RFRD
Radio Frequency Readout Device

PROJECT PLAN VERSION 2.0

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1 Introduction

1.1 Project statement

Our goal in this project is to develop an RF communication system with which we can read a sensor value from a passive tag from at least five meters away. In an acronym, the goal of our project is to develop a Radio Frequency Readout Device (RFRD), we will be using a capacitance sensor for the first sensor build.

1.2 purpose

All across America, light poles line the side of the streets. These light poles are anchored to the ground using washers in combination with bolts. However, there is currently not a systematic approach in place to ensure that the washers and bolts are tightly secured. Currently, workers have to manually check each individual bolt on each light pole every single year. Our project is to design a system that can solve this issue by telling workers whether the washers are secured or if they need to be tightened.

1.3 Goals

Semester-goals:

- Successfully program Mega2560 Microcontroller with Arduino to send a signal to a 13.56 MHz signal Oscillator to produce a 13.56 MHz signal
- Successfully transmit a 13.56 MHz signal across two (square coil) antennas
- Build a breadboarded IC prototype of our multiplexor logic circuit and corresponding power rectifier, 13.56 MHz clock counter, and data modulator that can operate at a 13.56 MHz signal.
- Conduct performance tests for our capacitive sensor design on Cadence

Potential Semester-goals:

- Build a breadboarded prototype of our capacitive sensor
- Transmit modulated data from our logic circuit prototype over across two antennas
- Model appropriate demodulator for demodulating incoming data from the IC prior to sending it to the Microcontroller
- Work on an Analog to Digital converter that converts the incoming analog data before sending it to the Microcontroller

Goals for next Semester:

- Address any design issues encountered during prototyping phase
- Develop Demodulator and Analog to Digital Converter on reader end
- Determine how we will differentiate multiple tags- either through inclusion of embedded nonvolatile memory or distinct time delays for tags in close proximity (i.e. for each of the tags corresponding to the bolts of a single light post)
- Integrate the components on the tag side into an integrated circuit design
- Finalize the capacitive sensor design

- Integrate each of the three subsystems of our design (including the RFRD Reader, the RFRD Tag, and the antennas for interaction between the reader and tag)
- Be able to successfully obtain the capacitance data from five meters using an IC that will harvest energy from a reader to power a capacitance sensor and transmit said data back to the reader
- Develop a user interface for accessing the data from the Microcontroller and displaying it in an orderly and user friendly fashion

2 Deliverables

The goal of the first semester is to have a functional lab-ready prototype device that serves as a proof of concept for each of the subsystems in the project as well as the overall system. By semester's end, we intend to have:

- A batteryless system capable of receiving and sending a signal
- A custom circuit capable of processing and transmitting static data
- A reader that is capable of accepting and transmitting data to a sample RFID tag
- Each of the subsystems integrated into a single, functional system
- A website containing information and documents regarding our project

By the end of the project next semester, we intend to have:

- A batteryless system capable of receiving and sending a signal, consisting of:
    - A custom RFID circuit capable of transmitting capacitance data
    - A reader that is able to receive tag data and transmit received data to an external source
    - Software capable of storing captured data locally and transmitting it to other devices.

3 Design

Fundamentally, the method will be to use backscatter. By modulating received radiation with a transistor, rectifier, and dc boost, we send information back to the reader, from the tag, as a series of bits.

Antennas will most likely be square coils; this geometry that has been shown to be effective for reception in initial breadboarding and a relatively popular geometry we have seen throughout our RFID research. Conversion of RF into DC will depend on a rectification circuit using diodes designed for fast switching and low turn-on voltage, likely some type of high speed Schottky diode. The DC will power an integrated circuit designed to generate a signal based on the capacitance values of the capacitors in the metal ring.

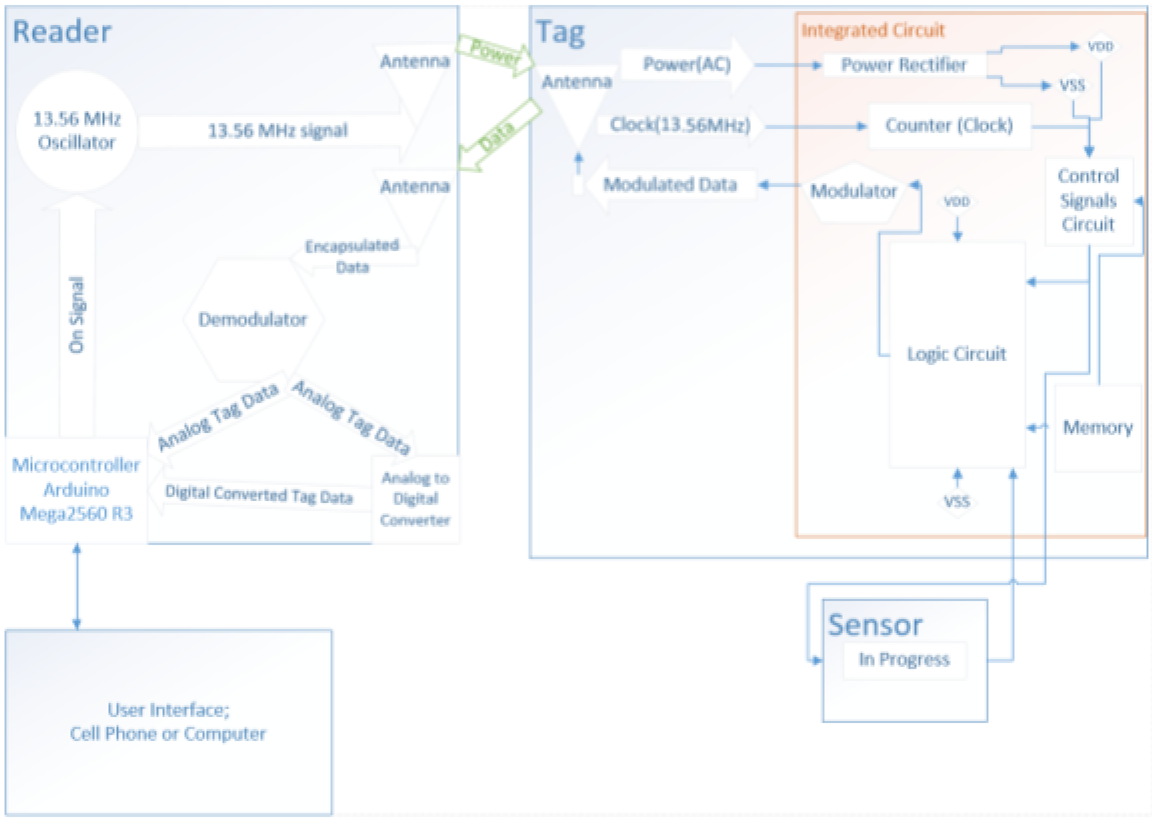
3.1 Previous work/literature

Our project consists of a new application of the radio frequency technology utilized for radio frequency identification devices. The main distinction in our project is that we are utilizing that technology to readout the measurement of a capacitance value independent of the integrated circuit rather than readout identification data. RFID technology has seen some of the most rapid growth of any sector in automatic identification devices since its initial development (Zhan viii). This being the case, there is a lot of research that has been conducted on RF technology.

One important characteristic of RFID performance is the range of transmission (we need to be able to operate at a range of 5 meters). A relevant paper specifically on the topic of performance limitations of passive ultra-high frequency RFID systems is a paper by the same name produced by Pavel Nikitin and K. V. S. Rao for Interlec Technologies Corporation (Nikitin, 1001). In it, they address limitations inherent on both the tag and reader ends. The largest limitation on the tag end is chip sensitivity-specifically with regards to receiving the minimum power necessary from the reader to power the RF tag (1012). There is a corresponding limitation on the reader end, where a limitation is placed on the maximum power of the signal by national regulations (1013). These limitations will probably provide us with one of the greatest challenges we will have to overcome in successfully implementing our design.

As for the readout-component of the project, we are engineering a novel system in that an RF tag for RFID holds non-variable data that will always be the same. We, however, are looking to send variable data measurements of capacitance, and so perhaps an even greater difficulty will be converting the capacitance data into a format that can be transmitted with RF technology.

3.2 Proposed System Block diagram



Full System Block Diagram

3.3 Assessment of Proposed methods

Reader:

For the reader module of the project, we initially had to choose between two different approaches to obtain the module itself. Our first choice would be to find and purchase a pre-built device that worked within the selected RF band and could either do what we needed to out of the box or be reconfigured or reprogrammed to do what we needed. However, this option presented itself to be too expensive to be feasible for our project, as they would normally cost in excess of $1000. Our second, and chosen, option would be to build our own reader module, either from scratch or from parts, which would require more work, but be significantly cheaper.

Building off of that choice, we then had to choose between building from scratch or from off the shelf parts. After doing some research into what goes into building an RFID reader we have decided to build our own. While an off the shelf part would be good when considering speed, we need something we can change if specifications change. More importantly, because we do not yet know how the data packets we will be receiving will be sent or structured, building it ourselves allows us to make small changes to accommodate what the IC team creates.

With this in mind we decided what components we need in the reader, first we need something to control signals, read data, and send it to an external device later. For this we are going to use an Arduino, we are looking at Arduino Mega2560 R3 at the moment. The Mega2560 has more than enough IO pins and processing power for what we want to accomplish, and after we are done testing with it we can see about changing to a smaller, or cheaper, model. Second we need a crystal oscillator and an antenna. The oscillator will be a crystal oscillator we purchase and the antenna will be designed by our antena team.

After we send the power through that oscillator and antenna we need to receive the data from the IC. Currently, we are planning to use two antennas because our antenna team believes that two antennas will be able to send and receive data easier, and likely further than a single antenna. We will then need to demodulate the data and run it through an Analog to Digital Converter (ADC). We have selected a demodulator that we will begin testing shortly, and we will be selecting an ADC once we can start receiving data from the IC and know what kind of ADC we need.

IC Team:

Our tag IC will contain most of the same circuitry as a standard ID tag, with the exception of the sensor circuitry. It will use the incoming RF signal to run a clock signal, and also rectify the RF to provide DC power. The sensor will consist of a set of capacitors to test, and a charge/discharge circuit for each capacitor. The capacitors will be of a known range of values, and the charge circuit will provide a charge pulse of sufficient time to charge them to a percentage of Vdd dependent upon their capacitive value. This percentage is then read into the modulator circuit to be interpreted as a high or low value.

While this does provide only a single bit of resolution for each sensed capacitor, the overall circuit will provide some redundancy to help mitigate errors in the sensor reading. Some modifications will be necessary for specific applications, as this design is strictly for a single usage case. These particular problems could have been avoided with the use of an off the shelf sensor that outputs a digital signal, but power and cost limitations restricted us to custom sensor design.

Antenna:

Having established a general picture for desired antenna geometry, the next step is developing a rectifier for the antenna that provides maximal dc power to the rest of the receiver circuit. This entails developing an impedance match between the antenna and the rectifier, which in turn requires a knowledge of antenna input impedance and rectifier circuit input impedance - both of which are best calculated numerically. Antenna input impedance calculation requires a Moment Method simulation, either as a script or from an existing simulation package. Rectifier input impedance calculation requires relevant models for the diodes we plan on using with implementation in ADS.

Less pressing is the issue of antenna implementation on the reader end - there need only be an impedance match between the driving / receiving circuitry, and the reader has power so we can buffer and amplify signals as needed. Not to say that the task is trivial on the receiver end - but the receiver represents a larger level of conceptual involvement and priority.

3.4 Validation

Reader:

Validation of the Reader module would be series of tests of sending and receiving packets in different capacities. Initially, our goal would be to have the reader simply sending out power and being able to receive a response from the tag that can be understood properly. Next, we will need to test the reader's ability to store data reliably for retransmission later.

Once that is finished we will need to test to see if the reader is able to send data to a computer after reading more than one tag, and have correct data for each tag. If we get that working we will decide if we need to include bluetooth functionality. If we need bluetooth functions or larger storage on the reader itself, we may add a Raspberry Pi to store and send data to external devices.

IC Team:

In order to validate our design, we will perform simulations in Cadence to verify operation of each section of the IC, once these sections are tested to be working close to specification, they will be combined to form the overall IC. Test and modification will also be done on the total circuit to debug any issues that arrive.

In addition to simulation testing, we plan to build a breadboard prototype to test the circuit with our own antennae. This will help verify the concepts of the device with real world interference, which is not available in a computer simulation.

Antenna:

Validation for the antenna portion of the project starts at rectification. If we can rectify a 13.56 MHz function generator signal into a dc waveform with reasonable efficiency, that will be the first point of validation. Directly after that would be driving a dc load of some sort, measuring the available dc power out from the rectifier, and, of course, using it to power the IC if possible.

From there, we can move to using the antenna to drive the rectifier with max efficiency. Intermediate steps to this goal include attaining the diode model for modeling in ADS and verification of impedance matching between the antenna and the rectifier. Determination of antenna impedance will require some sort of Moment Method calculation, and that task in itself will be a validation point if we have to develop our own script for it.

Complete Project:

Since the goal of our project is to accurately measure and transmit the capacitance value of a sensor capacitor from the RF tag to the RF reader, we will be able to validate that it is working properly by developing a user interface on a computer or mobile device that will display the incoming capacitance measurement readings. Thus the success of our project will be validated by comparing the capacitance value of the sensor capacitor with the reading on the other end.

4 Project Requirements/Specifications

4.1 FUNCTIONAL

- IC
  - The tag needs to be passive. It must harvest all of its power from the incoming signal from the reader.
  - Tags must include an antenna for signal reception/transmission.
  - Tags must include identification data in the form of nonvolatile memory that can be utilized to uniquely differentiate the tags for each of the bolts on a light post.
  - Capacitance sensors need to be able to determine whether the bolt is ‘tight’ or ‘loose’ (will readout a ‘0’ for tight or a ‘1’ for loose).
- Reader
  - The RFRD reader must be able to successfully retrieve capacitance data, from the RFRD tag at a minimum distance of 5 meters.
  - The reader should transmit and receive a signal with carrier frequency of 13.56 MHz for the purpose of testing and possibly 900 MHz for the final product in which the capacitance and identification data for each tag will be embedded.
  - The reader must be able to receive the incoming signal from each tag, capture the corresponding capacitance data, and identify which tags are linked with loose/tight bolts.
- Antenna
  - Receiving antenna must capture enough power to be able to drive every subsystem of the tag. This may require the transmitting antenna to be able to handle an especially large input power, given the 5 m target distance of the application.

4.2 NON-FUNCTIONAL

- IC
  - The RFRD tag must cost less than 50¢.
  - The tag size should be limited to the scale of millimeters, but is less crucial than cost considerations.
- Reader
  - The size of the reader is inconsequential.
  - The reader does not need to be battery-powered.
  - The cost of the reader is negligible compared to the cost of the tag.
- Antenna
  - Transmitting antenna should be a manageable size (should not need to be carted around, for example)
  - Receiving antenna should be appropriately durable and small enough to fit in its application.

5 Challenges

Reader Team:

We are currently planning to use two antennas to send and receive data. RFID systems we have looked at use a single antenna. We are not sure why they have decided to use a single antenna, but that uncertainty concerns use.

We are waiting for parts for testing. We know we will need to convert the analog signal we get from our antenna to a digital signal, but we are unsure what kind of ADC we need. None of us have had much experience with designing, testing, or choosing ADC components.

IC Team:

The main challenge for the IC team is designing a system that can run off very little power. Specifically, we have to be capable of harvesting power from five meters away and running the entire IC/sensor off that power. Additionally, the tag can only cost a few cents.

One challenge is that we are conflicted over whether to design this system solely for measuring capacitance or for measuring any output characteristic of any interchangeable transducer. If determining capacitance is our only goal, our tag design stands to be greatly simplified. If the goal is to be able to implant any transducer to modulate the backscattered signal and send data back to the reader, then the project has the extra challenges of determining a common standard for our transducers and demonstrating each of their efficacies in a more complicated circuit.

Antenna:

For the rectifier circuit, it looks like we know what diodes we want but they are surface mount diodes and it is doubtful that we have access to surface-mount rapid prototype boards. As an alternative, we may require an accurate ADS model for that diode, as ADS will tell us much more about the functionality of those diodes in our circuit than a rapid prototype test on a bench could anyways. It does not even have to be the diode from the rectenna paper necessarily - it could just be a diode whose behavior is generally representative of diodes designed to carry RF at power levels on the order of mW. Attainment of a part model of this sort could take some time-expensive negotiations with parts vendors.

For the impedance match between the antenna and rectifier circuit, we will need some method for calculating antenna impedance quickly. This way, depending on which antenna we would like to test in front of the rectifier, we can quickly develop a lumped element circuit impedance model for which a matching network can be developed. This could require us to get access to HFSS (the challenge being administrative) or implement a Moment Method script for calculating antenna impedance (the challenge being conceptual).

6 Timeline

6.1 First Semester

A graphical representation for the first semester timeline is provided in the appendix on page 11.

Antenna team:

a. Attain an ADS model for a suitable RF diode. Test it in ADS, attaining a plot of input impedance vs. frequency.
b. Test the ADS rectifier model with an impedance match network in front of it; verify optimal power transfer for impedance match.
c. Find or implement a tool that will calculate antenna impedance for a range of geometries. Empirically determine the optimal antenna, or at least a trend which leads to the optimal antenna, using either HFSS or breadboarding.
d. Develop, implement, and test a PCB layout given the above decided antenna and rectifier.
e. The antenna and rectifier now having been decided on for the receiving end, look into necessities for the reader module side of the project. Note that amplifiers, oscillators, and modulators are all likely purchasable.

Reader Team:

a. Build and test the current components to receive data from an HF RFID tag.
b. Test with the prototype created by the IC team to receive data and test capacitance from a range.
c. Test how far we can get read the 13.56 MHz signal, we will attempt to reach 1 meter this semester.
d. Configure the Arduino Mega 2560 as the controller and have it send the data to a computer through the USB port.

IC Team:

Integration:

Primary goal: Start integrating system components at levels which by themselves are conceptually most challenging. Demonstrate proof of concept functionality for at least one method by executing theoretical and empirical research into the method.

1. Sending and receiving appreciable RF power at appreciable distance:
    a. With antennas connected to signal generators and spectrum analyzers.
    b. With reader module, sourced from DC power, sending to antenna connected to spectrum analyzer.
    c. With reader module, sourced from DC power, sending to antenna connected to tag.
2. Rectifying incoming RF power into a DC source at an appreciable voltage and current.
3. Receiving appreciable amount of backscatter or otherwise reflected radiation from the tag.

4. Implement signal processing, analog or digital, to received radiation from tag to make an approximate capacitance measurement.

6.2 Second Semester

Primary goal: Extend on accomplishments of first semester. Research and development into all aspects of project improvement.

1. Make the system workable from farther away.
    a. More efficient impedance matching and circuit design.
    b. Research into higher gain antennas.
2. Make the system transmit more information.
    a. Develop electronics on the receiver tag that allow for transmitting various forms of information.
3. Make the system robustly workable for a wider range of applications.
    a. Develop a system for standardizing transducers and potentially manage an ADC. This ADC could hold values in a register which it counts through in sending its data.
    b. Make the system communication protocol workable for an indefinite amount of tags close together (ideally less than 3).

7 Conclusions

The goal for this project is to demonstrate an ability to measure a capacitance from five meters using our own RF communication protocol. After accomplishing this, the goal is to take steps towards researching and improving the system farther.

In that vein, the general project plan is to:

Implement the reader.

1. Purchase a controller and module.
2. Learn how to interface with them.
3. Decide on the reader antenna. Antenna used depends on instantaneous functional goals.
    a. If capacitance is all we want to measure, we will want to use a frequency independent antenna here so that we can take a frequency sweep to find the resonant frequency of the tag circuit.
    b. If we want to make the system adaptable to a wide variety of transducers, we need to use a single high-gain antenna for maximum power at a given operating frequency - determination of resonant frequency will no longer be the goal.

Implement the tag. Complexity of tag circuit, as well as tag antenna, depends on instantaneous functional goals.

1. Tag antenna: Same as the reader antenna. There might be a yagi array here for initial proof of concept but it will probably come down to choosing between a frequency independent spiral antenna and a dipole.
2. If capacitance is all we want to measure, determine a range for desired capacitances. This means getting a desired distance range using the capacitance equation for parallel plate capacitors. This desired capacitance range will determine the values for the known series inductance and known series capacitance to place in the circuit.
3. If we want to be able to receive a value sourced from a wide variety of interchangeable transducers, we will likely have to implement a sensor circuit capable of outputting a PWM signal or digital 8-bit square wave given a certain input characteristic, plus a rectifier to power said sensor circuit with our reader's RF.

8 References

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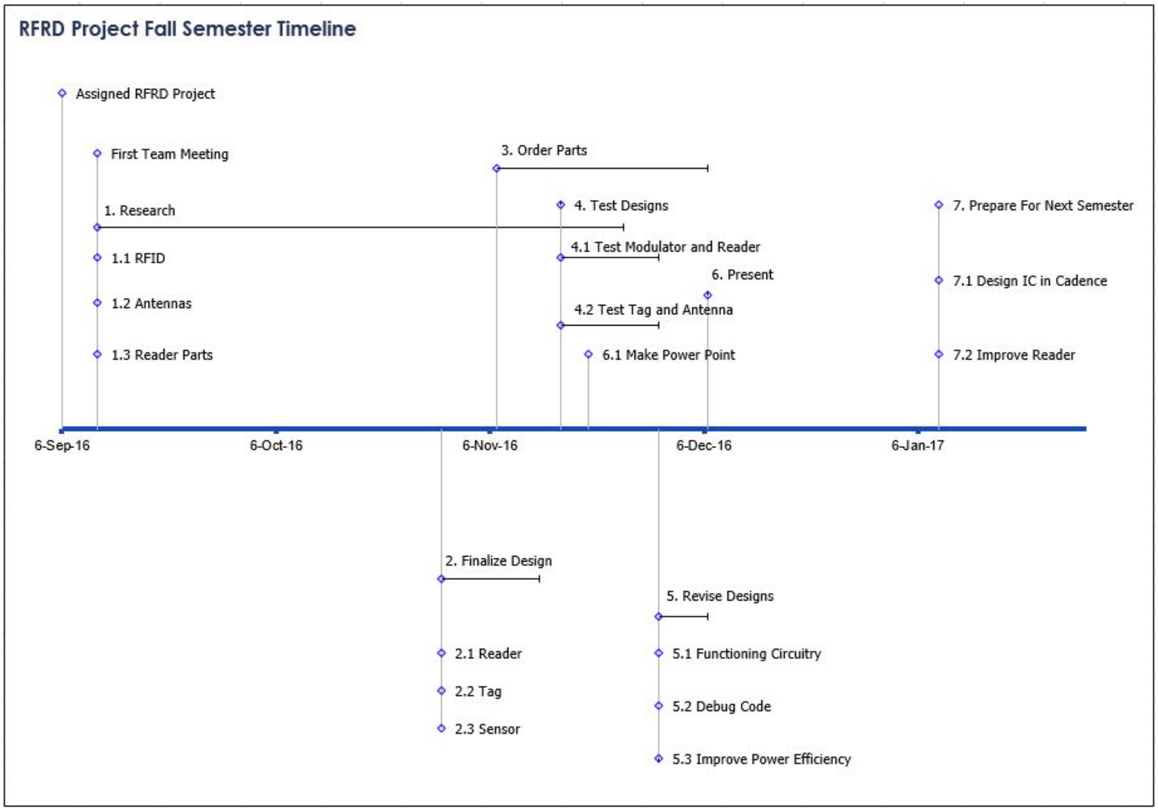
9 Appendices



Originally, our goal was to order parts in mid October and test in late October with redesign occurring in November. However, due to some new information given to us in October, we had to redesign our implementation to match the new constraints. This set us back a little bit, but we are still planning on having a working prototype by the end of the semester to present in December.