RFRD
Radio Frequency Readout Device

PROJECT PLAN

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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

This project, in just the application for which we designed it, allows us to take a capacitance measurement from a distance. For two metal plates of constant material between them, a capacitance measurement is essentially a distance measurement - so anywhere this tag is implanted would let us gauge the distance between two metal plates - potentially useful for nondestructive evaluation of any construction.

Going past merely measuring capacitances, this tag could let us transmit information given any transducer capable of generating a series of digital voltages to correspond to a value.

1.3 Goals

Measure capacitance 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.

Demonstrate ability to measure given other transducers at five meters.

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 circuit capable of processing transmitted data
- A reader that is capable of accepting and transmitting data to an external device
- Each of the subsystems integrated into a single, functional system
- A website containing information about our project

3 Design

We have two primary ideas to obtain capacitance information from the tag.

1. Backscatter: By modulating received radiation with a transistor, rectifier, and dc boost, we send information to the reader, from the tag - either through PWM or as a series of bits.
2. Resonant frequency determination: By determining the resonant frequency of the RLC circuit in the tag with known L, C, and R values placed in the tag's circuit, we can calculate the capacitance of the test capacitor.

Antenna design depends on the method used.

1. Backscatter: Likely a high gain yagi array for the reader, and a half-wave dipole at the tag for size constraints.
2. Resonant frequency determination: Frequency-independent antennas at both the reader and the tag so that we don't alter performance of the reader-tag system as we sweep looking for the tag's resonant frequency.

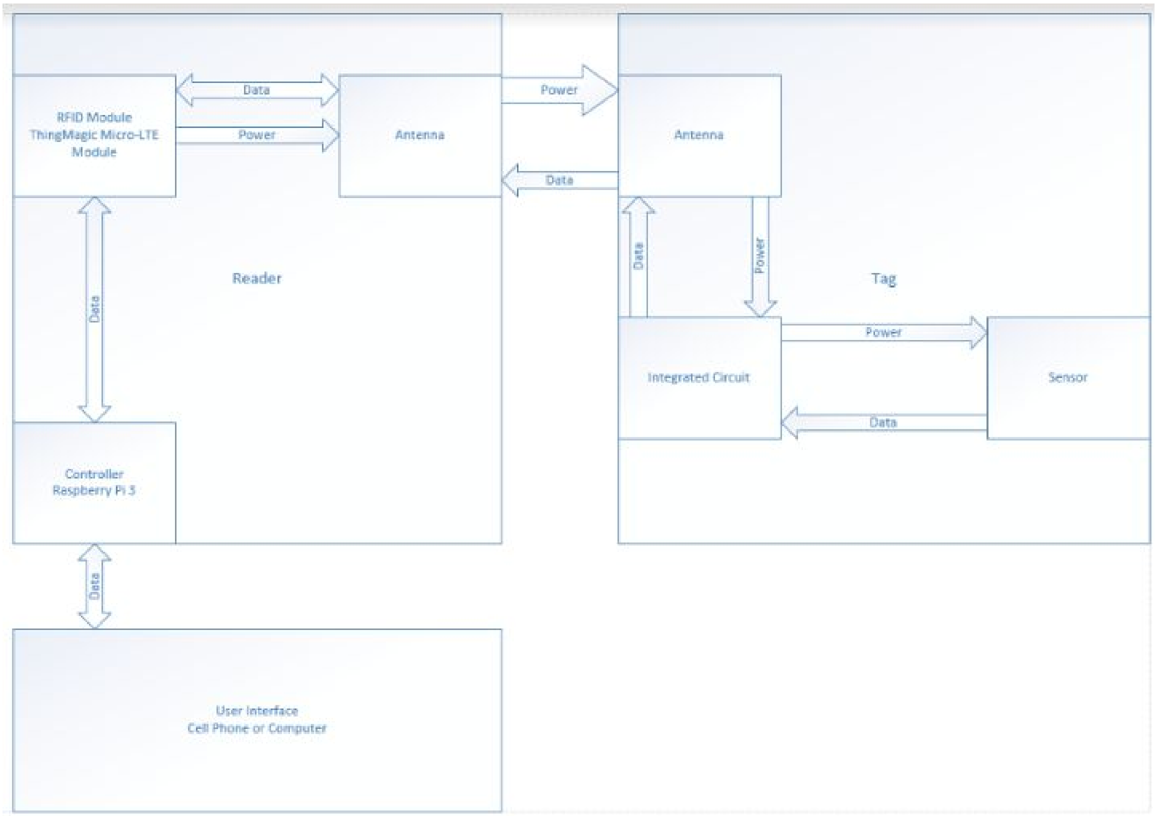
3.1 Previous work/literature

Our project consists of a new application of the radio frequency technology utilized for radio frequency readout 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



3.3 Assessment of Proposed methods

Provide a short discussion about the different approaches available and the approach you want to follow in your work.

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 a RFID module alone, we decided to go with building the reader module from off the shelf parts. The first part considered was the computer that would power the reader, our choices being either Arduino or Raspberry Pi. The decision was quickly made to make the reader using the Pi 3, as it has far superior hardware specifications and includes built-in bluetooth for communication outside the device,2 compared to the Arduino's very low processing power and storage and lack of native bluetooth.

Finally, with the use of the Raspberry Pi, we also had a short discussion on choices of programming languages and target mobile platform. For the mobile platform, due to the more open nature of the Android OS, we decided to target that for the potential mobile app versus iOS, which requires Macs to develop for, which only two of us have, has more restrictions on uses of Bluetooth, and would be more expensive to obtain devices. As for programming languages on the reader computer, this will entirely depend on the RFID module that we choose, though the general consensus is C as most embedded-type readers seem to support it.

IC Team:

We currently have two methods of measuring capacitance values. One method uses the resonance of a series RLC to block backscatter at it's resonant frequency. The other method uses an RC voltage divider which outputs to a Schmitt trigger, or a similar device, to modulate the backscatter.

The resonant circuit may be limited in its sensing range, and will still require a modulator circuit to send tag ID information.

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 a packet and being able to receive a response from the tag that can be understood properly. Next, we would need to test the reader's ability to store data reliably for retransmission later. Then, we would need to test to see if the reader is able to send data to a mobile device properly and that the mobile device will be able to store the data for a longer period of time or send it off to a cloud-based server.

IC Team:

Validation for a properly operating tag will depend on the method that we choose to execute. Initial validation will be sought through tests independent of the reader. If the series RLC method is utilized, we will have to send the circuit an AC signal simulating that of the reader and measure the backscatter from the circuit across a range of incoming frequencies. We will then see if we can find the resonant frequency based on where the backscatter goes to zero and use that value to obtain the value of the sensor capacitor.

If the later method of direct measurement is utilized with the schmitt-trigger circuit we will likewise send a signal simulating that incoming from the reader to the circuit. If we are able to obtain the expected output of a periodic square wave, the hope is that we will be able to use the variable amplitude of that wave to derive the corresponding value of the sensor capacitor.

Complete Project:

Since the goal of our project is to accurately measure and transmit the capacitance 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

Must receive a reasonable approximation of the correct capacitance / transducer value.

Must do so from at least five meters.

Must operate in a legal RFID range: 902 MHz to 928 MHz.

Must be able to store data that is retrieved from the tags in a mobile device in some capacity

4.2 NON-FUNCTIONAL

Documentation: Guide to implementation, systems level diagram at various levels, user guide.

Reader and tag are manageable in size. Reader should not take more than one person to operate and the tag should be 4 mm x 10 mm x 3 mm.

5 Challenges

Include any concerns or details that may slow or hinder your plan as it is now. These may include anything to do with costs, materials, equipment, knowledge of area, accuracy issues, etc.

Reader Team:

The RFID module is being used to send power and receive data simultaneously. At the moment we do not fully understand what the reader is doing, but we have found that it is going to be needed for functionality to work. To assume that we could implement the circuitry of the RFID module with our existing knowledge base sounds like a bit of a stretch.

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.

6 Timeline

You may want to include a Gantt chart/something similar to help visualize your timeline to complete the project.

6.1 First Semester

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

Antenna team:

Choose an antenna:

a. Frequency-independent: Useful for calculation of test capacitance through determination of resonant frequency. Allows for sweeping the operating frequency of the tag while keeping other electrical variables constant in the reader-tag system.
b. Yagi array: High gain, directive, narrowband antenna, useful for when we are interested in working at one operating frequency.
c. Half-wave dipole: Very easy to construct for a given operating frequency. Easy to match impedance with and ease of construction allows for quickly adaptable tests.

Reader Team:

a. Choose and purchase an UHF RFID module that will work at the ranges we need, and can be configured for whatever data we get from the IC.
b. Configure a Raspberry Pi 3 as the controller for the UHF RFID module so that it can receive data from the module and store it in the Pi. The data should then be able to be accessed from a cell phone app or another computer.

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

Armstrong, Shain. (2011, Nov 24). *RFID Basics: How RFID Tags Work.* Online. Available: Types of RF Coupling

Marzuki, Arjuna et al. *Advances in RFID Components Design: Integrated Circuits.* Online. Available: RFID Integrated Circuit Design

Nikitin, Pavel and K. V. S. Rao. *Performance Limitations of Passive UHF RFID Systems.* Online. Available: Performance limitations of UHF Passive RFID systems

Nikitin, Pavel et al. "Power Reflection Coefficient Analysis for Complex Impedances in RFID Tag Design." *IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES,* Vol. 53, No. 9, Sep. 2005.

Rodjegard, Henrik and Anders Loof. "A differential charge-transfer readout circuit for multiple output capacitive sensors." *Sensors and Actuators*, A 119 (2005), pp. 309–315.

What is Lola? Online. Available: LoRa Module for Long Range Data Sending

Yao, Wang et al. "Design of a passive UHF RFID tag for the ISO18000-6C protocol." *Journal of Semiconductors,* Vol. 32, No. 5. May, 2011.

Yazdi, Navid. "A generic interface chip for capacitive sensors in low-power multi-parameter microsystems." *Sensors and Actuators,* 84 (2000), pp. 351-361.

Zhan, Sanyi. "Analysis and design of metal-surface mounted radio frequency identification (RFID) transponders" (2008). *Graduate Theses and Dissertations.* Paper 11730.

9 Appendices

Title: RFRD Project Timeline

Date	Task	Days	Height	Axis	Label
9/6/2016	Assigned RFRD Project		45	42619	Assigned RFRD Project
9/11/2016	First Team Meeting		37	42624	First Team Meeting
9/11/2016	1. Research	75	27	42624	1. Research
9/11/2016	1.1 RFID		23	42624	1.1 RFID
9/11/2016	1.2 Antennas		17	42624	1.2 Antennas
9/11/2016	1.3 Reader Parts		10	42624	1.3 Reader Parts
10/17/2016	2. Order Par	14	-20	42660	2. Order Parts
10/17/2016	2.1 IC Parts		-30	42660	2.1 IC Parts
10/21/2016	2.2 Reader Parts		-35	42664	2.2 Reader Parts
10/21/2016	2.3 Antenna Materials		-40	42664	2.3 Antenna Materials
10/24/2016	3. Test Syste	30	35	42667	3. Test Systems
10/24/2016	3.1 Test Power Harvester		30	42667	3.1 Test Power Harvester
10/24/2016	3.2 Test Modulator and Re		23	42667	3.2 Test Modulator and Reader
10/24/2016	3.3 Test Backscatter Circu		10	42667	3.3 Test Backscatter Circuitry
11/14/2016	4. Revise De	16	-25	42688	4. Revise Designs
11/14/2016	4.1 Working Circuitry		-30	42688	4.1 Working Circuitry
11/14/2016	4.2 Debug Code		-35	42688	4.2 Debug Code
11/14/2016	4.3 Improve Power Efficie		-40	42688	4.3 Improve Power Efficiency
12/5/2016	5. Present	0	25	42709	5. Present
12/5/2016	5.1 Plan For Next Semeste		20	42709	5.1 Plan For Next Semester