or solution) to achieving your goals. What constrained you from achieving these goals (if something did)? What could be done differently in a future design/implementation iteration to achieve these goals?

Thus far we have thoroughly researched and discussed the function of antennas, varieties of antennas and which type best fits our project. We have chosen and designed a Yagi-Uda antenna. We have ordered and received our test board. We have performed preliminary tests with the test board and a store bought dipole antenna and had a measurable load power of around 400 nanowatts. Our next goal is to build our physical Yagi-Uda antenna and begin testing in a number of different environments to hopefully show we can power an LED completely wirelessly.

8.3 References

List technical references and related work / market survey references. Do professional citation style (ex. IEEE).

[1]
https://www.allaboutcircuits.com/technical-articles/wireless-rf-energy-harvesting-rf-to-dc-conversion-powe rcast-hardware/

8.4 Appendices

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar data that does not directly pertain to the problem but helps support it, include it here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc,. PCB testing issues etc., Software bugs etc.

8.4.1 Team Contract

Team Members:

1) Sam Runkel 2) Jacob Walczak

3) Greg Schmitt 4) Benjamin Brown

5) Tanner Garity 6) Christopher Marting

Team Procedures

Day, time, and location (face-to-face or virtual) for regular team meetings:

- Team meetings: face to face on Tuesday after 491
- Advisor meetings: bi-weekly on Mondays in Dr. Songs office

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):

- Discord

3. Decision-making policy (e.g., consensus, majority vote):

- Majority

4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):

- Description of meetings with the group and advisor. And keeping track of how long. Ben Brown will archive this on a shared google doc.

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:

- Communicate once every week or two
- Don't let it become a problem and let the team know whats up

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:

- Do what you said you would accomplish and if you cannot, then communicate with the team in advance so we can work together to get it done

3. Expected level of communication with other team members:

- Try to make it to meetings and check in at least bi-weekly if you are busy and cannot make meetings

4. Expected level of commitment to team decisions and tasks:

- Do what you said you were going to do and if you can't get it done then ask for help in advance

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):

- Communication and organization Leadership - Sam Runkel
- Head Researcher - Tanner Garity
- Testing - Jacob Walczak
- Antenna Expert - Christopher Marting
- Hardware Research and Product Testing - Greg Schmitt
- Conflict resolution - Ben Brown
- All team members are expected to be flexible and contribute in all areas of leadership roles stated above

2. Strategies for supporting and guiding the work of all team members:

- Checking in weekly to see if help is needed or if conflicts need to be resolved by Ben

3. Strategies for recognizing the contributions of all team members:

- Verbal Praise
- Pat on the back
- Firm handshake

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

- Jacob Walczak - Matlab, Antennas, EE courses
- Ben Brown - EE courses, conflict management, Matlab
- Sam Runkel - EE courses, Leadership, communication, Matlab, Python
- Christopher Marting - EE courses, Antennas, Python, Java, C
- Tanner Garity - EE courses, VLSI circuit design, Ki Cad, control systems
- Greg Schmitt - EE courses, technical documentation, Matlab, Arduino, C

2. Strategies for encouraging and support contributions and ideas from all team members:

- Always being open to new ideas and being open minded

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)

- Talk to Ben Brown

Goal-Setting, Planning, and Execution

1. Team goals for this semester:

- Get necessary materials
- Working Blueprint
- Energy Harvesting circuit with screen

- Begin work on frequency swapping

2. Strategies for planning and assigning individual and team work:

- Decide weekly at team meetings what work need to be done and assign tasks that are in line with the individual's designated position or skills

3. Strategies for keeping on task:

- Weekly check ups on everyone's contributions

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?

- Try to solve any obstructions with Ben Brown
- Make sure everyone's opinions are valued
- Meet in the middle
- Everyone is treated fairly

2. What will your team do if the infractions continue?

- Firstly speak to Ben Brown to try to solve any issues
- Secondly, take it to a group meeting
- Thirdly, mention the infraction to the professor

****

a) I participated in formulating the standards, roles, and procedures as stated in this contract.

b) I understand that I am obligated to abide by these terms and conditions.

c) I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.

1) Sam Runkel DATE 4/24/2022

2) Jacob Walczak DATE 4/24/2022

3) Greg Schmitt DATE 4/24/2022

4) Benjamin Brown DATE 4/24/2022

5) Tanner Garity DATE 4/24/2022

6) Christopher Marting DATE 4/24/2022