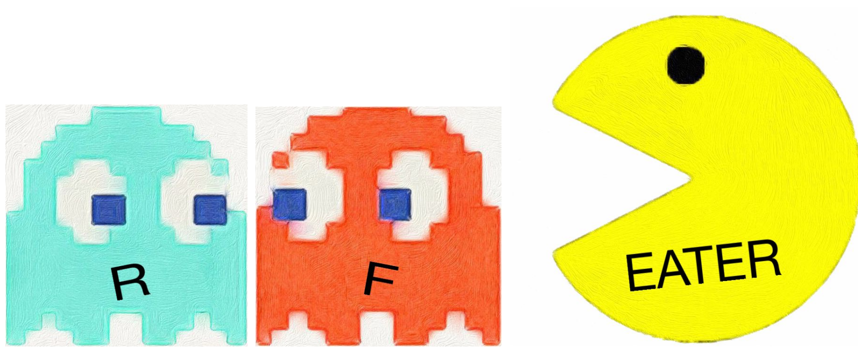
EEC 134 Project Report

RF/Microwave System Design

Fall - Winter 2016

Professor Liu



Team RF Eater

Qun Xia

Yueming Qiu

Tianyi Gao

Jiaming She

Abstract

This two quarters we work on a Frequency Modulated Continuous Wave (FMCW) radar system, which can detect wide range of distant of an object. In this report, we will take about the designing procedures and details.

Introduction

FMCW radar can be used to locate and detect objects, while Doppler radars can help to determine the speed of an object. We mainly focused on the FMCW radar in our senior design project. Our radar system include one transmitting antenna and one receiving antenna. Let the transmitting antenna send out a signal. The signal will reach the object and be reflected back. The receiving antenna will receive the signal that is reflected back. Then we can use laptop to analyze the signal received in order to detect the distance between the radar and the object.

Designing Procedure

In fall quarter, we learned the knowledge needed for radar system design. Through each instructed lab, we got a general idea of the function and characteristic of each RF component. We also got familiar with PCB designing in fall quarter. Based on the experience from fall quarter, we made the improvement plan at the beginning in winter quarter. Since all of our group member have no background with embedding system, we decided to use laptop to do the real-time signal processing but focus more on the accuracy of the measurement. In fall quarter, unfortunately, the PCB our team designed and assembled in were all failed, so we decided to focus more on improving the PCB from fall quarter instead of designing more new PCBs. We divided the baseband circuit into three smaller PCB instead of a large one, which made the debugging easier. We totally designed four PCBs for our radar system, one for each of the following: function generator, voltage regulator and reference, active low-pass filter with gain stage and low-noise amplifier. We also took off the attenuator. We planned to keep using metal box for other RF components except the low-noise amplifier, which we believed will be more stable and safe. Based on our plan, we made the quarter 2 schedule as shown in Fig 1.

- ***Timeline with Gantt Chart***

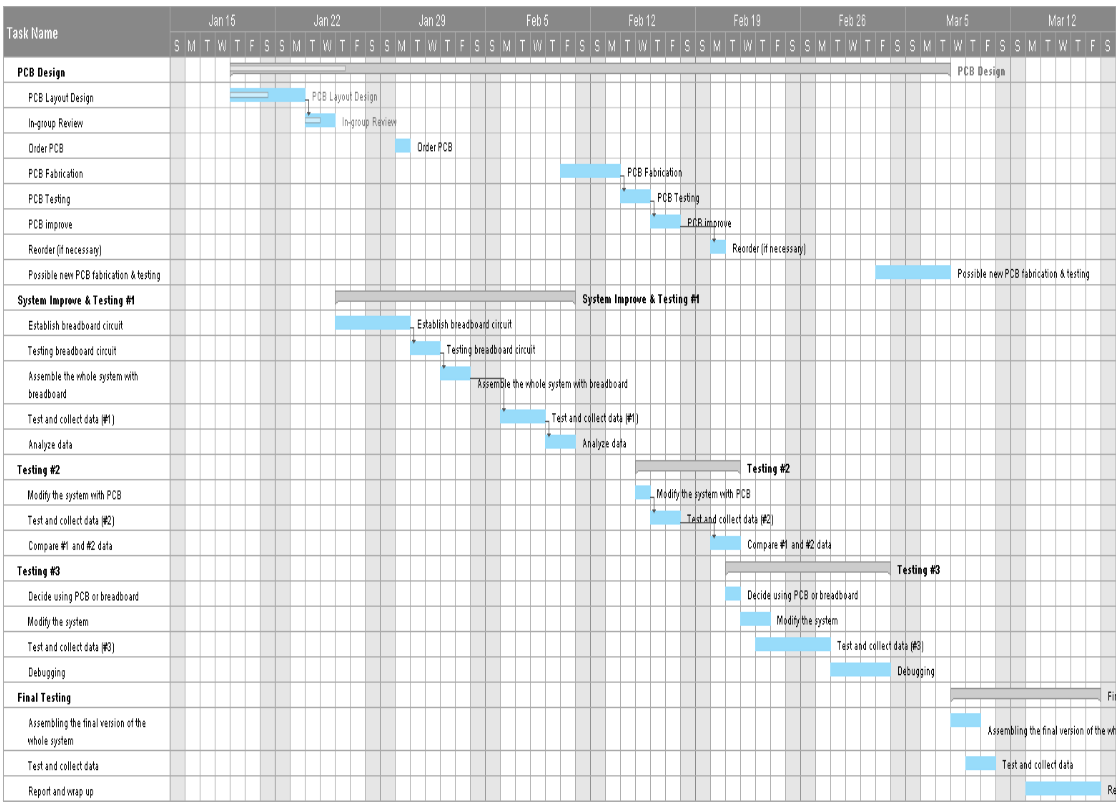


Fig 1. Timeline

- ***Calculations***

In fall quarter, we measured the gain of our can antenna and it is 7.348dB. Based on this value and the following equation, we calculated the propagation loss for our system.

$$P_r = \frac{P_t G_t \sigma}{(4\pi R^2)^2} \frac{G_r \lambda^2}{4\pi} = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4}.$$

Distance	Propagation loss
50m	96.2dB
25m	84.13dB
5m	56.17dB
1m	28.21dB

Table 1. Propagation Loss

- ***Block Diagram for our Radar System***

We made the block diagram for our final radar system according to the calculations.

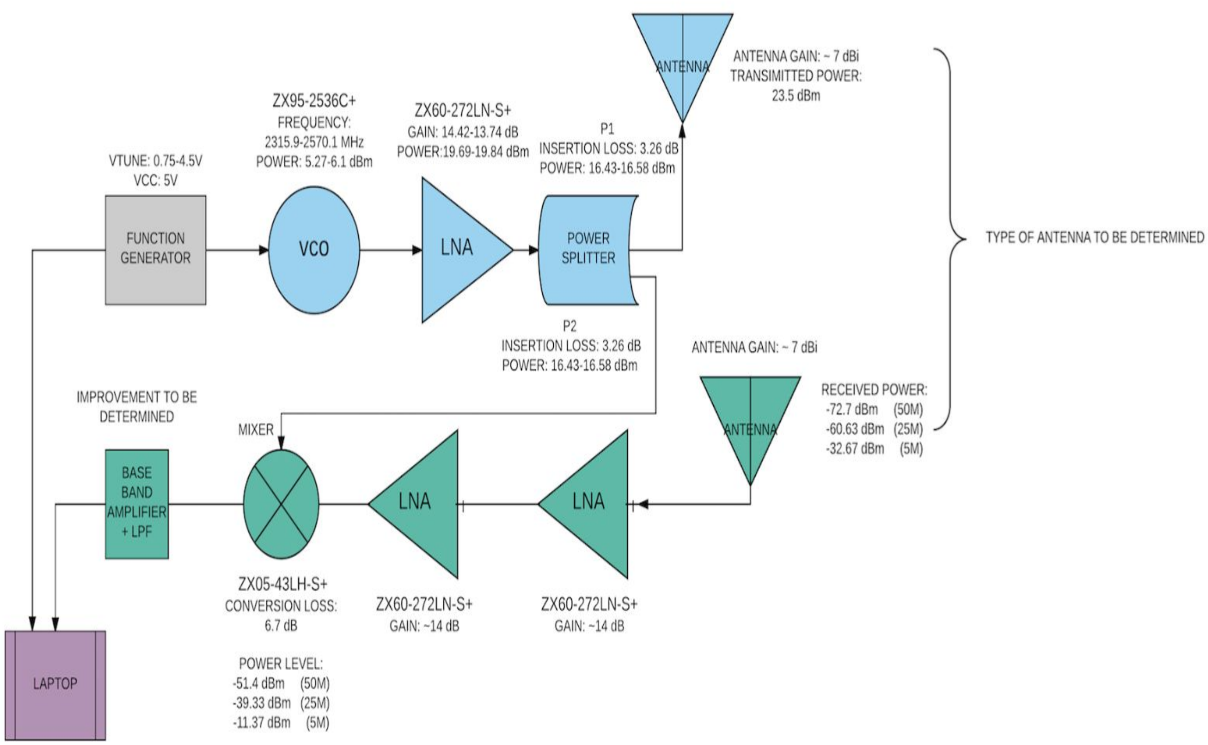


Fig 2. Block Diagram for the Radar System

- ***PCB Design, Assembling and Testing***

We totally designed four PCBs for our radar system, one for each of the following: function generator, voltage regulator and reference, active low-pass filter with gain stage and low-noise filter. When assembling the PCBs, we used the equipment from EFL lab in Bainer Hall. Compared with the warm plate we used for heating our PCBs in fall quarter, the flow oven in the EFL lab is more efficient and easy to use. We figured out that the PCBs from fall quarter were all failed could be caused by that the heated temperature for the PCBs were not high enough.

1. <u>Voltage regulator and Reference</u>

The first PCB we designed was the voltage regulator and reference. This PCB contained two major components, LM317 and LT1009. LM317 worked as a voltage regulator. LT1009 with a 3.6K ohm resistor will work as precision voltage reference. The PCB is supposed to have one output for 5V and one output for 2.5V when having a 8V power input.

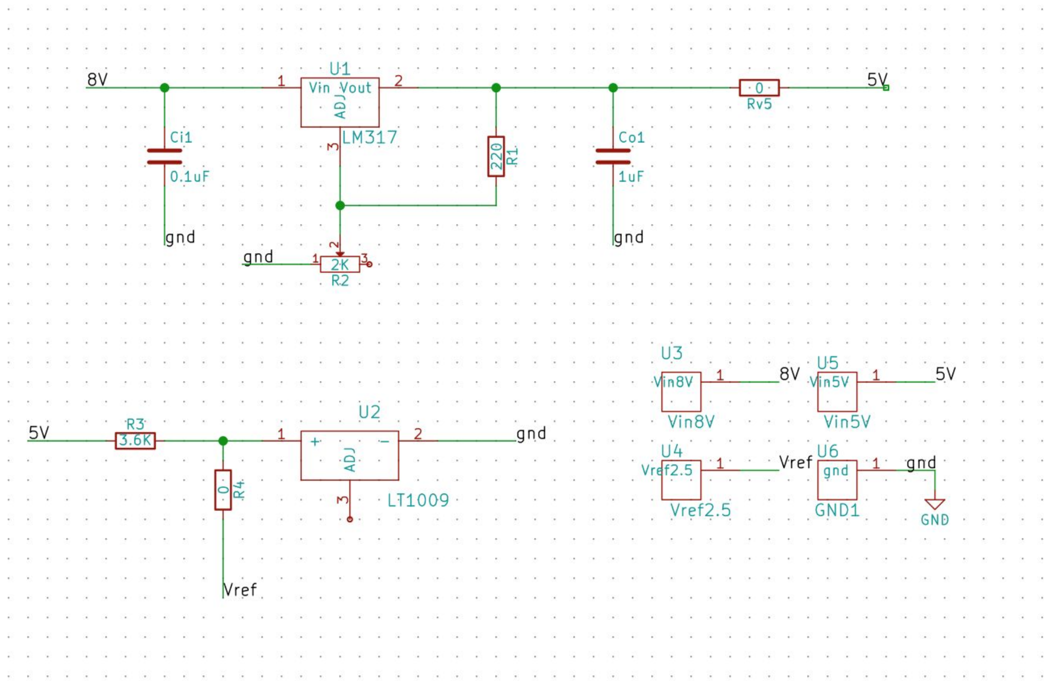


Fig 6. Schematic for Voltage Regulator and Reference

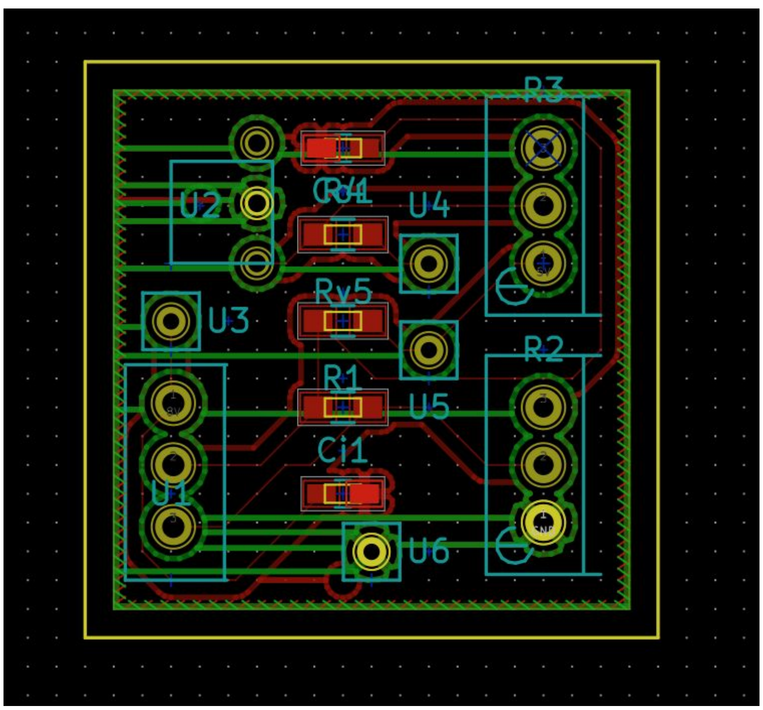


Fig 6. PCB Layout for Voltage regulator and reference

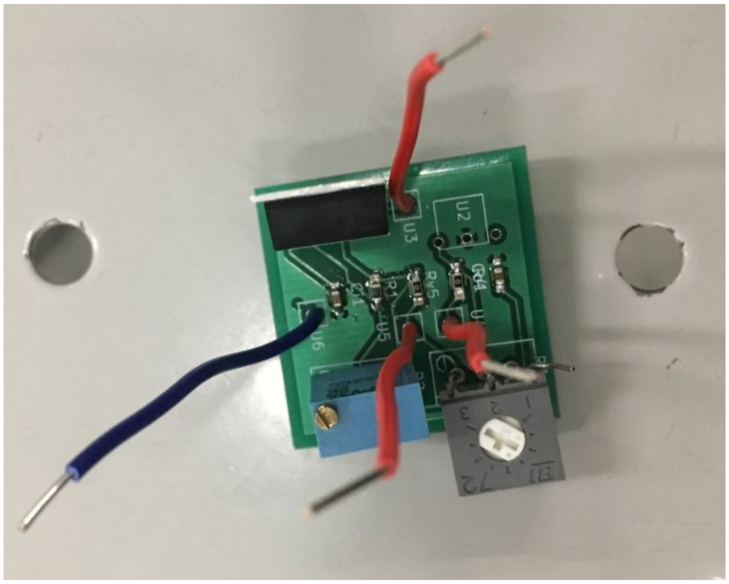


Fig 7. Assembled Voltage Regulator and Reference PCB

In order to test the PCB, we connected the input of the PCB to a 8V power supply. Then we used the multimeter to measure the voltage at the output for 5V. We adjust the potentiometer until we got 5V. Then we measured voltage at the reference output pin. The voltage was 2.49V, which suggested that the PCB for voltage regulator and reference PCB worked well. Then we will use this PCB combined with the bench power supply working as a power supply for the rest of the PCBs and circuits.

2. Function Generator

The second PCB we designed was the function generator, which include two major components, teensy 3.1 and MCP4921. Teensy 3.1 is a microcontroller that will generate a triangle wave and a square wave. MCP4921 is a Digital-to-Analog Converter (DAC) that can convert the voltage value from teensy into frequency value that will go into voltage controlled oscillator (VCO) later.

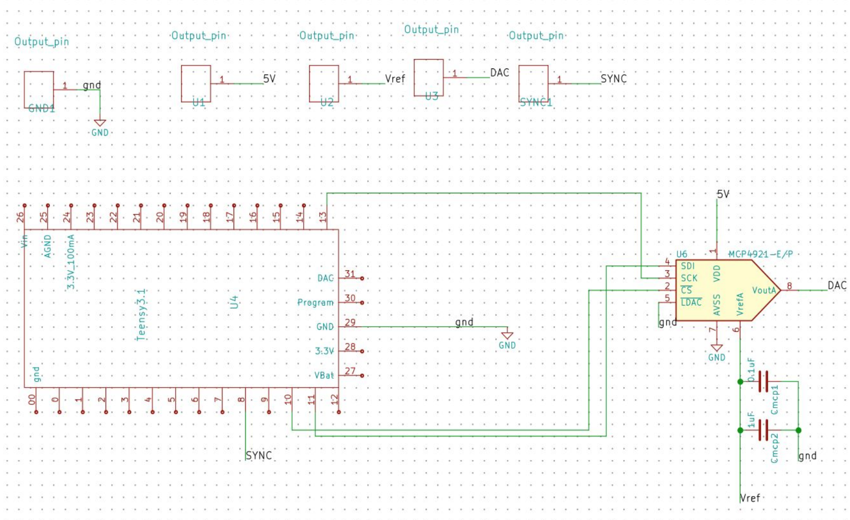


Fig 3. Schematic for function generator

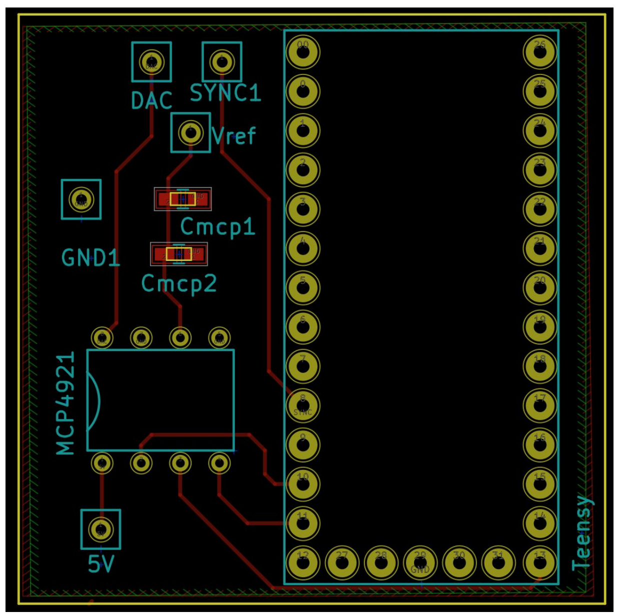


Fig 4. PCB Layout for function generator

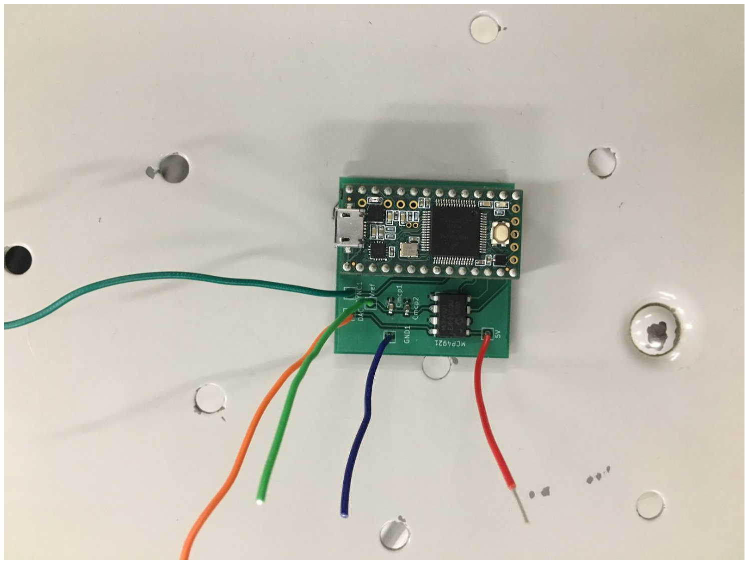


Fig 5. Assembled Function Generator

The function generator should generate a triangle wave with a 0.5-4.5V input range and 40ms period. We modified the code for teensy given in fall quarter to achieve the values we want:

```
#include <SPI.h> // Include the SPI library

word outputValue = 411;// A word is a 16-bit number
int incr = 1;

const int slaveSelectPin = 10; //set the slave select (chip select) pin number
const int SYNC = 8;  //set the SYNC output pin number

void setup()
{
    // Set pins for output
    pinMode(SYNC, OUTPUT);                          // SYNC pin
    digitalWrite(SYNC, LOW);                    // Sync pulse low
    pinMode(slaveSelectPin, OUTPUT);                        // Slave-select (SS) pin
    SPI.begin();                               // Activate the SPI bus
    SPI.beginTransaction(SPISettings(16000000, MSBFIRST, SPI_MODE0));
}
```

```
void loop()
{


  if (outputValue == 3680 || outputValue == 410){
    incr = -incr;
    digitalWrite(SYNC, !digitalRead(SYNC));
  }

  outputValue = outputValue + incr;

  byte HighByte =highByte(outputValue);    // Take the upper byte
  HighByte = 0b00001111 & HighByte;       // Shift in the four upper bits (12 bit total)
  HighByte = 0b00010000 | HighByte;       // Keep the Gain at 1 and the Shutdown(active low) pin off
  byte LowByte = lowByte(outputValue);     // Shift in the 8 lower bits

  digitalWrite(slaveSelectPin, LOW);
  SPI.transfer(HighByte);            // Send the upper byte
  SPI.transfer(LowByte);             // Send the lower byte
  digitalWrite(slaveSelectPin, HIGH);         // Turn off the SPI transmission
}
```

Fig 6. Teensy Code

For testing the function generator PCB, we uploaded the code in Fig 6 to teensy. Then we connected the output of the PCB to oscilloscope. When powering up the teensy, we can see a perfect triangle wave shown on oscilloscope. The minimum voltage was 0.5V and the maximum voltage was 4.5V. The period was 38ms. These data suggested that our function generator PCB worked correctly. We will use this PCB to generate the signal going into the transmitting side of the radar system.

3. <u>Active Low-Pass Filter + Gain Stage</u>

The active low-pass filter (LPF) plus gain stage worked for filtering out spurious signals and amplifying the desired received baseband radar signals.

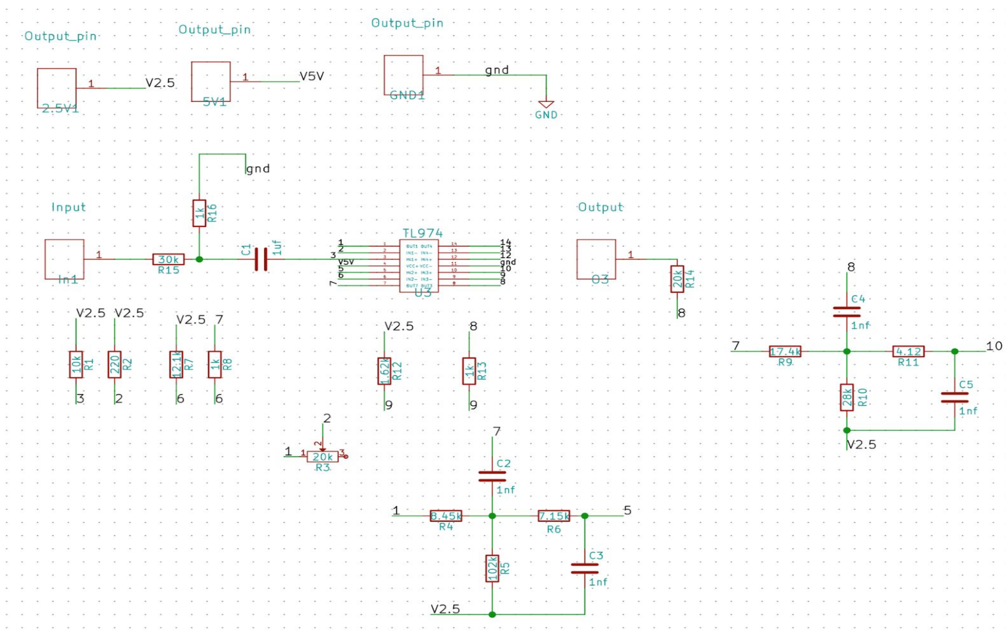


Fig 7. Schematic for LPF + Gain Stage

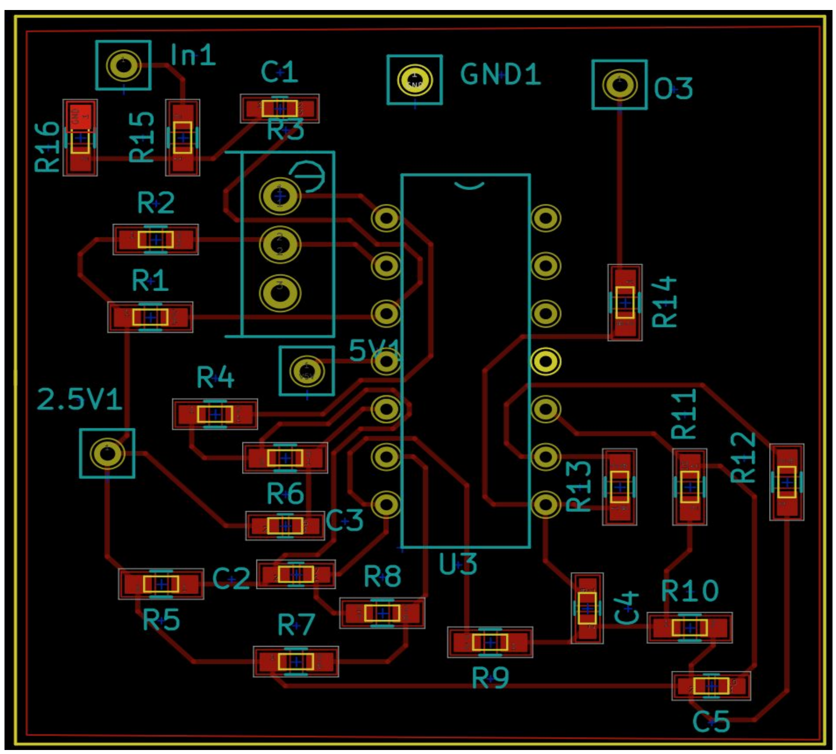


Fig 8. PCB Layout for LPF + Gain Stage

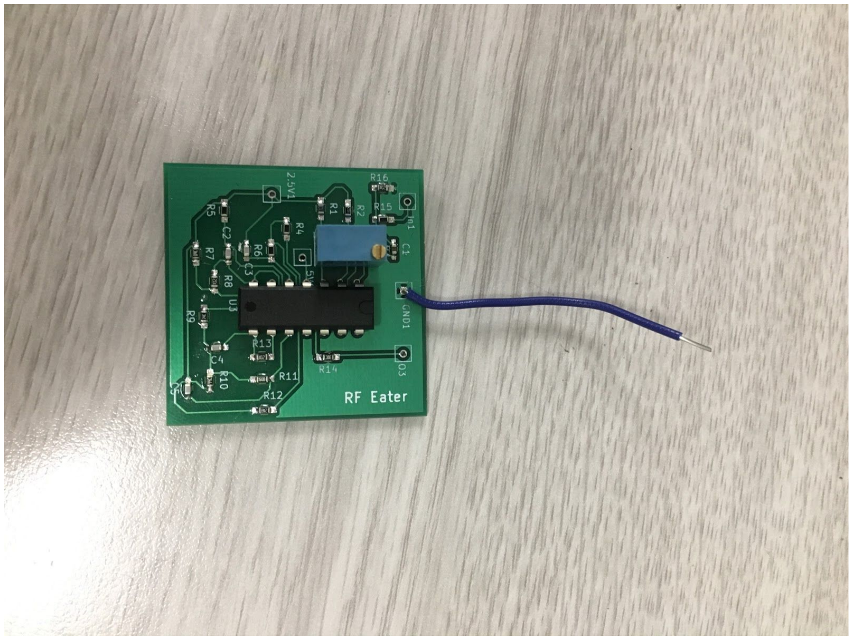


Fig 9. Assembled LPF + Gain Stage PCB

In order to test the LPF + Gain Stage PCB, we connected the 5V and 2.5V power input pins with the voltage regulator and reference PCB. Then we used the function generator in the lab room to generate a 100 mVpp and 1k Hz signal and connect it to the input of the gain stage. We used the oscilloscope to show the output signal of the filter. By adjusting the potentiometer, we set the output peak to peak voltage of the PCB to be 3V and got the perfect sinusoidal wave as shown in Figure 10. This plot suggested that our PCB worked properly.

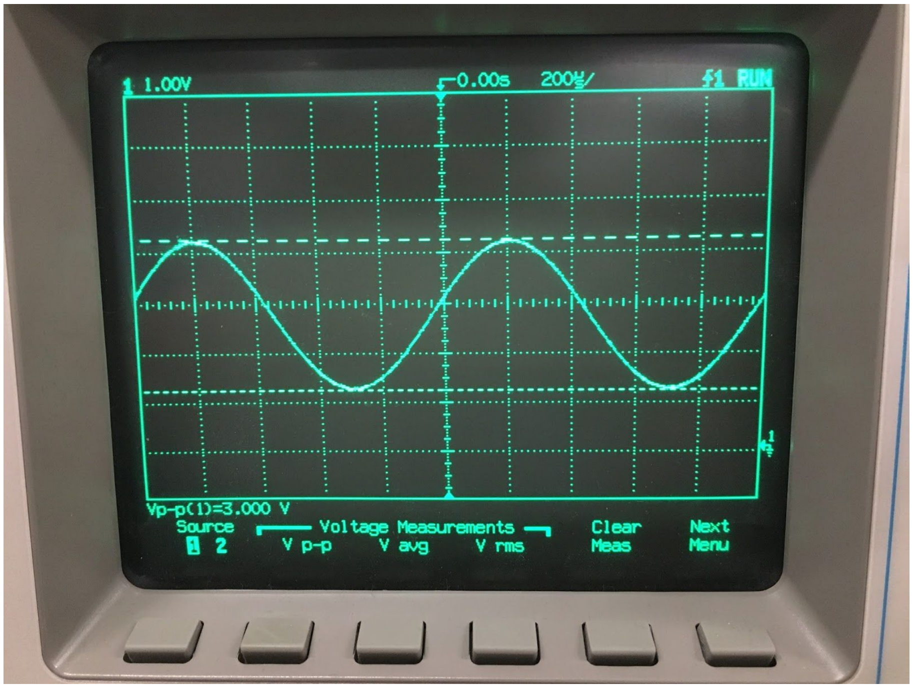


Fig 10. Output Signal of LPF + Gain Stage PCB

4. Low-Noise Amplifier (LNA)

For the RF components in our system, we only designed a PCB for the low-noise amplifier. We planned to use one LNA in the transmitting circuit and two LNAs in the receiving circuit. Compared the radar system from fall quarter, we added one more LNA in the receiving circuit. We believed that adding one more LNA could help with getting stronger signal for analyzing. Thus, we assembled three LNA PCBs in our radar system.

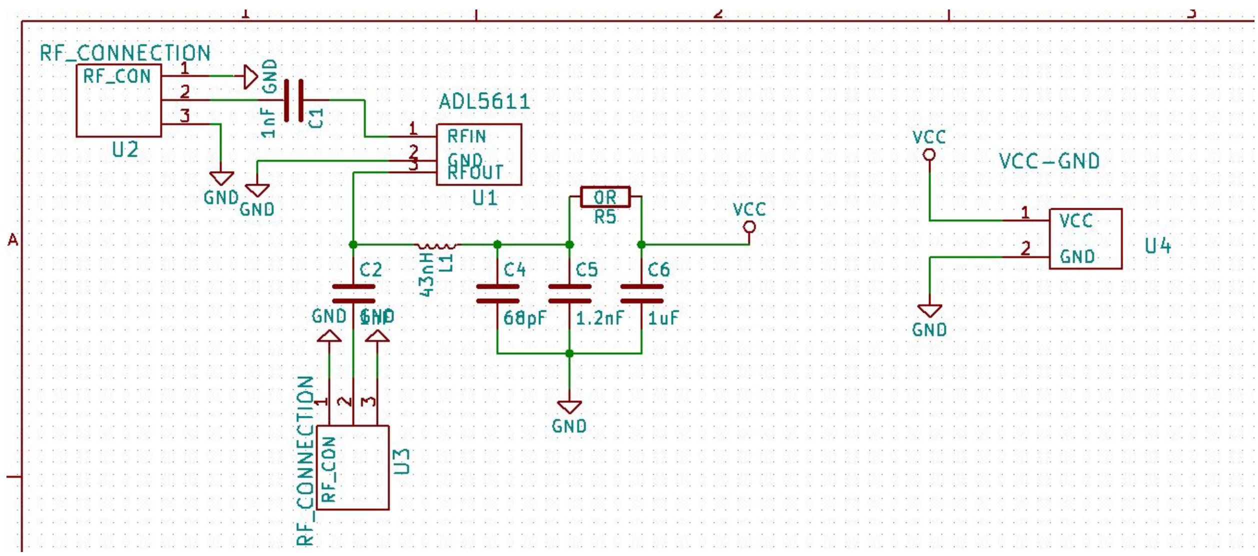


Fig 11 schematic for Amplifier

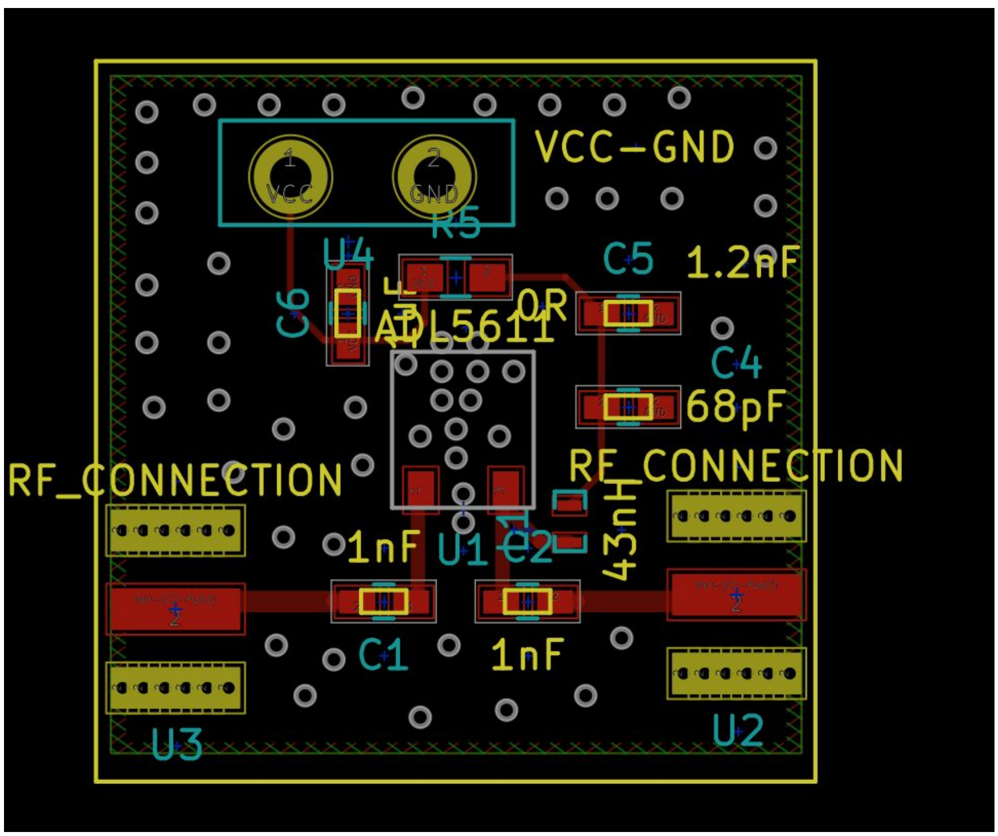


Fig 12 PCB Layout for LNA

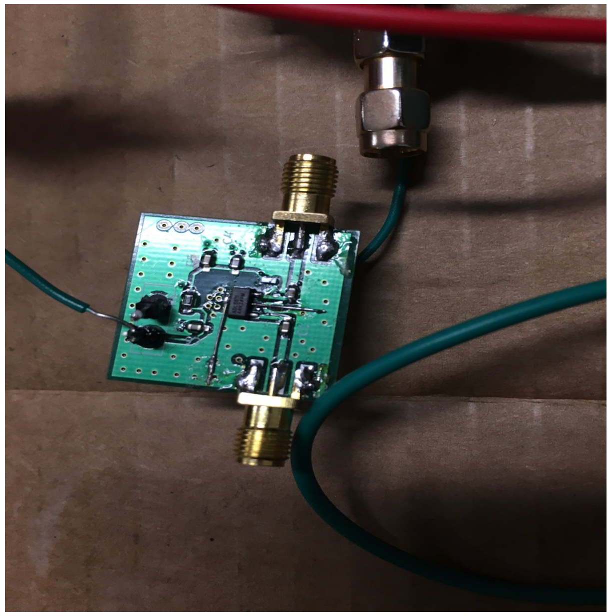


Fig 13 Assembled LNA PCB

In order to test the LNA PCBs, we performed the lab 2 from fall quarter again by replacing the metal box circuit with PCB. According to our measurement, the gain of all three PCBs are 12 dB, 19.2 dB and 12.2 dB respectively. The current going into the PCB was about 1.2A. However, the lab 2 manual from fall quarter said it was supposed to be 0.5A. We first thought they all worked properly. However, in our future testing with whole radar system, we found out that the LNA generated too much signal instead of generated just one. Thus, we gave up using the PCBs we designed and used metal box circuits for our final design.

- ***Antenna***

Considering the weight, size and the stability of the whole system, we decided not to use coffee cans for both transmitting and receiving antennas from last quarter. We finally decided to use can antenna only for the transmitting antenna because the gain for can antenna is bigger than the patch antenna. Since patch antenna are more light and steady, we decided to use patch antenna as the receiving antenna. By considering the operating situation we need, we purchased the Yagi Antenna online as our patch antenna. The Yagi antenna is able to operate at 2.4GHz.

Due to the measurement with the spectrum analyzer, we calculated out the patch antenna gain to be :

-29.5dBm = 0.00117 mW

$G = (4\pi * 1/ 0.125) * \sqrt{(0.00117 / 1)} = 3.439 = 5.364\text{dBi}$

With the help from the TA, we performed the coupling tests for the two antennas and decided that the distance between two antennas should be 10 inches.

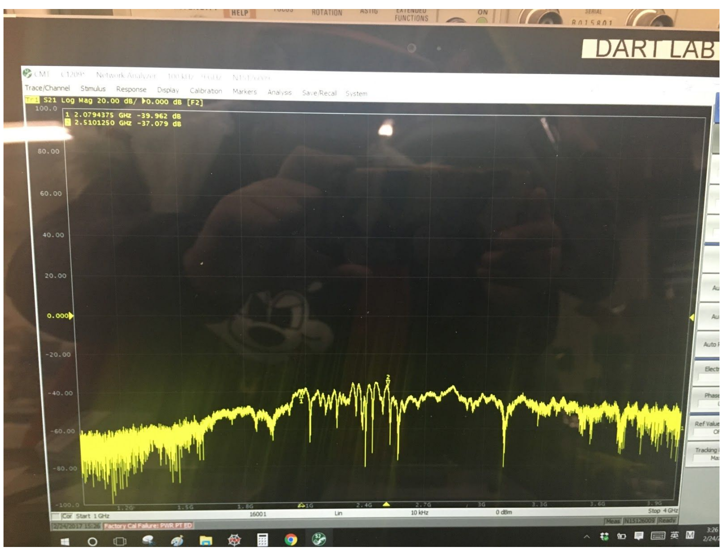


Fig 14 Coupling test

According to the test for return loss (S11), the patch antenna and can antenna were working with reasonable frequency. The bandwidth for the patch antenna is 0.6GHz, and the bandwidth for the can antenna is 0.45GHz.

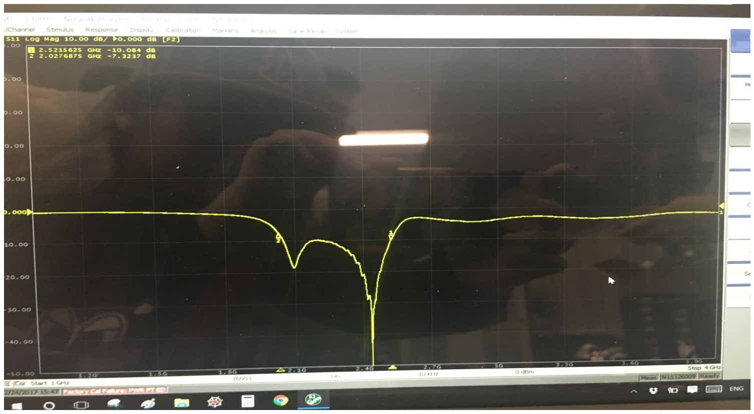


Fig 15. S11 result for patch antenna

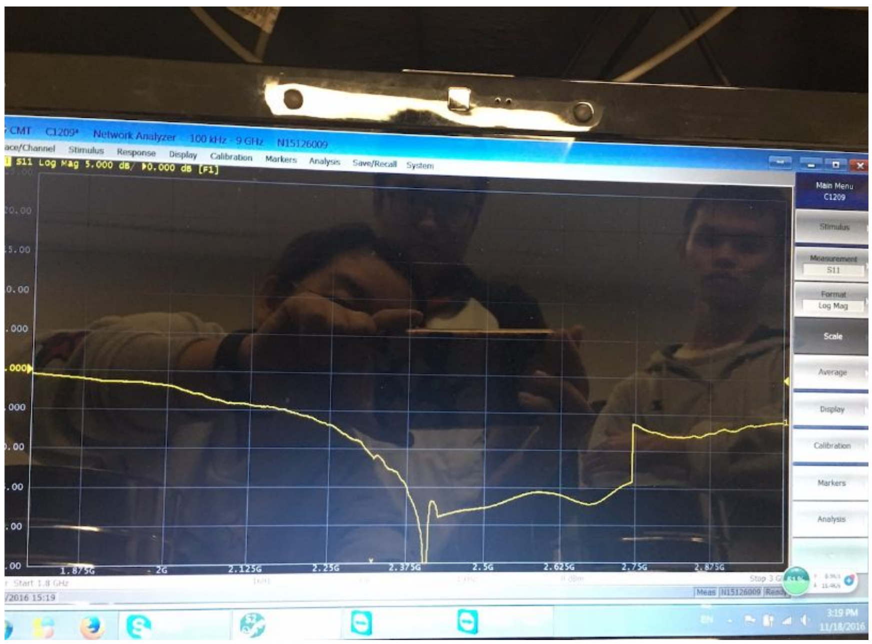


Fig 16. S11 result for can antenna

- ***Testing***

During this quarter, we have made several testings. In general, there were three testing phases for our project. Through all the testing procedures, we have modified our radar system for several times. We also modified some major components and tried several different forms of the components. We finalized our radar system in Phase 3.

1. Phase 1

Before we got our PCB back, we started the first testing phase with breadboard circuits and metal box RF components. In the first phase of testing, we built a radar system that is similar to the one we built in fall quarter. We modified the system a little bit. We rearranged the circuit for baseband on one breadboard. We tried our best to keep the legs for resistors and capacitors shorter and made each part of the circuit close enough to each other. The baseband circuit became simpler and clearer. This also helped decrease the power loss in the circuit and make the circuit more accurate. We also took off the attenuator and added one more LNA at the receiving end. We replaced both can antennas with two patch antennas.

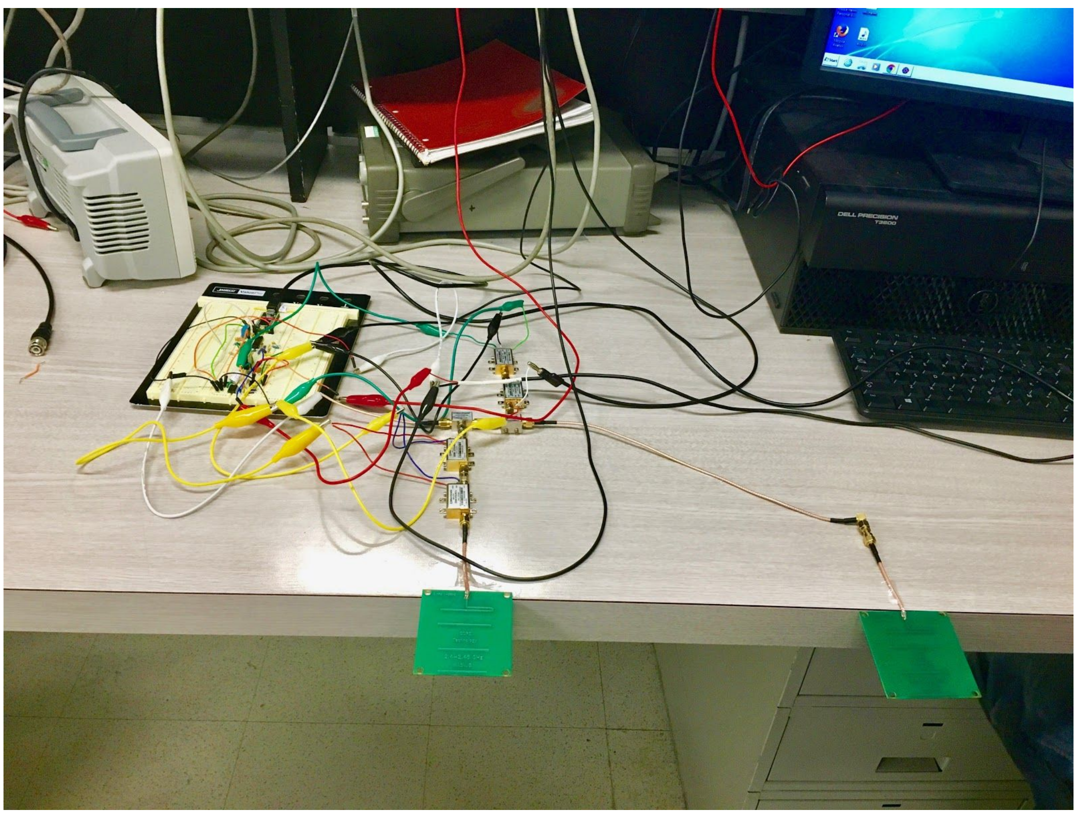


Fig 17. Phase 1 Radar System

We used the software Audacity in the computer in our lab room to test the whole system as instructed in lab 6 from fall quarter. Then we used the python code given in fall quarter to analyzed the audio data we collected.

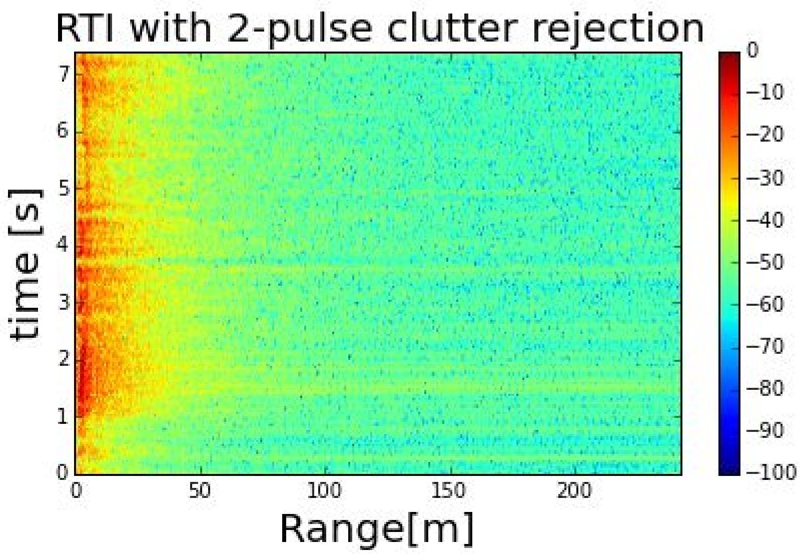


Fig 18. Phase 1 test result

Fig 18 shows the plot generated by the python code. The plot was not clear enough to tell the position of the objects. Since there were so many objects in the lab room, too much reflections from those objects could be a possible reason that resulted the plot we got. It was also possible that the signal that received by the receiving antenna was too weak. We made modifications and improvements to our radar system in the second testing phase.

2. Phase 2

When we received our PCBs, we started built the radar system with our PCBs. We replaced all the three LNAs with PCBs, but then a problem happend with the circuit. When we turned on the power supply, the power supply showed that there was overload happening in the circuit. But when we disconnected the LNAs from the circuit, there were no overloading happening. We thought the LNA PCBs may have too much gain.

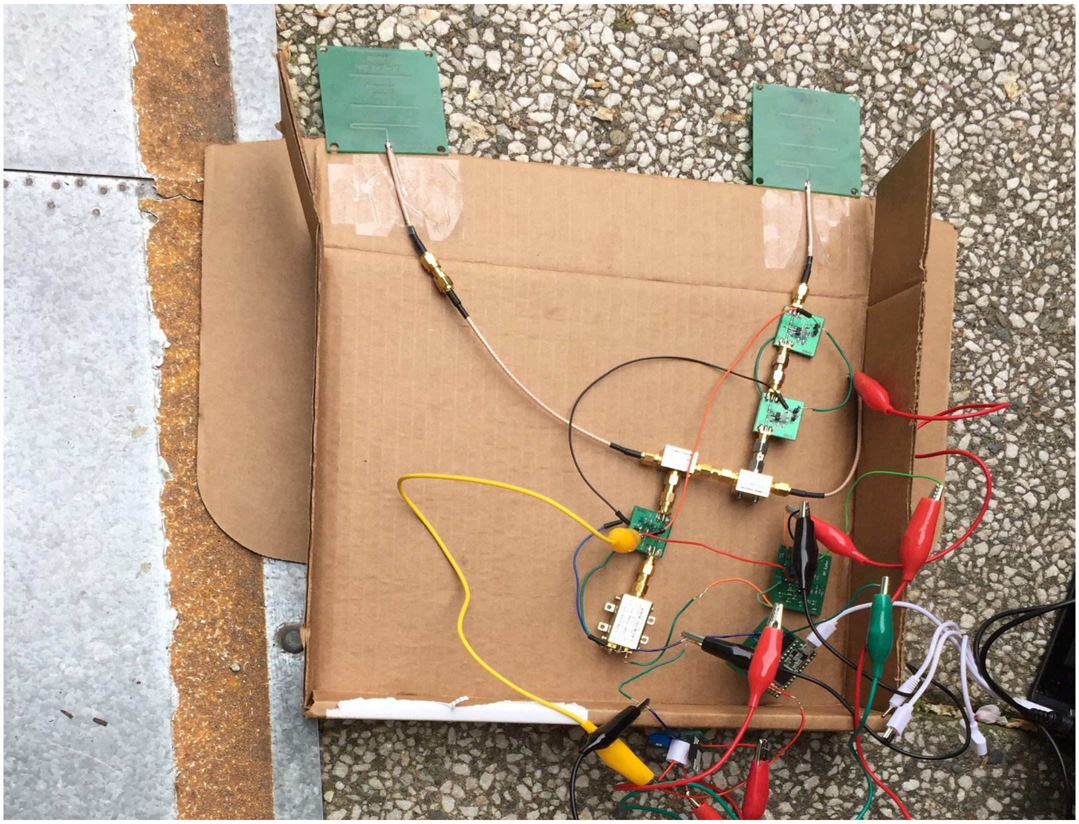


Fig 19. Phase 2 system with LNAs in PCB

Then we modified the system and replaced two of the LNAs with metal box circuits. The overloading problem was solved. We also replaced the transmitting antenna with can antenna, because we found out that the can antenna has more gain than the patch antenna due to our measurement. We performed test again. We first tested inside the lab room and got the following result.

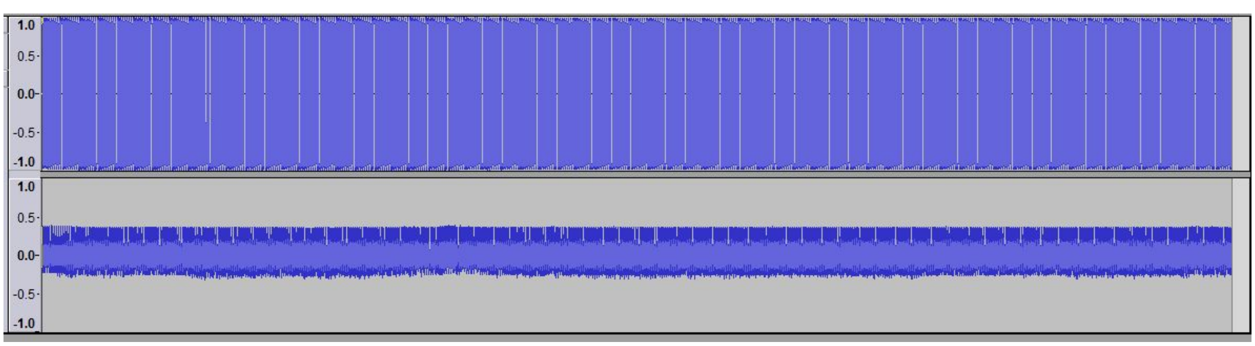


Fig 20. In-room test audio file

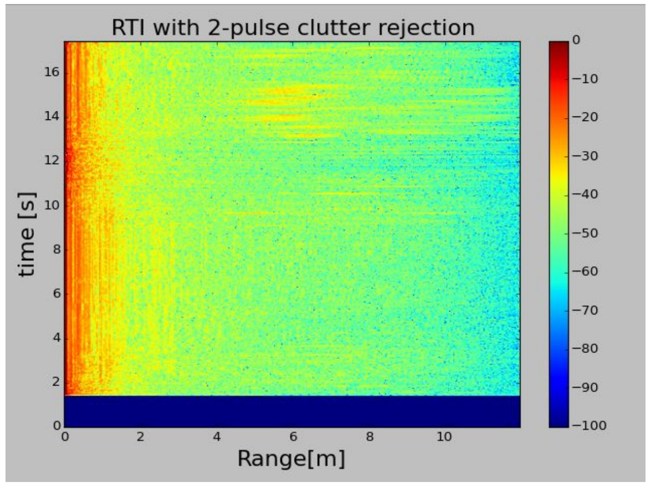


Fig 21. Phase 2 system in-room test result

However, we found out that the resulting plot generated by the python code was still not too clear. By taking a detailed look with the audio file, we discovered that the audio plot was constant, which suggested that the radar system did not work properly. Suggested by TA and Professor Liu, we decided to check the transmitting side and receiving side of our system separately. We tested our PCBs again but found no problems. Then we performed the labs from last quarter again to test each RF components but found no problems. Finally we decided to ask one of the TAs, Daniel, for help. With the help from Daniel, we found out that there was some problem with the PCBs we designed for low-noise amplifier. The LNA took in too much signal instead only one desired signal. Thus, we had to use the metal box circuits for all the LNAs in our radar system. This became the final version of our system.

3. Phase 3

In the third phase of testing, we finalized our radar system.

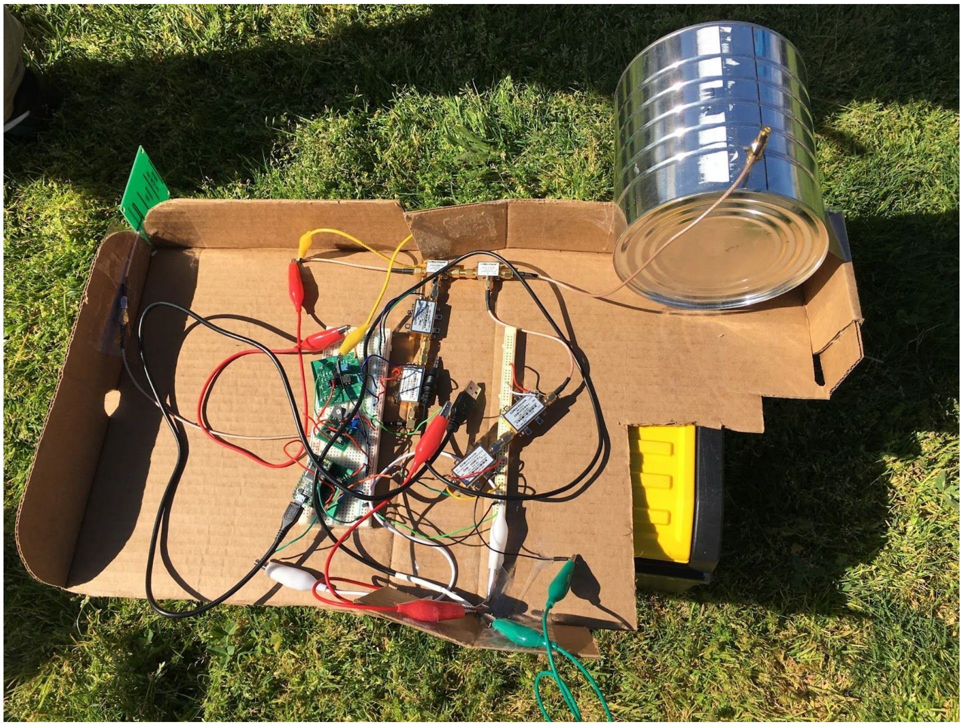


Fig 22. Final Radar System

We first tested the system in the lab room. We got a very clear plot this time. As shown in the following plot, we could see a clear path shown one of our group member walking away from the radar and then walked back.

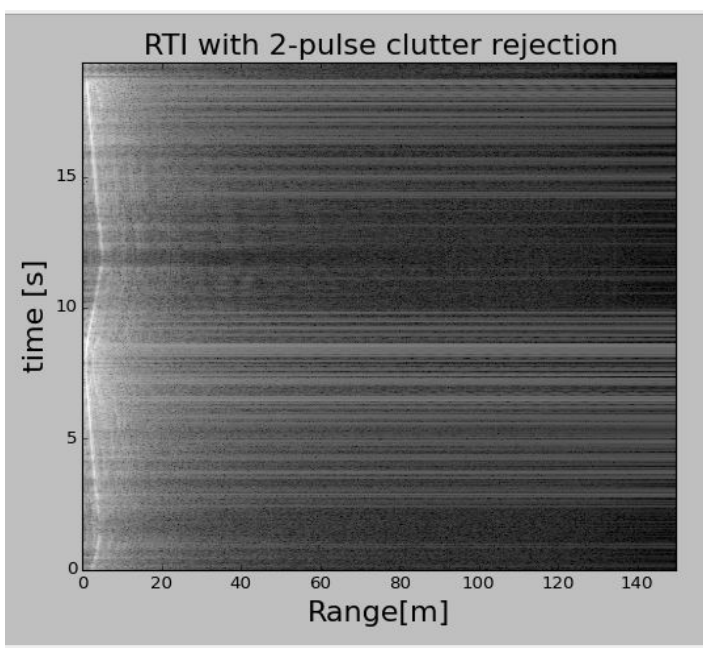


Fig 23. Final Radar System In-room Testing Result

In the final test competition, we used this final radar system and got the following results for each test.

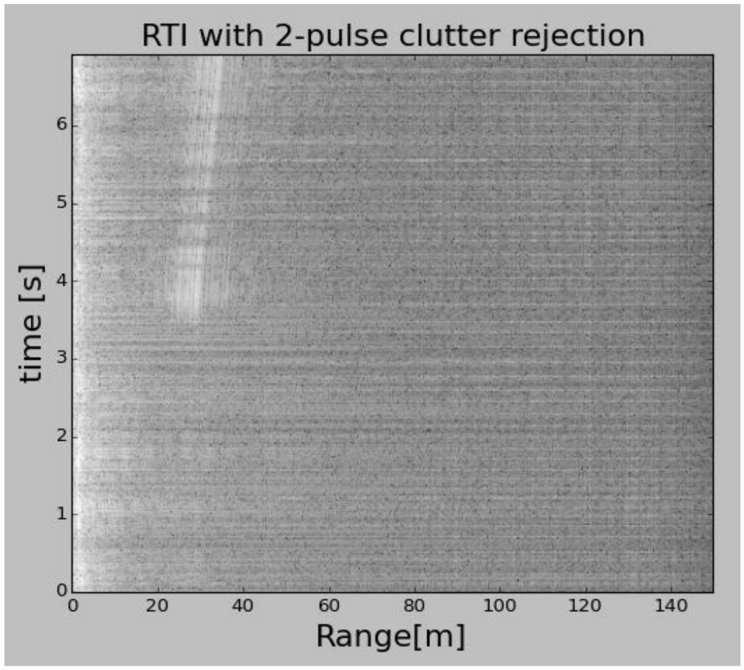


Fig 24. Final Test 1

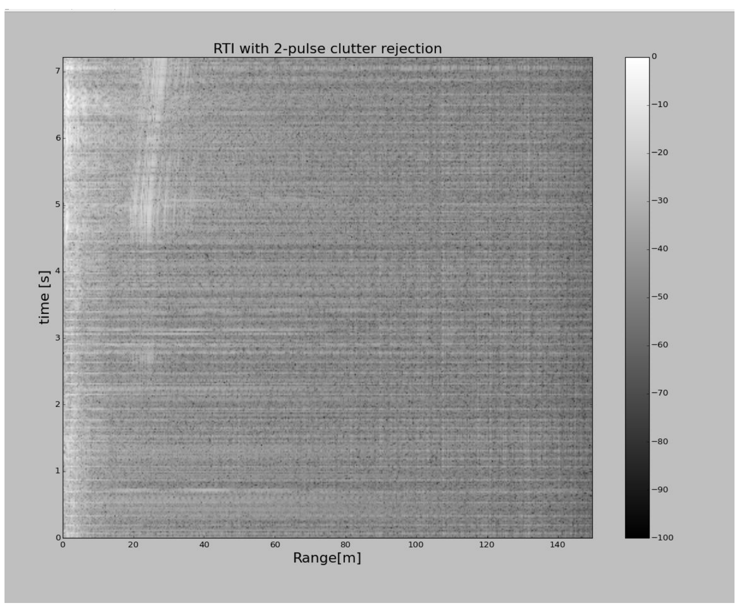


Fig 25. Final Test 2

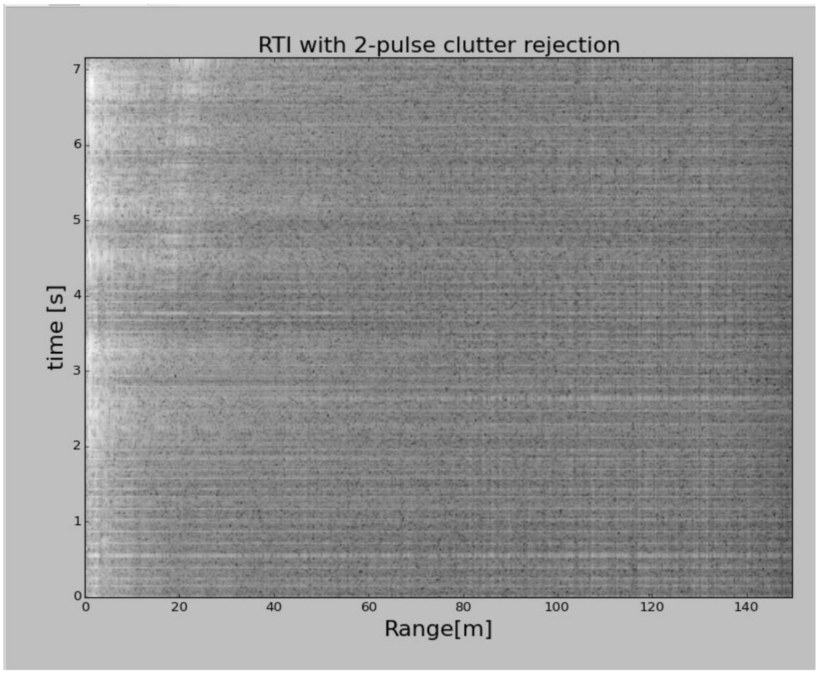


Fig 26. Final Test 3

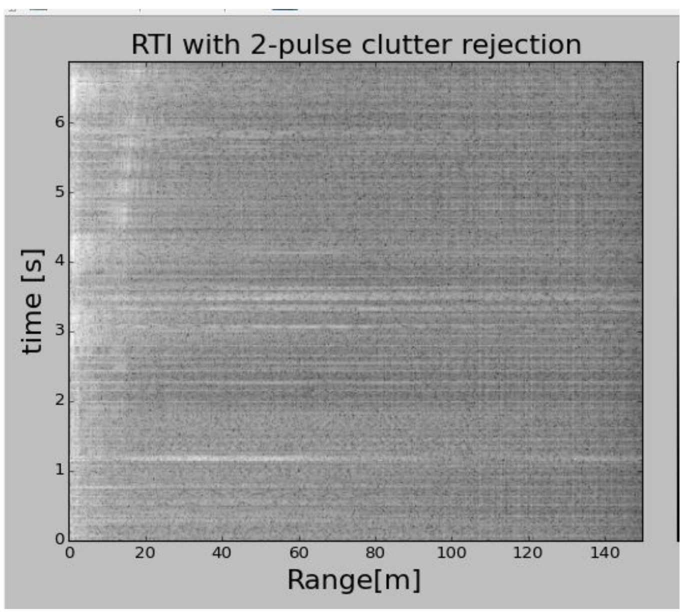


Fig 27. Final Test 4

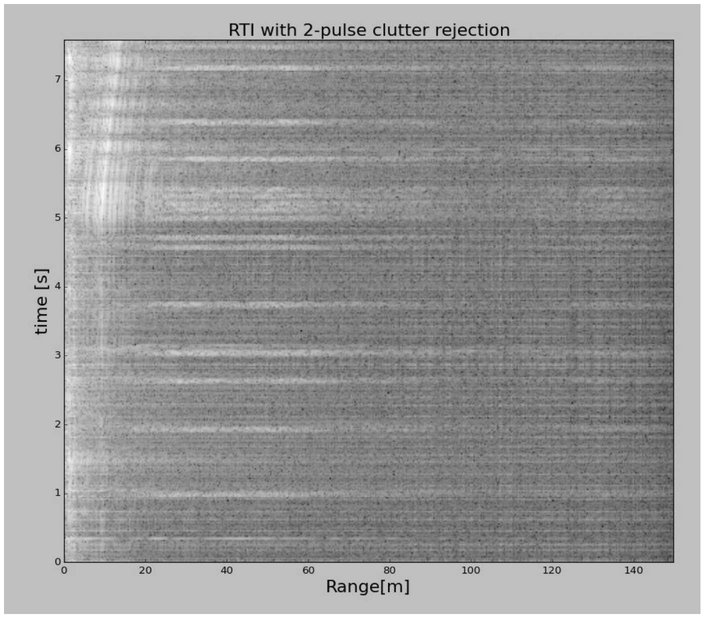


Fig 28. Final Test 5

As shown in the all five figures above, our radar system can detect the metal plate as far as 50 meters. From all those five figures, we can clearly know that TA were walking from nearly 50m toward to us. The results we got are showing in the below figure.

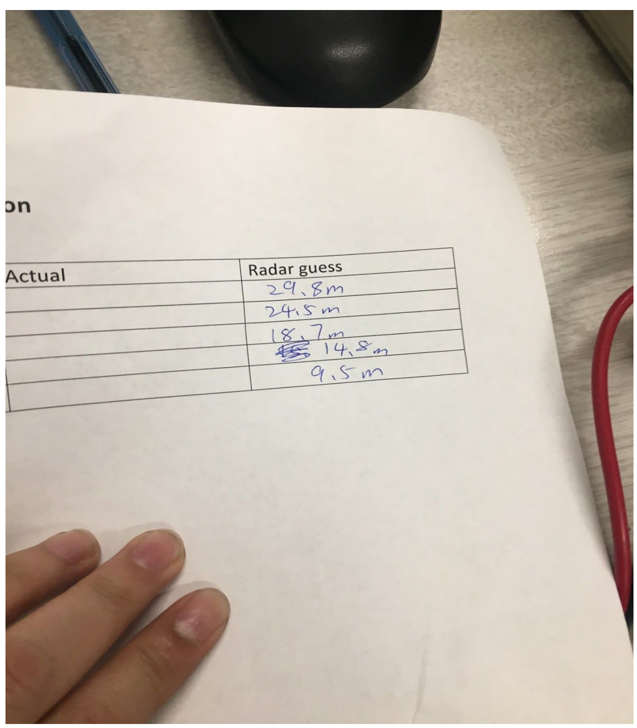


Fig 29. Final Test Guessing Results

Bill of material

Components	Price
1 × 8-DIP MCP4921 DAC IC	\$2.54
1 × LT1009 precision reference IC	\$1.05
1 × 14-DIP TL974IN quad Op-Amp IC	\$0.98
1 × Mini-Circuits ZX60-272LN-S+ RF amplifier	\$39.95
2 x PCB	Free
2 x PCB	\$30 each
2 x Antenna	\$5.99 each
TOTAL	\$116.5

Weight

The weight of our whole radar system is about 800 g.

Conclusions

We have made a rough comparison between the final test guessing results and the real results recorded by the TA. For first three tests, which were further, the errors were all about 10 meters. However, for the last two tests, which were close, the errors were much smaller.

The results suggested that our radar system worked but have large errors when measuring objects from further distance. The possible reason could be caused by big power loss for signal traveling in long distance. There is still a large space to improve our system.

During the two quarters, we have learned a lot about radar system design according to this senior design projects. It was a great experience taking this designing course. We all believed that this experience will be very helpful for our career in the future.

Appendix

- ***Datasheet***

a) VCO: ZX95-2536C+

• TD-SCDMA / HSDPA

Electrical Specifications

MODEL NO.	FREQ. (MHz)		POWER OUTPUT (dBm)	PHASE NOISE dBc/Hz SSB at offset frequencies,kHz Typ.				TUNING VOLTAGE RANGE (V)		TUNING SENSI-TIVITY (MHz/V)	TUNING PORT CAP (pF)	TUNING 3 dB MODULATION BANDWIDTH (MHz)	NON HARMONIC SPURIOUS (dBc)	HARMONICS (dBc)		PULLING pk-pk @12 dBr (MHz)	PUSHING (MHz/V)	DC OPERATING POWER Vcc (volts)	DC OPERATING POWER Current (mA)
	Min.	Max.	Typ.	1	10	100	1000	Min.	Max.	Typ.	Typ.	Typ.	Typ.	Typ.	Max.	Typ.	Typ.		Max.
ZX95-2536C+	2315	2536	+6	-75	-105	-128	-148	0.5	5	57-77	13.6	70	-90	-18	-10	2.5	2.5	5	45

Maximum Ratings

Operating Temperature	-55°C to 85°C
Storage Temperature	-55°C to 100°C
Absolute Max. Supply Voltage (Vcc)	5.6V
Absolute Max. Tuning Voltage (Vtune)	7.0V
All specifications	50 ohm system

Permanent damage may occur if any of these limits are exceeded.

NOTE: When soldering the DC connections, caution must be used to avoid overheating the DC terminals. See Application Note AN-40-10 .

Outline Drawing

b) Power splitter ZX10-2-42+

Electrical Specifications (T_{AMB}=25°C)

FREQ. RANGE (MHz)	ISOLATION (dB)		INSERTION LOSS (dB) ABOVE 3.0 dB		PHASE UNBALANCE (Degrees)	AMPLITUDE UNBALANCE (dB)
f_L-f_U	Typ.	Min	Typ.	Max.	Max.	Max.
1900-4200	**23**	**10**	**0.2**	**1.2**	**5.0**	**0.3**
2600-3400	23	17	0.2	0.6	4.0	0.3

Typical Performance Data

Frequency (MHz)	Total Loss[1] (dB) S-1	Total Loss[1] (dB) S-2	Amplitude Unbalance (dB)	Isolation (dB)	Phase Unbalance (deg.)	VSWR S	VSWR 1	VSWR 2
1900.00	3.45	3.45	0.00	12.33	0.70	1.79	1.08	1.07
2040.00	3.42	3.44	0.02	13.42	0.71	1.71	1.09	1.08
2180.00	3.37	3.36	0.01	14.64	0.74	1.62	1.10	1.09
2460.00	3.26	3.26	0.01	17.92	0.91	1.47	1.09	1.08
2600.00	3.19	3.19	0.00	20.16	1.05	1.39	1.08	1.08
2760.00	3.19	3.18	0.01	23.66	1.02	1.26	1.05	1.05
2920.00	3.10	3.12	0.02	27.75	1.18	1.14	1.02	1.03
3240.00	3.11	3.11	0.00	23.53	1.50	1.07	1.03	1.02
3400.00	3.13	3.16	0.03	20.10	1.54	1.19	1.05	1.10
3540.00	3.23	3.27	0.04	17.91	1.30	1.31	1.07	1.05
3680.00	3.26	3.29	0.03	16.12	1.55	1.40	1.07	1.06
3820.00	3.31	3.36	0.05	14.58	1.52	1.51	1.09	1.08
4100.00	3.48	3.52	0.03	12.21	1.48	1.78	1.15	1.15
4150.00	3.54	3.58	0.04	11.90	1.37	1.83	1.16	1.16
4200.00	3.52	3.55	0.03	11.51	1.50	1.87	1.17	1.18

1. Total Loss = Insertion Loss + 3dB splitter loss.

c) Mixer ZX05-43LH-S+ :

Frequency Mixer WIDE BAND

ZX05-43LH+

Level 10 (LO Power +10 dBm) 824 to 4200 MHz

CASE STYLE: FL905

Connectors	Model
SMA	ZX05-43LH-S+

+RoHS Compliant
The +Suffix identifies RoHS Compliance. See our web site for RoHS Compliance methodologies and qualifications

Maximum Ratings

Operating Temperature	-40°C to 85°C
Storage Temperature	-55°C to 100°C
RF Power	50mW

Permanent damage may occur if any of these limits are exceeded.

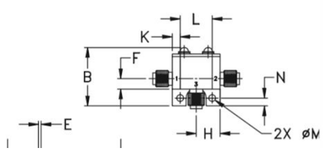
Coaxial Connections

LO	2
RF	3
IF	1

Features
- wide bandwidth, 824 to 4200 MHz
- low conversion loss, 6.1 dB typ.
- excellent L-R isolation, 35 dB typ.
- rugged construction
- small size
- useable as up and down converter
- protected by US patents, 6,790,049 and 7,027,795

Applications
- cellular
- defense and weather radar
- defense communications
- PCN
- WCDMA
- WIFI
- blue tooth
- VSAT
- ISM

Outline Drawing



Electrical Specifications

FREQUENCY (MHz) LO/RF f_L-f_U	IF	CONVERSION LOSS* (dB) Typ.	σ	Max.	LO-RF ISOLATION (dB) Typ.	Min.	LO-IF ISOLATION (dB) Typ.	Min.	IP3 (dBm) Typ.
824-4200	**DC-1500**								
824-2500		6.3	0.1	8.1	35	28	24	7	15
2500-4200		5.7	0.1	8.8	28	23	20	11	14

1 dB COMPR.: +5 dBm typ.
* Conversion loss at 30 MHz IF. σ is a measure of repeatability from unit to unit.

Python code for analyzing the results:

```
# -*- coding: utf-8 -*-
#range radar, reading files from a WAV file
# Originially modified by Meng Wei, a summer exchange student (UCD GREAT Program, 2014)
from Zhejiang University, China, from Greg Charvat's matlab code
# Nov. 17th, 2015, modified by Xiaoguang "Leo" Liu, lxgliu@ucdavis.edu

import wave
import os
from struct import unpack
import numpy as np
from numpy.fft import ifft
import matplotlib.pyplot as plt
from math import log

#constants
c= 3E8 #(m/s) speed of light
Tp = 20E-3  #(s) pulse duration T/2, single frequency sweep period.
fstart = 2315E6 #(Hz) LFM start frequency
```

```
fstop = 2536E6 #(Hz) LFM stop frequency
BW = fstop-fstart #(Hz) transmit bandwidth
trnc_time = 0 #number of seconds to discard at the begining of the wav file


window = False  #whether to apply a Hammng window.

# for debugging purposes
# log file
#logfile = 'log_new.txt'
#logfh = open(logfile,'w')
#logfh.write('start \n')

#read the raw data .wave file here
#get path to the .wav file
#filename = os.getcwd() + '\\running_outside_20ms.wav'
filename = os.getcwd() + '\\mar23-7.wav'     # The initial 1/6 of the above wav file. To save time
in developing the code
#open .wav file
wavefile = wave.open(filename, "rb")

# number of channels
nchannels = wavefile.getnchannels()

# number of bits per sample
sample_width = wavefile.getsampwidth()

# sampling rate
Fs = wavefile.getframerate()
trnc_smp = int(trnc_time*Fs) # number of samples to discard at the begining of the wav file

# number of samples per pulse
N = int(Tp*Fs)  # number of samples per pulse

# number of frames (total samples)
numframes = wavefile.getnframes()

# trig stores the sampled SYNC signal in the .wav file
#trig = np.zeros([rows,N])
trig = np.zeros([numframes - trnc_smp])
# s stores the sampled radar return signal in the .wav file
#s = np.zeros([rows,N])
s = np.zeros([numframes - trnc_smp])
```

```
# v stores ifft(s)
#v = np.zeros([rows,N])
v = np.zeros([numframes - trnc_smp])

#read data from wav file

data = wavefile.readframes(numframes)

for j in range(trnc_smp,numframes):
   # get the left (SYNC) channel
   left = data[4*j:4*j+2]
   # get the right (Data) channel
   right = data[4*j+2:4*j+4]
   #.wav file store the sound level information in signed 16-bit integers stored in little-endian
format
   #The "struct" module provides functions to convert such information to python native formats,
in this case, integers.

   if len(left) == 2:
      l = unpack('h', left)[0]
   if len(right) == 2:
          r = unpack('h', right)[0]
      #normalize the value to 1 and store them in a two dimensional array "s"
   trig[j-trnc_smp] = l/32768.0
   s[j-trnc_smp] = r/32768.0

#trigger at the rising edge of the SYNC signal
trig[trig < 0] = 0;
trig[trig > 0] = 1;

#2D array for coherent processing
s2 = np.zeros([int(len(s)/N),N])

rows = 0;
for j in range(10, len(trig)):
   if trig[j] == 1 and np.mean(trig[j-10:j]) == 0:
      if j+N <= len(trig):
         s2[rows,:] = s[j:j+N]
         rows += 1

s2 = s2[0:rows,:]

#pulse-to-pulse averaging to eliminate system performance drift overtime
```

```
for i in range(N):
    s2[:,i] = s2[:,i] - np.mean(s2[:,i])

#2pulse cancelation

s3 = s2
for i in range(0, rows-1):
    s3[i,:] = s2[i+1,:] - s2[i,:]

rows = rows-1
s3 = s3[0:rows,:]

#apply a Hamming window to reduce fft sidelobes if window=True
if window == True:
    for i in range(rows):
        s3[i]=np.multiply(s3[i],np.hamming(N))

######################################
# Range-Time-Intensity (RTI) plot
# inverse FFT. By default the ifft operates on the row
v = ifft(s3)

#get magnitude
v = 20*np.log10(np.absolute(v)+1e-12)

#only the first half in each row contains unique information
v = v[:,0:int(N/2)]

#normalized with respect to its maximum value so that maximum is 0dB
m=np.max(v)
grid = v
grid=[[x-m for x in y] for y in v]

# maximum range
max_range =c*Fs*Tp/8/BW
# maximum time
max_time = Tp*rows

plt.figure(0)
plt.imshow(grid, extent=[0,max_range,0,max_time],aspect='auto', cmap =plt.get_cmap('gray'))
plt.colorbar()
plt.clim(0,-100)
plt.xlabel('Range[m]',{'fontsize':20})
```

```
plt.ylabel('time [s]',{'fontsize':20})
plt.title('RTI with 2-pulse clutter rejection',{'fontsize':20})
plt.tight_layout()
plt.show()

#plt.subplot(612)
#plt.plot(grid[5])

#plt.subplot(613)
#plt.plot(grid[6])

#plt.subplot(614)
#plt.plot(grid[20])
#
#plt.subplot(615)
#plt.plot(grid[30])

#plt.subplot(616)
#plt.plot(grid[40])
```