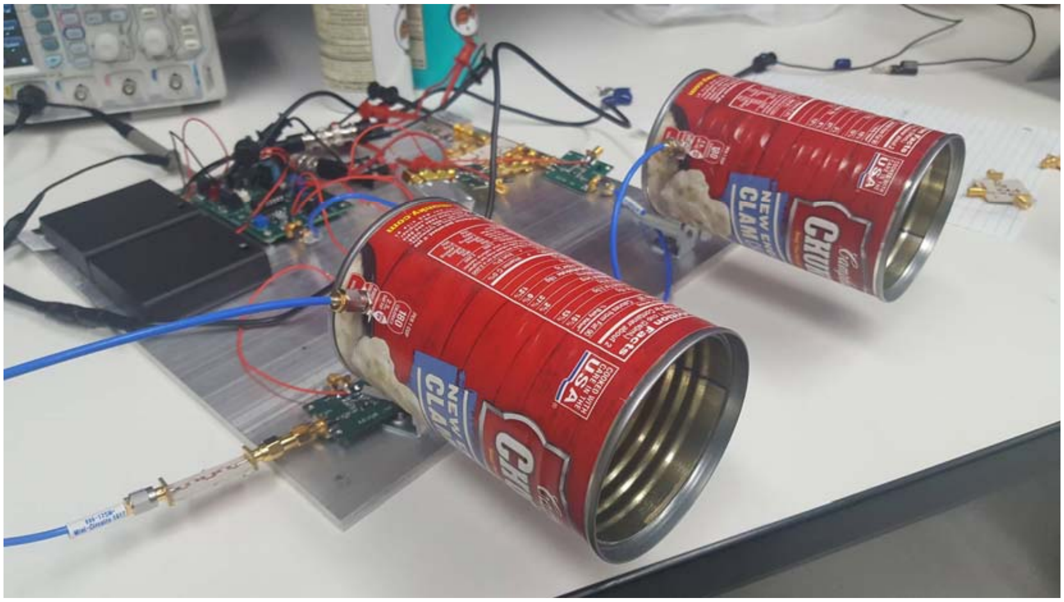
5.9 GHz Radar with homemade antennas

(EE150 - Topics in Electrical Engineering: High Frequency Labroatory)



Sung Hoon Choi, Victor Han

California Institute of Technology

Final Report

RADAR Project

Sunghoon Choi

Abstract

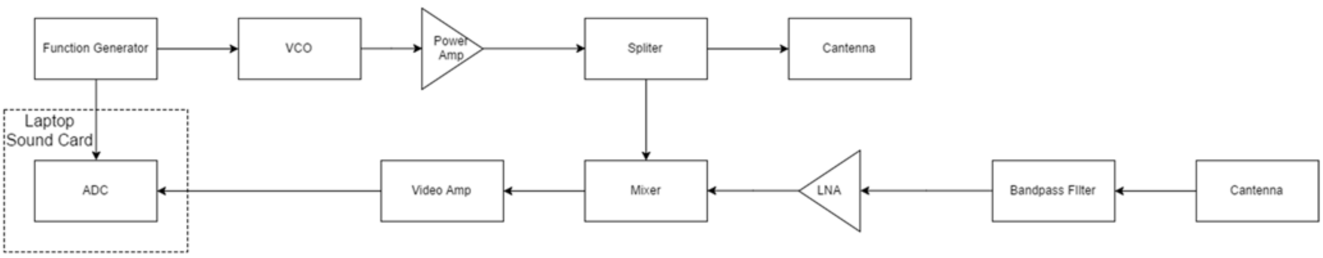
This report describes the design, implementation, performance, and analysis of our RADAR.

Introduction

Our radar uses the Doppler shift of electromagnetic wave to measure the velocities of objects in front of the radar. It uses two cantennas as the transceiver and receiver antennas. The sizes of cantennas were determined to maximize the gain at 5.9GHz while preventing the bandwidth from reaching 2.4GHz ISM(Industrial, Scientific, Medical) band. We used a band pass filter at the receiver to get rid of interfering frequencies. The entire RADAR consists of Low-Noise Amplifiers, a video amp, an oscillator(VCO), a Wilkinson power divider, a mixer, and a bandpass filter.

Design description and strategy

-Block Diagram of the RADAR system

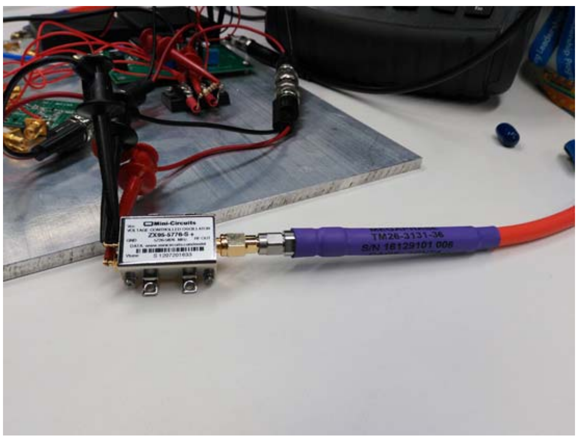


The RADAR generates the signal by using the VCO. After splitting the signal into two by using the Wilkinson power divider, it amplifies the signal and transmits it through the transceiver cantenna. When the receiver cantenna receives a signal, the signal goes through a band pass filter. We can remove interfering frequencies by this step. The signal which has passed the band-pass filter gets amplified by a series of power amplifiers. Then, the transmitted signal and received signal go through the mixer. The transmitted signal goes to LO input while the received signal goes to RF input. Finally, the IF output signal gets amplified by a video amp and is transmitted to our laptop for Doppler processing.

We decided to use a commercial oscillator for VCO since tuning its frequency range is difficult. For the power splitter, we used the Wilkinson Power divider. It was designed to split the power into two as accurately as possible. For LNAs, we used the design that we made in lab3. It was designed to minimize the noise while amplifying the power at 5.9GHz. For the mixer, we used the mixer that we designed in lab4. The mixer's design was aimed for maximizing the RF and LO isolation. We used the video amp which our instructor designed. For the bandpass filter, we had to fabricate a new one since our old bandpass filter's center frequency was about 6.9GHz. The new fabricated band pass filter's center frequency was around 5.9Hz. For the cantennas, we used two Chunky™ cans to make transceiver and receiver and tried to prevent them from walking into ISM band. For performance trades, we found a trade-off between the gain and noise temperature of LNAs. However, we rather decided to maximize the gain since the received signals were very weak. Also, there was a trade-off of performance for cantennas. When the size of cantennas got bigger, the gain of cantennas increased. However, it increased the bandwidth as well and caused the dange or having 2.4GHz ISM band within the bandwidth. We found a compromise point and decided that the size of Chunky™ cans would be optimal for this project.

Circuit Fabrication Details

1. VCO



We used a commercial oscillator.

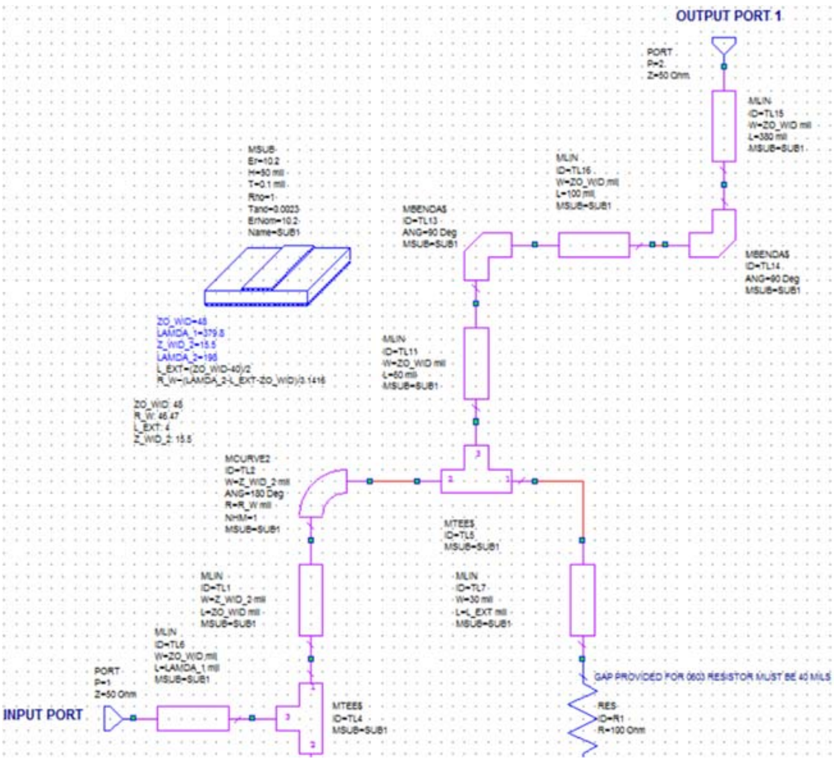
Its performance will be described in the next section.

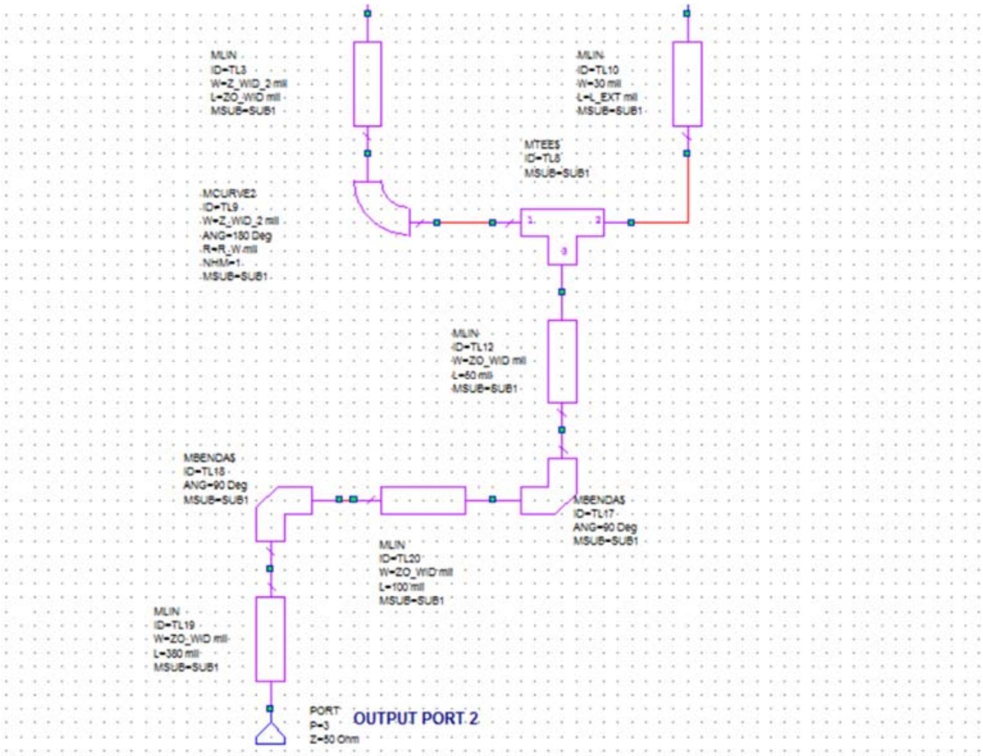
2. Wilkinson Power divider

Wilkinson Power Divider was designed to output two -3dB outputs.

We used the same Wilkinson Power Divider that we fabricated in lab2.

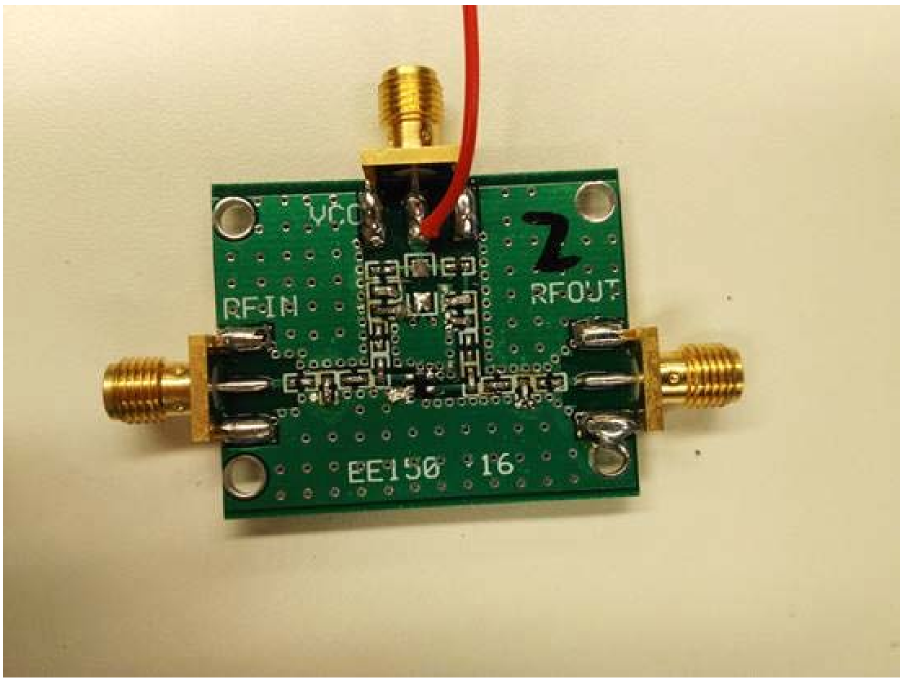
Its performance will be described in the next section.





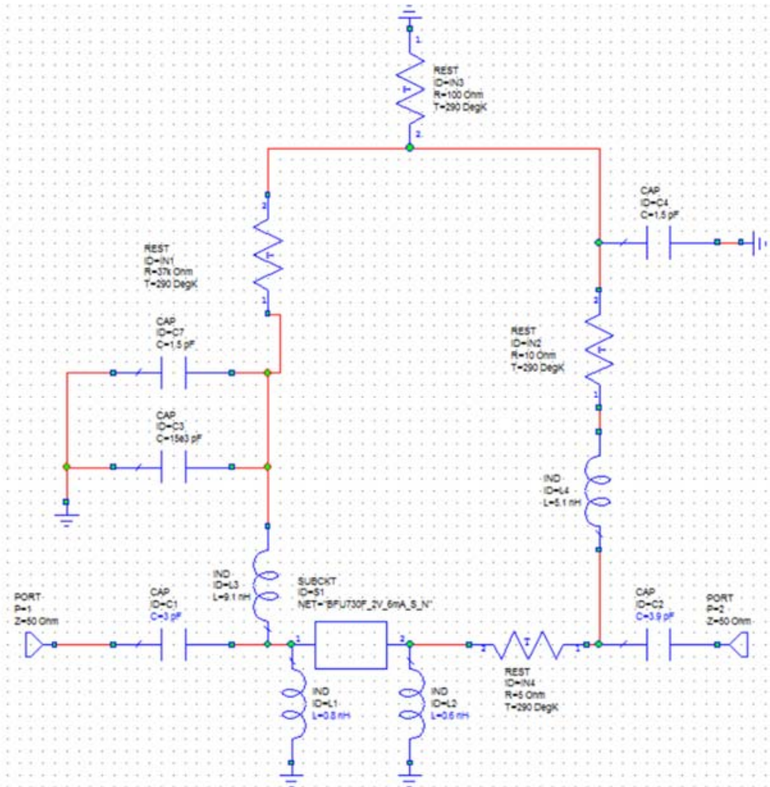
(Schematic of the fabricated Wilkinson Power divider)

3. LNA



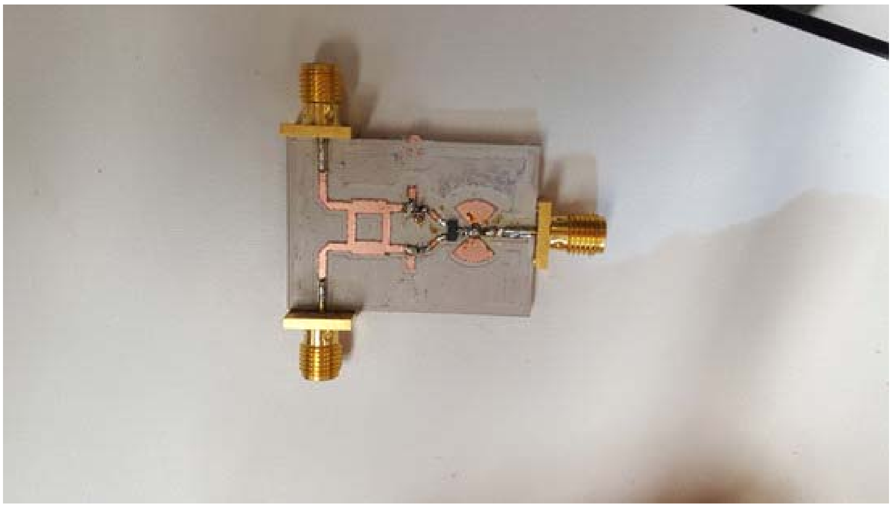
We used the same LNA design made in lab 3 and fabricated five LNAs for the RADAR.

Its performance will be described in the next section.



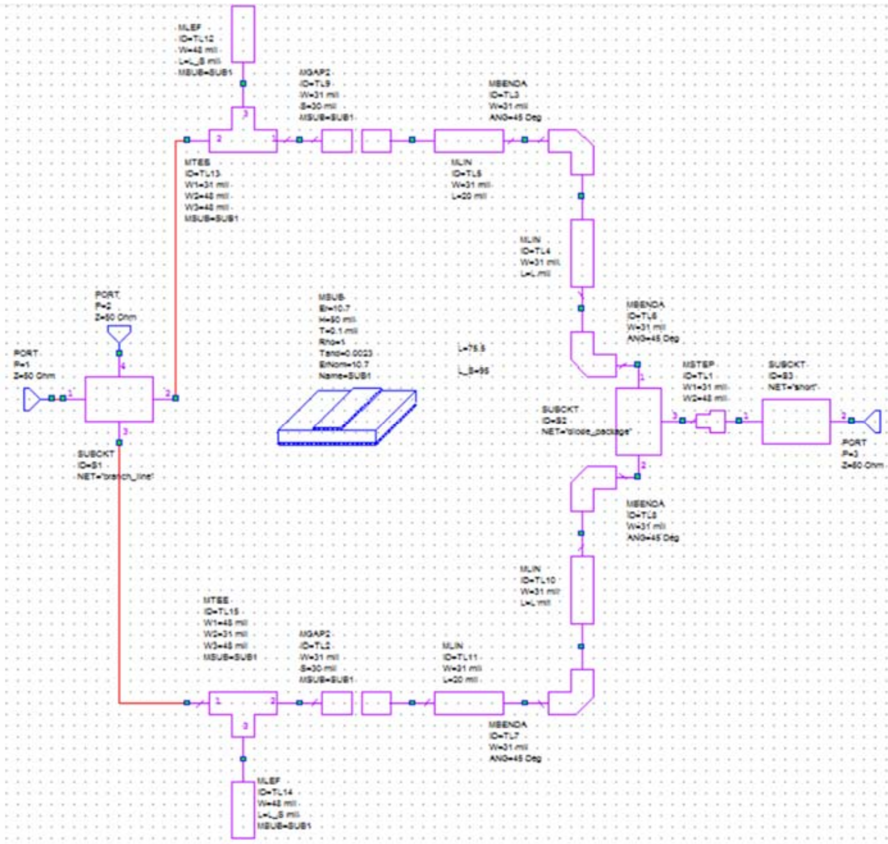
(Schematic of the fabricated LNA)

4. Mixer



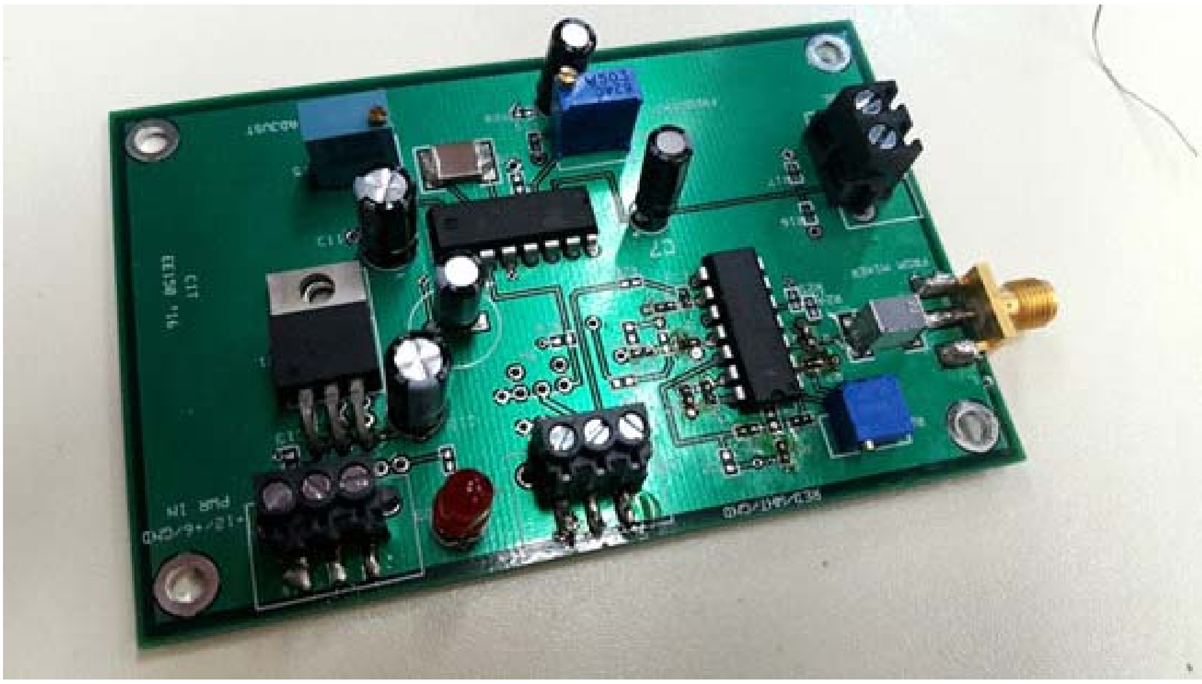
We used the same Mixer that we fabricated in lab 4.

Its performance will be described in the next section.



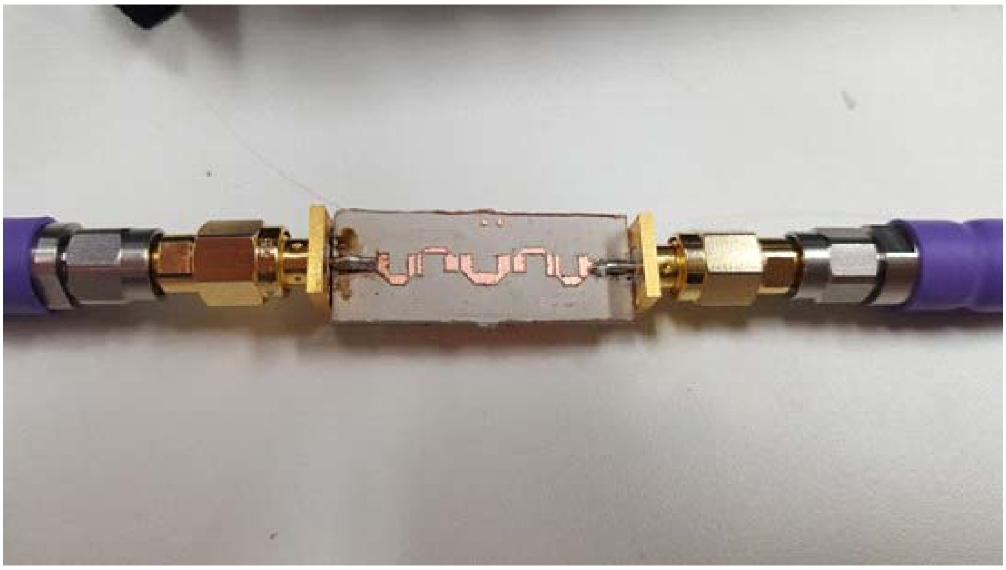
(Schematic of the fabricated Mixer)

5. Video Amp



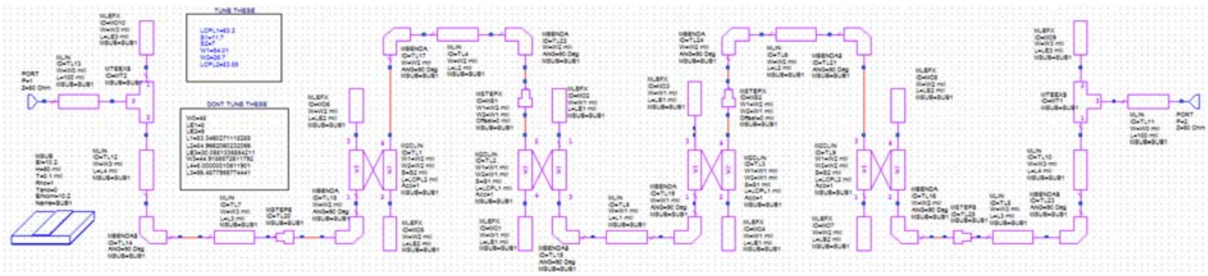
We assembled the video amp designed by the instructor.

6. Band Pass Filter



For the bandpass filter, we had to fabricate a new one since our bandpass filter in lab3 didn't work well.

Its performance will be described in the next section.

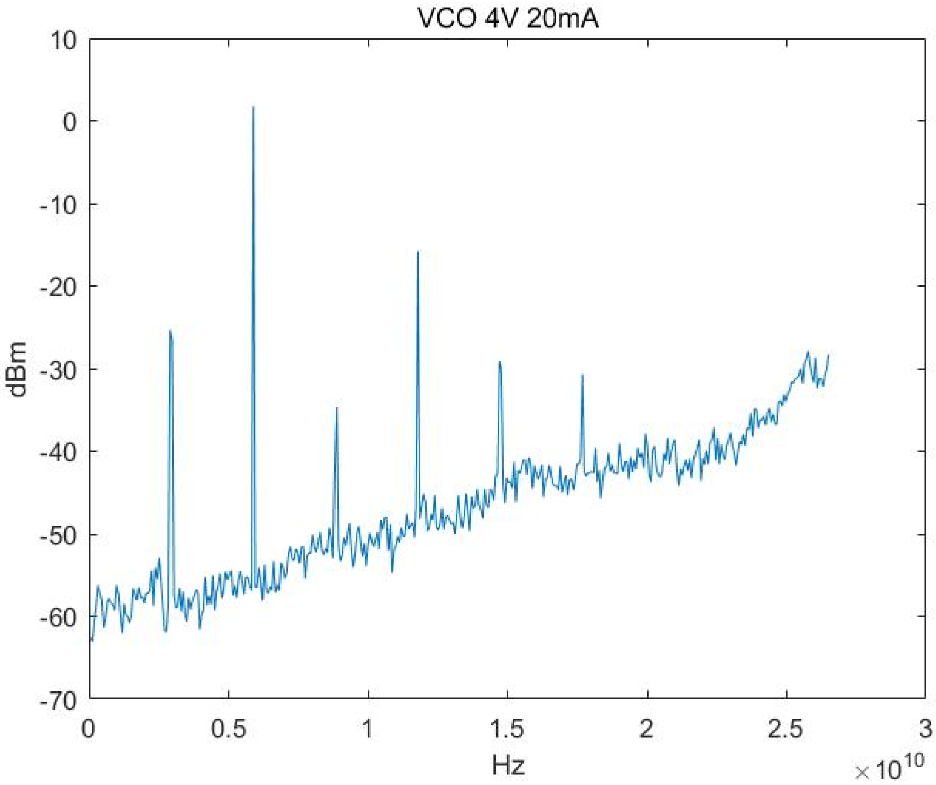


(Schematic for the fabricated Band Pass Filter)

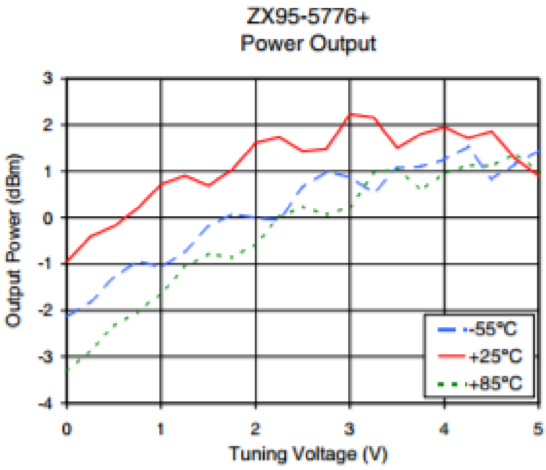
Sub-component performances

1. VCO

We used a commercial VCO. Below is the measured performance.



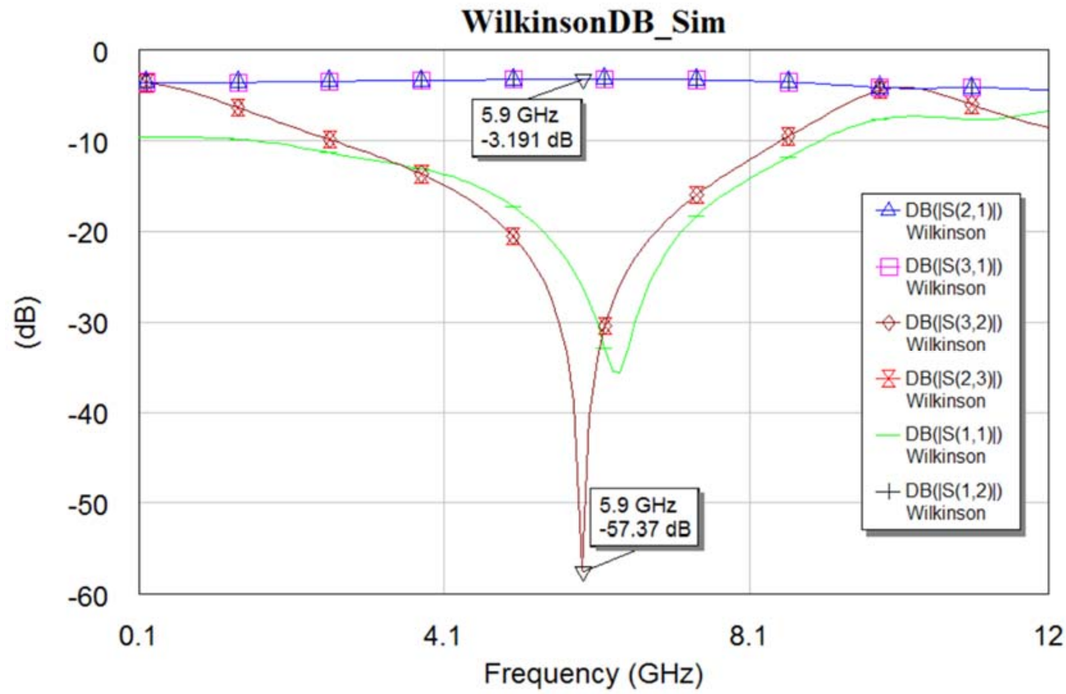
Below is the power output graph from ZX95-5776+ mini circuit datasheet.

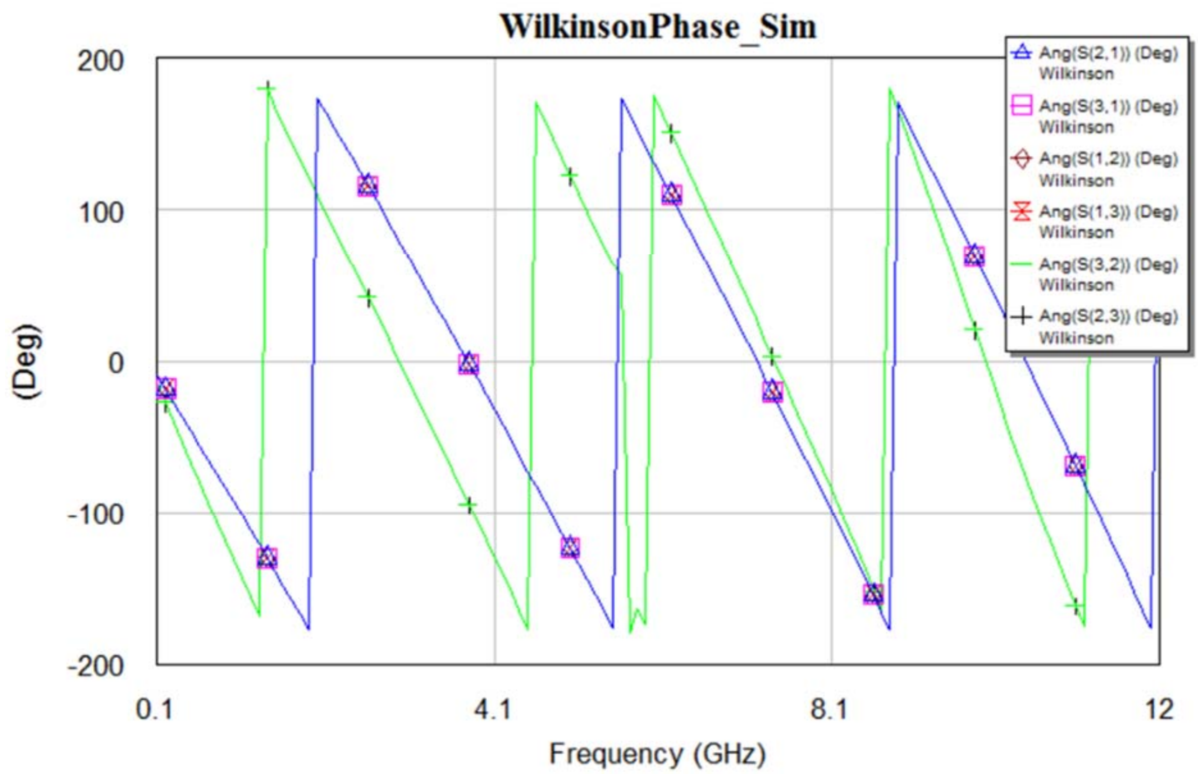


Although the datasheet"s graph does not contain frequency information, the measured performance matched the datasheet roughly.

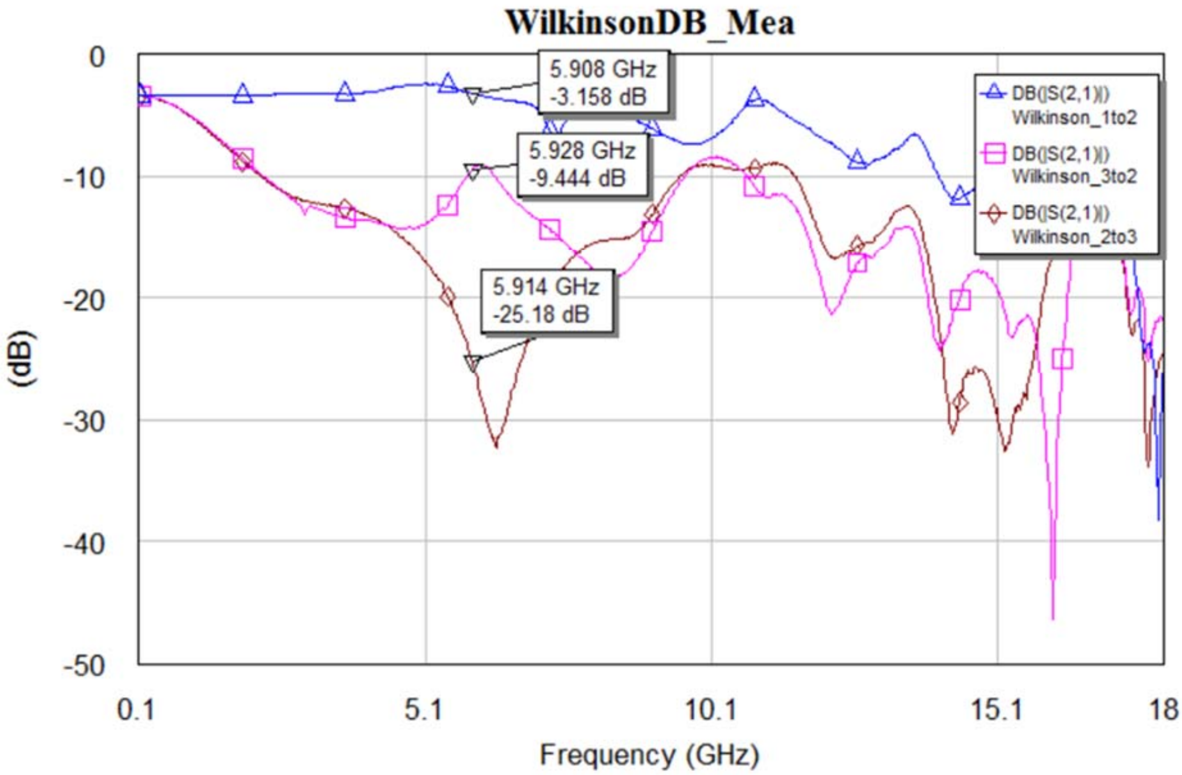
2. Wilkinson Power divider

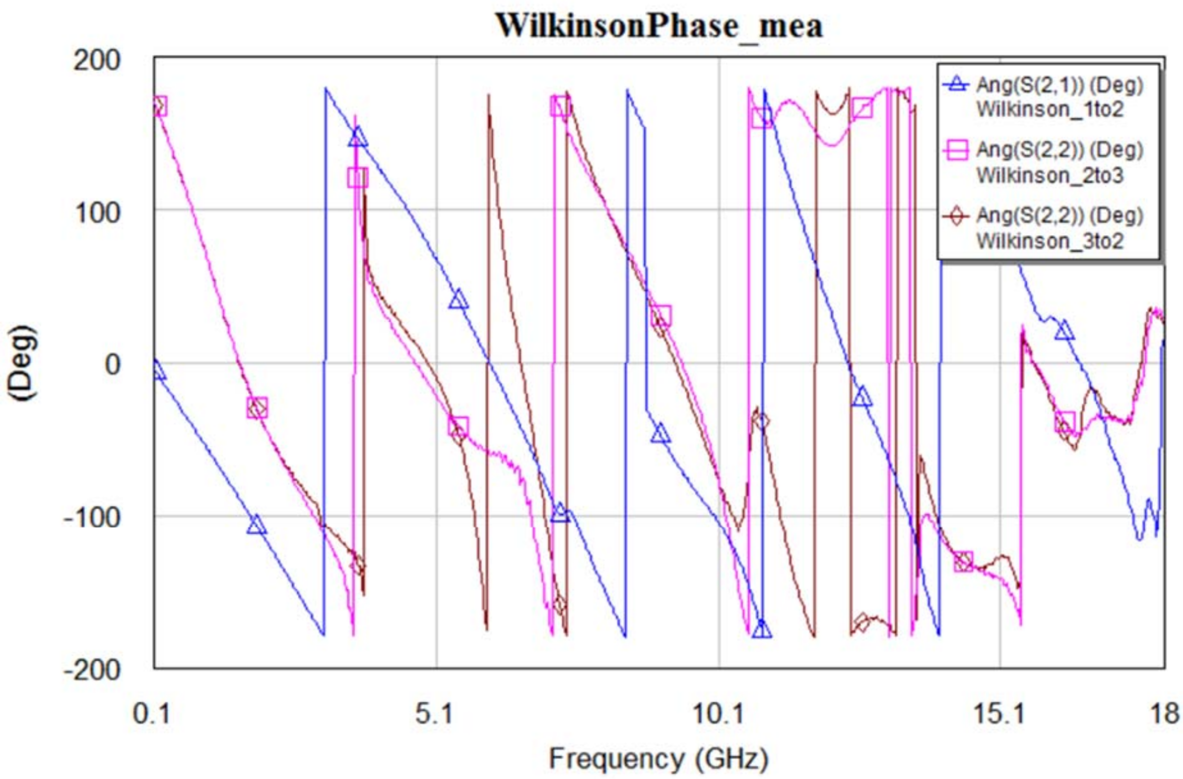
i. Simulation:


WilkinsonDB_Sim
5.9 GHz
-3.191 dB
5.9 GHz
-57.37 dB
DB(|S(2,1)|)
Wilkinson
DB(|S(3,1)|)
Wilkinson
DB(|S(3,2)|)
Wilkinson
DB(|S(2,3)|)
Wilkinson
DB(|S(1,1)|)
Wilkinson
DB(|S(1,2)|)
Wilkinson
(dB)
Frequency (GHz)
0
-10
-20
-30
-40
-50
-60
0.1
4.1
8.1
12


WilkinsonPhase_Sim
Ang(S(2,1)) (Deg)
Wilkinson
Ang(S(3,1)) (Deg)
Wilkinson
Ang(S(1,2)) (Deg)
Wilkinson
Ang(S(1,3)) (Deg)
Wilkinson
Ang(S(3,2)) (Deg)
Wilkinson
Ang(S(2,3)) (Deg)
Wilkinson
(Deg)
Frequency (GHz)
200
100
0
-100
-200
0.1
4.1
8.1
12

ii. Measurement:

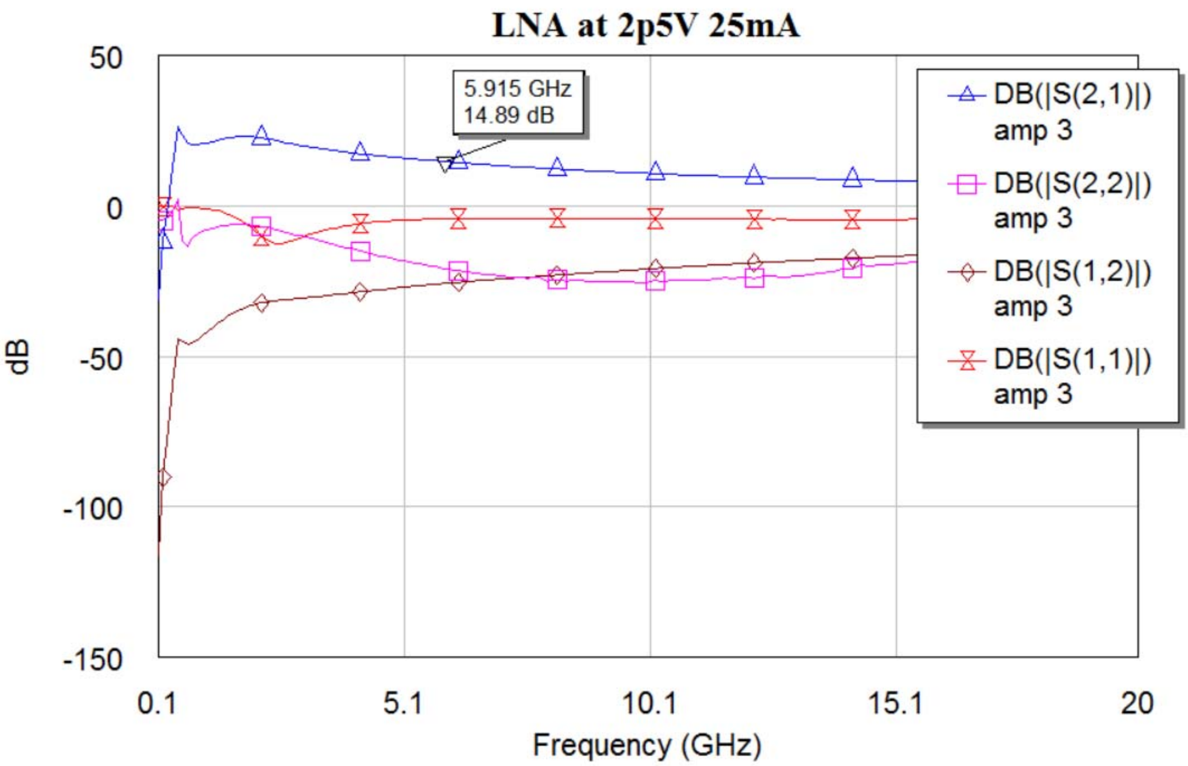




Although the power was well divided into halves (-3dB for each) at 5.9GHz in our measurements, the response of S_{21} and S_{31} are not as consistent as they were in simulation. In the measurement, they fluctuate more throughout the entire frequency. Also, S_{32} in our measurement(-25.18dB) is a bit larger than S_{32} in simulation(-32.31dB). Besides, the centered frequency for S_{32} has shifted right and became bigger than 5.9GHz. These results tell us that the isolation between output ports was not perfect.

3. LNA

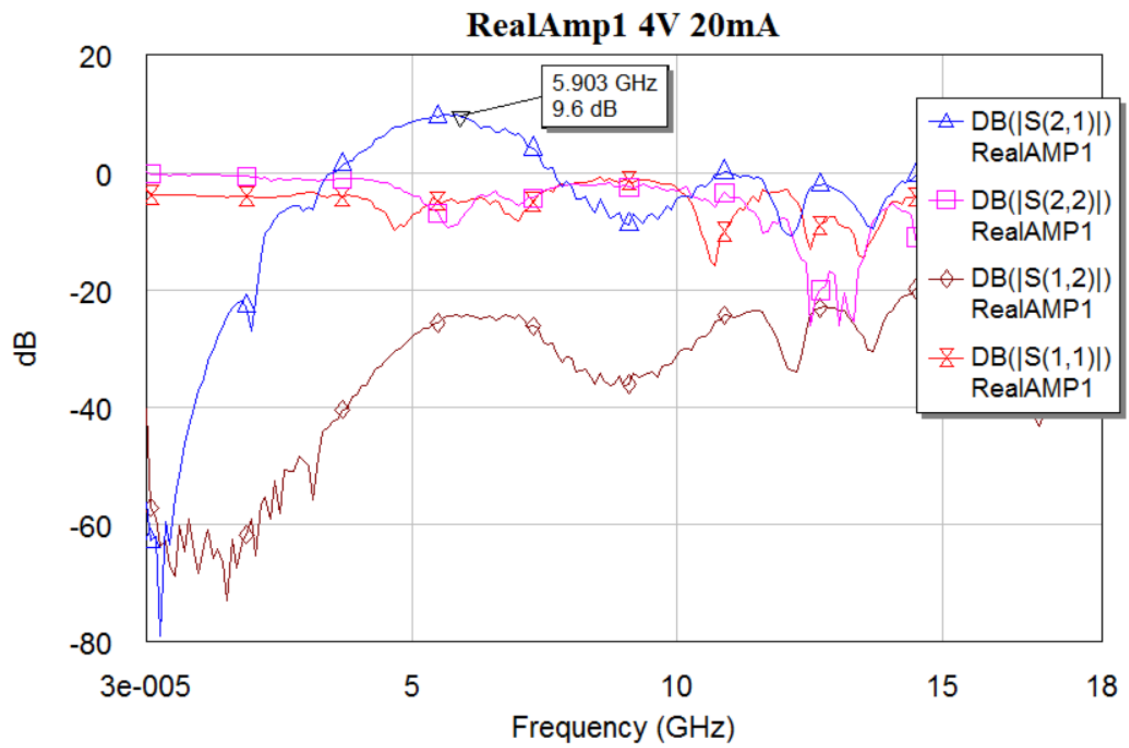
i. Simulation:



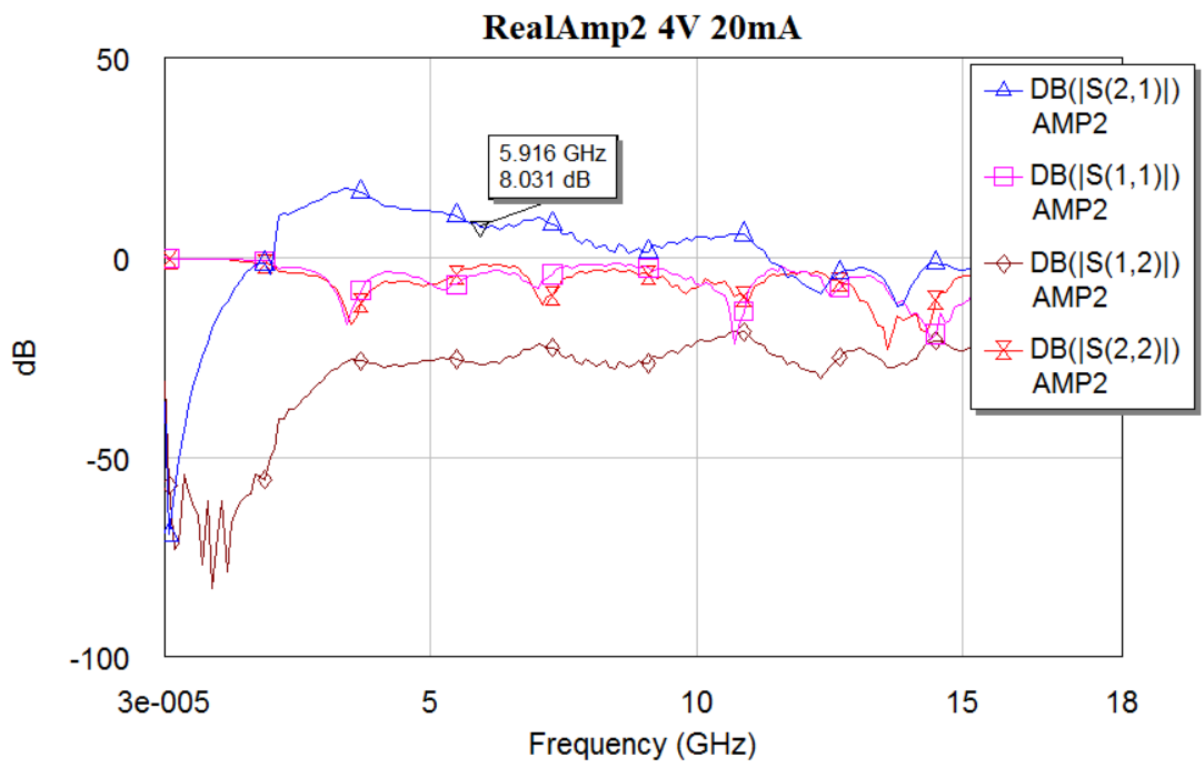
ii. Measurement:

We fabricated five LNAs for the RADAR system.

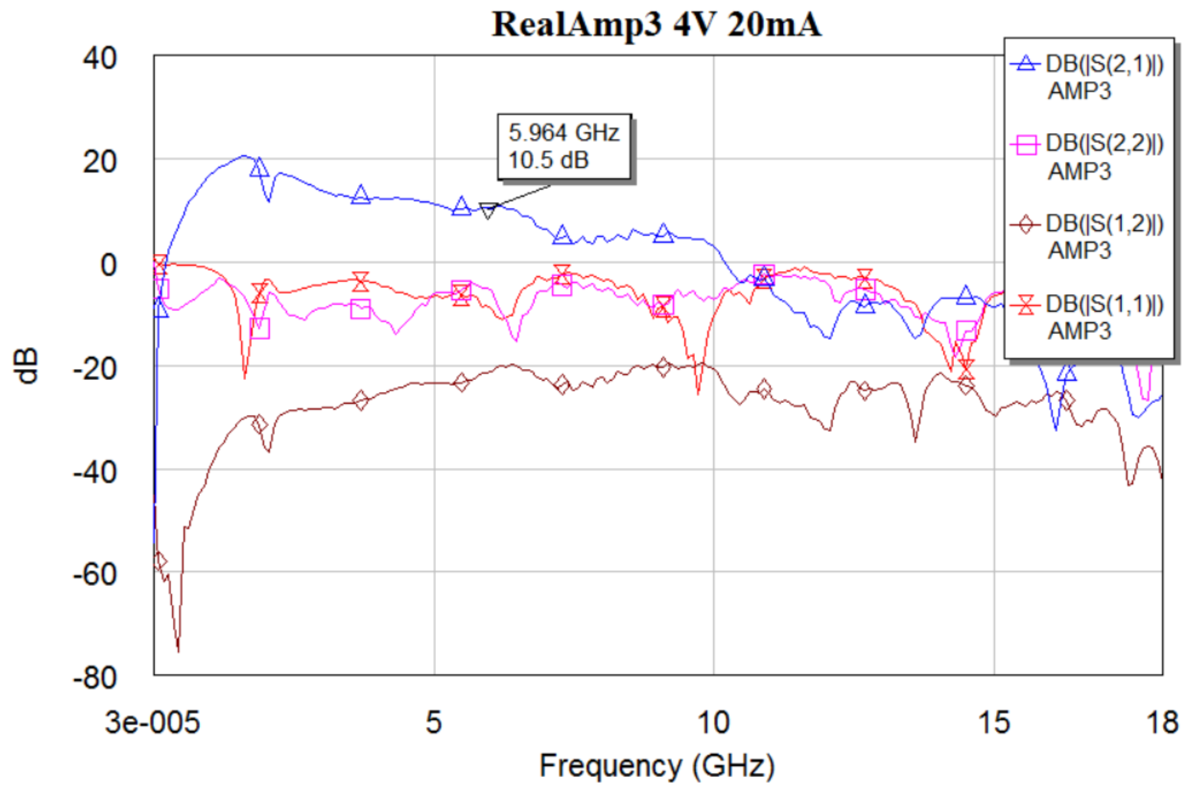
LNA1:


RealAmp1 4V 20mA
5.903 GHz
9.6 dB
DB(|S(2,1)|)
RealAMP1
DB(|S(2,2)|)
RealAMP1
DB(|S(1,2)|)
RealAMP1
DB(|S(1,1)|)
RealAMP1
20
0
-20
-40
-60
-80
dB
3e-005
5
10
15
18
Frequency (GHz)

LNA2:

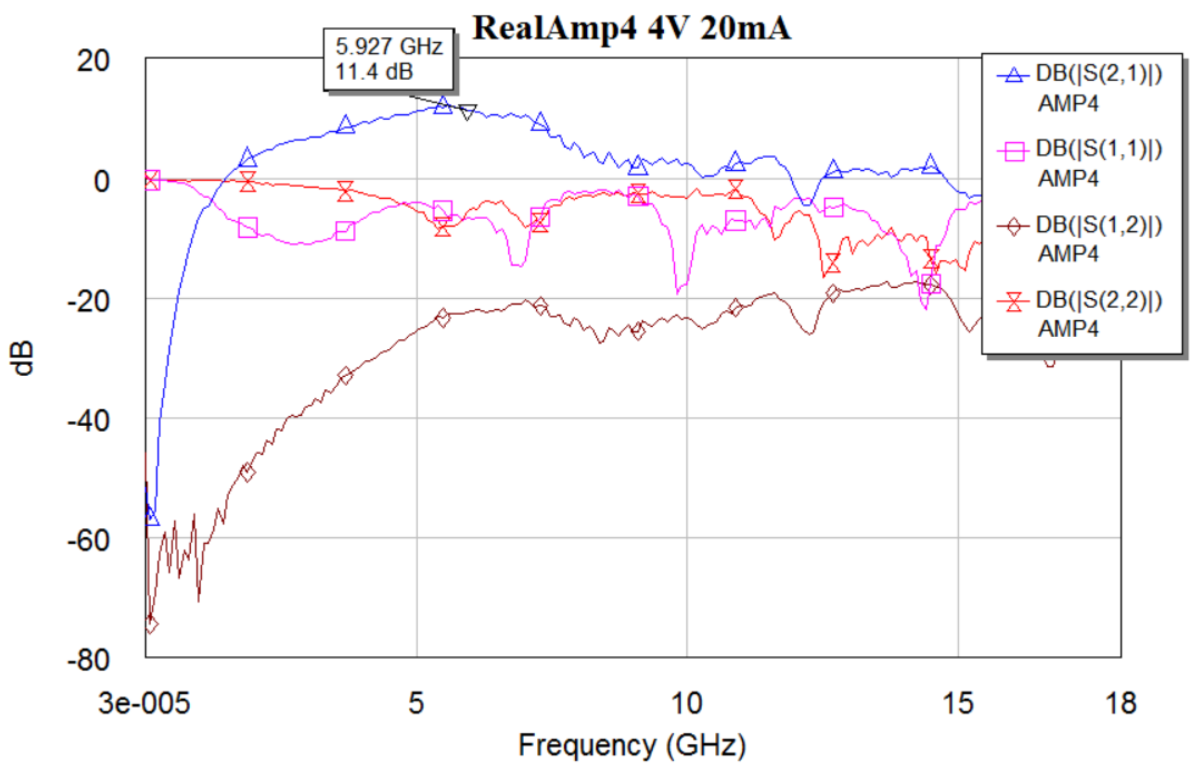

RealAmp2 4V 20mA
5.916 GHz
8.031 dB
DB(|S(2,1)|)
AMP2
DB(|S(1,1)|)
AMP2
DB(|S(1,2)|)
AMP2
DB(|S(2,2)|)
AMP2
50
0
-50
-100
dB
3e-005
5
10
15
18
Frequency (GHz)

LNA3:



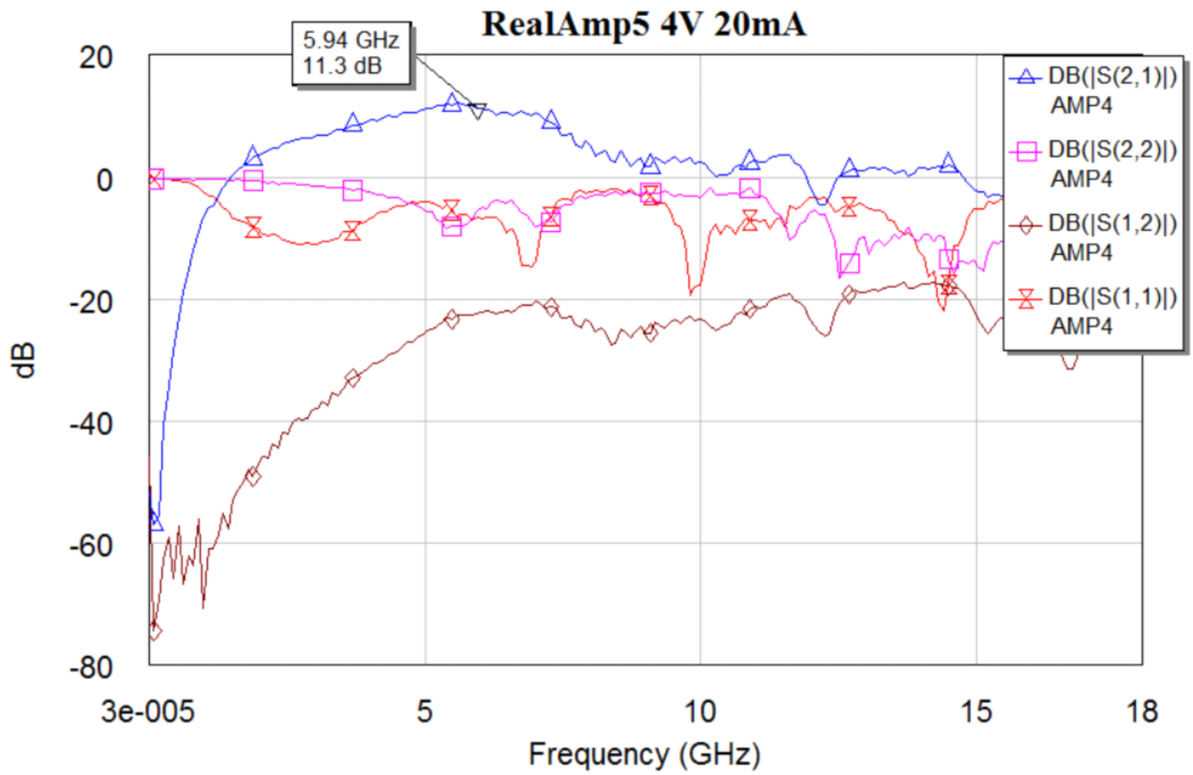
RealAmp3 4V 20mA
5.964 GHz
10.5 dB
DB(|S(2,1)|)
AMP3
DB(|S(2,2)|)
AMP3
DB(|S(1,2)|)
AMP3
DB(|S(1,1)|)
AMP3
dB
40
20
0
-20
-40
-60
-80
3e-005
5
10
15
18
Frequency (GHz)

LNA4:



RealAmp4 4V 20mA
5.927 GHz
11.4 dB
DB(|S(2,1)|)
AMP4
DB(|S(1,1)|)
AMP4
DB(|S(1,2)|)
AMP4
DB(|S(2,2)|)
AMP4
dB
20
0
-20
-40
-60
-80
3e-005
5
10
15
18
Frequency (GHz)

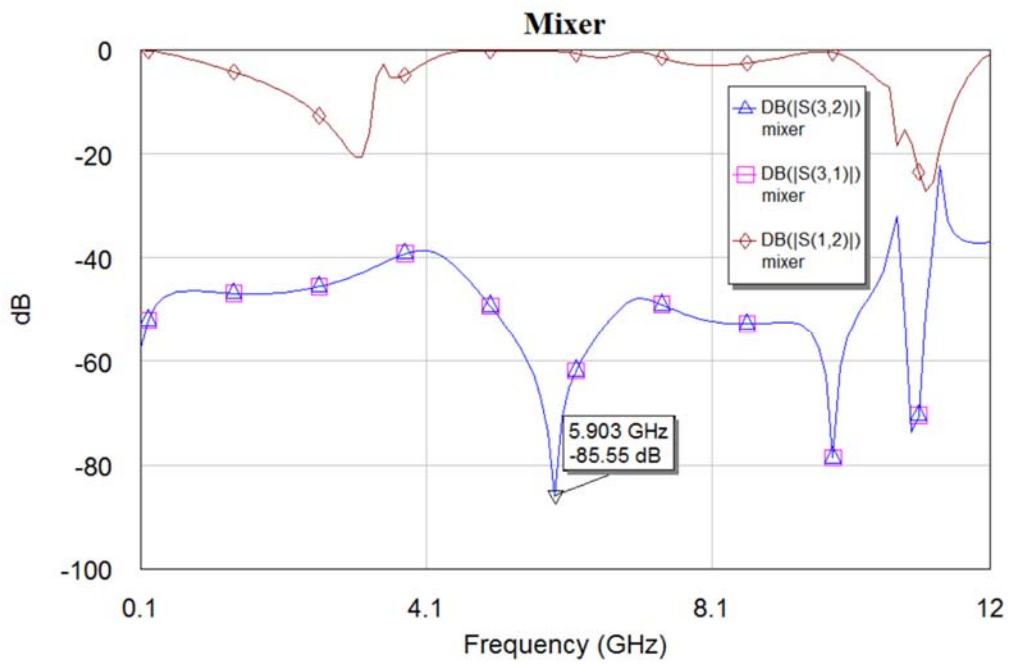
LNA5:



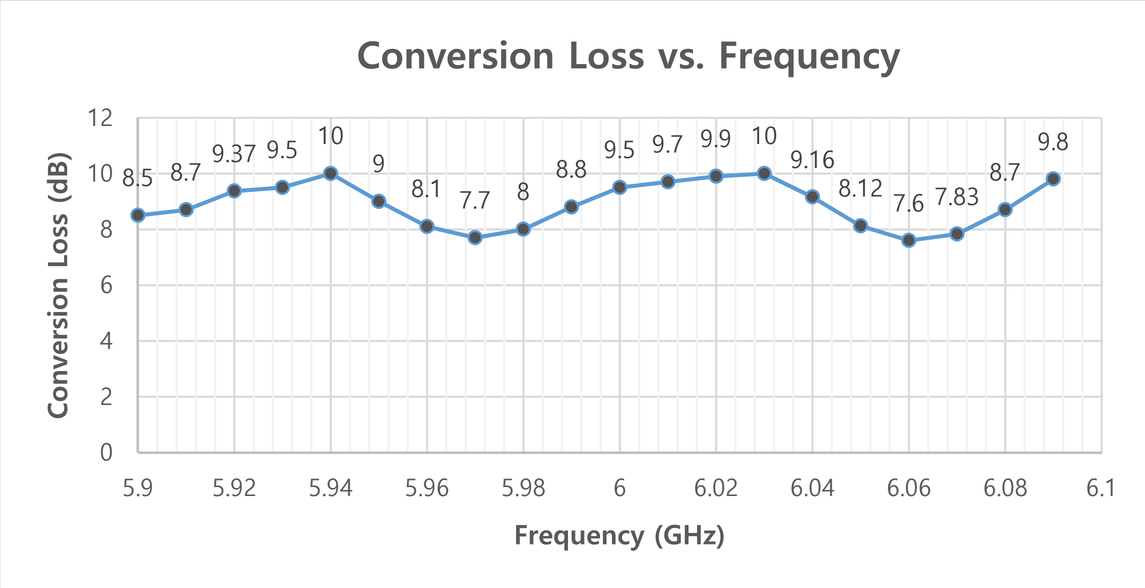
The gains of our measured LNAs were a bit smaller than that of the simulated LNA.

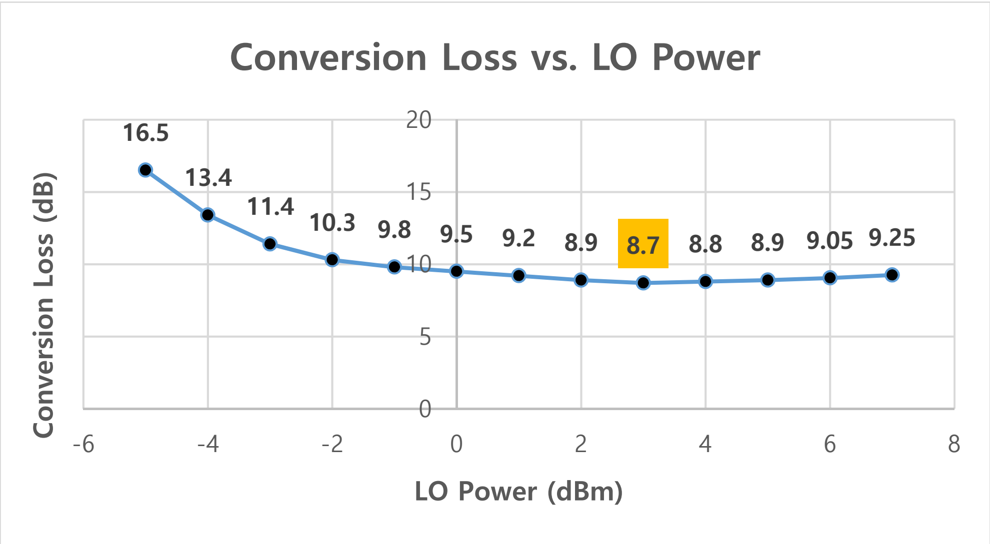
4. Mixer

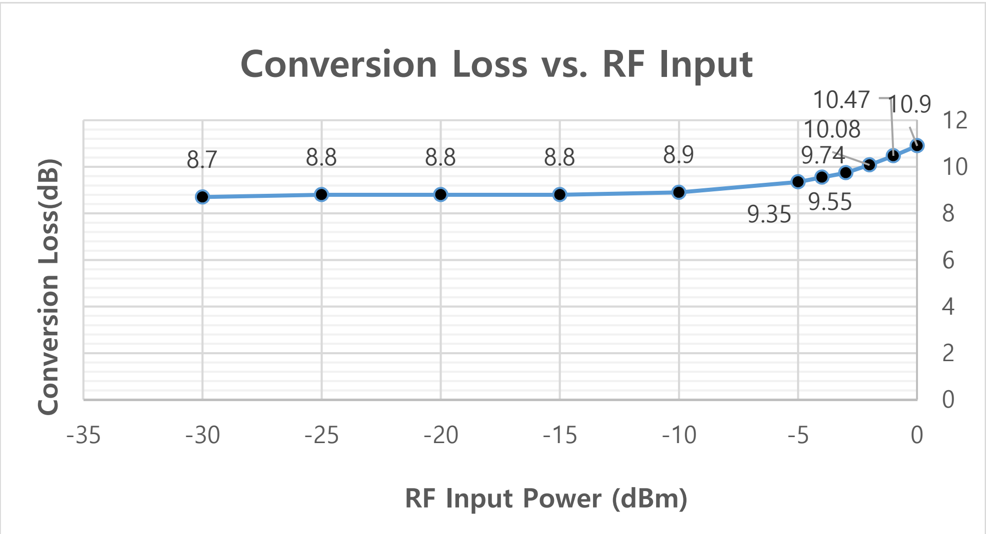
i. Simulation:

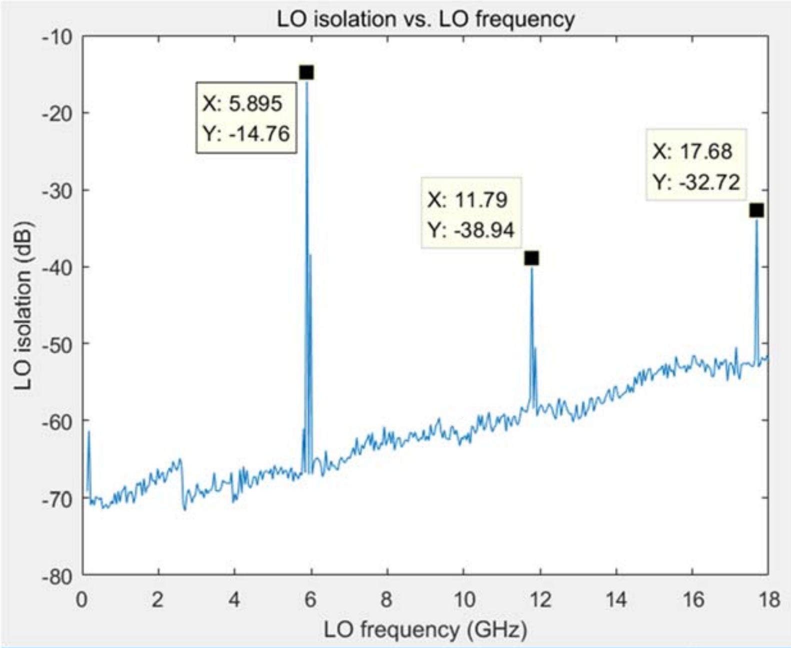


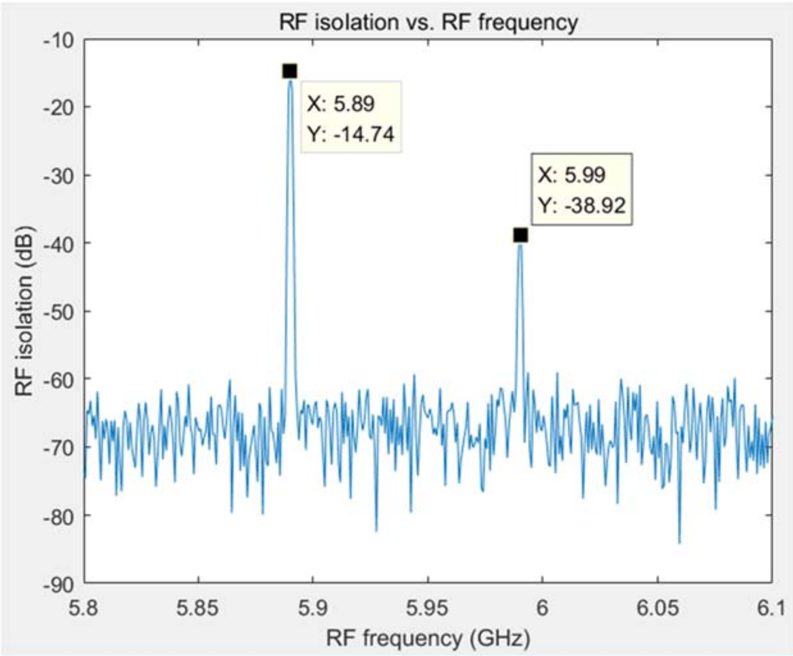
ii. Measurement:


Conversion Loss vs. Frequency
Conversion Loss (dB)
Frequency (GHz)
8.5
8.7
9.37
9.5
10
9
8.1
7.7
8
8.8
9.5
9.7
9.9
10
9.16
8.12
7.6
7.83
8.7
9.8


Conversion Loss vs. LO Power
Conversion Loss (dB)
LO Power (dBm)
16.5
13.4
11.4
10.3
9.8
9.5
9.2
8.9
8.7
8.8
8.9
9.05
9.25


Conversion Loss vs. RF Input
Conversion Loss(dB)
RF Input Power (dBm)
8.7
8.8
8.8
8.8
8.9
9.35
9.55
9.74
10.08
10.47
10.9

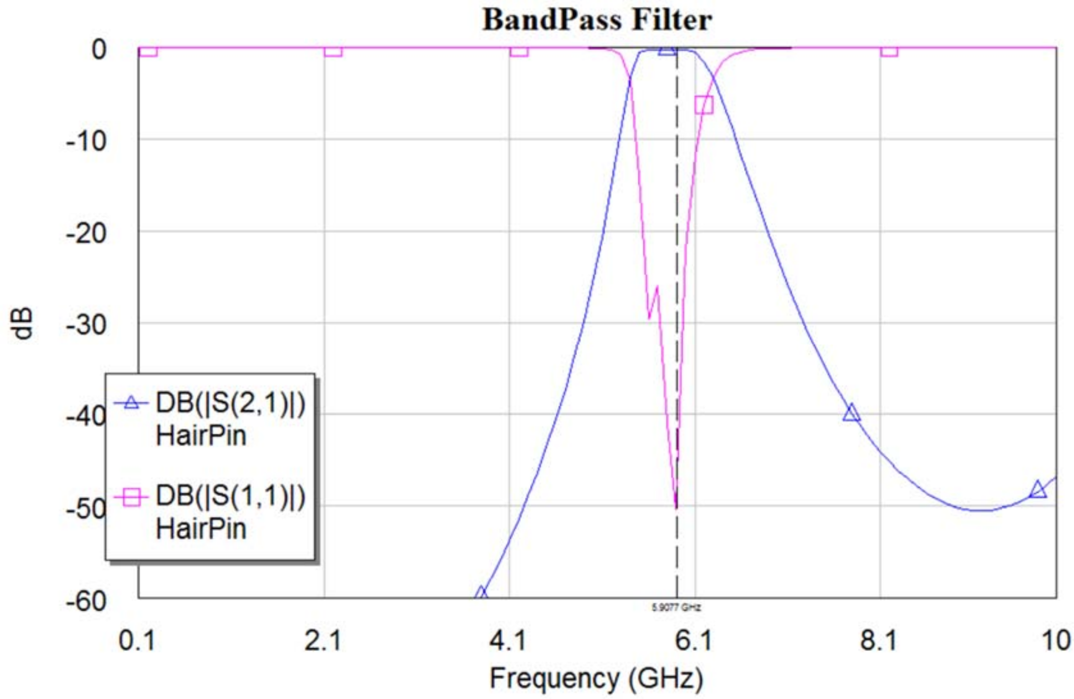




For the mixer, we could get almost the same result as we expected. The LO isolation and RF isolation were successfully maximized at 5.9GHz, which is the frequency that we aimed for. (To be more strict, the RF and LO isolation were centered at 5.89GHz while our simulation result was centered at 5.9GHz)

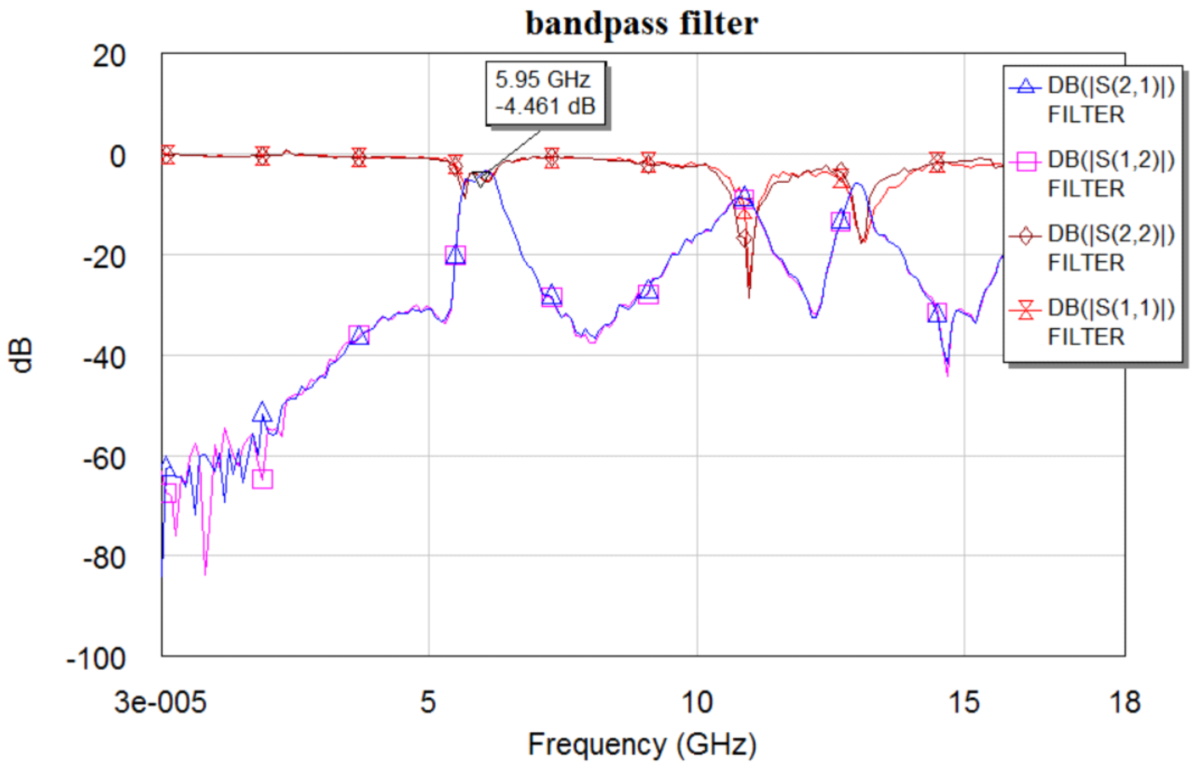
5. Band Pass Filter

i. Simulation:



ii. Measurement:

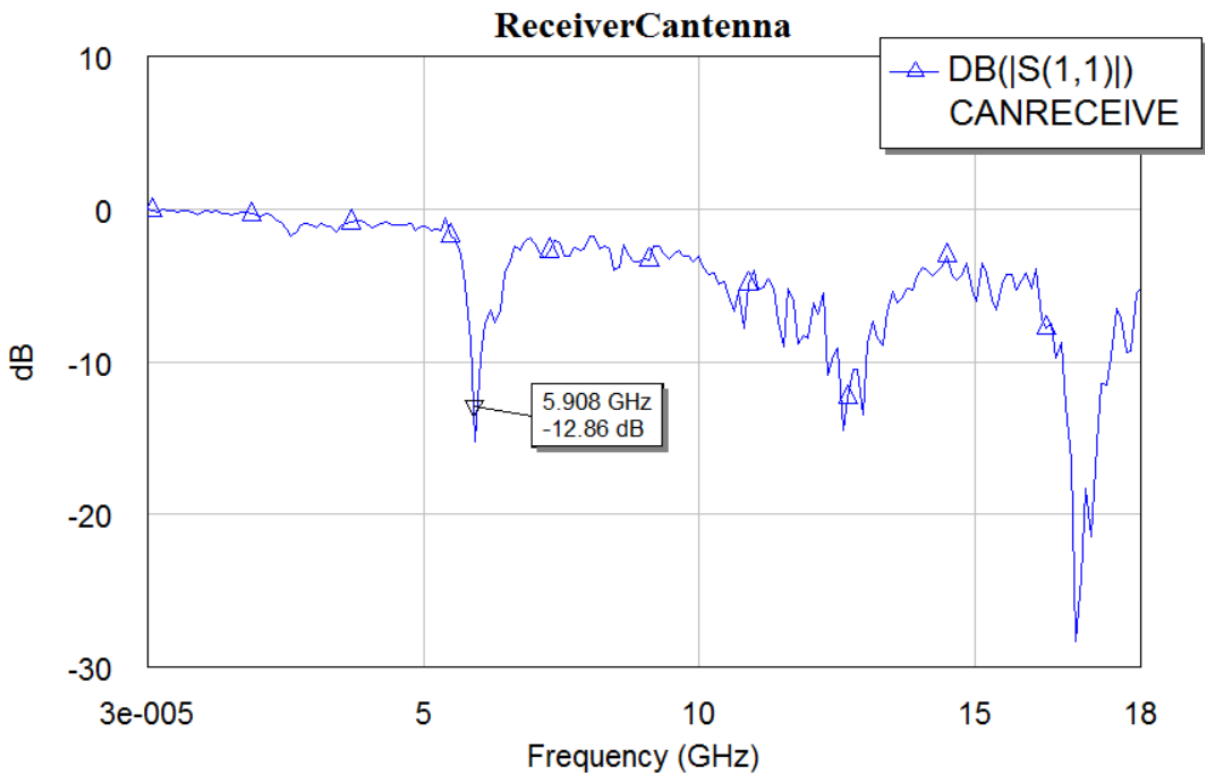
(We fabricated a new bandpass filter since our old bandpass filter's center frequency was off from 5.9GHz)



Although the power gets decreased by 4.461dB at 5.9GHz unlike the ideal filter, it still has a good characteristic of a band pass filter.

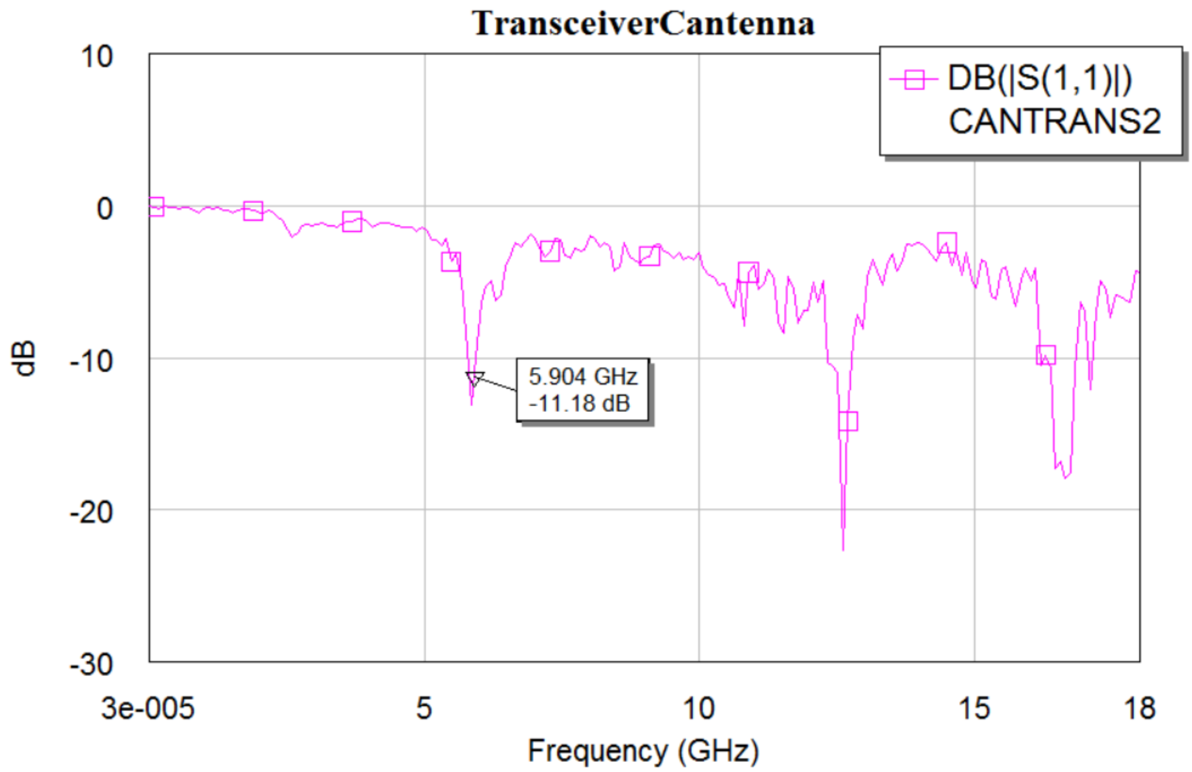
6. Receiver Cantenna

Below is the measured plot of the Receiver Cantenna. There's no MWO simulation for cantennas.



As we can see, the reflection rate is very small at 5.9GHz.

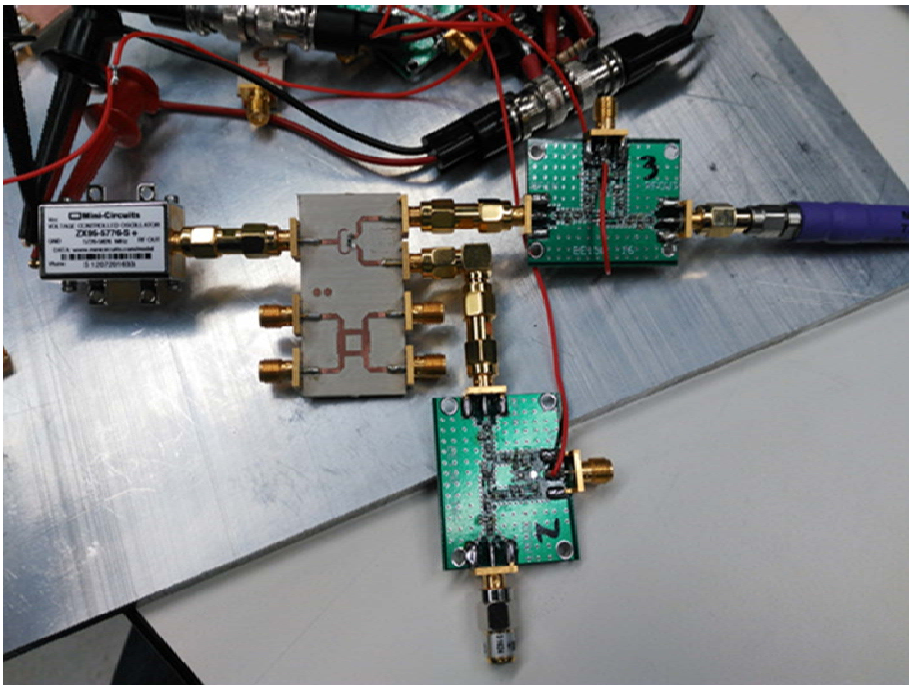
7. Transceiver Cantenna



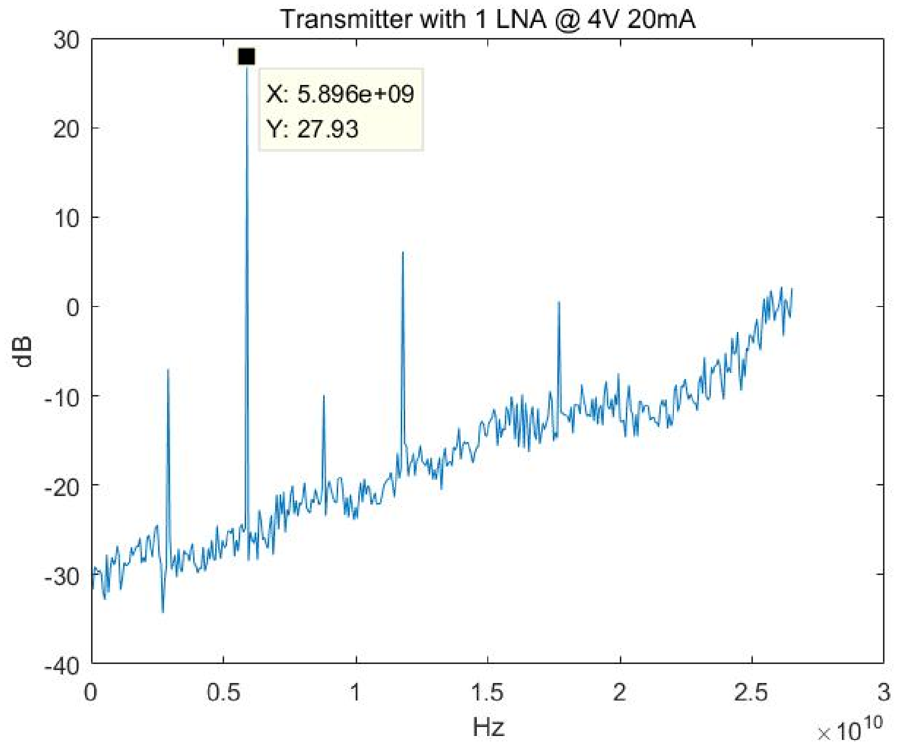
The transceiver cantenna was designed to perform identically to the receiver cantenna.

System-level testing

1. Transmitting signal(VCO) connected to a Low Noise Amplifier

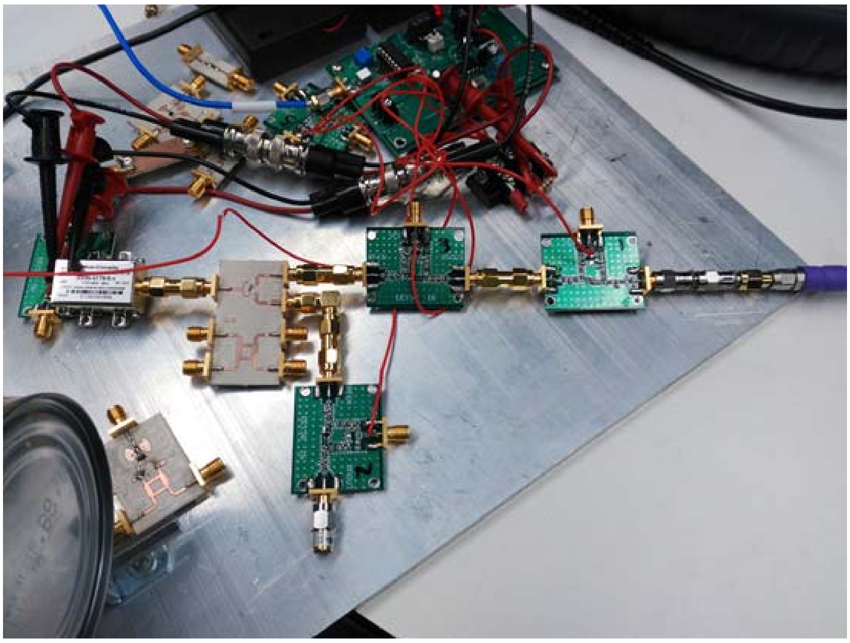


Below is the measurement result:

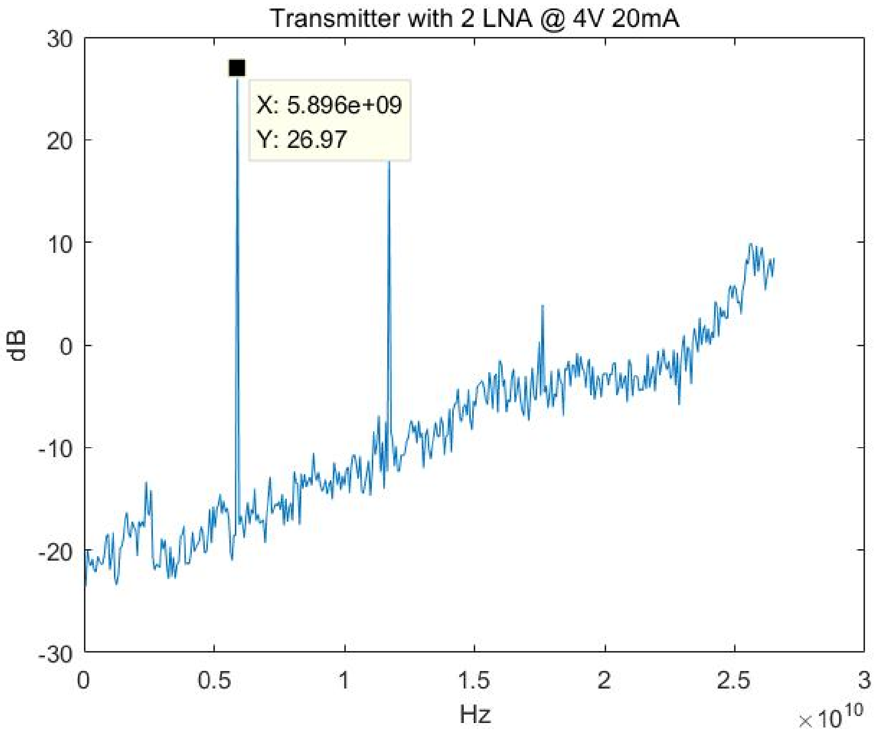


We tried to make the transmitted signal's power as large as possible to enhance the radar performance. Note that a 10dB attenuator was used for the measurement to prevent the damage to FFox. (The graph is already adjusted by adding 10dB to the data)

2. Transmitting signal connected to two LNAs.

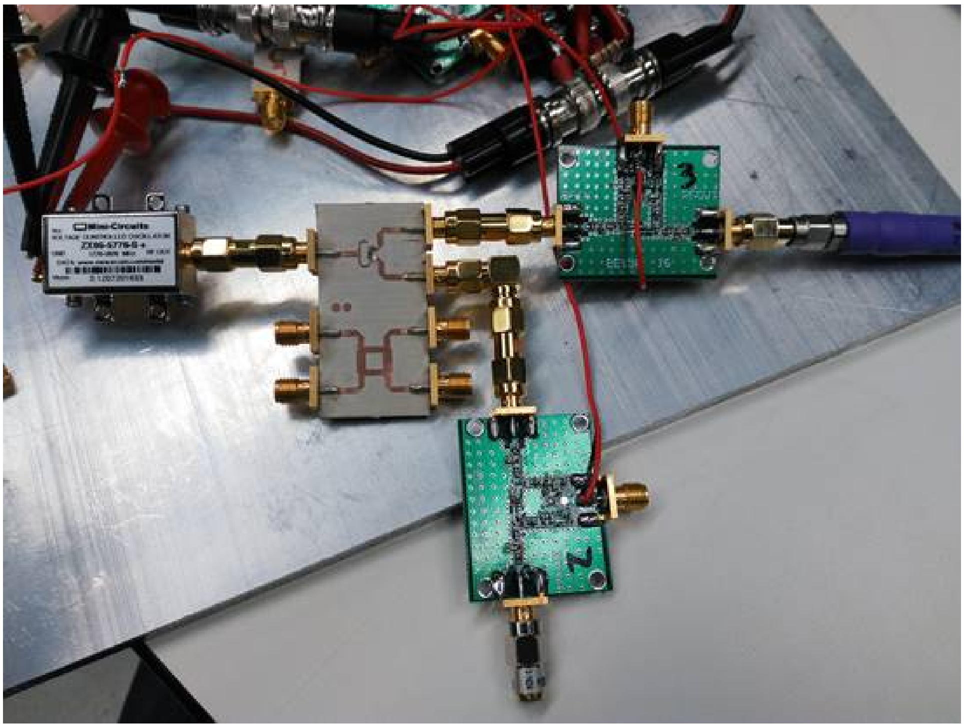


Below is the measurement result:

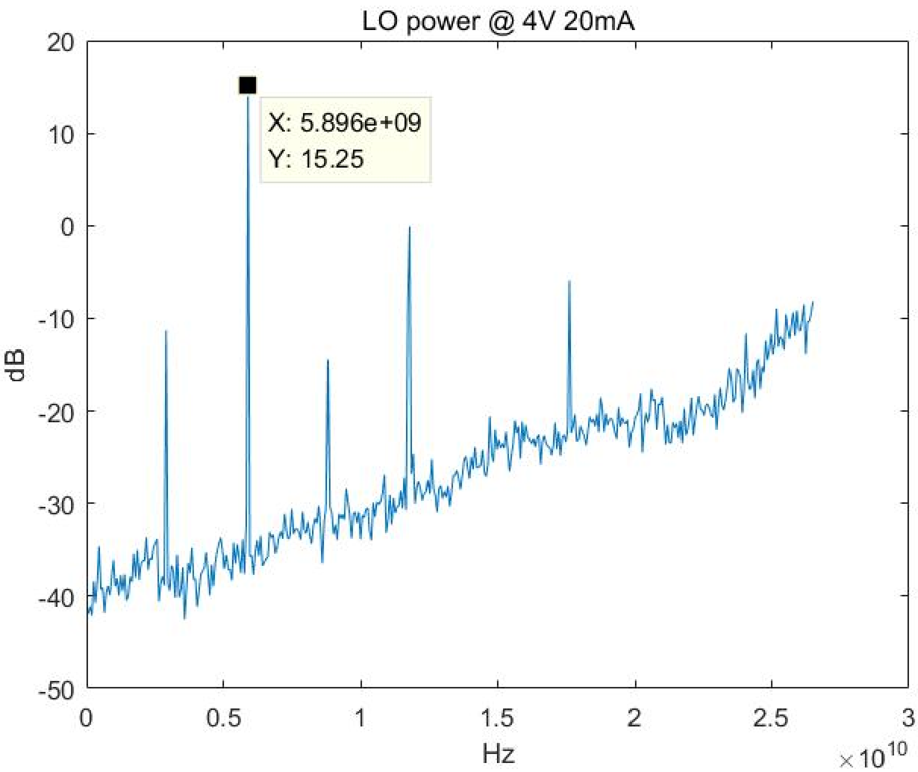


We added one more LNA to the transmitter to amplify the signal. But surprisingly, the output signal got weaker. Note that a 19dB attenuator when measuring to prevent the damage to FFox. I added 19dB to the original data to get a correct plot.

3. LO power to the mixer

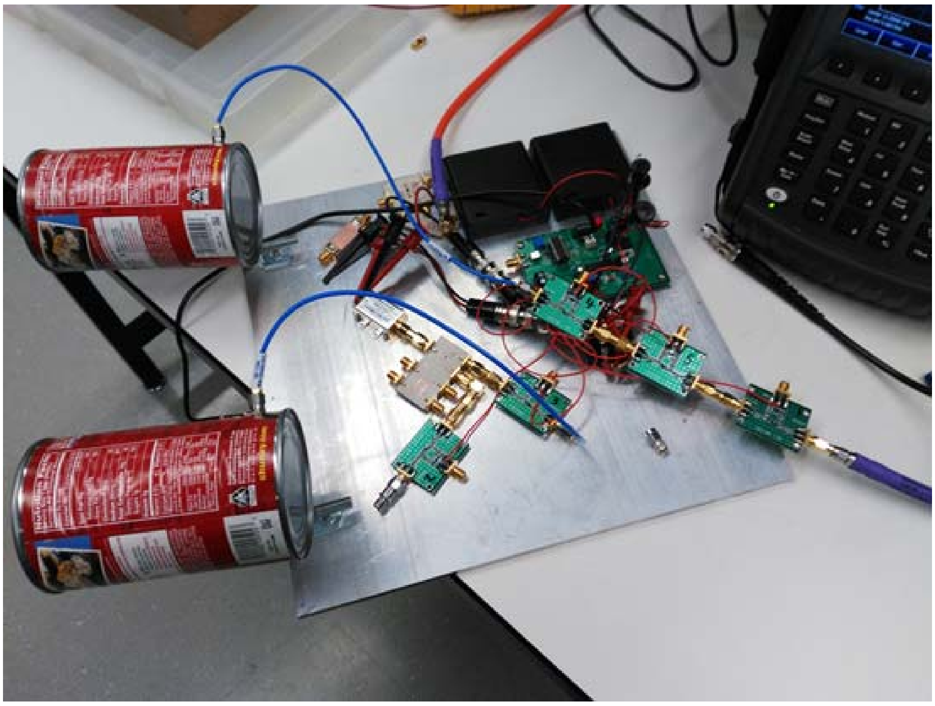


We measured the LO power to the mixer.



We checked the LO power going into the mixer to figure out if the transmit power is well delivered to the mixer. We could check that it was being delivered well.

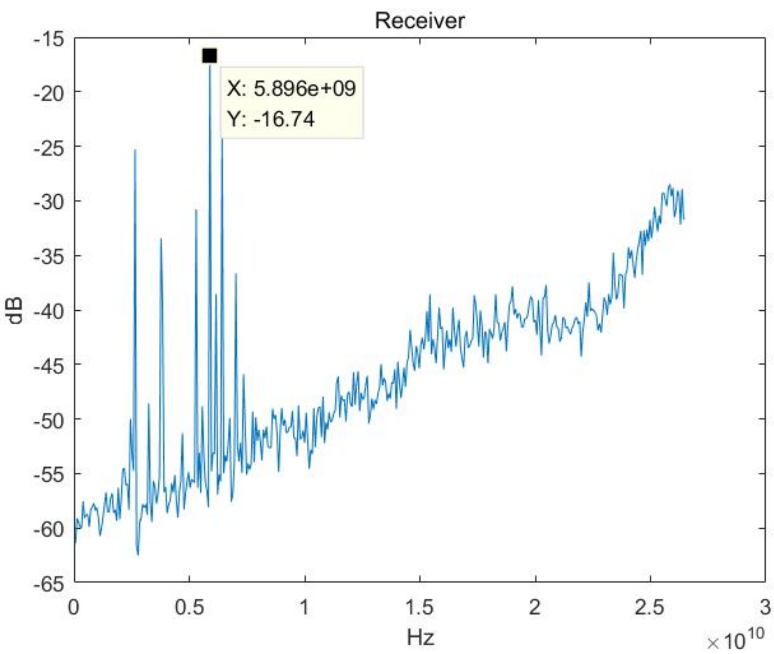
4. Receiver



(Since we didn't take the picture for this step, I posted a random picture here. The actual measurement done in this step was measuring the Receiver Cantenna's output directly.)

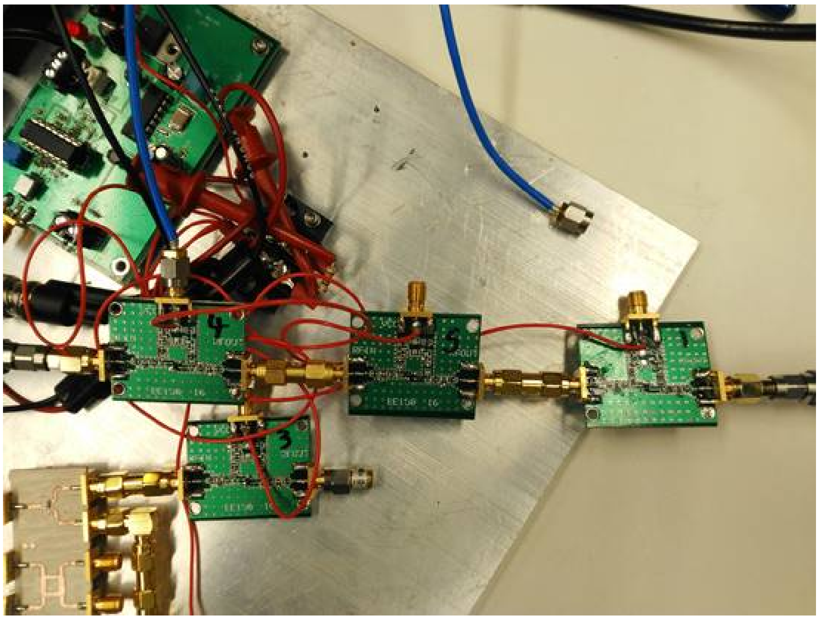
We measured the magnitude of the received signal at the Receiver Cantenna directly.

Below is the measured result:



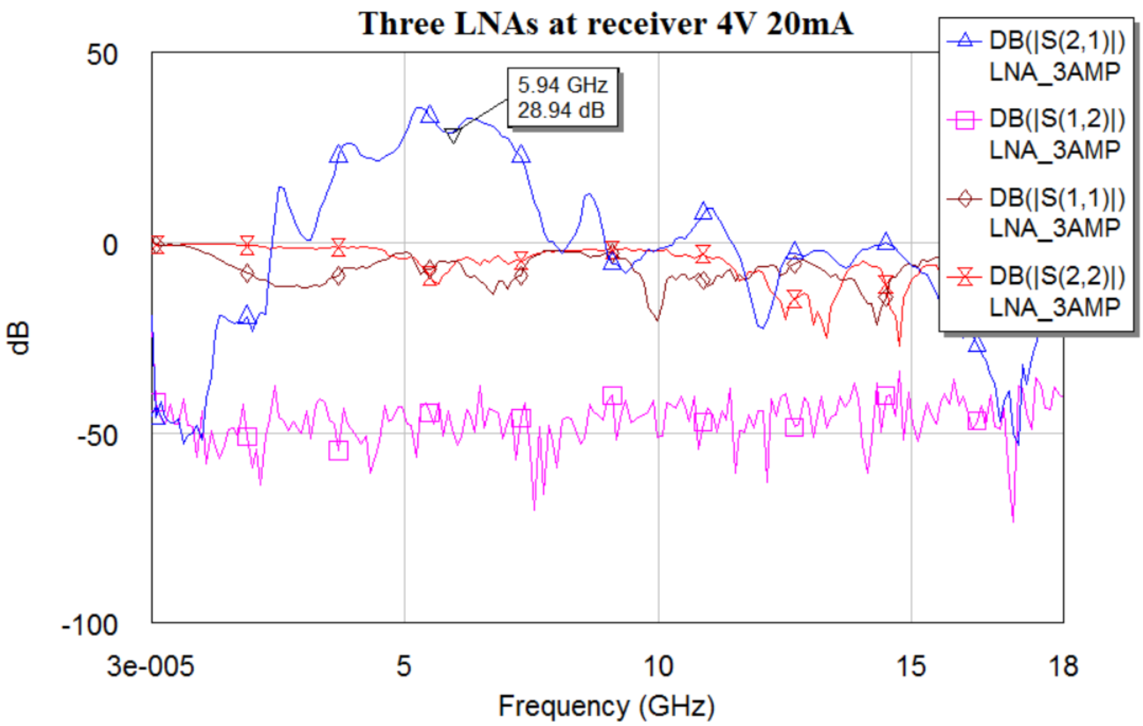
As we can see, the magnitude of the received signal was very small. Thus, we decided to amplify it by using a number of amplifiers.

5. Three LNAs connected to the Receiver



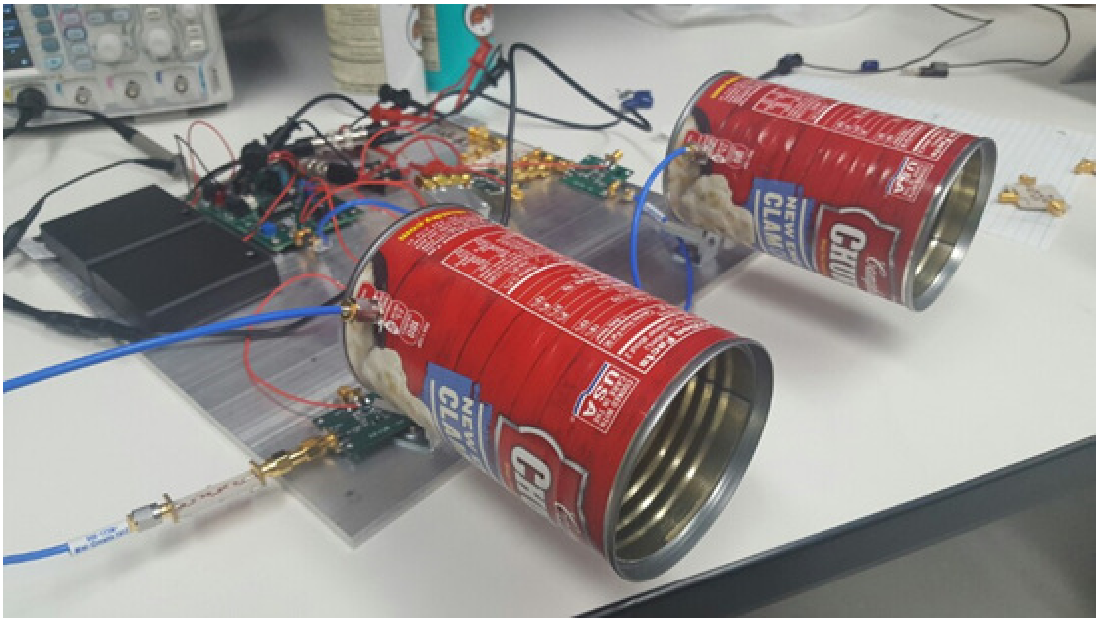
We cascaded three LNAs to the receiver to amplify the received signal.

Below is the measurement:

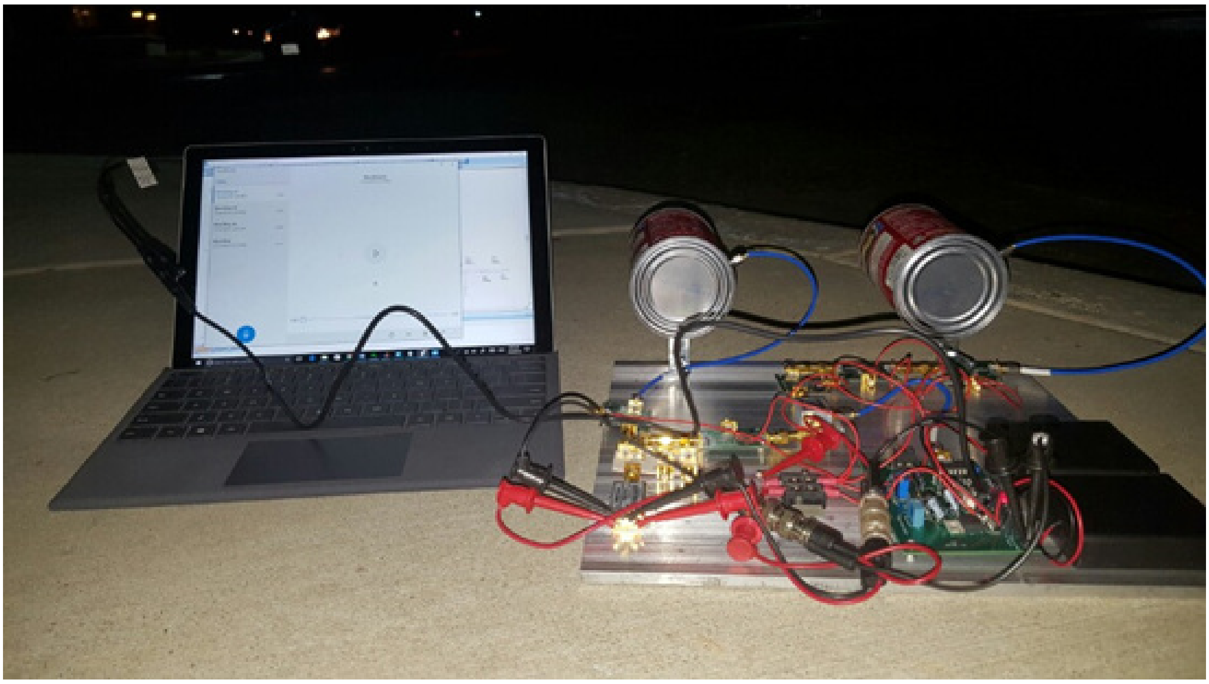


Since the received signal is very small, we had to amplify the signal as much as we could. When we cascaded three LNAs to the receiver, we could get around 29dB at 5.9GHz.

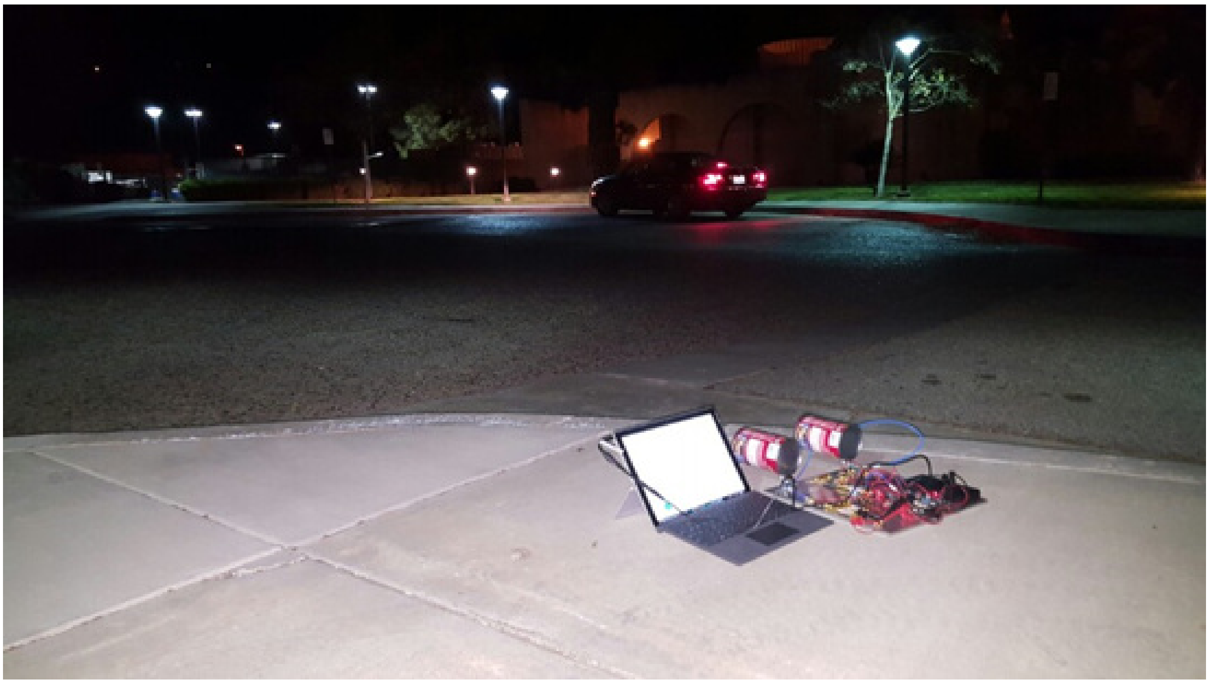
Presentation and Analysis of final results



(Completed RADAR)

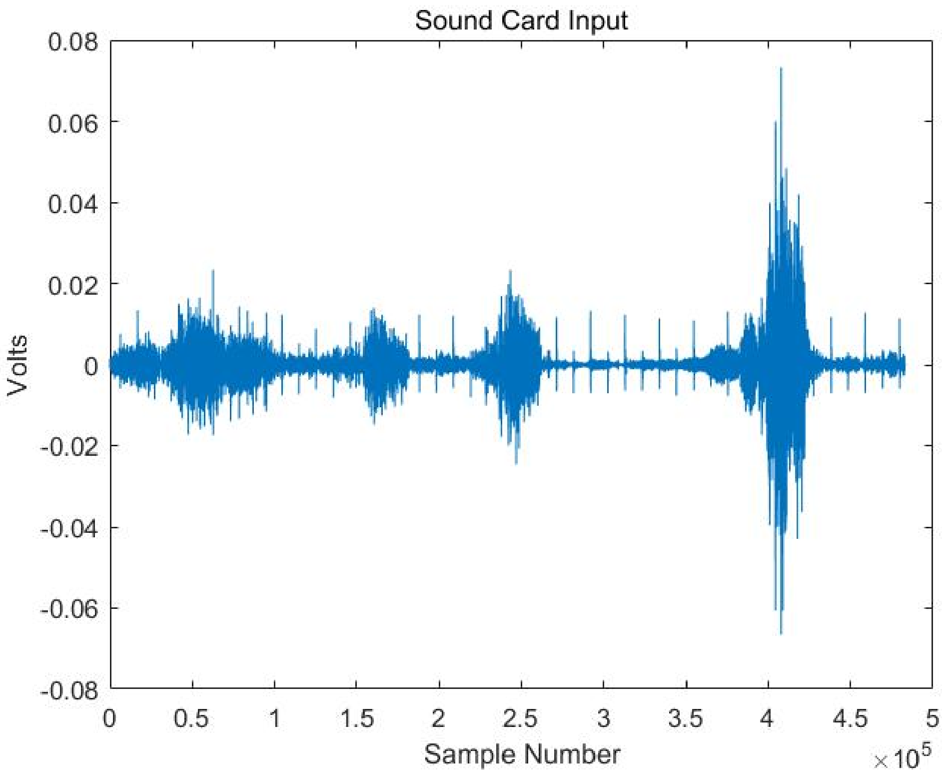


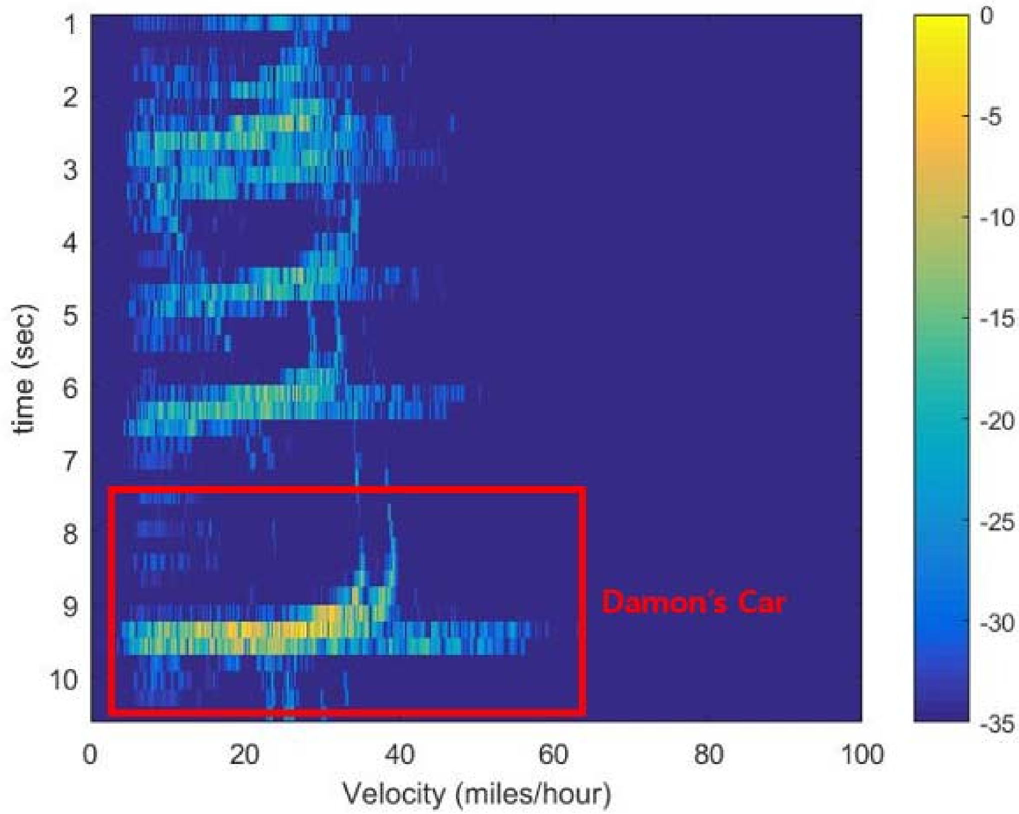
(Went outside to test the completed RADAR)



(Measuring Victor's Car's velocity at 3:00am Sunday)

(Unfortunately, we missed taking a picture when we were demoing to Damon...)





(The velocity measured at the demo day. The measured velocity plot generated by read_data_doppler_mod_CIT.m MATLAB code)

On the velocity plot above, the green spots around 8sec~10sec represent Damon's car. Fortunately, our RADAR worked successfully. As we can see on the plot, the green trace of Damon's car starts at 8sec. This tells us that our RADAR's range was quite long enough to measure a distant object. Also, Damon's car was running around 40miles/hour and our measurement matched it within 10% error range. If we have a second chance, we would try to get rid of those noise from other frequencies and also try to extend the range of our RADAR longer.

Summary

Through this lab, I could utilize all the knowledge of RF circuit components I learned in EE150 class. We used LNAs, a Mixer, a Band-Pass Filter, VCOs, and Cantennas to make the RADAR work. Through this lab, I could practice finding a compromise point for each circuit components since there's always a tradeoff of performances. Finding a proper aperture size of Cantennas was also a practice of finding a compromise point between the gain and bandwidth. If there was extra time, I would try to make a SAR system with the radar. To build a SAR system, we should not only revise our MATLAB code but also increase the range of the radar since the range of our radar was not quite long enough for SAR systems. Also, I would try making the range of the radar longer than that of the one we made in this lab.