Radio Frequency Readout Device

DESIGN DOCUMENT

Team 11
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http://sdmay18-11.sd.ece.iastate.edu/design_documents.html

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1 Introduction

1.1 ACKNOWLEDGEMENT

Advisor: Daji Qiao and Nathan Neihart

Client: Daji Qiao

Facilitator and IC Design/Fabrication/Test Engineer - Bailey Akers

Antenna Principal Engineer - Lyle Bishop Jr.

IC Design/Fabrication/Test Engineer - Colin Sunderman

Power Harvesting Engineer - Pengyu Qu

RFRD Communication Protocol Engineer - Nathan Mulbrook

Task Assistance – Chengrui Yang and Scott Melvin (with technical advices)

1.2 PROBLEM AND PROJECT STATEMENT

The purpose of this project is to reduce the time it takes to check each nut for tightness on bolts of large lamppost structures. Each nut currently must be manually checked for tightness with large tools to ensure that the structure is sound.

To address this problem, this project will use a Radio Frequency Readout Device (RFRD) to read if each nut is secured tightly or if it needs to be properly torqued. This RFRD will be usable in a vehicle at a distance to reduce the time it is needed to check each structure. The RFRD reader will be designed to power a RFRD tag, which will read the capacitance value of washers between a bolt and nut. The capacitance value will be transmitted back to the RFRD reader and tell the user if the nut is tight or loose.

1.3 OPERATIONAL ENVIROMENT

The RFRD tag will be attached to a metal lamppost structure and will be subject to weather conditions. The RFRD reader will be used in a vehicle or dry weather conditions.

1.4 INTENDED USERS AND USES

The RFRD reader and tag are intended to be used by civil engineers and construction workers on lampposts and other larger structures that require inspections to the structures integrity and tightness of its fasteners.

1.5 ASSUMPTIONS AND LIMITATIONS

The primary assumption that this project makes is that the washer will not be covered by any metal covering that could prevent RF communications with the device. We also assume that the temperature will remain within normal atmospheric temperatures such as those in Iowa, use in extreme locations such as the arctic would put additional constraints on the project.

There are a few design constraints that the end project must comply with, they are listed below.

- The tag must not rely on wired power sources.
- The tag must be low cost and the final product must cost less than a dollar.
- The tag must have long-term stability and reliability.
- The tag must have a minimal installation difficulty and low training requirements.

1.6 EXPECTED END PRODUCT AND DELIVERABLES

The end product will be comprised of a proof of concept for the technology. This includes all hardware designs with enough detail to allow for the mass production of the tags, and the software that runs on the tag itself and the software needed to interface with it.

The hardware designs will include everything needed to build the tag. A parts list will be compiled that includes part numbers and costs for all hardware components needed. A detailed designs and instructions will be included to instruct in the process of building the tags.

There is software required for both the tags and the reader. This will be complete compliable code that can be loaded into their respective devices with little to no configuration. The source code and documentation on its functioning will be included.

2. Specifications and Analysis

2.1 PROPOSED DESIGN

The goal of this project is to design a radio frequency readout device (RFRD) to use in an anchor bolt surveying application.

We have three major components of our design:

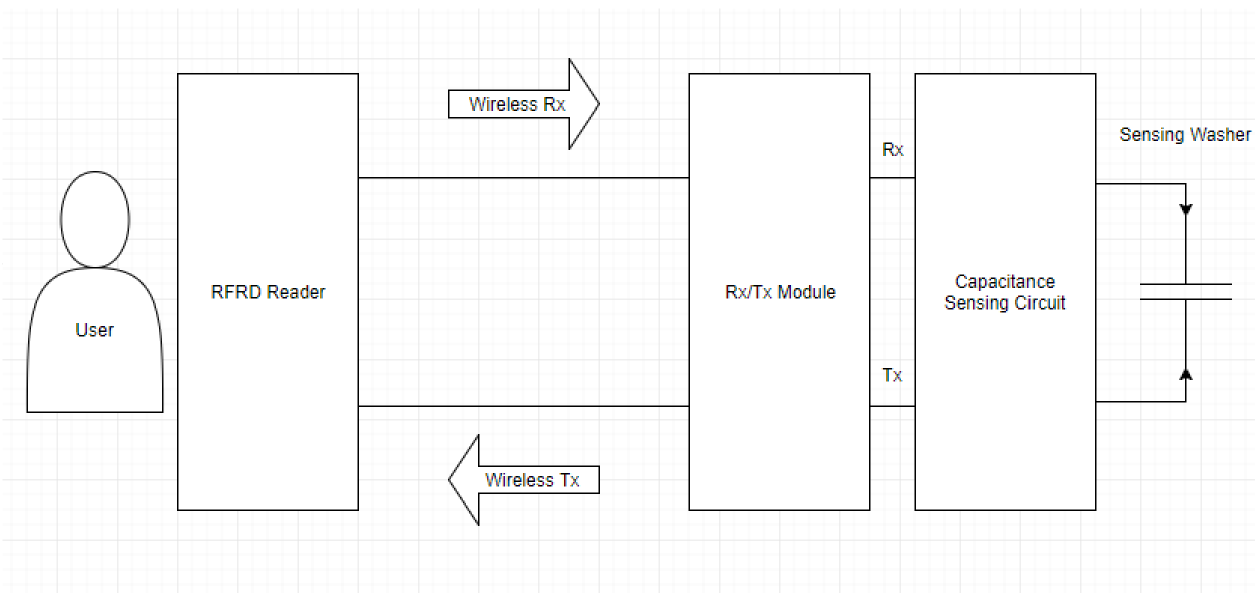
1) Capacitance sensing circuit

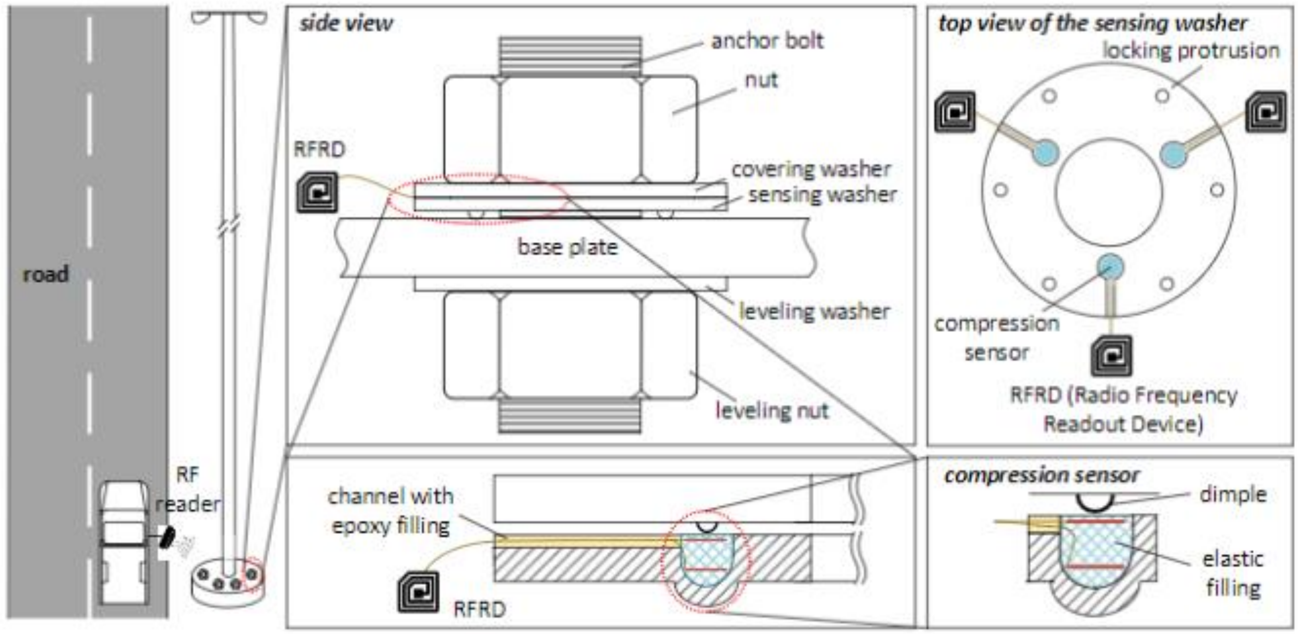
2) Rx/Tx module including antenna and power harvesting circuitry

3) RFRD reader

A simple block diagram for our design is as follows:

Figure 1: RFRD Block Diagram





We tested the washer design by soldering two wires, one on the covering and another on the sensing washers. We then measured the capacitance of the system using an LCR meter. We concluded as follows:

Test 1: Resting washers: 20 pF

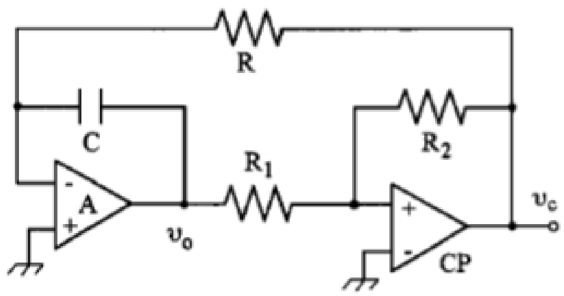
Test 2: No contacting washers: 2 pF

Test 3: Pressured washers: 30 – 40 pF

Relaxation Oscillator:

We are designing a relaxation oscillator to measure from 20 – 50 pF with ~1% measuring error. We referenced a design in the published IEEE article, "Limitations of a Relaxation Oscillator in Capacitance Measurements" by Yili Liu, Song Chen, Masakatsu Nakayama, and Kenzo Watanabe.

Figure 3: Relaxation Oscillator Circuit



(a)

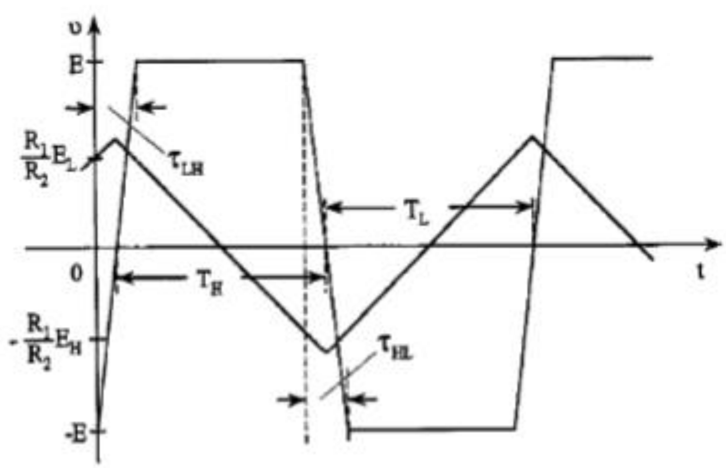
We can use relaxation oscillators to measure capacitance since they are designed to produce a pulse signal that changes the oscillation period linearly with capacitance measured in C (circuit above).

Figure 4: Oscillation Period Equation

The oscillation period T is thus

$$T = T_H + T_L = CR\frac{R_1}{R_2}\left(2 + \gamma + \frac{1}{\gamma}\right). \qquad (6)$$

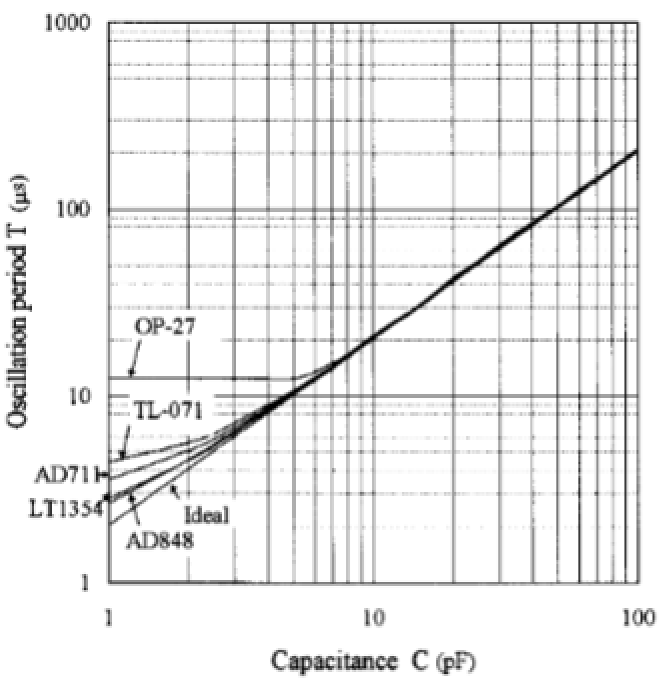
Figure 5: Output from relaxation oscillator



Op Amps for Relaxation Oscillator:

For this application, we will need to use very low-power op amps. In the article, they tested five op amps to measure the percent error achieved with each op amp. The below op amps are not a very low-power application.

Figure 6: Percent Error for Tested Op Amps



In order to calculate our very low-power op amp criteria, we used the following equations from the above IEEE article.

Figure 6: Op amp equations

The derivation of (18) assumes

$$SR > \frac{E}{CR}. \quad (19)$$

For the error to be less than ε%, an op-amp and a comparator with the following specifications are required:

$$A_o \omega_c > \frac{100}{\varepsilon CR}\left\{1 + \frac{1}{2\alpha}\left(1 + \frac{C_i}{C}\right)\right\} \quad (20)$$

$$\tau < \frac{2\alpha\varepsilon CR}{100}. \quad (21)$$

These derivations tell us our minimum slew rate, gain-bandwidth product, and time response delay our op amp needs to satisfy in order to produce an error less than e%.

Our end goal with the capacitance sensing circuit is to fabricate the circuit on a printed circuit board with surface mount technology.

Capacitance measurement circuit collaborators: Bailey Akers and Colin Sunderman

Rx/Tx Module Design:

Antenna Design:

The design team is looking into designing a small antenna to use for our application. The goal is to design an antenna with a received power rating of ~ 1 mW. We are currently looking at how to approximate the received power in the near-field approximation.

RFRD Reader/Communication Protocol Design:

The communication between the tag and the reader will be one-way digital communications. A microcontroller will be utilized on the tag for reading and processing the information collected from the capacitance sensor. The microcontroller will send the information to the reader were it will be displayed to the user.

The microcontroller we will be using will be from ST's line of ultra-low power ARM based MCU's. These are ARM Cortex M0+ processors capable of running in the micro amp range. ST also has a very easy to use loot chain that will allow the software to be easily written or ported to other ST microcontrollers.

The information being sent form the reader will be of very little complexity and length allowing us to use a very simple protocol. It will be comprised of a single digital string that contains the tag ID, the status of the tag, the status of the washer including if the pressure on the washer has changed, and a checksum to allow for the detection of any errors that might occur during communications.

For initial testing and prototyping, we will be using a software-defined radio for the receiver. This is a type of radio were all the processing is done in software running on a computer and allows for greater flexibility of protocols. This will allow us to implement any protocol or communication system that we may need. There are many options for SDR's and we have not yet decided on an exact product.

2.2 DESIGN ANALYSIS

Our group has been focusing on doing research that will allow us to understand the complex details surrounding our project. For the capacitance measuring circuit we have found a design we would like to use and have been doing research into what kinds of op amps to use. Our main issue with this design is that it is less accurate at measuring capacitances in the lower picofarad range, but we don't believe that this error will be great enough to affect the results of our measurements. We are doing research into power harvesting techniques to see how much power we can expect to get in a near field and what type of antenna we should be using.

3 Testing and Implementation

No testing has been done at this time. Initial testing will begin in the next 1-2 weeks.

4 Closing Material

4.1 CONCLUSION

With this project, we hope to reduce the time required to perform maintenance on highway infrastructure. We will do this by providing workers with better tools to check the fasteners that hold much of this infrastructure together. We have researched many options and ways that we can accomplish this goal and believe the strategy outlined above to the best direction to take.