Radio Frequency Readout Device (RFRD)

May 1718
RFRD

Team Introduction

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- Luke Myers
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- Michael Miller
- Robert Buckley
- Vaughn Dorsey

Project Overview

- **Develop Multi-Purpose Remote Readout Device**
- **Specific Test Scenario: Street lamps across the United States**
  - 4 – 8 bolts per lamp
  - Thousands of lamps per state
- **Problem**
  - Need to test for tightness of bolts
- **Clients**
  - Dr. Qiao
  - Dr. Song

Initial Objective

- **Functional Requirements**
  - Read distance of 5 meters
  - Passive RFID technology
    - Only power available from energy harvesting
  - Send sensor data from capacitive sensor
- **Non-Functional Requirements**
  - Maximum cost of $0.50/tag
  - Size of tag on the order of millimeters
  - Size of tag antenna on the order of centimeters

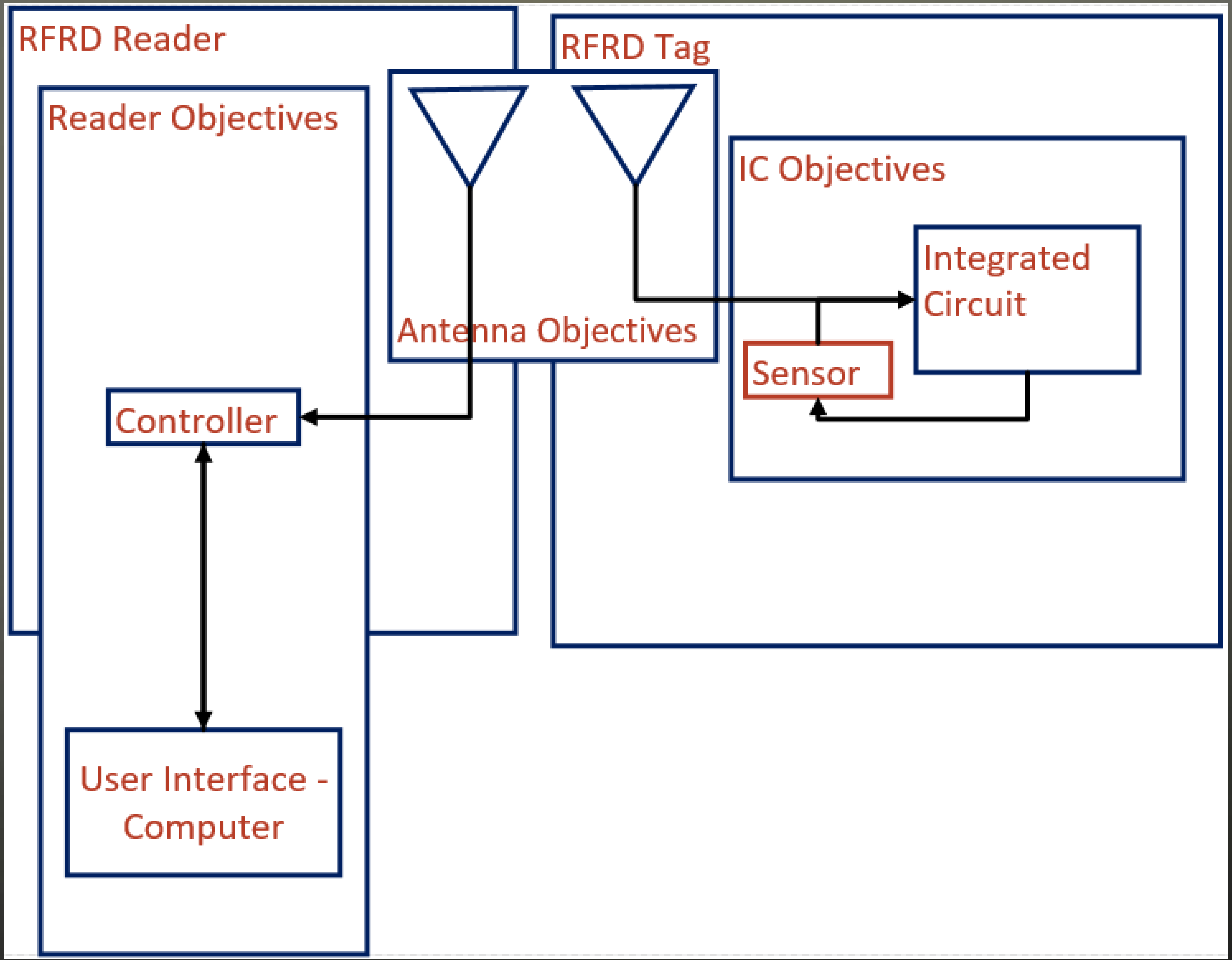
Defining Project

- **Research**
  - How does RFID work?
    - A reader sends a signal to a tag which siphons the signal for energy
    - The tag then modulates that signal and sends back a static packet
  - What do we need to change?
    - The tag to be able to read a sensor
    - The tag needs to be able to send back this sensor's variable data

Defining Project

- **Research**
  - Limitations
    - RFID technology we have access to is limited to a part of the Industrial, Scientific, and Medical (ISM) bands
    - Bands Allowed: 125 kHz, 13.56 MHz, 900 MHz
    - Maximum Output Power: 1 Watt
  - What do we need to use?
    - From our research, 900 MHz is the only range which can reliably send over 5 meters, but it has issues
    - 900 MHz is too expensive to work with, we worked with our client and chose to use 13.56 MHz at the cost of possible distance

Team Division



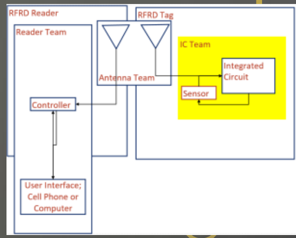
Work Division

- **IC Objectives**
  - Split into two main objectives
    - Create a working prototype using discrete components
    - Design an IC chip in Cadence
- **Antenna Objectives**
  - Design antennas and rectifier
  - Optimize power transfer
- **Reader Objectives**
  - Build a reader we can use to test our device
  - Convert the antenna signal to usable data

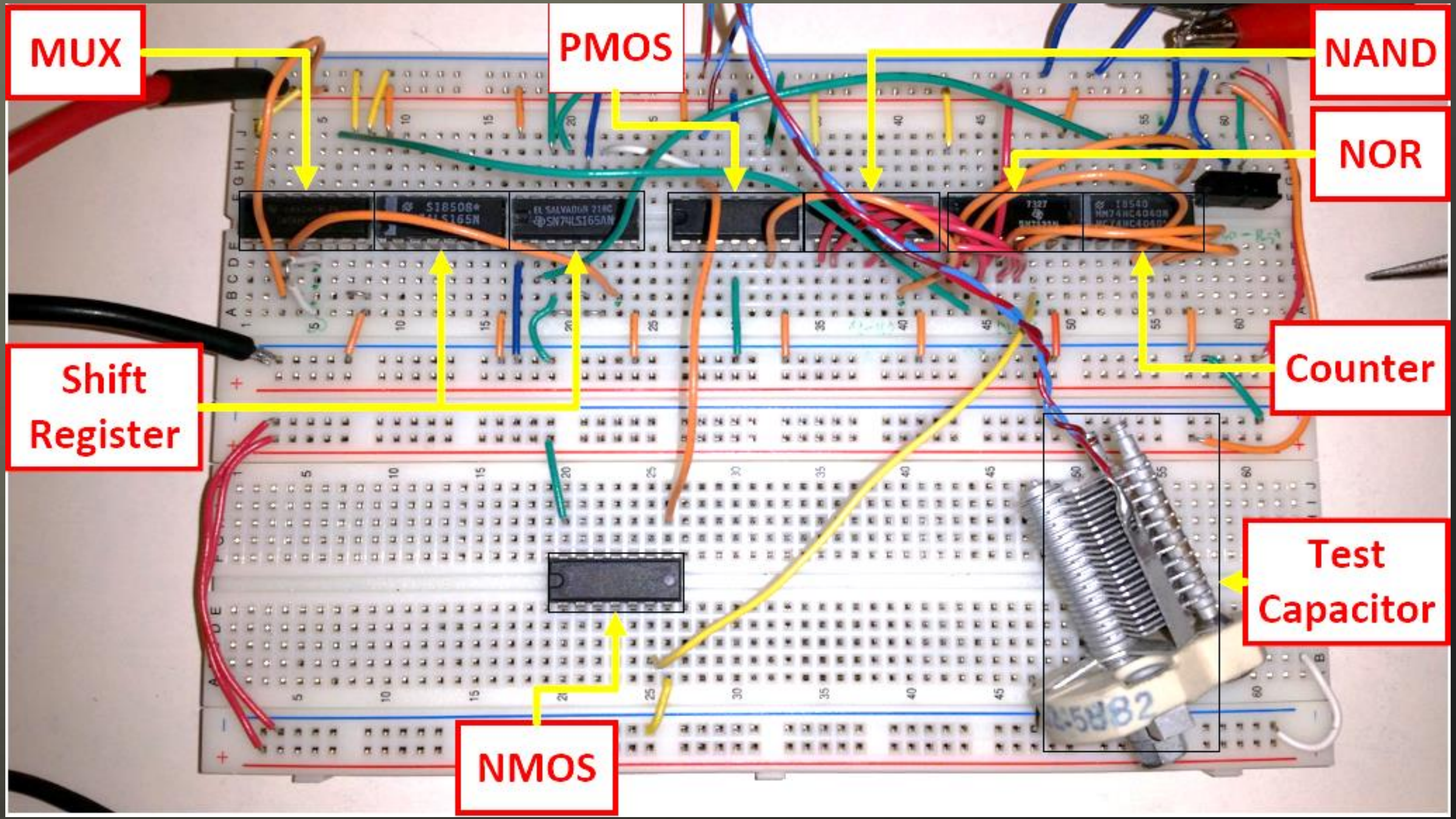
Design Decisions

- **Tag Approach**
  - Use a Parallel-In Serial-Out data system to output static and dynamic data
  - Control capacitor charging/discharging through a clock system
- **Antenna Approach**
  - Square coil antenna – logistically easiest to implement and modify
  - Near-field inductive coupling
- **Reader Approach**
  - Arduino chosen for better low level processing
  - Direct connection to computer to simplify data transfer

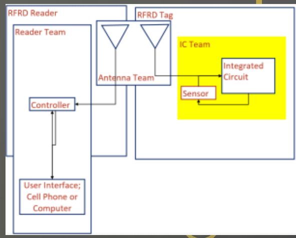
Initial Breadboard Design

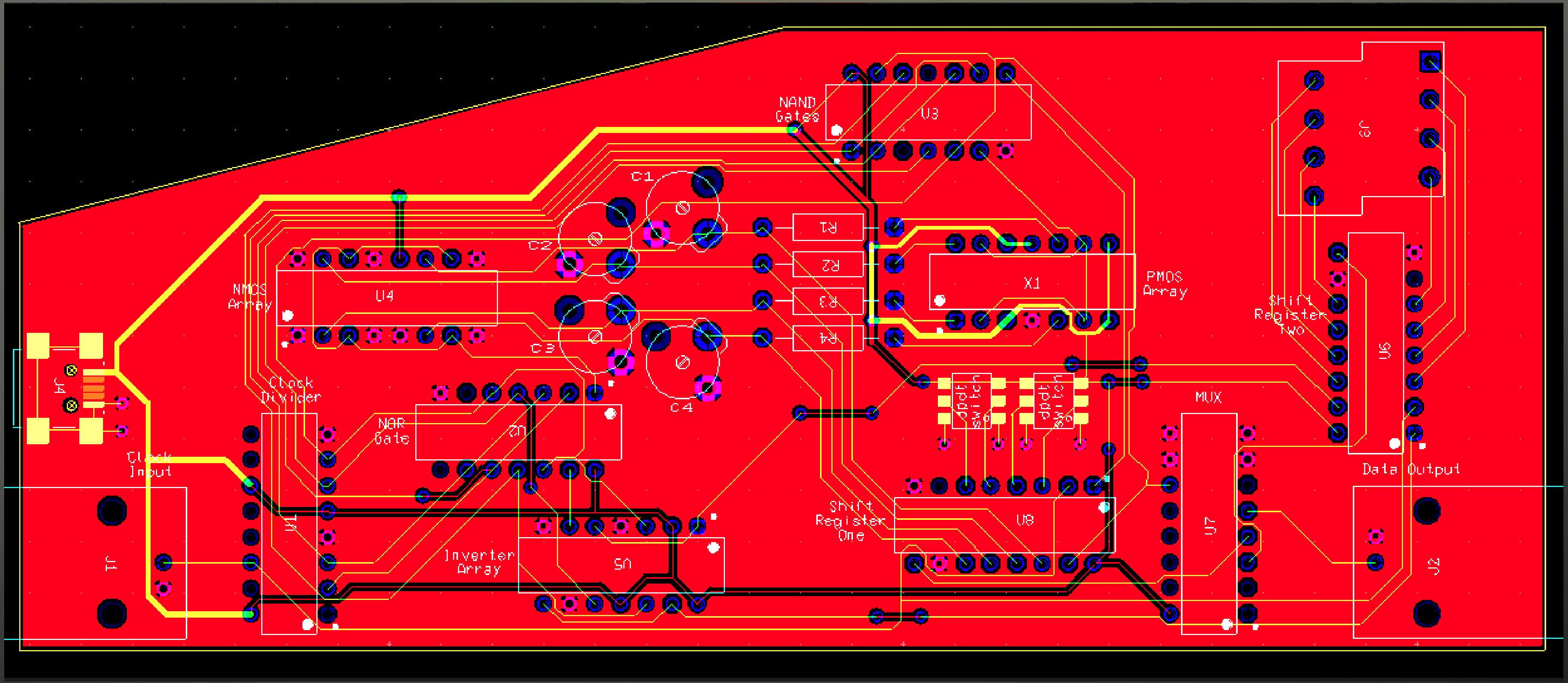


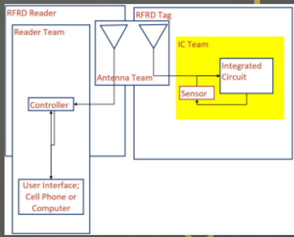
- **Test Results**
  - Extremely noisy
  - Functionally operational at low frequencies



PCB Revision A: Design

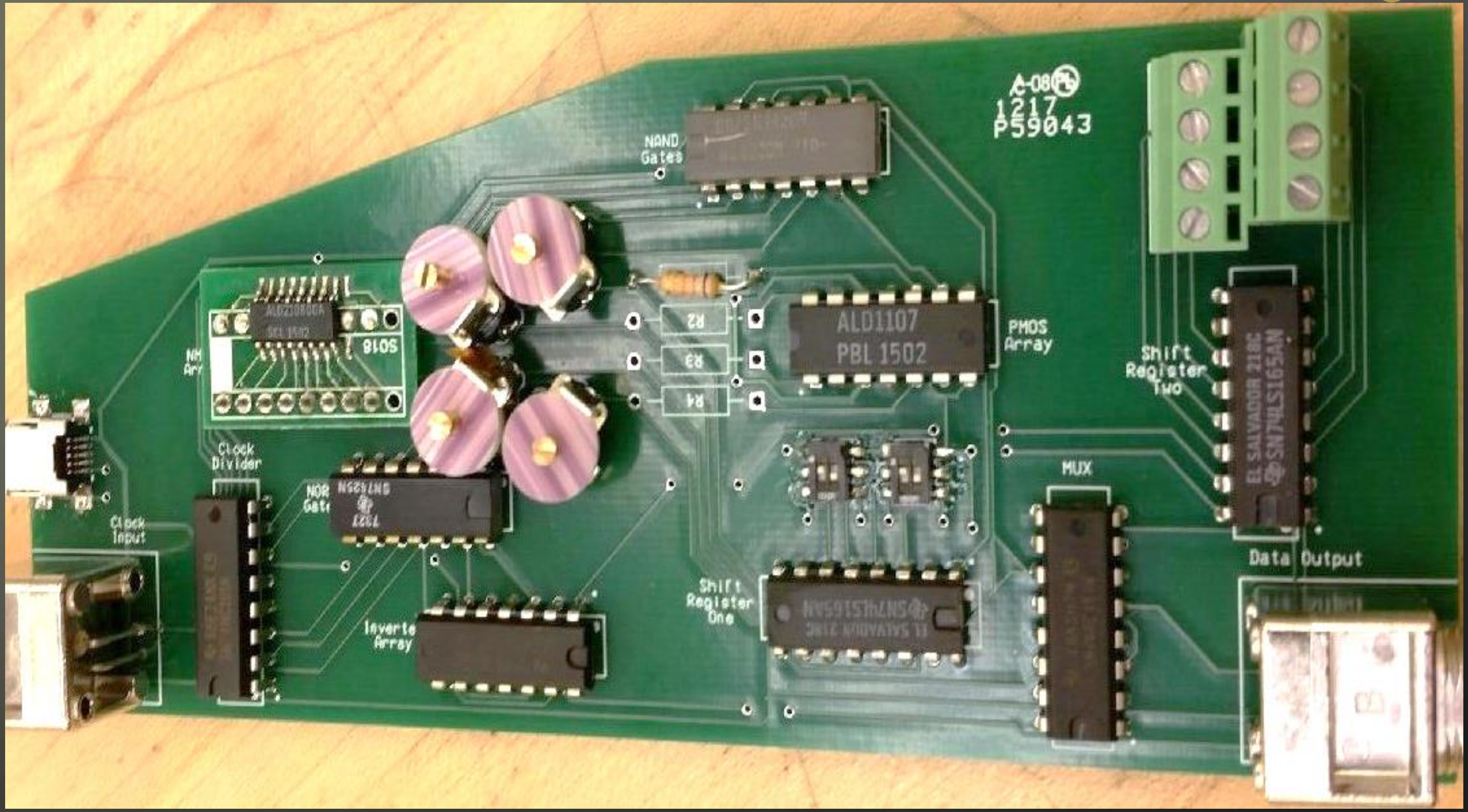




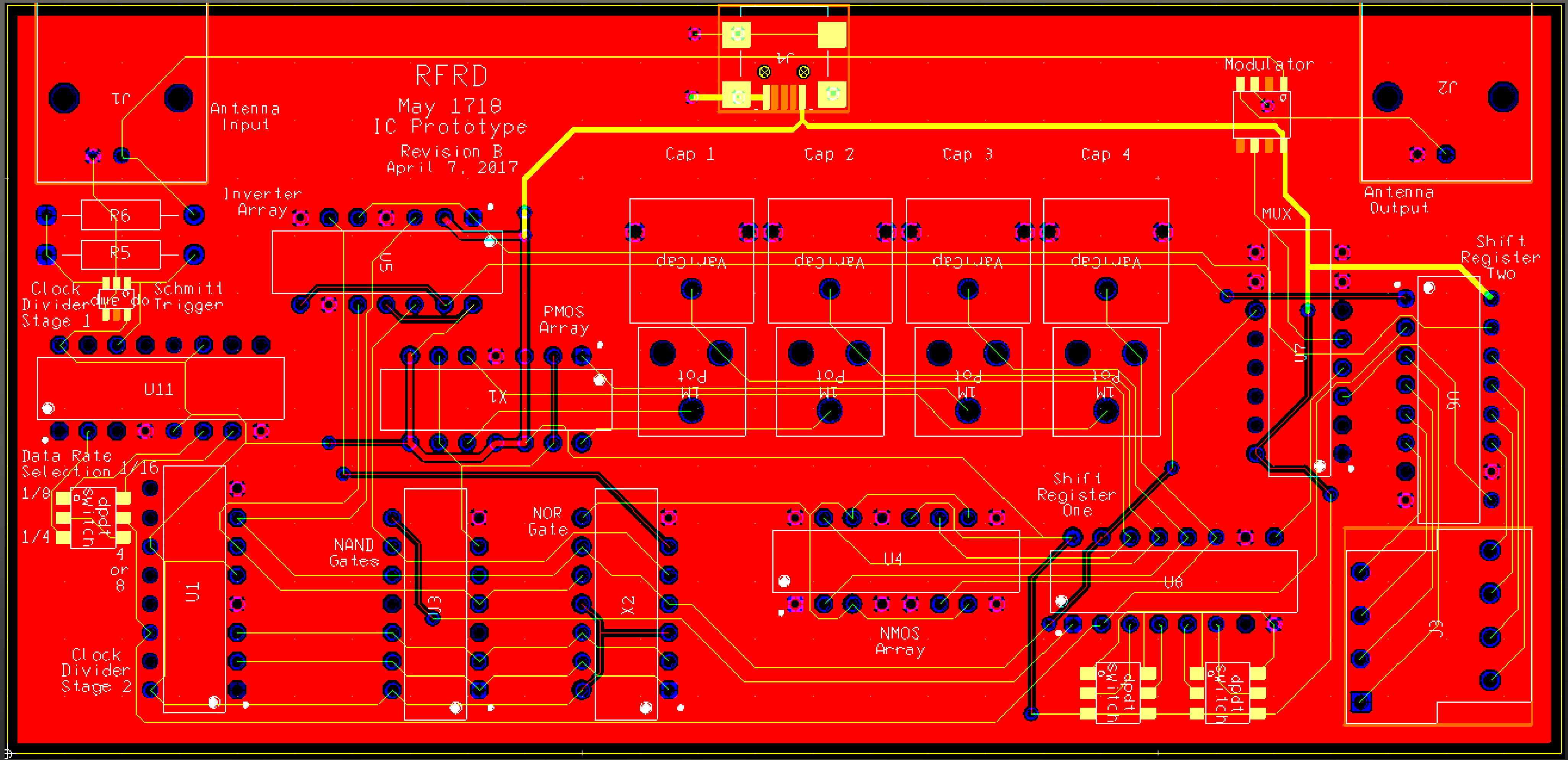


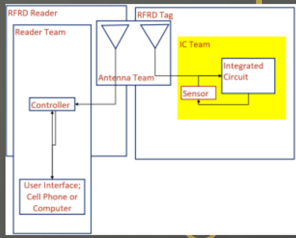
PCB Revision A: Testing

- **Test Results**
  - Signal can be read at 2-4 inches with current antenna
  - Greatly reduced noise
  - Modulation is needed
  - Need component to turn input wave into a square wave

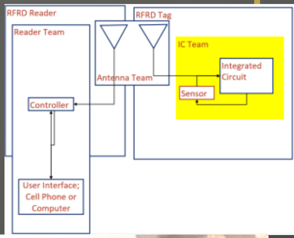


PCB Revision B: Design

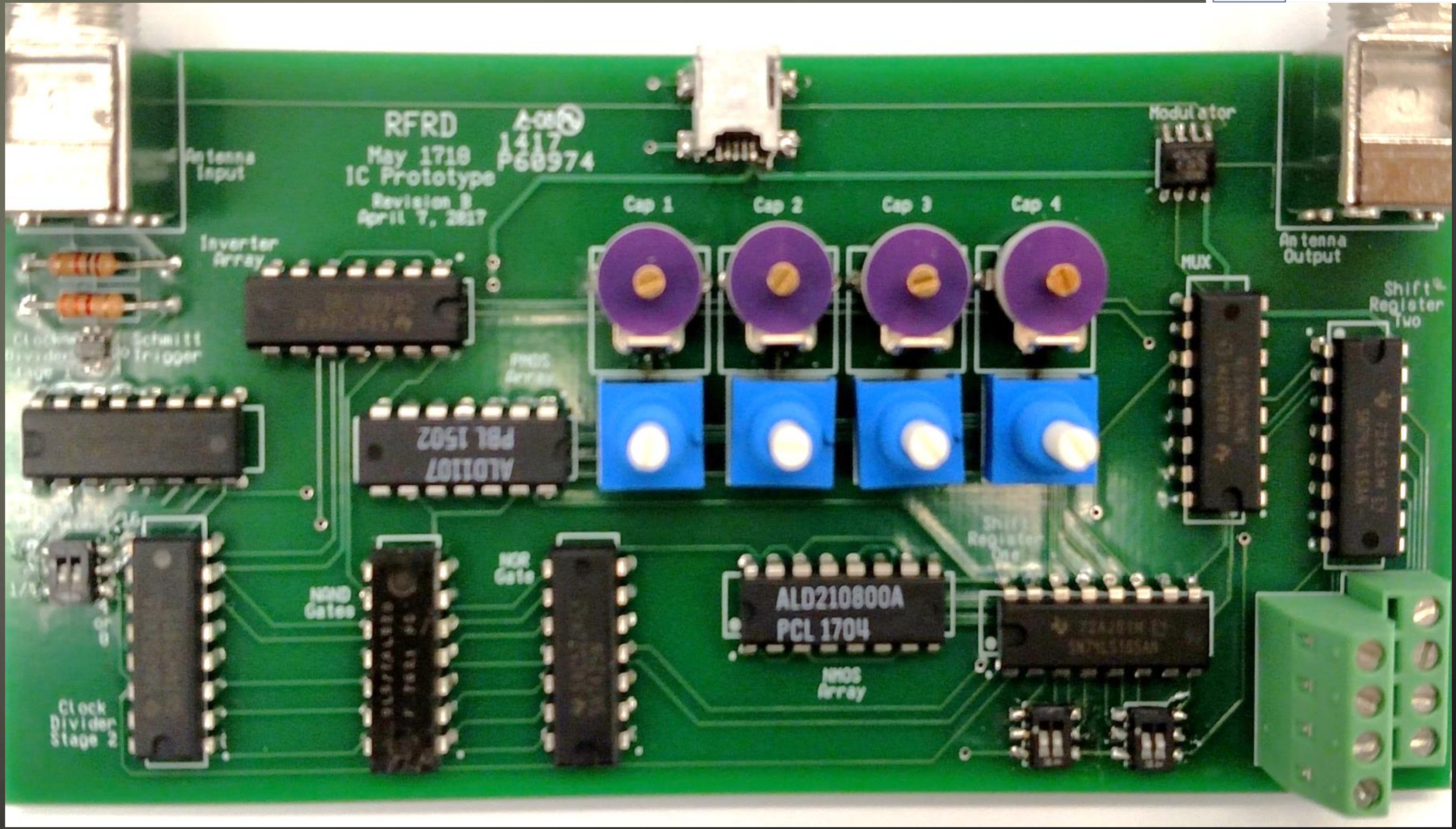




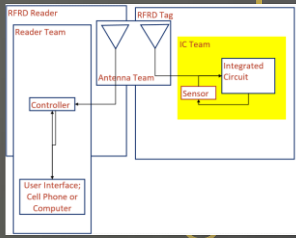
PCB Revision B: Testing



- **Test Results**
  - Signal can be read at 2-4 inches with current antenna
  - Modulator and Schmitt Trigger implemented



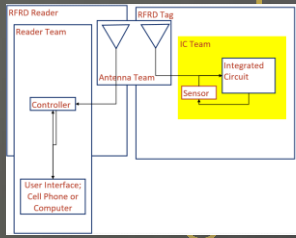
PCB Revision C: Design



Future Design Objectives

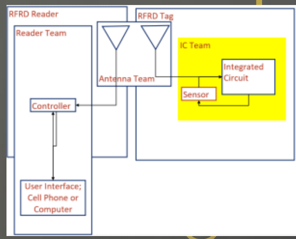
- Slight trace redesign to conserve space and further mitigate noise
- Use antenna input and a rectifier to generate power
- Improve modulator design

Integrated Circuit

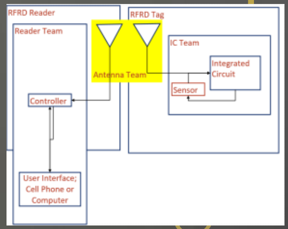


- **Modulator**
  - Modulation prepares IC output signal (w/ sensor and ID data) for transmission between antennas
  - Current design uses ASK modulation: data multiplied with carrier wave
    - Simple method for testing our IC tag
    - SA602A mixer chip took up minimal additional space on PCB Revision B
    - High levels of noise make long range transmission impossible
- **Future Design Objective**
  - Successfully implement backscatter modulation
  - Explore possibility of utilizing FSK modulation
    - Avoid adverse effects of system/channel noise

Integrated Circuit

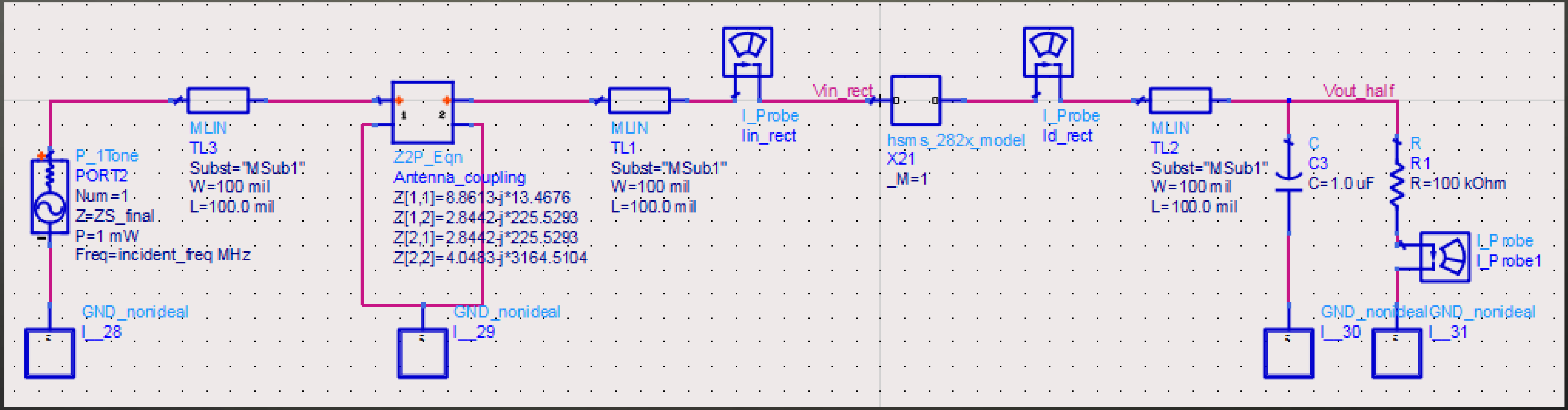


- **Cadence Design**
  - Majority of core components work
    - Data shifter, modulator, counters, capacitor sensor
  - Components still being simulated
    - Comparator, memory, rectifier
- **Future Design Objectives**
  - Rectifier diodes we used are made in a special process
  - Comparator using internally compensated Op-Amp



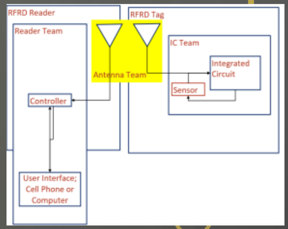
Power Harvester (1/2)

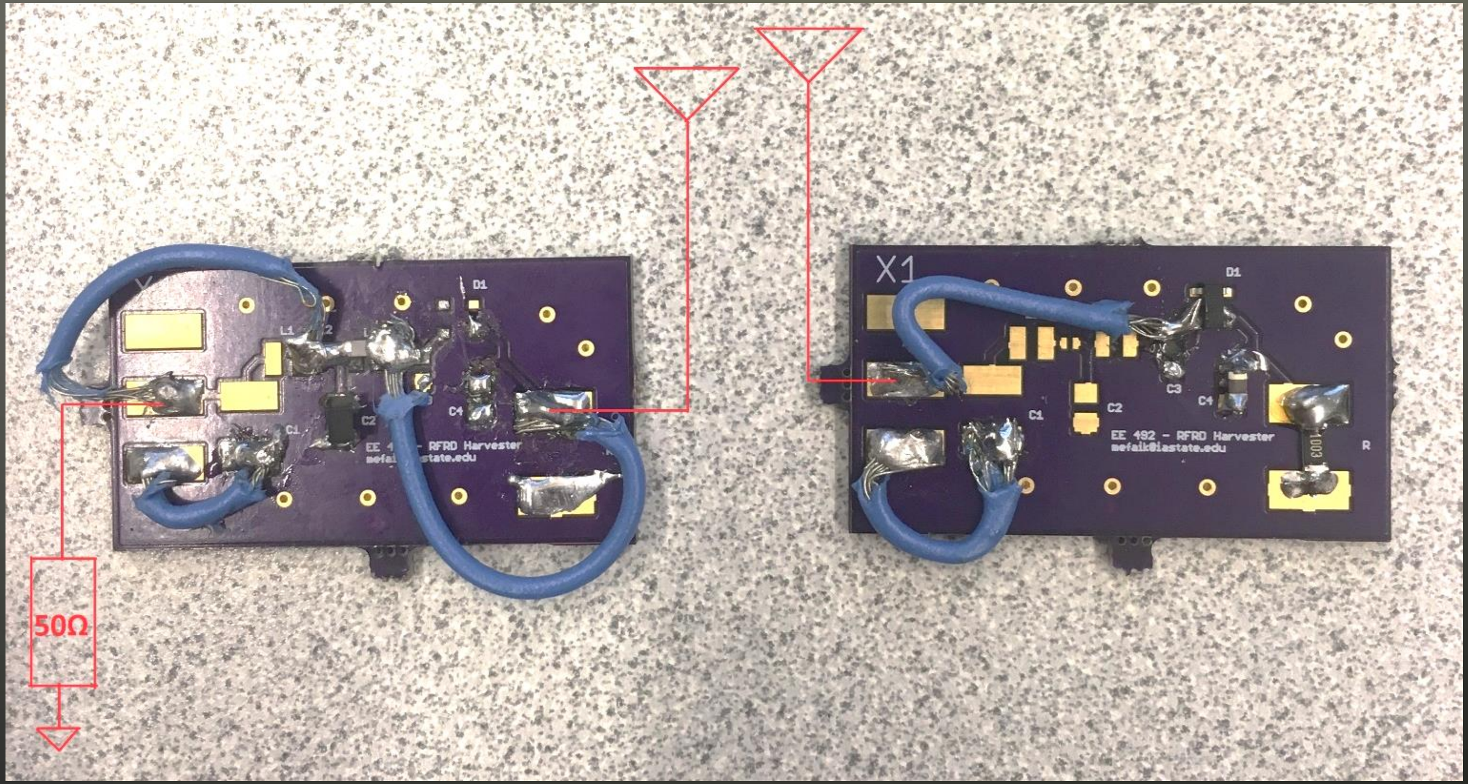
- **Power Harvester:**
  - *Purpose:* Generate enough energy from incoming RF to power IC for one cycle
  - *Design notes:*
    - Must account for antennas' Z-parameters
    - Half-wave rectifier performed better than full-wave
  - *Below*: Schematic from ADS – Source pull simulation to determine optimal Z_S



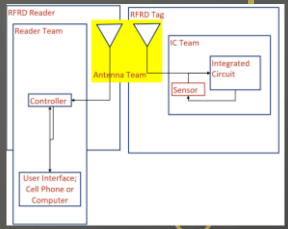
Power Harvester (2/2)

- **Power Harvester: Layout and Build**
  - *Below*: Schematic mixed with hardware for clarity
    - 50 Ω source > L-match > Antenna > Diode > Parallel RC

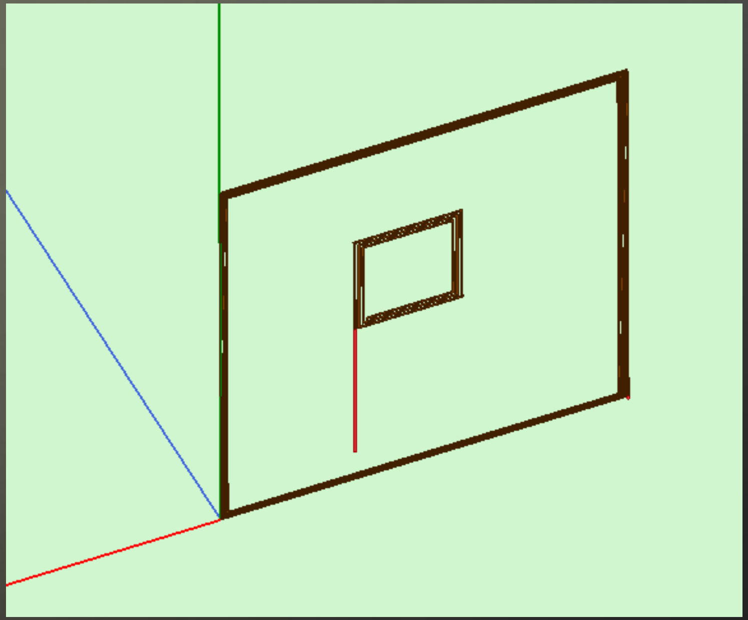




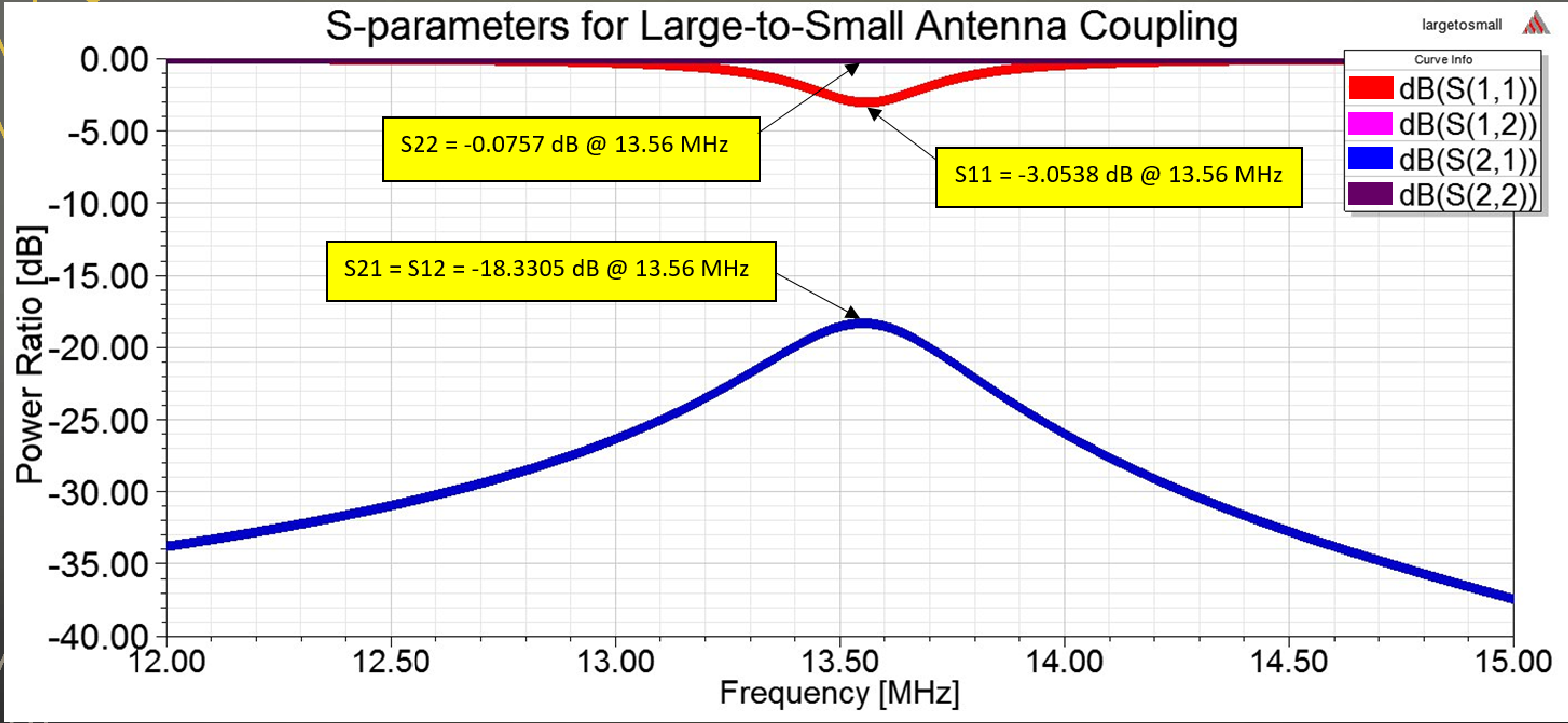
Antenna

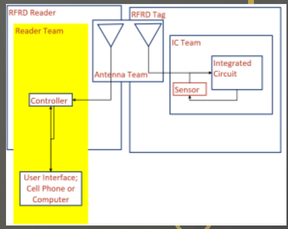


- **Difficulty of Attaining Hardware Implementation**
  - Thin traces, characteristic is sensitive to geometry, and coupling is poor even in the best case
  - Copper fell apart during waterjet cutting



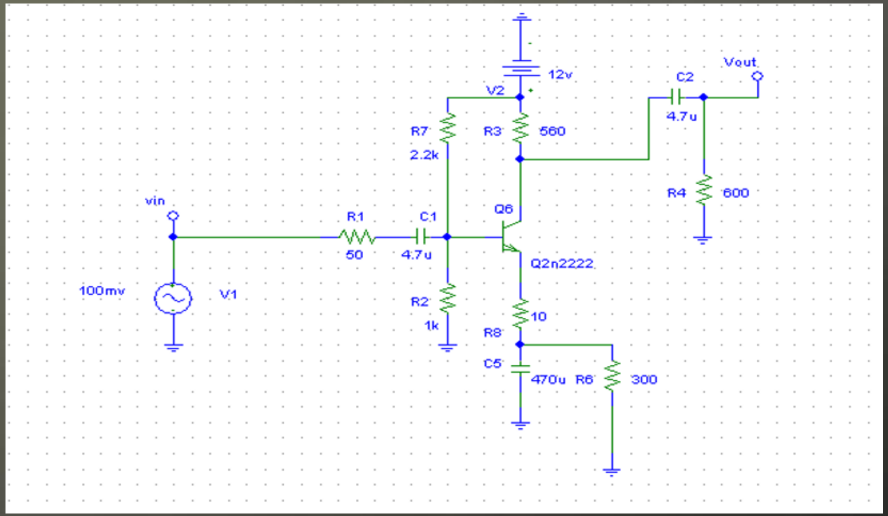
- **Coupling Characteristic Shown (next slide)**
  - 11.2” x 11.2” (reader) to 3” x 3” (tag) square coils in ANSYS
  - Poor coupling necessitates low power
  - At this stage, electrical size is most significant performance factor


S-parameters for Large-to-Small Antenna Coupling
largetosmall
Curve Info
dB(S(1,1))
dB(S(1,2))
dB(S(2,1))
dB(S(2,2))
S22 = -0.0757 dB @ 13.56 MHz
S11 = -3.0538 dB @ 13.56 MHz
S21 = S12 = -18.3305 dB @ 13.56 MHz
Power Ratio [dB]
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
12.00
12.50
13.00
13.50
14.00
14.50
15.00
Frequency [MHz]

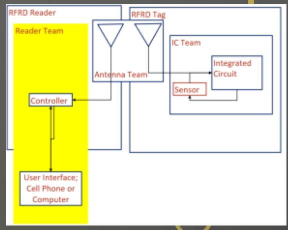


Reader Hardware

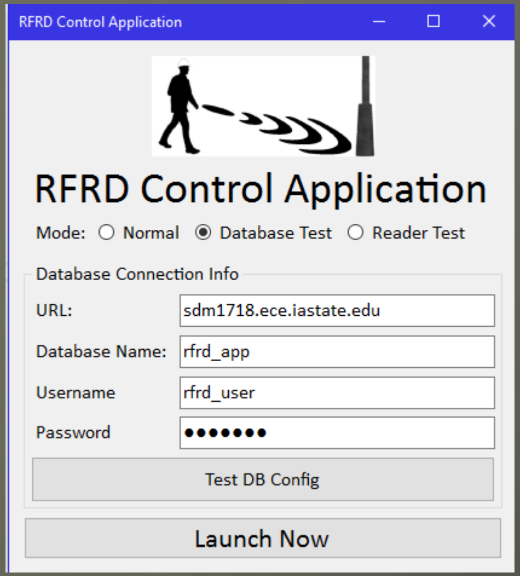
- **Design Factors**
  - The prototype is designed for 13.56 MHz, but should be scalable to 900 MHz.
  - Class A amplifier
  - LPF de-modulator envelope detector
    - Blocks 13.56 MHz carrier
    - Outputs high/low data string

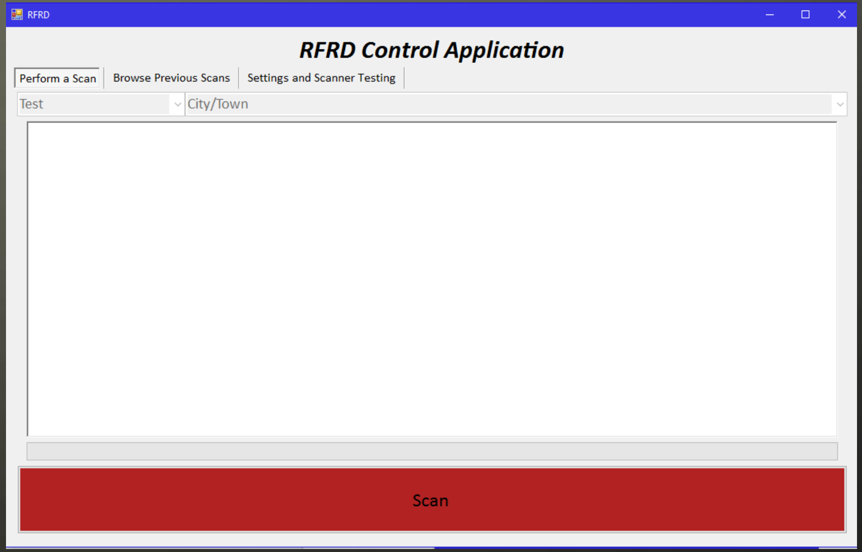


Reader Software

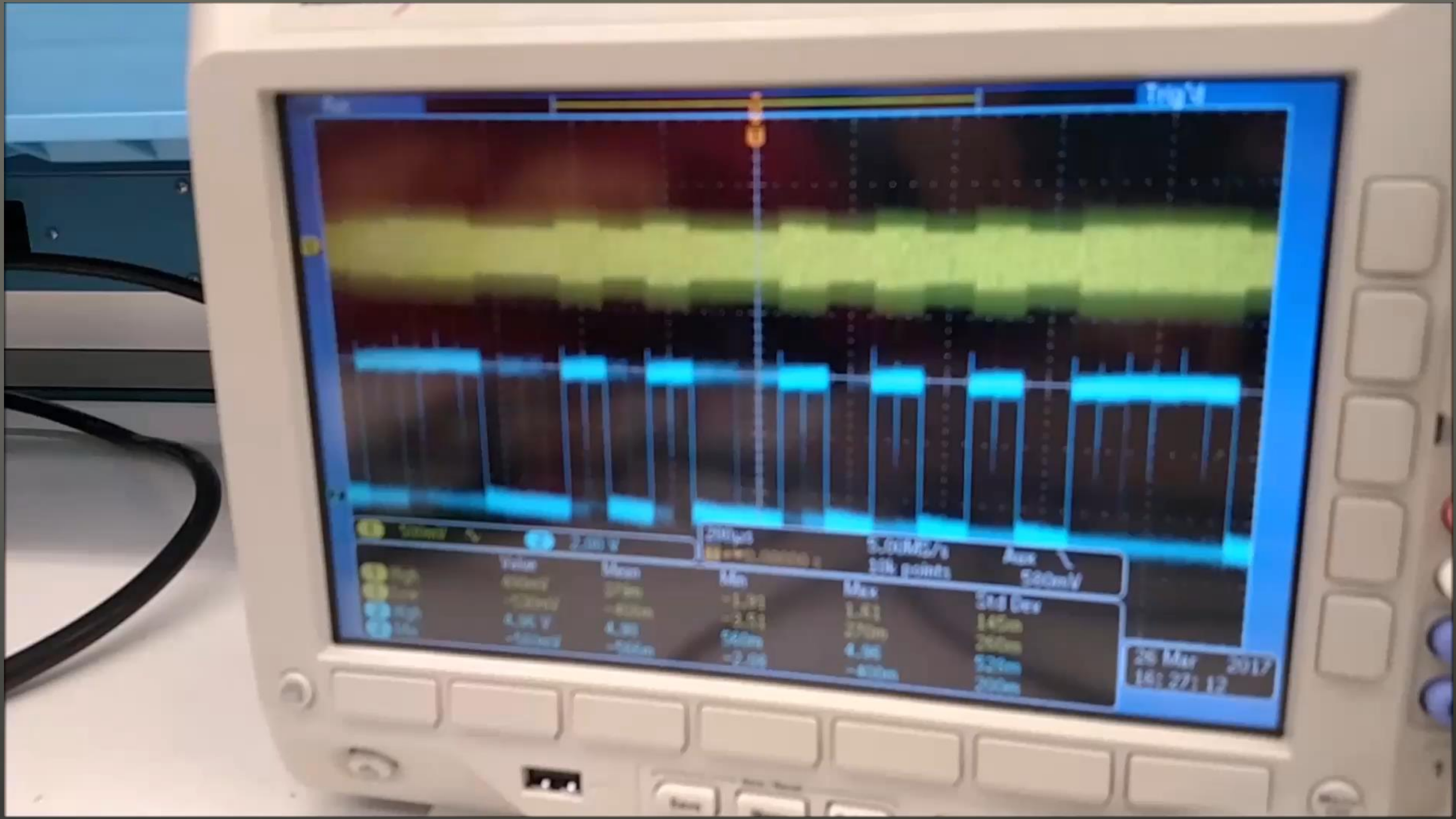


- **User Interface**
  - Created using C# and Windows Forms
  - Uses SQL Server for data storage
  - Able to communicate with Arduino over USB



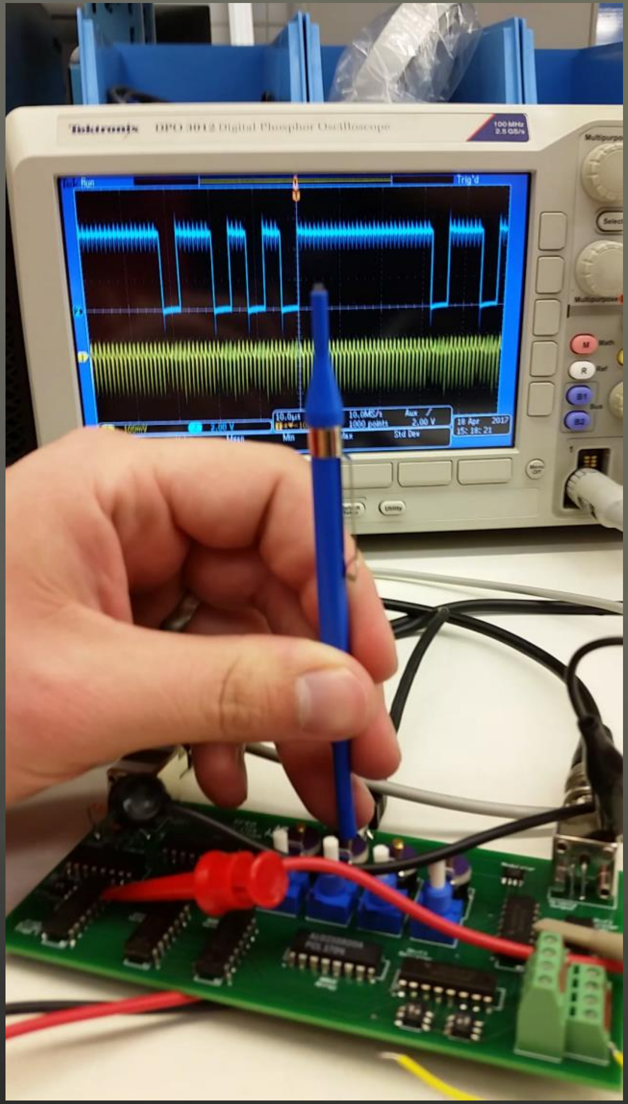


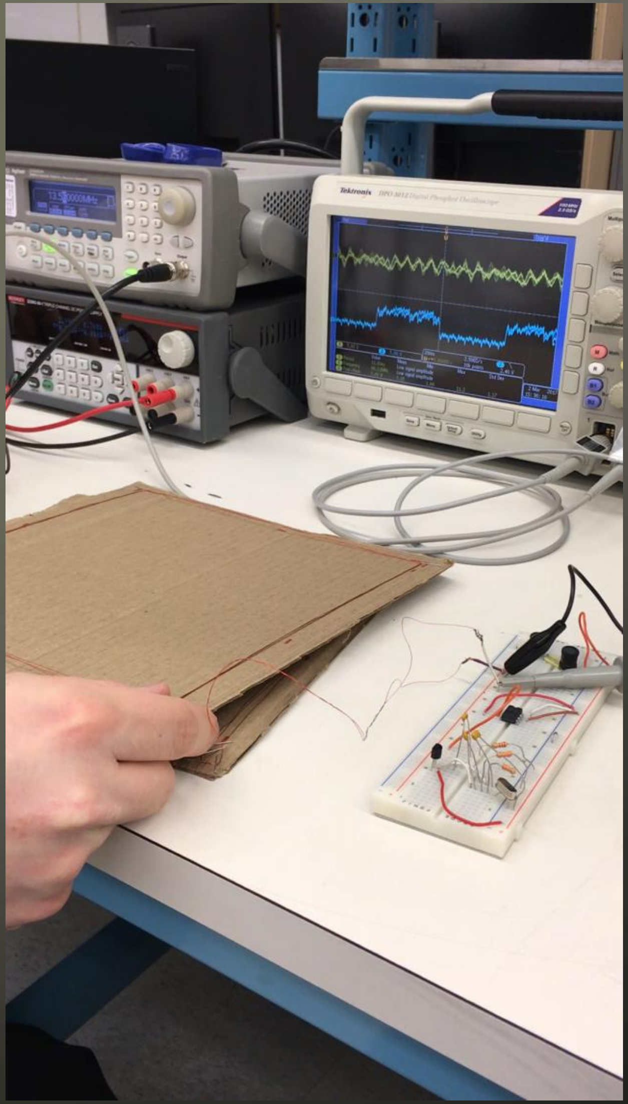
Movie and Questions



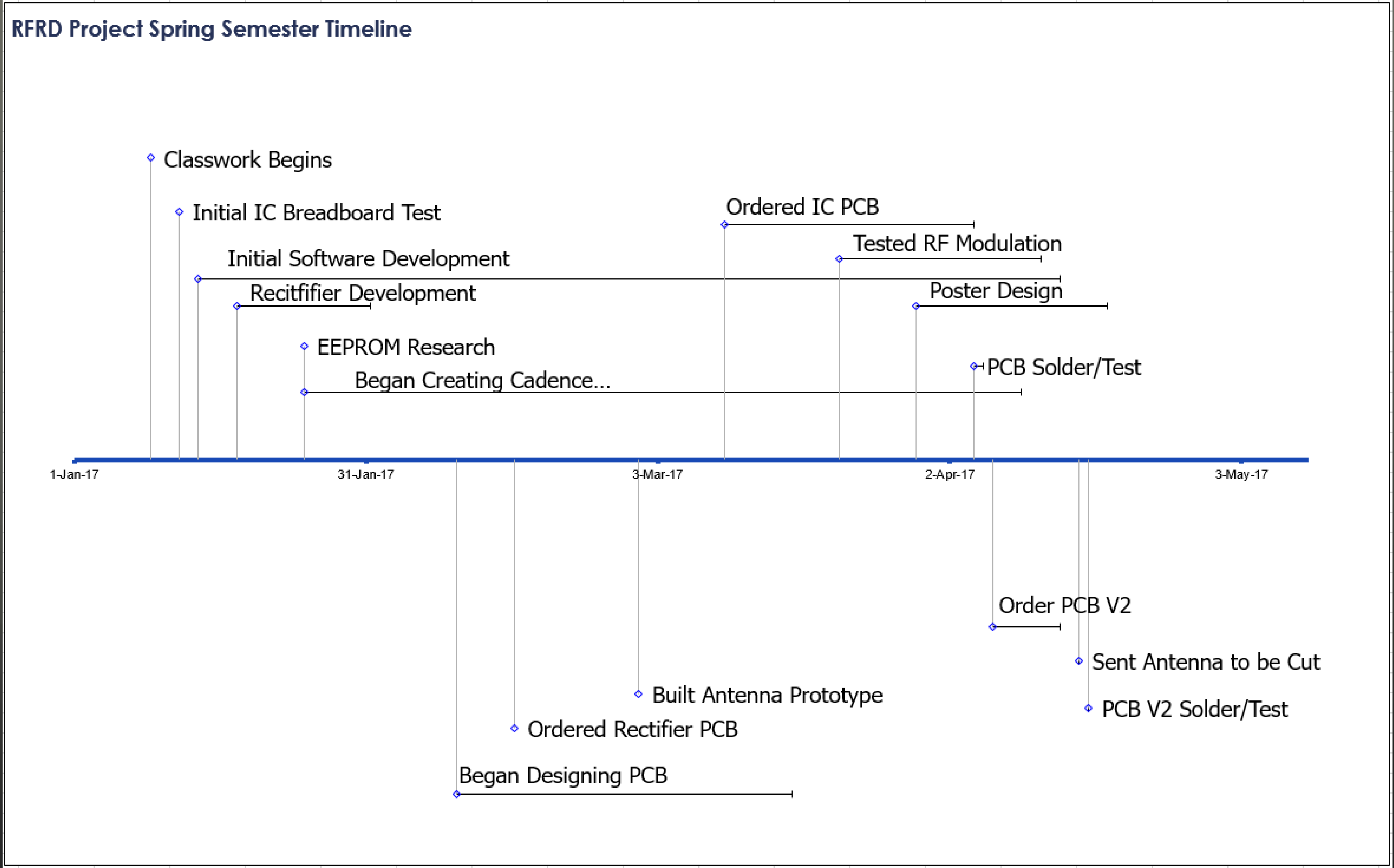
Video of the modulation working and sending across test antenna

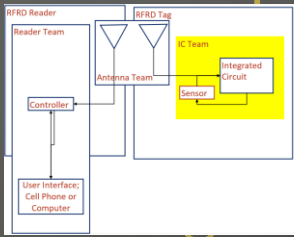
Sensor and Antenna





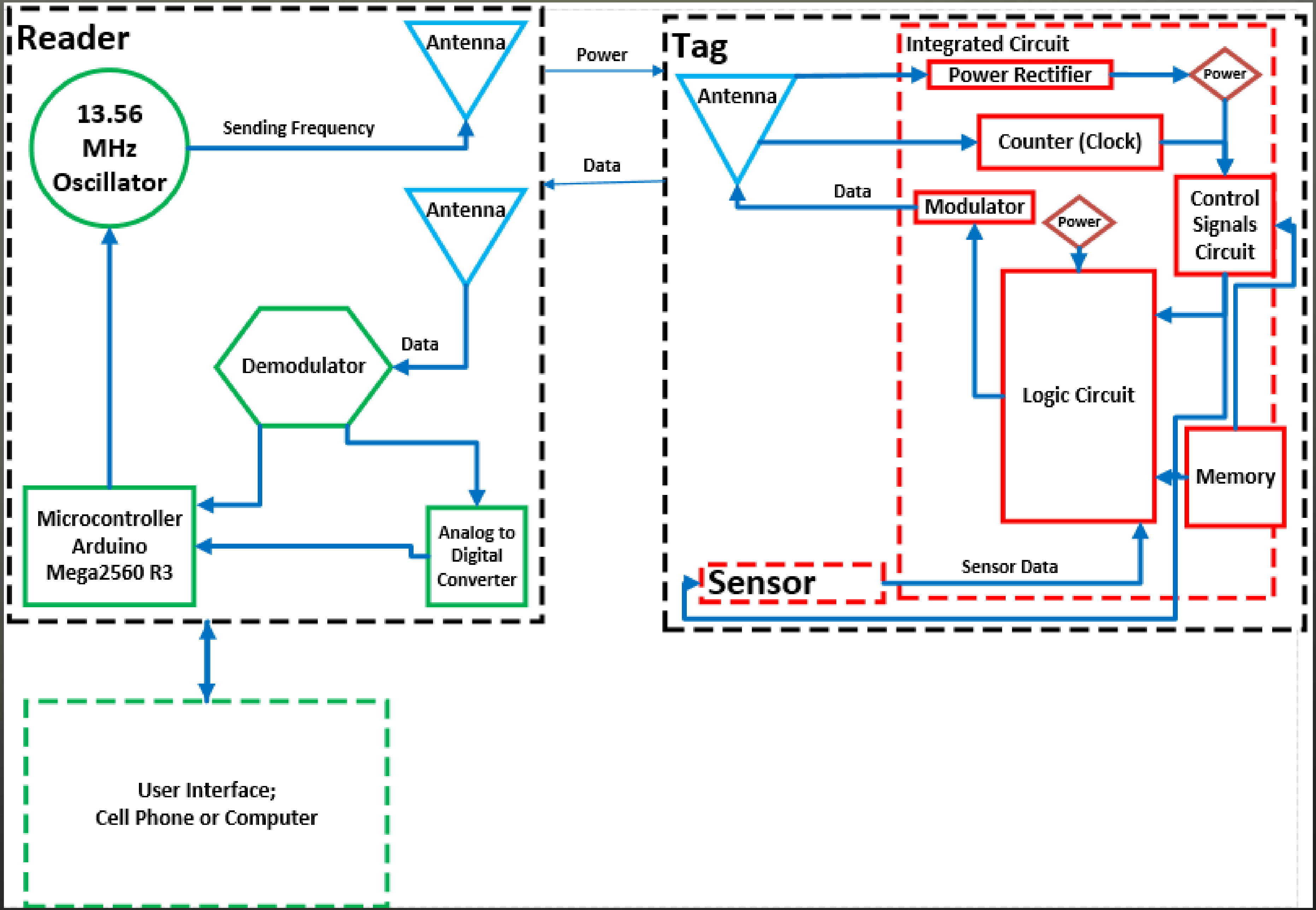
Timeline


RFRD Project Spring Semester Timeline
Classwork Begins
Initial IC Breadboard Test
Initial Software Development
Recitfifier Development
EEPROM Research
Began Creating Cadence...
Ordered IC PCB
Tested RF Modulation
Poster Design
PCB Solder/Test
1-Jan-17
31-Jan-17
3-Mar-17
2-Apr-17
3-May-17
Order PCB V2
Sent Antenna to be Cut
PCB V2 Solder/Test
Built Antenna Prototype
Ordered Rectifier PCB
Began Designing PCB

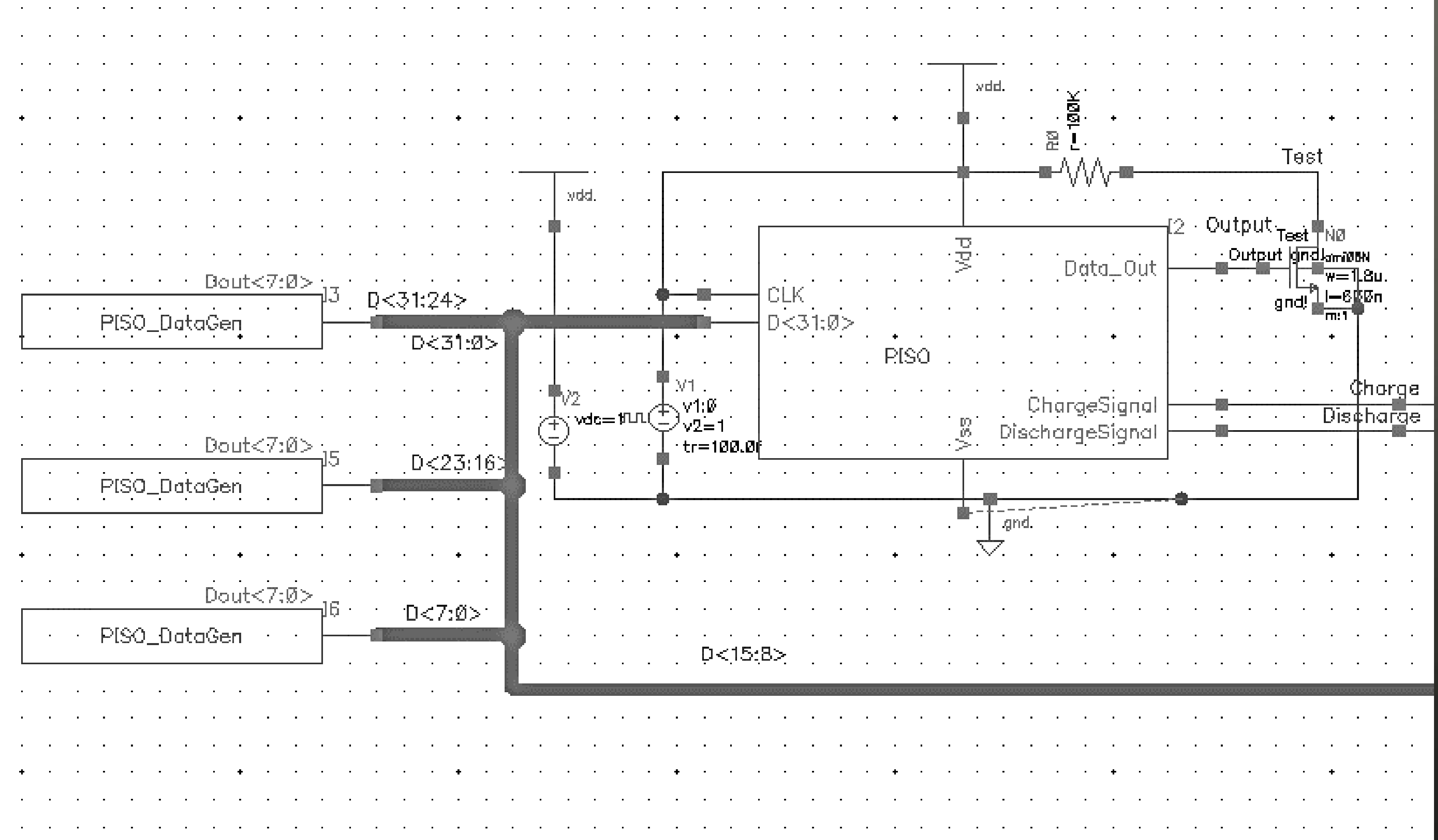


Integrated Circuit

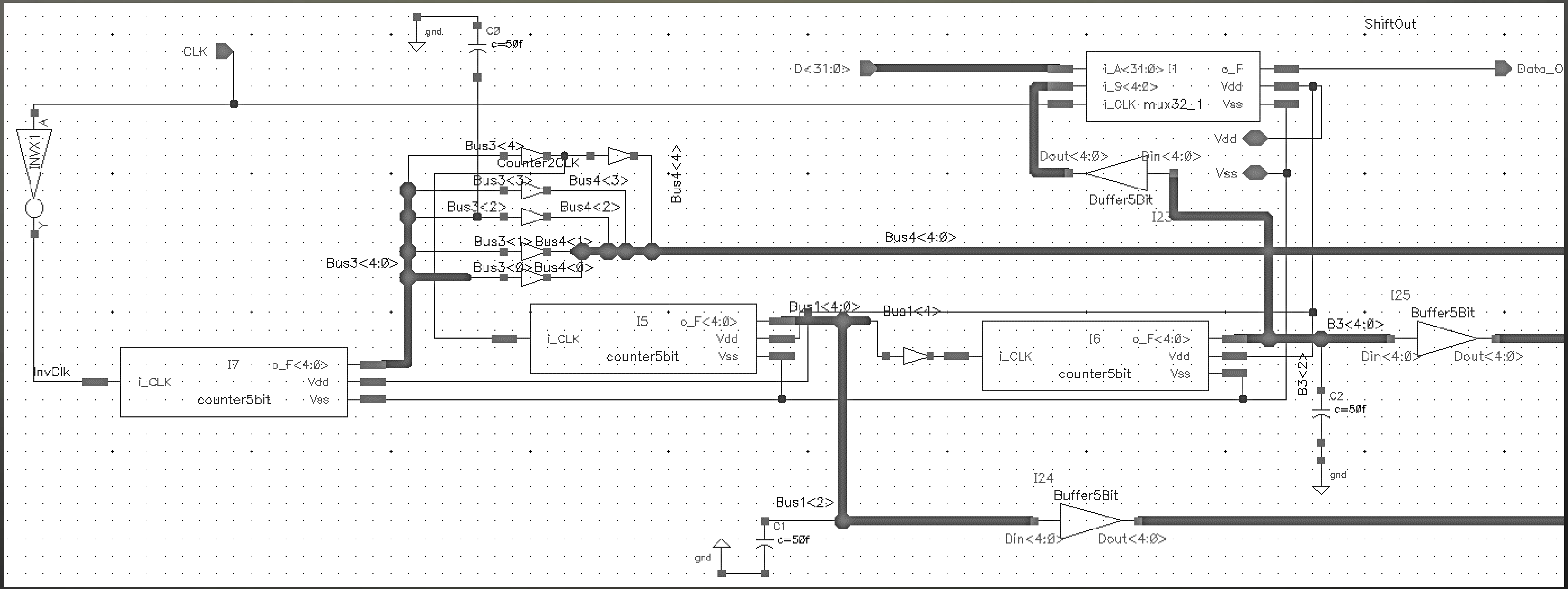
- **Alternate Design Consideration**
  - Capacitance Reading Chips with Microcontroller
    - MSP430 G2x11 Microcontroller ($0.51)
      - Low power consumption, 8 GPIO
      - Might be able to control up to 6 Capacitor Sensors
    - MTCH101 Capacitor Sensor ($0.38)
      - Can only read every .5-.8 seconds in low power mode
      - May require 4+ per tag.
  - Main reason for rejection: cost non-functional requirement


Reader
13.56
MHz
Oscillator
Sending Frequency
Antenna
Antenna
Data
Demodulator
Microcontroller
Arduino
Mega2560 R3
Analog to
Digital
Converter
Power
Data
Tag
Antenna
Integrated Circuit
Power Rectifier
Power
Counter (Clock)
Data
Modulator
Power
Control
Signals
Circuit
Logic Circuit
Memory
Sensor
Sensor Data
User Interface;
Cell Phone or Computer

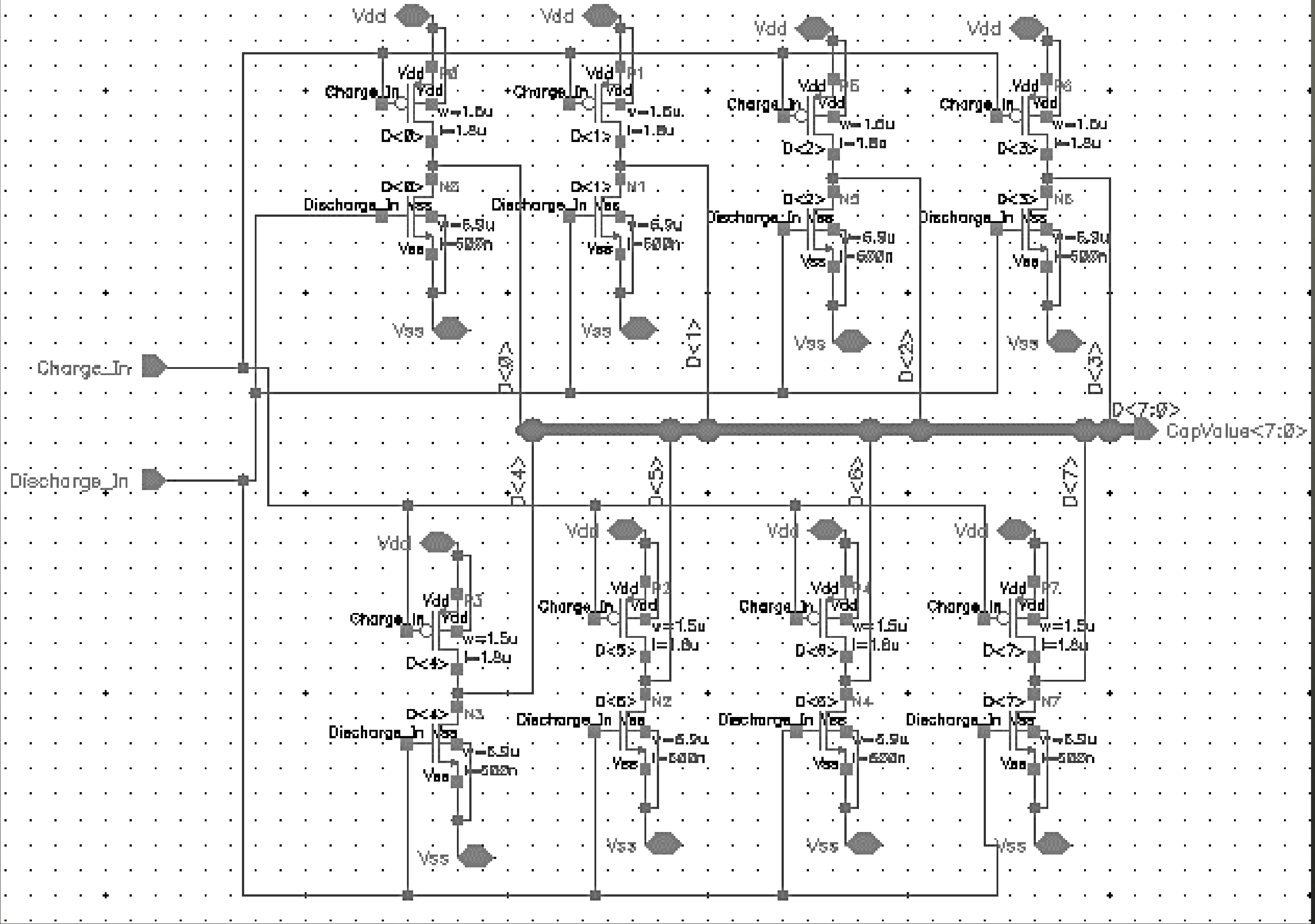
Cadence Schematic
Shift Register and Data Simulation



Cadence Schematic
Counter & Parallel In Serial Out Data

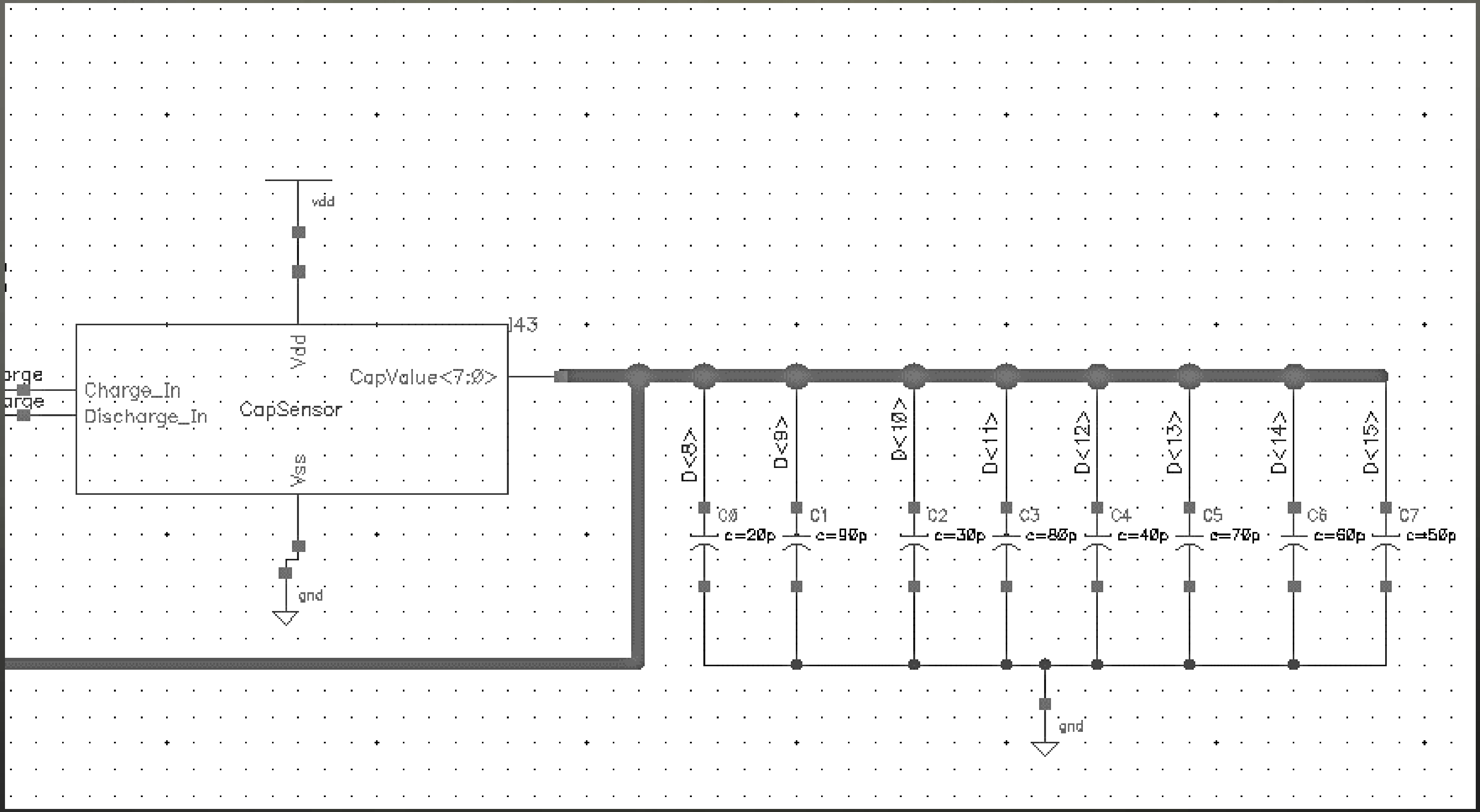


Cadence Schematic
Cap Sensor Design



Cadence Schematic

Capacitor Reading Simulation



Cadence Schematic

Cap Charge/Discharge logic