# Design and Building of the Radar System

## Team One

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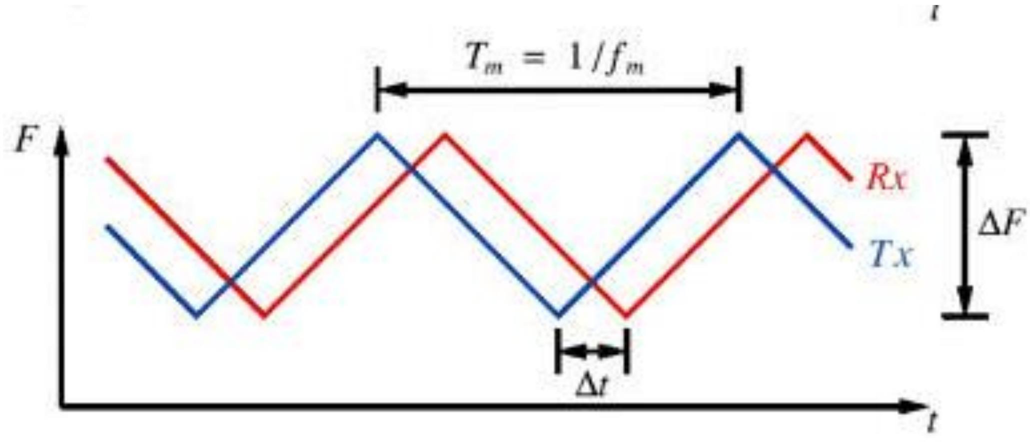
## Abstract

High frequency circuits can be used in a wide range of applications. One of these being with modern day radar systems, oftentimes these are used by police in tracking speed of cars and by scientists for researching the distance an object is from a signal. The goal of this project was to design a homemade radar system with parts and components that could be obtained commercially for a budget of under $300 in total. This report serves as an informative guide on the concepts and theory behind radar systems as well as the design report for building such a system.

## Introduction and Theoretical Concepts

The radar system was first conceptualized in quarter with four main parts being the RF Board, the Antennas, the Baseband Board and the Digital Signal Processing (DSP).

In order to tell the distance of an object an electromagnetic signal at sufficiently high frequency (we used 2.4 GHz) can be transmitted and the reflected wave received by another antenna. This is called frequency modulated continuous wave radar, where a known stable frequency is transmitted and modulated over time. The returning signal will be received at another frequency due to the Doppler effect and the difference of the two is proportional to the distance an object is from the radar system. For this system of frequency modulation numerous waveforms can be used. We chose to use a triangular waveform because that is what we covered in class and it is shown below.



## Design of the Radar System

With the task of creating our own radar system we initially decided that there were four major parts that needed completion, the RF Board, the Antennas, the Baseband Board, and the DSP. The design, planning, and implementation of each is discussed below with the name of the person who was responsible for leading each part to make sure it got done.

System block diagram

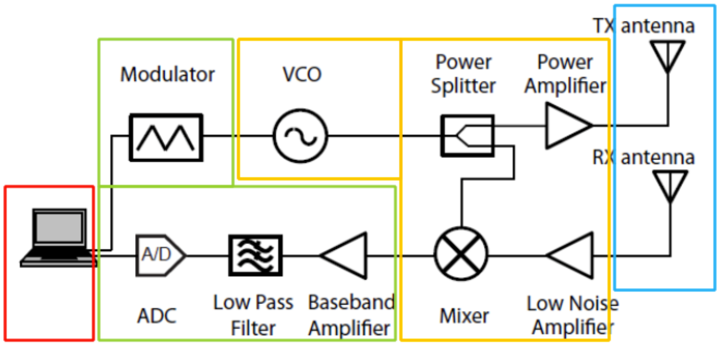
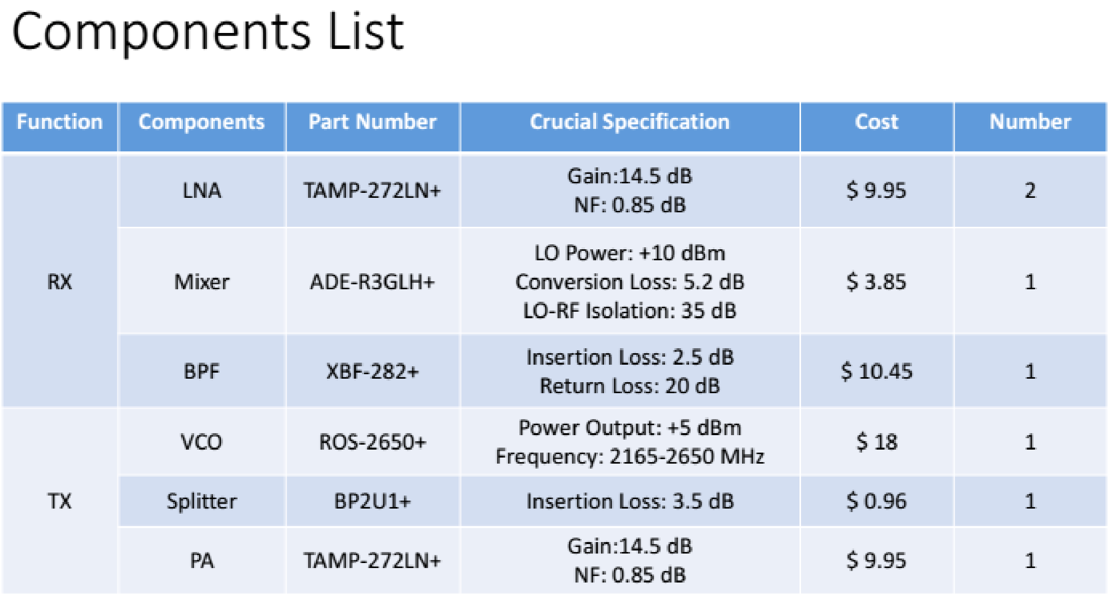


Figure 4: Block diagram of a typical FMCW radar system.

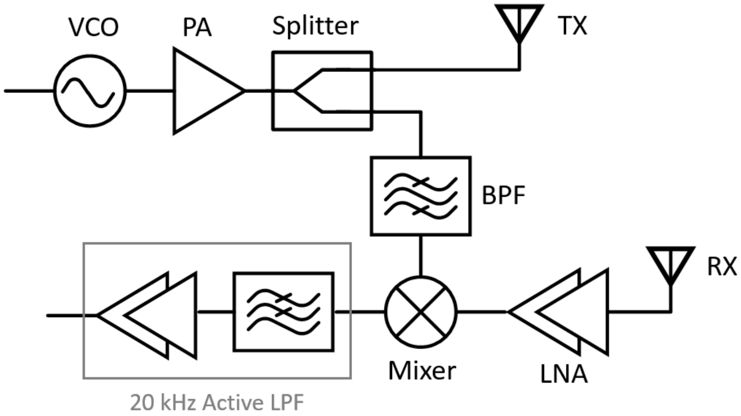
### RF Board-Jo Han Yu

For the RF board we used the same architecture as in quarter one and much of the same design but selected superior components and optimized the board schematics and layout for improved radar performance. The components we selected are shown below as well as the architecture from the radar theory portion of the course.

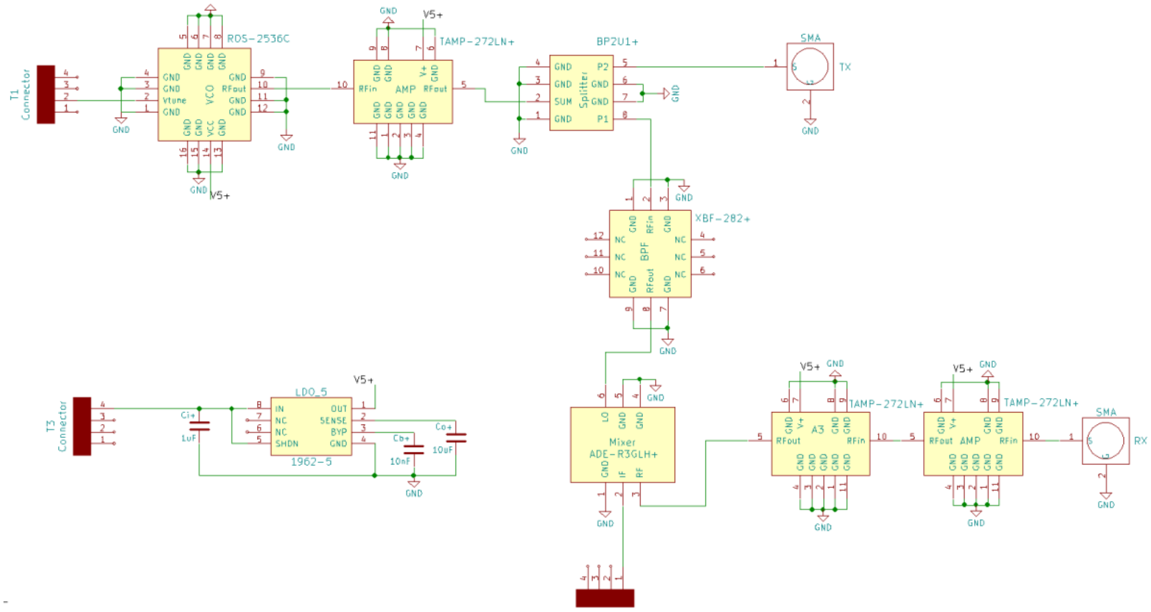


Components List

| Function | Components | Part Number | Crucial Specification | Cost | Number |
|---|---|---|---|---|---|
| RX | LNA | TAMP-272LN+ | Gain:14.5 dB<br>NF: 0.85 dB | $ 9.95 | 2 |
| | Mixer | ADE-R3GLH+ | LO Power: +10 dBm<br>Conversion Loss: 5.2 dB<br>LO-RF Isolation: 35 dB | $ 3.85 | 1 |
| | BPF | XBF-282+ | Insertion Loss: 2.5 dB<br>Return Loss: 20 dB | $ 10.45 | 1 |
| TX | VCO | ROS-2650+ | Power Output: +5 dBm<br>Frequency: 2165-2650 MHz | $ 18 | 1 |
| | Splitter | BP2U1+ | Insertion Loss: 3.5 dB | $ 0.96 | 1 |
| | PA | TAMP-272LN+ | Gain:14.5 dB<br>NF: 0.85 dB | $ 9.95 | 1 |



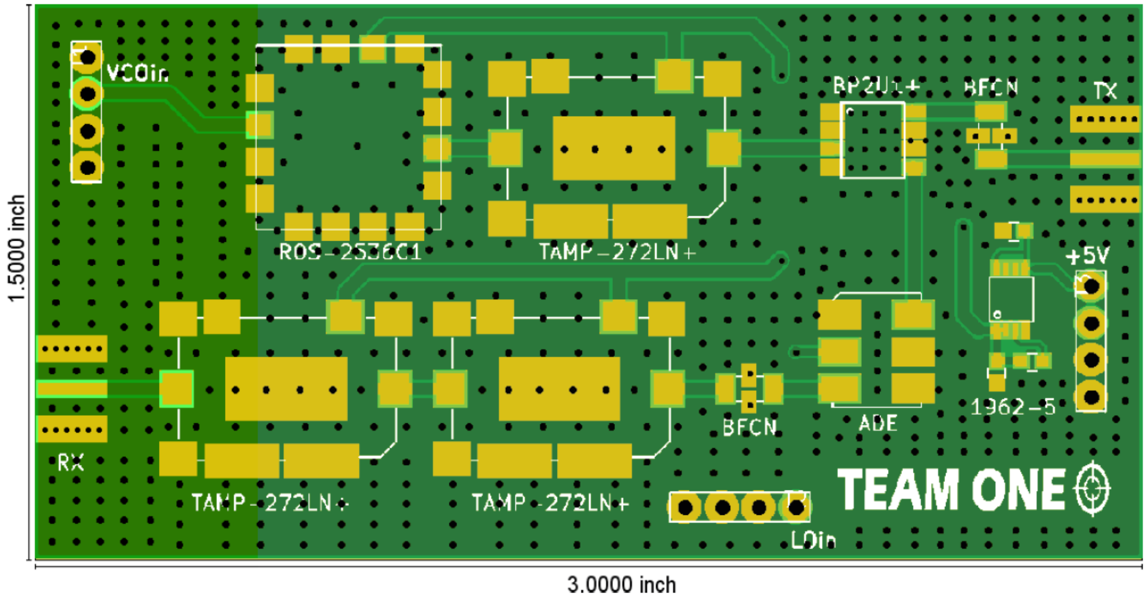
In addition to the selection of components the schematic was re-drawn and the layout remade for ordering of PCB's from the student supplier bay area circuits.



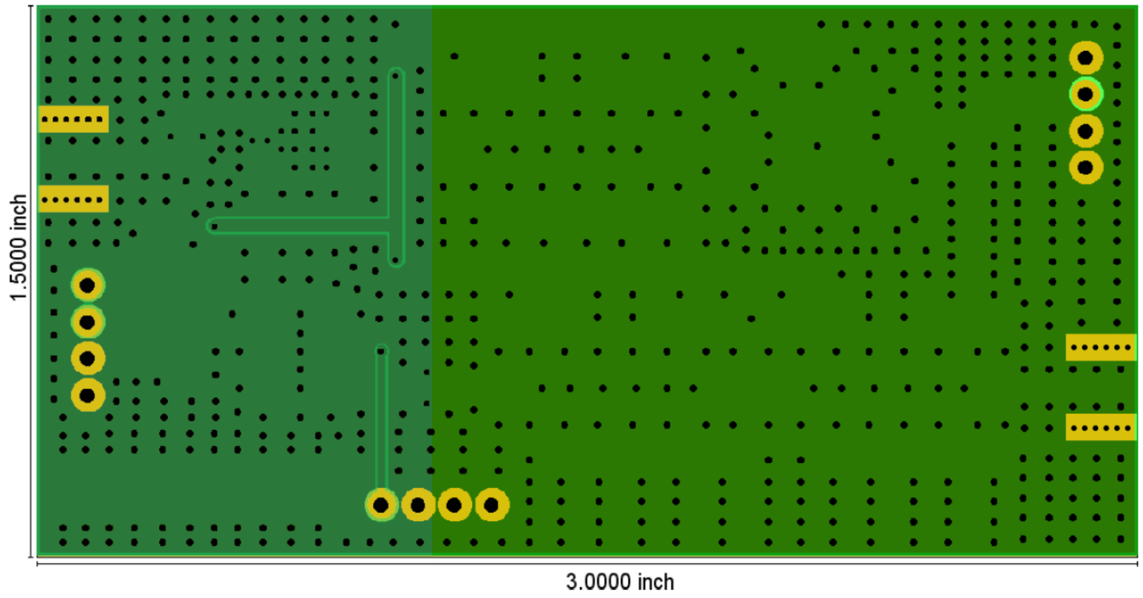
Here, we should be careful to avoid RF path being crossed. This would affect the impedance of CPWG line on the board which is not good for RF components. Besides, when you try to solder these RF components, you should not use too much solder which also can affect the impedance of input and output.

The corresponding PCB design layout is as follows

Top View



Bottom View



Antennas-Alex Coffman

For the antenna system a balance of directivity and gain was important. Primarily we tried to select the most lightweight antenna as possible. This led us to the decision of a PCB antenna and to meet directivity requirements the Yagi antenna was the best choice. From the previous quarter coffee can horn antennas were kept, as backups for the system in case the Yagi PCB did not work out.

The first step in designing a Yagi PCB is to simulate the antenna in a high frequency electromagnetic field simulation, HFSS. Once this has been done and we know an antenna will work according to simulations the antenna could be made in eagle PCB design software. Since experience with antenna design was needed to create the antennas from scratch pre-made designs were used as templates with the constraints that PCB types should match those being ordered from Bay Area circuits. Several of the requirements for the Bay Area Circuits PCB Design are that it may only contain two layers and the board is printed onto FR4 substrate. This are important points to note because they limit the designs for Yagi PCB's that can be used.

Initially the plan was to submit a design simulated by Texas Instruments for a multi-layer Yagi PCB with supplied specs and dimensions.

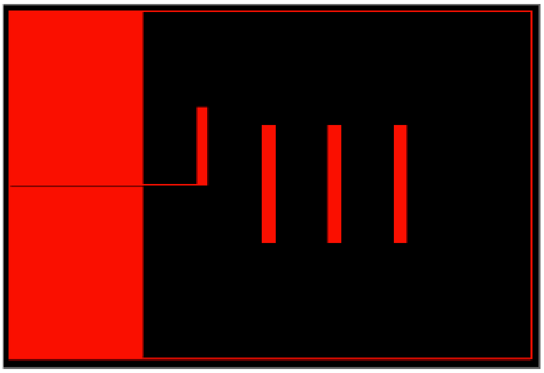


**Figure 3. Layer 3** (Top, Antenna Top Layer)

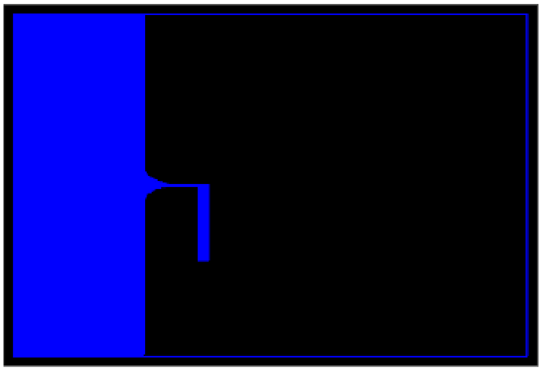
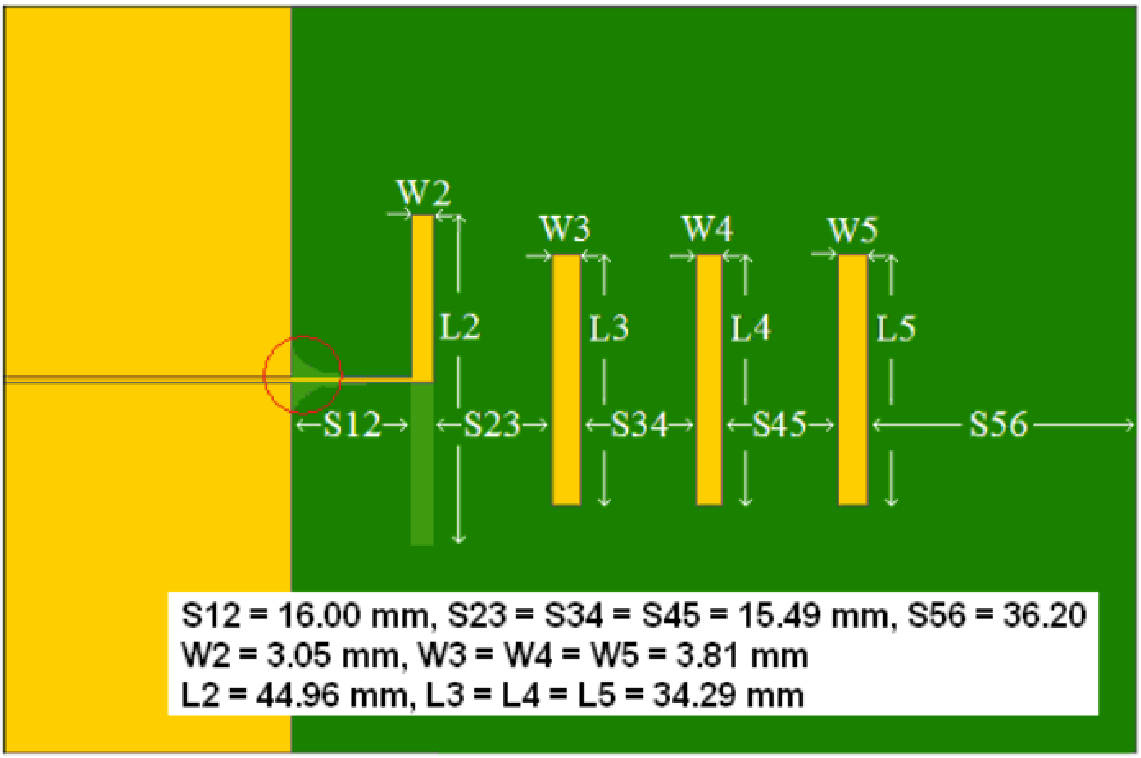
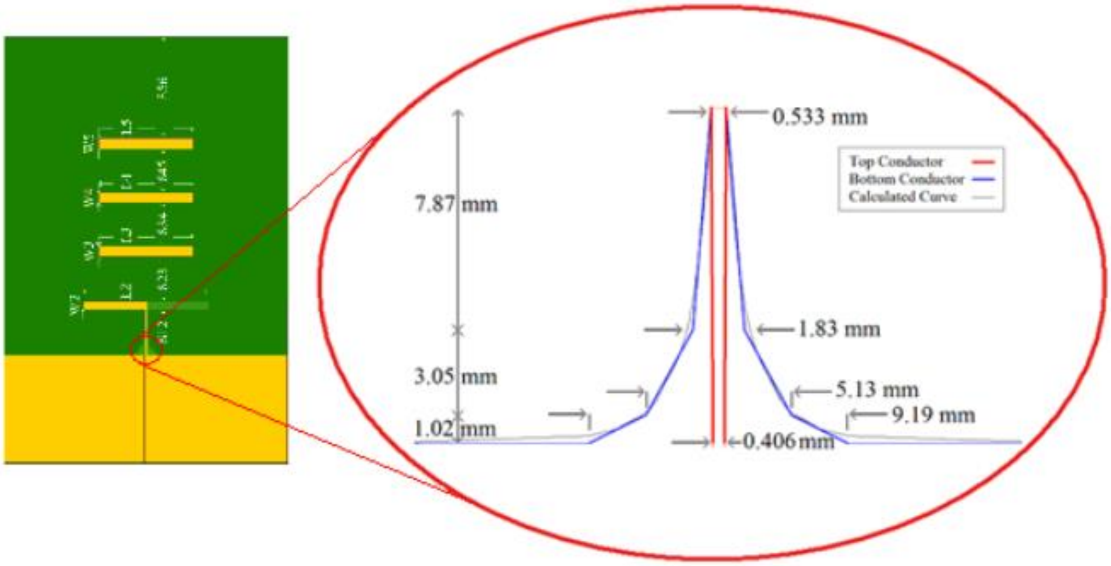
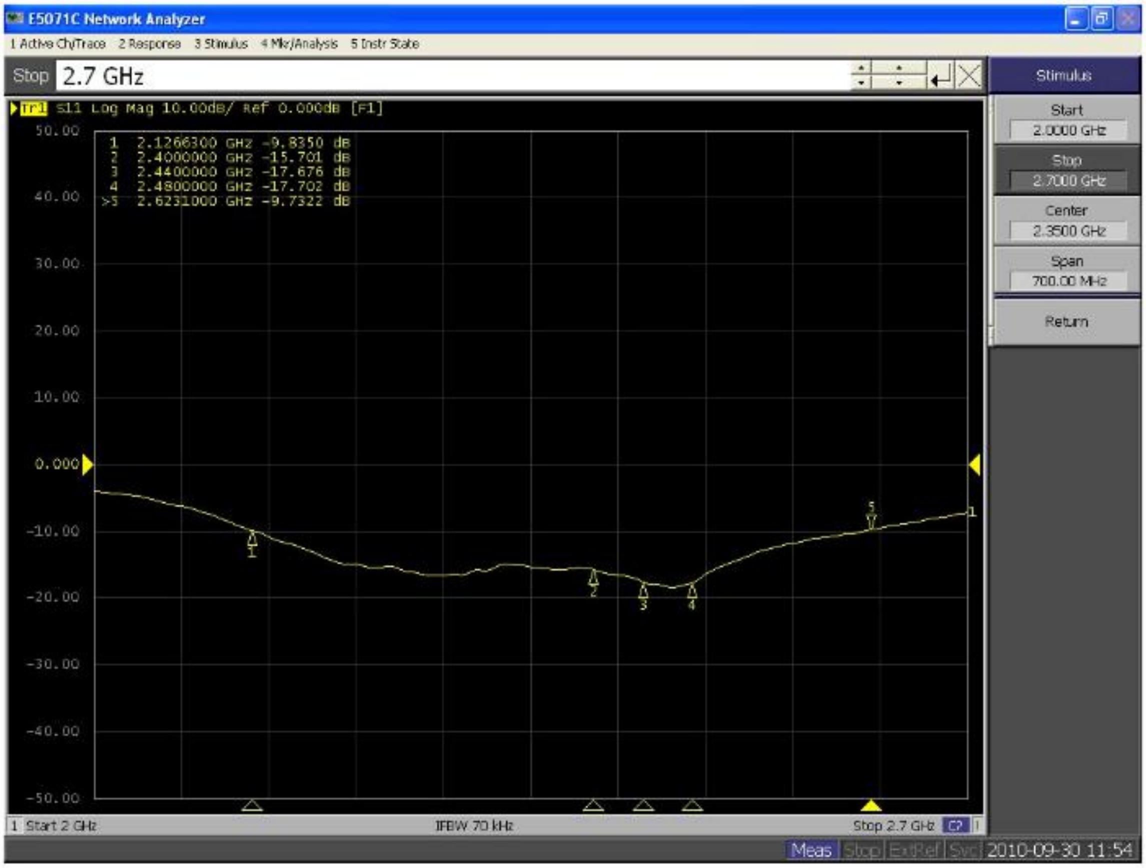


**Figure 4. Layer 2** (Inner, Antenna Bottom Layer)





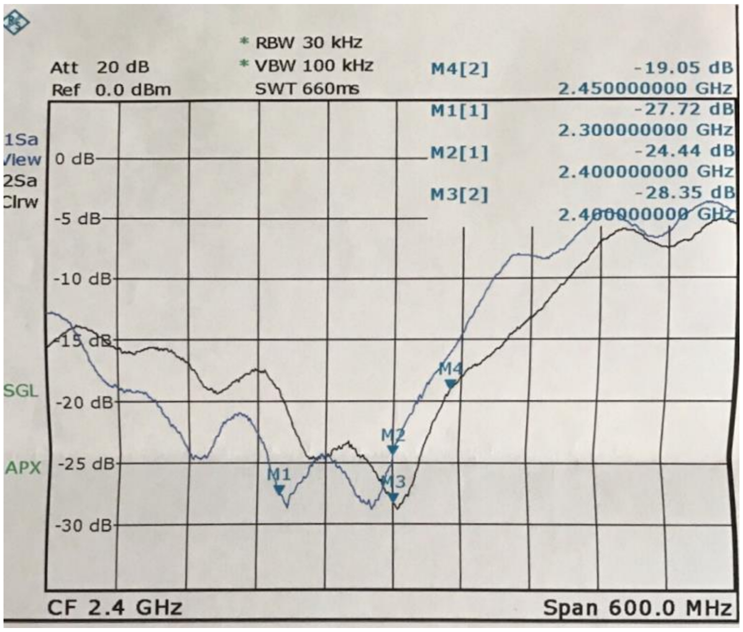
This antenna was ideal for our purposes because of the PCB it was lightweight and because of the Yagi 2.4GHz design it was highly directive and of the appropriate frequency. The bandwidth was also sufficiently large and met our requirements.



```
Tr1 S11 Log Mag 10.00dB/ Ref 0.000dB [F1]
 1  2.1266300 GHz -9.8350 dB
 2  2.4000000 GHz -15.701 dB
 3  2.4400000 GHz -17.676 dB
 4  2.4800000 GHz -17.702 dB
>5  2.6231000 GHz -9.7322 dB
```

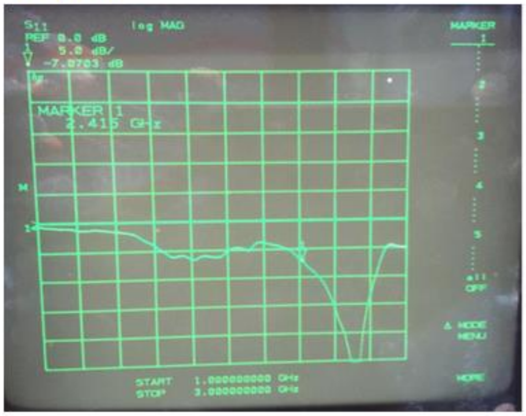
In the end unfortunately the antenna did not end up working because several of the requirements for ordering from Bay Area Circuits student PCB were not met.

A backup Yagi PCB antenna provided by the TA was used in addition to the quarter one coffee cans were used instead.

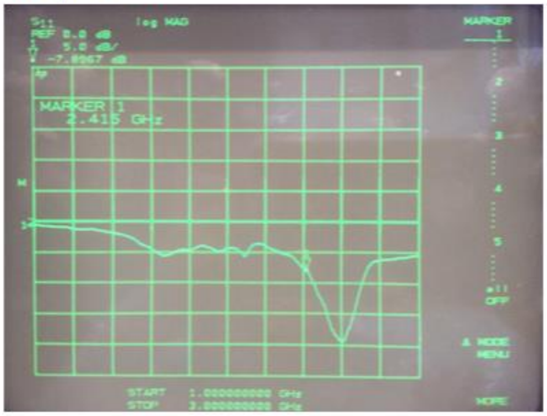


The provided Yagi antennas worked reasonably well with good return loss results.

**TX port**



**RX port**



Baseband-Jin Hua Cao

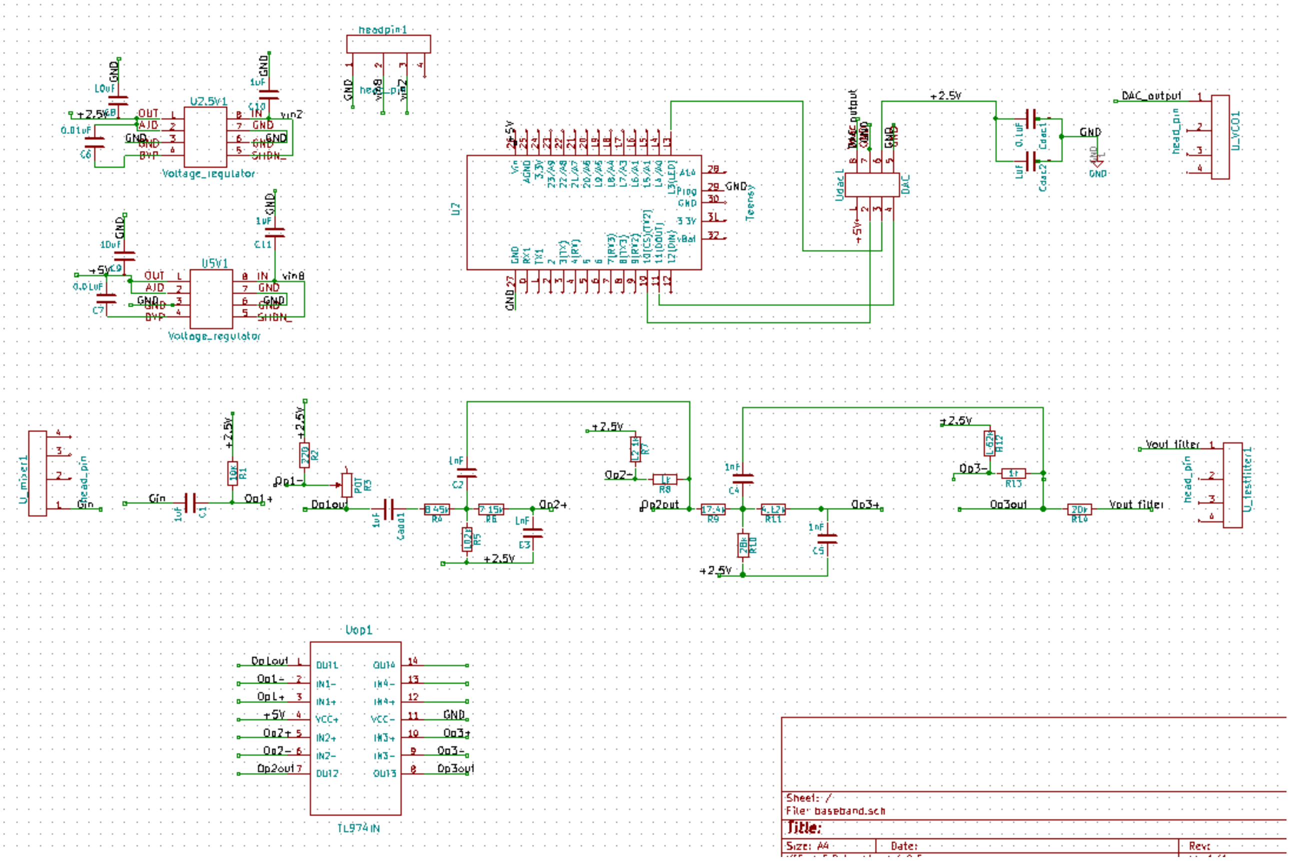
The baseband plays an important role. The baseband part includes modulator, ADC, Low pass filter and Baseband-amplifier. The modulator generates the triangular wave, which will go through the VCO in the transmitter part. For the receiver, the signal from the mixer will be amplified by the amplifier and then go through a low pass filter, the signal is then sampled by the ADC and processed in the computer.

The baseband schematic is first modelled in Kicad, then the layout is obtained and the PCB is fabricated from Bay Area Circuit. The schematic is shown in Fig. 2. The modulator is realized by using the Teensy 3.1 and DAC. The baseband receiver part is realized by the amplifier and low-pass-filter. Besides, to achieve the stable DC supply, the regulator is used to generate the 5V and 2.5V. The specified components used are listed in Table I. The top and bottom baseband PCB are shown. After the soldering, the final PCB is shown.

Table I: Lists of Baseband components

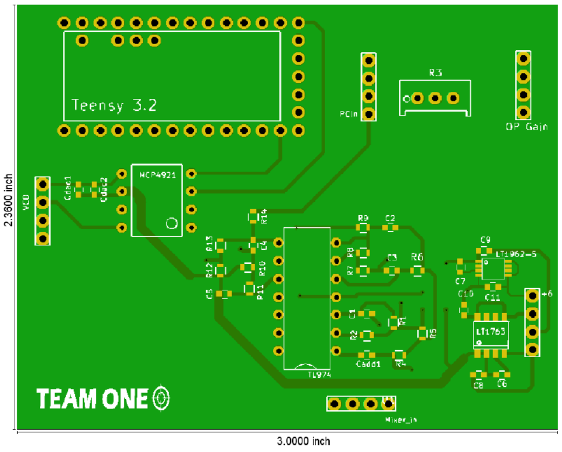
| Components | Part number | Price | Number |
|---|---|---|---|
| Amplifier | TL974 | $0 | 1 |
| ADC | Sound Card | $0 | 1 |
| Teensy | Teensy 3.2 | $0 | 1 |
| DAC | MCP4921 | $0 | 1 |
| Regulator_5V | LT1962 | $3.52 | 1 |
| Regulator_2.5V | LT1763 | $4.78 | 1 |

What follows is the schematic diagram for the baseband as well as the PCB layout.

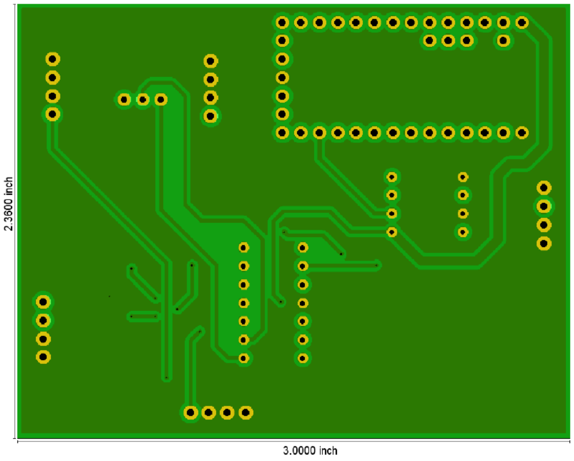


The corresponding PCB layout design for the baseband board is as follows

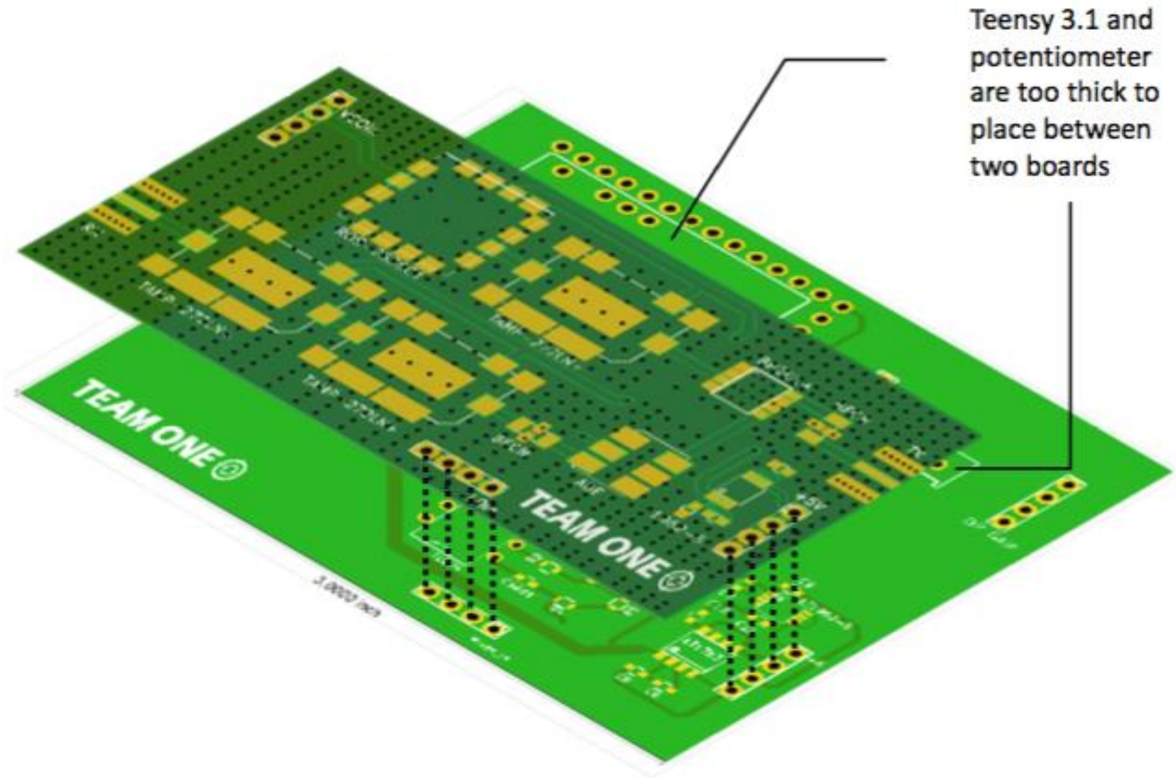
Top view



Bottom View

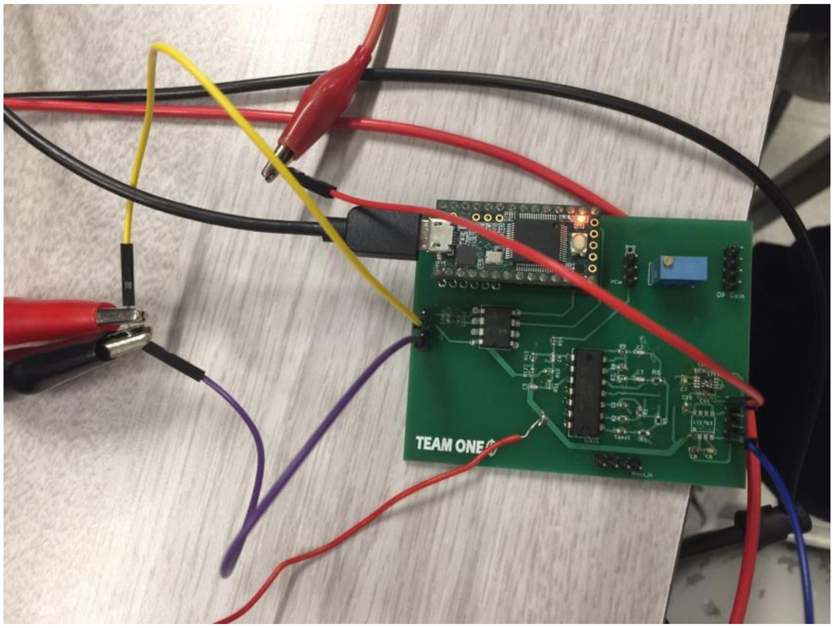


The RF board and the Baseband boards are assembled in connection with one another so that the system is smaller and more compact as shown bellow

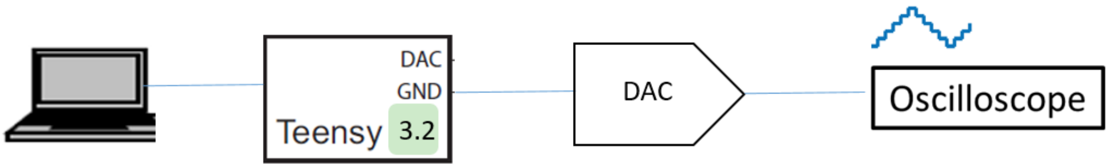


Teensy 3.1 and potentiometer are too thick to place between two boards

Test result of the Baseband

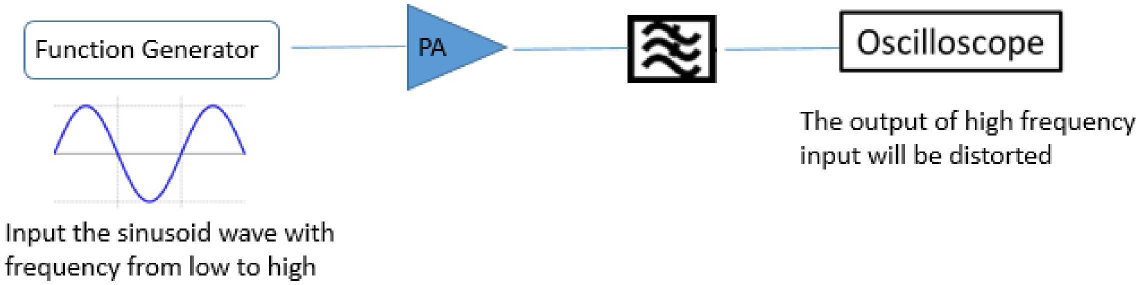


1. The testing setup for the transmitter part of the baseband is shown as follows:



The result for the DAC output is shown below, when the frequency is lower, we can get the triangular wave. When the frequency increases, the DAC output becomes the stair wave. Besides, by changing the Arduino code, the amplitude of the output could also be changed adaptively.

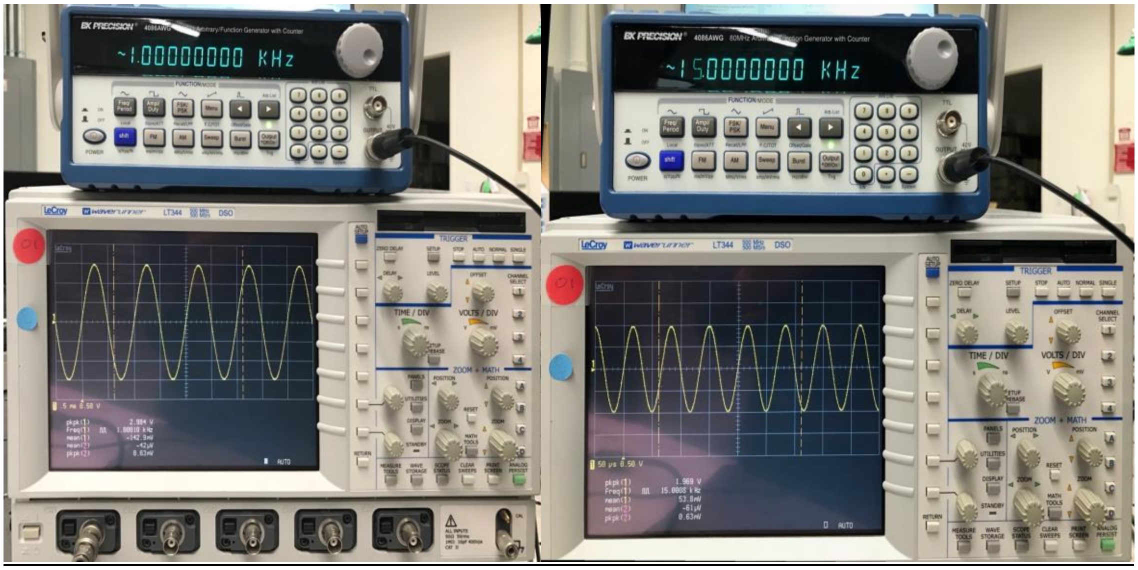
2. The testing setup for the receiver part of the baseband is shown as follows:



Input the sinusoid wave with frequency from low to high

The output of high frequency input will be distorted

The output of the filter is shown as follows: when the input frequency is low, the output is the sine wave, the cutoff frequency of the filter is about 15Khz, where the output power is half of that of the low frequency.



3. The regulator test: During the test, the regulator for the 2.5V does not work when the 5V regulator works. The 2.5V regulator and 5V regulator could not work at the same time. To solve this problem, additional power supply voltage is used. The reason for this problem is still unknown. And this will be regarded as the future work. It is possibly that during the PCB layout, there is something wrong with the two regulator.

### DSP-Hao Lin Yang

#### **Code**

Our team use MATLAB to analyze the digital data for radar image. To realize the real-time analyze, the function of audioread() is necessary and the detailed code and explains are as following:

```
close all;
clear all;
recObj = audiorecorder(Fs, 16, 2);
disp('Start speaking.')
recordblocking(recObj, 10);
disp('End of Recording.');
q= getaudiodata(recObj);
plot(q);
data = 0;
figure;
plot(q);
```

For this part, we use audiorecorder function to realize the recording SYNC and output signal for 10 second and recording format is a audio file with 2 channels, 16bits and example frequency is 44100Hz and output is a matrix named ‘q’.

```
load handel.mat
filename = 'handel.wav';
audiowrite(filename,q,Fs);
clear q Fs
[q,Fs] = audioread(filename);
sound(q,Fs);
```

This part is the key to connect recording section to the digital analysis section. Frist we load a intermediate named handel and input the digital data into this matrix. Finally using audiowrite function to output a wav file with frequency with 44100 Hz

```
FS=44100
c = 3E8;% speed of light
Tp = 12.8E-3; %(s) pulse time
N = Tp*FS; %# of samples per pulse
fstart = 2300E6; %(Hz) LFM start frequency
fstop = 2560E6; %(Hz) LFM stop frequency
BW = fstop-fstart; %(Hz) transmti bandwidth
f = linspace(fstart, fstop, N/2); %instantaneous transmit frequency
%range resolution
rr = c/(2*BW);
max_range = rr*N/2;
```

The aim of part is to set the parameter and figure the max distance range.

```
[Y,FS] = audioread('1.wav');%the input appears to be inverted
trig = -1*Y(:,1);%SYNC signal
%[Y,FS] = audioread('HU3.wav');
s = -1*Y(:,2);%radar signal
%parse the data here by triggering off rising edge of sync pulse
count = 0;
thresh = 0;
start = (trig > thresh);%convert data into binary
d=size(start,1)-N;
for ii = 100:(d)
if start(ii) == 1 & mean(start(ii-11:ii-1)) == 0
%start2(ii) = 1;
count = count + 1;
sif(count,:) = s(ii:ii+N-1);
time(count) = ii*1/FS;
end
end
disp('end_for')
%subtract the average
ave = mean(sif,1);
for ii = 1:size(sif,1);
sif(ii,:) = sif(ii,:) - ave;
end
```

```
zpad = 8*N/2;
%RTI plot
figure(10);
dbv = fft(sif,zpad,2);
v=dbv;
S =abs(v(:,1:size(v,2)/2));
m =mean(mean(v));
Z=S-m;
Z=abs(Z);
%Z=Z/abs((max(max(Z))));
%Z=20*log10(Z);
U=linspace(0,max_range,zpad);
imagesc(U,time,Z);
colorbar;
ylabel('time (s)');
xlabel('range (m)');
title('RTI without clutter rejection');

%pulse cancelor RTI plot
figure(20);
sif2 = sif(2:size(sif,1),:)-sif(1:size(sif,1)-1,:);
v = fft(sif2,zpad,2);
p=v;
R = linspace(0,max_range,zpad);
abv=p(:,1:size(v,2)/2);
m =mean(mean(p));
J=abs(p-m);
J=J/abs((max(max(J))));
J=20*log10(J);
K=J(:,1:size(J,2)/2);
imagesc(R,time,K);
colorbar;
ylabel('time (s)');
xlabel('range (m)');
title('RTI with 2-pulse cancelor clutter rejection');
```

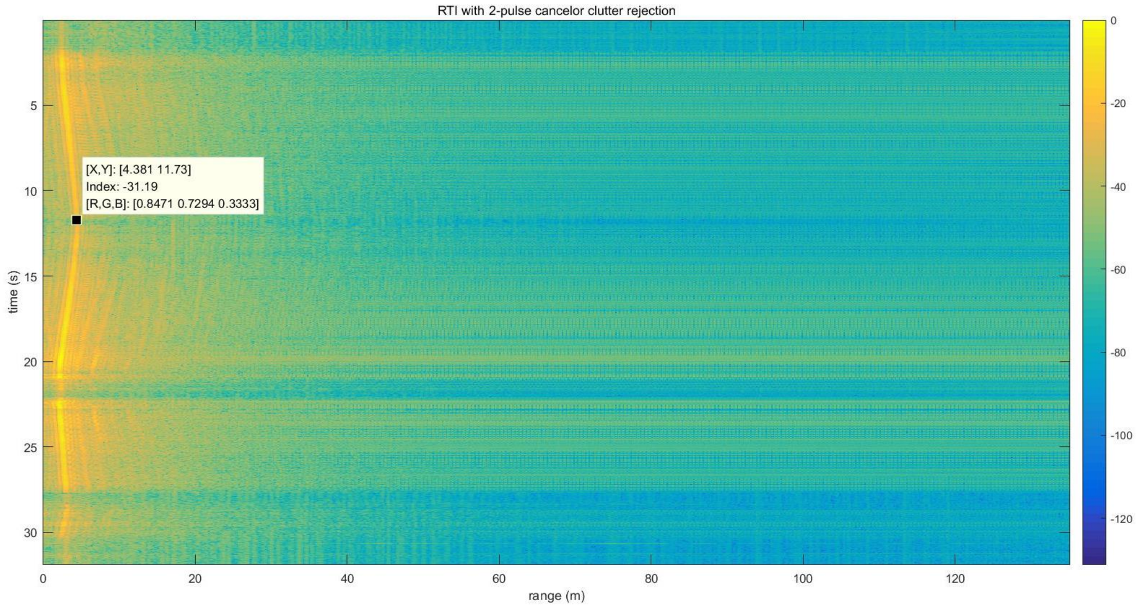
In this part, we use two function J=J/abs((max(max(J)))) and J=20*log10(J) to amplify the distance between each two number, but its tradeoff is also to amplify the noise, which has a bad influence on the final output.

## Field Test Results in the Laboratory

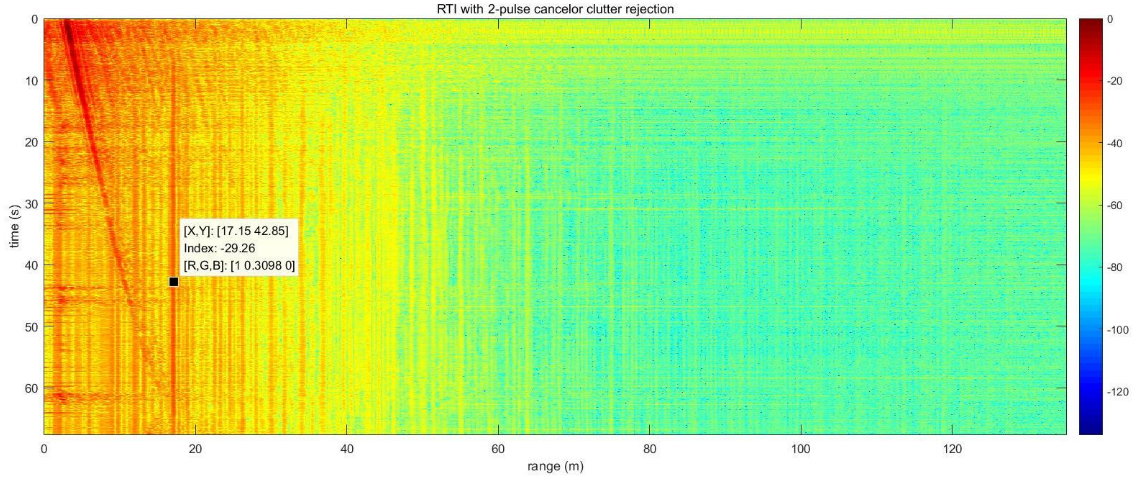
After all parts of the system are ready, we first do a simple test in the laboratory. We move the metal plate toward and backward to the system to see whether it can detect correct distance and movement of the plate. As shown in the photo below, there is a large rolling metal door 17 meters away.

Fig. Indoor testing in laboratory

First, we try to move the metal plate backward and stop at around 4.5 meters away from our system, then move toward the system again. As MATLAB result shown below, it clearly represents the movement of the metal plate.



Next, we would like to test the limit of our system. We slowly move the metal plate toward the large rolling door (backward our system). As MATLAB result shown below, there is a line around 17 meters which represents the rolling door. While the metal plate is closer to the system, received signal amplitude would increase. This tells us that when target is too close to our system, the signal intensity might be too strong to let the system saturate.

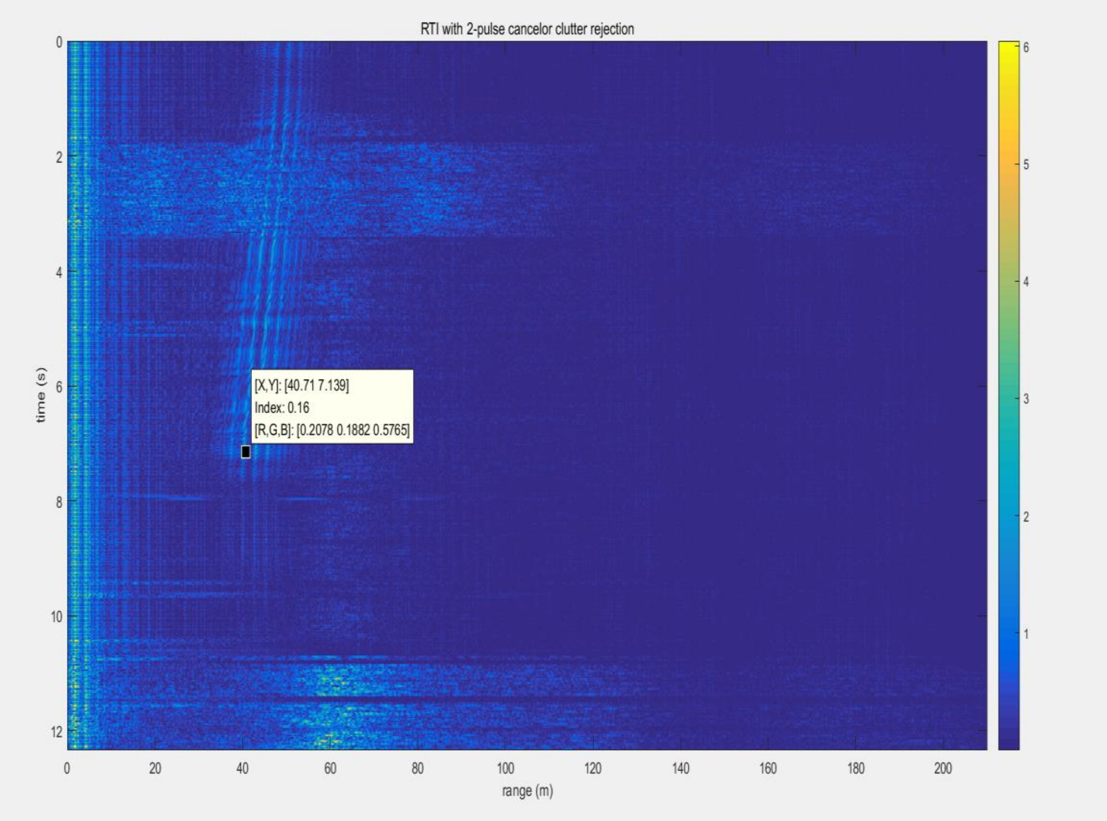


## Competition Result

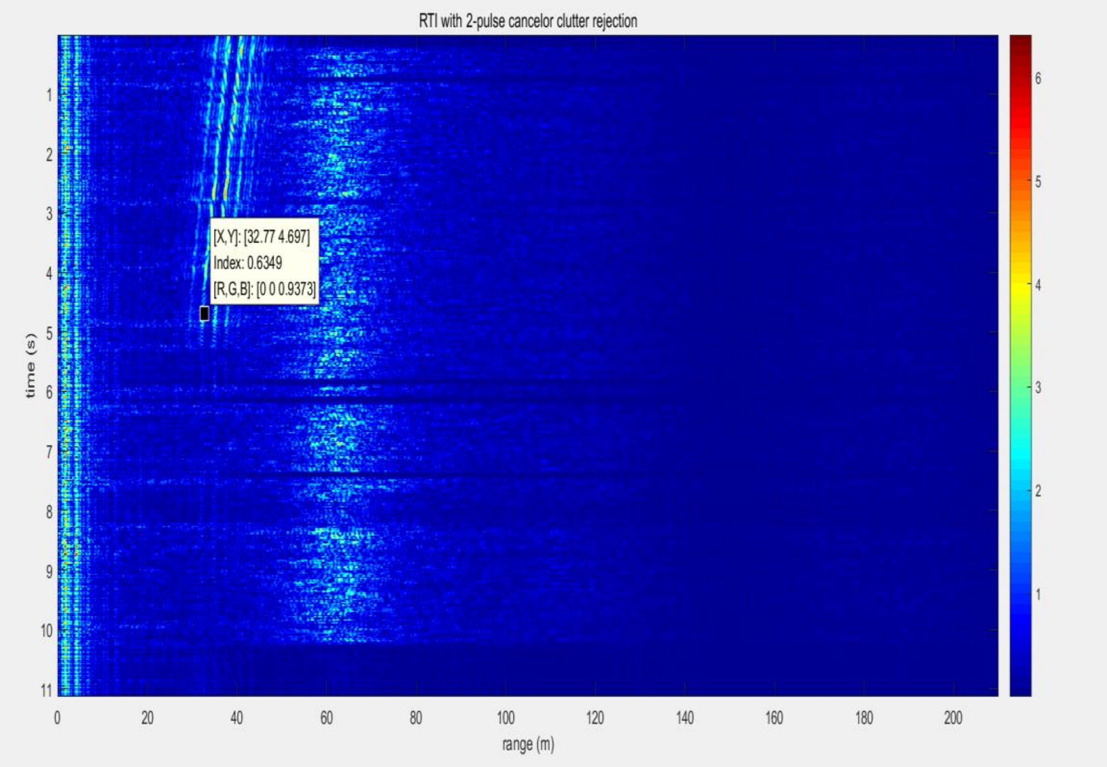
This is the chart of our test results:

| Times | Test Distance |
|---|---|
| 1 | 40.72 |
| 2 | 32.79 |
| 3 | 27.42 |
| 4 | 18.49 |
| 5 | 11.11 |

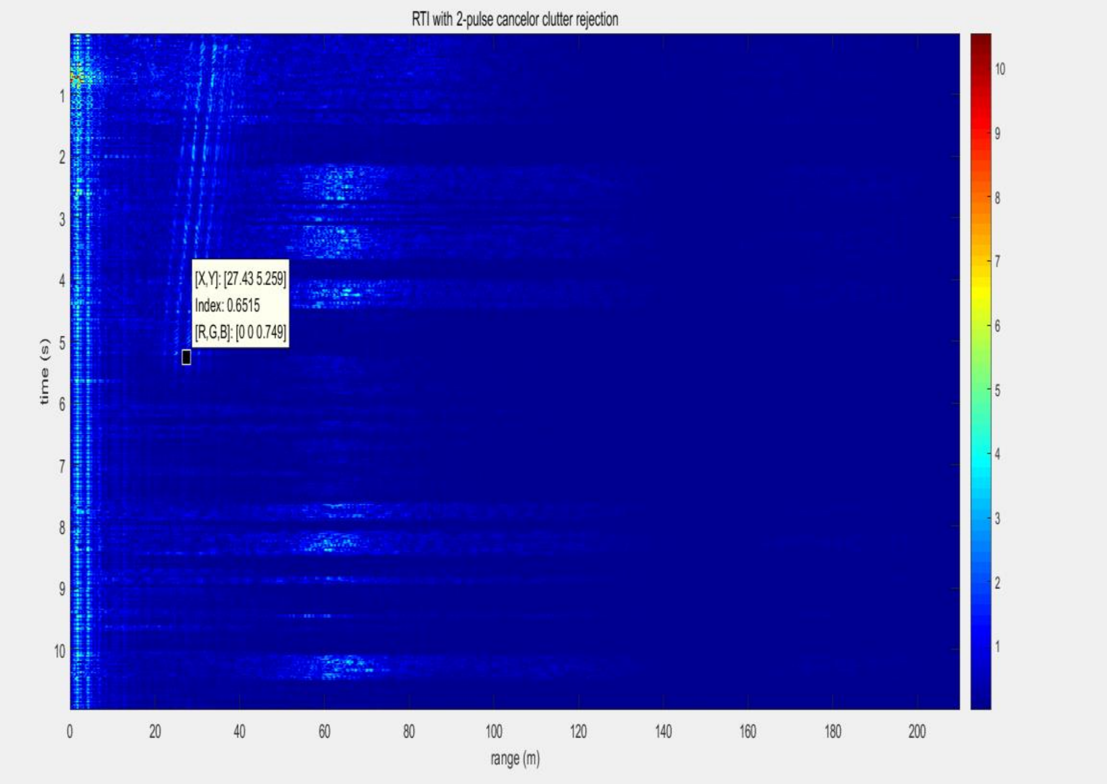
Here are the image that we gain by the MATLAB analysis:



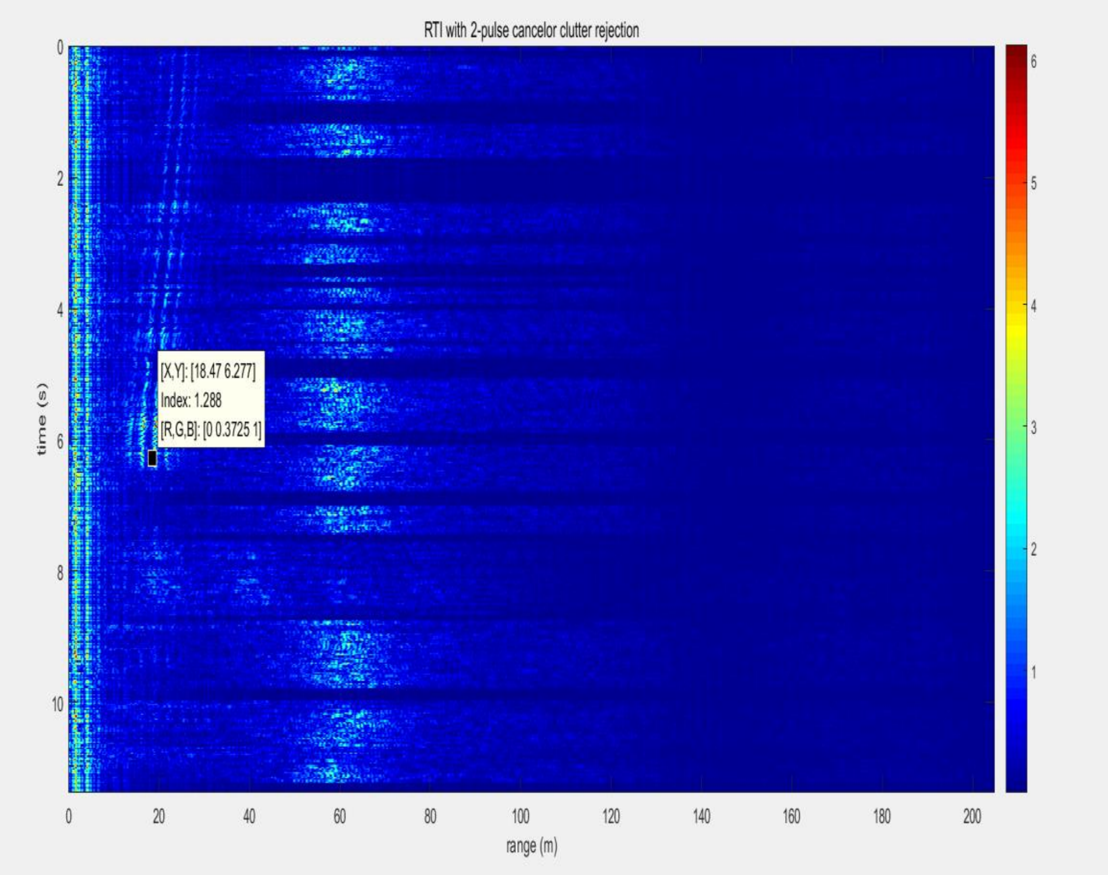
First Time



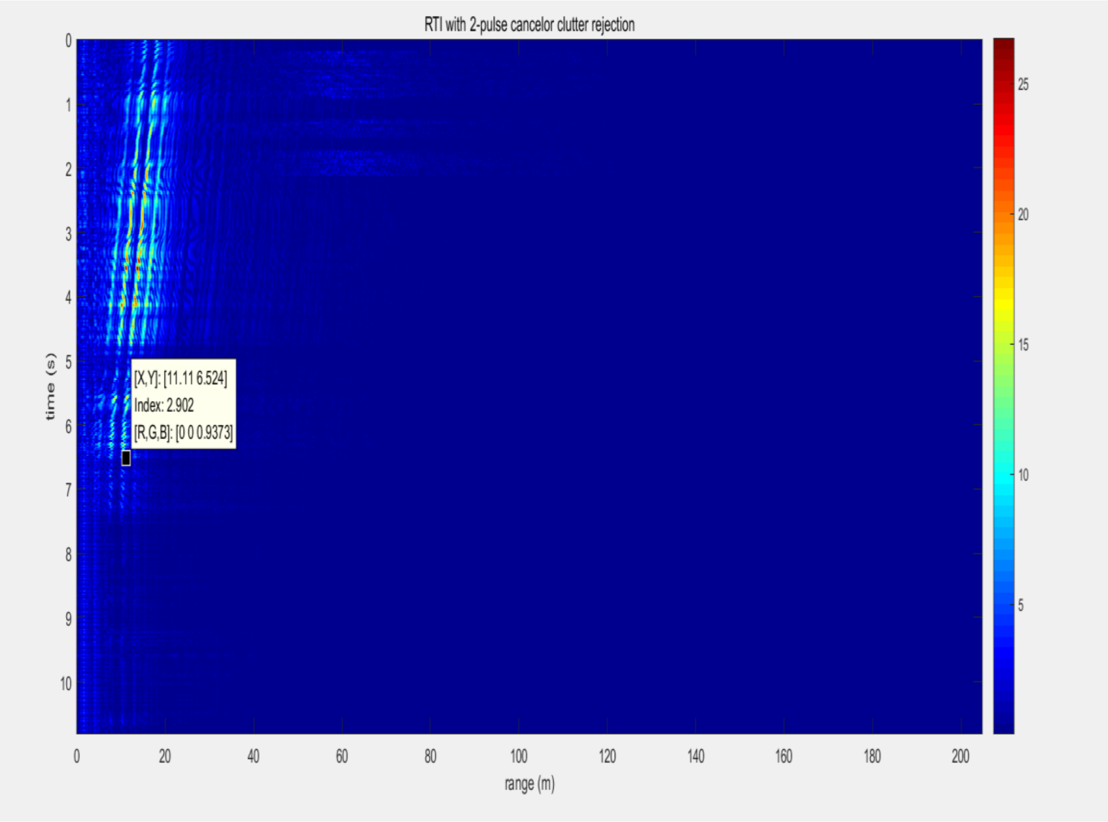
Second Time


RTI with 2-pulse cancelor clutter rejection
[X,Y]: [27.43 5.259]
Index: 0.6515
[R,G,B]: [0 0 0.749]
time (s)
1
2
3
4
5
6
7
8
9
10
0
20
40
60
80
100
120
140
160
180
200
range (m)
1
2
3
4
5
6
7
8
9
10

Third Time


RTI with 2-pulse cancelor clutter rejection
[X,Y]: [18.47 6.277]
Index: 1.288
[R,G,B]: [0 0.3725 1]
time (s)
0
2
4
6
8
10
0
20
40
60
80
100
120
140
160
180
200
range (m)
1
2
3
4
5
6

Fourth Time



Fifth Time

## Problem

Our problem is clear there are four lines on the plot. We never encounter such problem during several tests we have before and we think the reason is from the amplify inside the laptop. We may need to avoid amplifying too much from saturation. Since the distance between each lines seems to be same, this problem may come from harmonics. We then picked up the brightest line which should be the original signal.