Final Group Report

Team TSM

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Abstract

This report presents 2.5Ghz center frequency radar system based on concept of FMCW. The main goal of 2.5Ghz radar system is that (1) measuring wide range of object's distant and (2) measuring a speed of moving object. This radar system has a built-in DSP and LCD unit for real time processing and display distance and speed of objects. The limitation of detecting frequency is between 0.01Hz to 10KHz. The choice of transmitting signal bandwidth is 52.16MHz and the period of modulation signal is 1.6ms. Therefore, the minimum and maximum distance that can be detected are 0m and 46.01m. In addition, the minimum and maximum speed that can be detected 0.0012 m/s and 1200 m/s .

Introduction

As opposed to the pulsed radar system, frequency modulated continuous wave (cw) radar is used for measuring the frequency of the return signal, the frequency difference between the transmitted and returned signal can be measured and from there, we could calculate the distance of objects using equation 1. The FMCW radar also measures target velocity using doppler effect(equation 2). The FMCW radar system has very high accuracy of the range measurement.

We design FMCW radar because of those advantages. We choose the modulation signal as triangular, because the triangle waveform gives us same frequency difference when the object is not moving.

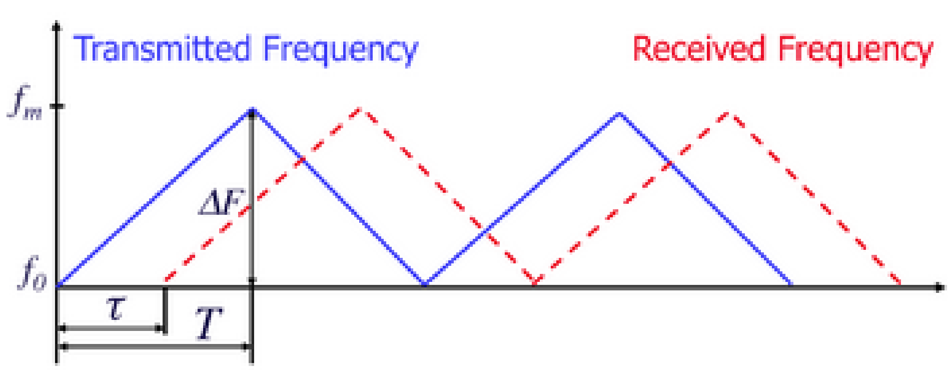

Figure 1 - FMCW Concept

The signal travels to the object and come back to receiver. It moves distance 2d, which d is the distance of the target from radar. The travelling time can be calculated as $\frac{2d}{c}$, where c is the speed of light. Therefore, the distance of the target can be calculated as:

$d = \frac{c*T*(f_r - f_0)}{2*BW}$ ------------ (1)

Speed of the object can be measured by taking advantage of the Doppler effect. The transmitted signal is fixed at 2.5Ghz. When the transmitted signal hits a moving target, the reflected signal is shifted in frequency according to the following relationship,

$fr = (1 + \frac{\Delta V}{c}) \times f0$ −−−−−−− (2)

where fr is the frequency of the received signal, Δv is the relative velocity of the target to the radar, and $f0$ is the frequency of the transmitted signal.

Design Goals:

- Minimize size of the PCB for reduce noise and weight.
- Built-in DSP for real time signal processing and modulation signal generation.
- LCD screen for displaying distance and speed.

Description of the Project

The project contains three parts to achieve the goals:

Part 1: Signal generation, transmission and detection: Signal from VCO goes into splitter. Two separated signals go to the power amplifier and the mixer. One signal from power amplifier goes into the antenna and the signal is transmitted. The signal goes to the mixer acts LO signal for the mixer. Our design uses the concept from lab 6 from EEC 134A. We use Teensy 3.1 to create triangle wave. It makes possible to transmit FM wave. The IF signal from the mixer go to VGA to make 1V pick-to-pick voltage before going to LPF. LPF has 4.5 gain. Therefore overall signal strength before DSP, it was 4.5V pick-to-pick.

Part 2: Digital signal processing by the microcontroller: The teensy 3.1 is used for measure the frequency of detected target and calculate distance and speed of the target. The teensy 3.1 measures the elapsed time during a single cycle. And our code requires

Teensy to store thirty times frequency data. The average frequency of the thirty times is the approximately frequency we use to calculate distance and speed. Finally, The result will be displayed on the on-board LED screen.

Part 3: The last part is the PCB implementation of the circuit. The circuit will be implemented RF module and If module on 2-layer PCB boards based on the designed the block diagram.

Design Details

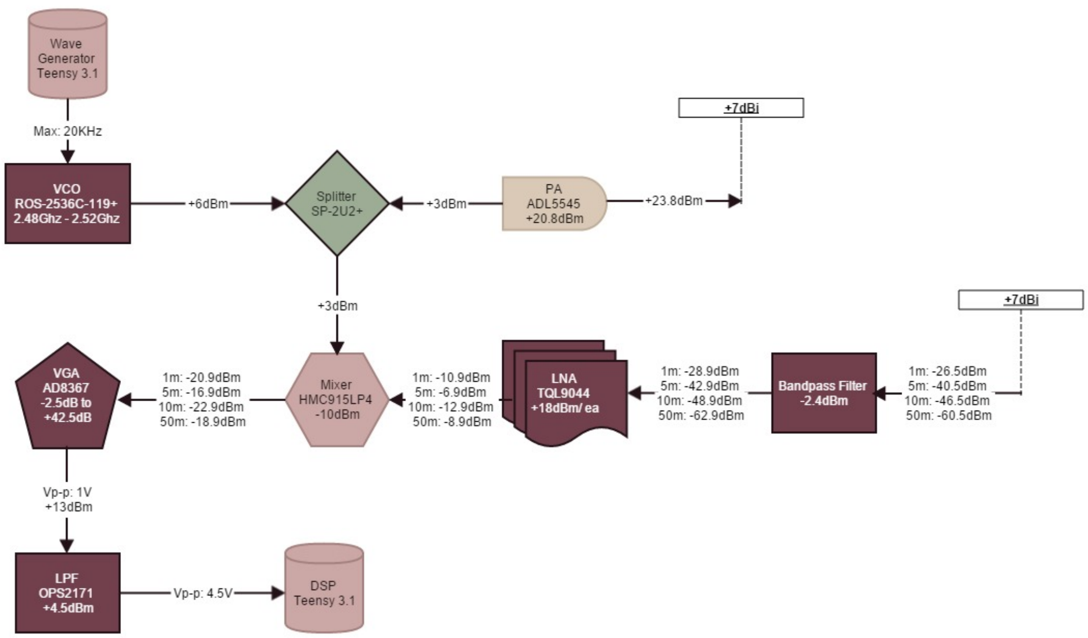

Figure 2 - Overall Block Diagram

RF Module	IF Module	VCO
Lownoise Amplifier TQL9044(70mA)	AGC AD8367(VGA)(250mA)	VCO ROS-2536C-119+(45mA)
Power Amplifier ADL5545 (56mA)	Lowpass Filter OPS2171(10mA)	
RF Mixer		

HMC915LP4(117mA)		
Voltage Regulator LM1085		
Bandpass Filter BFCN-2435+		
Splitter SP-2U2+		

Table 1 - Components

PCB design

The goal of PCB design was Minimize size of the PCB for reduce noise and weight. Figure 3 is proto type design. We tried to place all components in one PCB board. However, the prototype PCB had long signal trace and huge empty space.

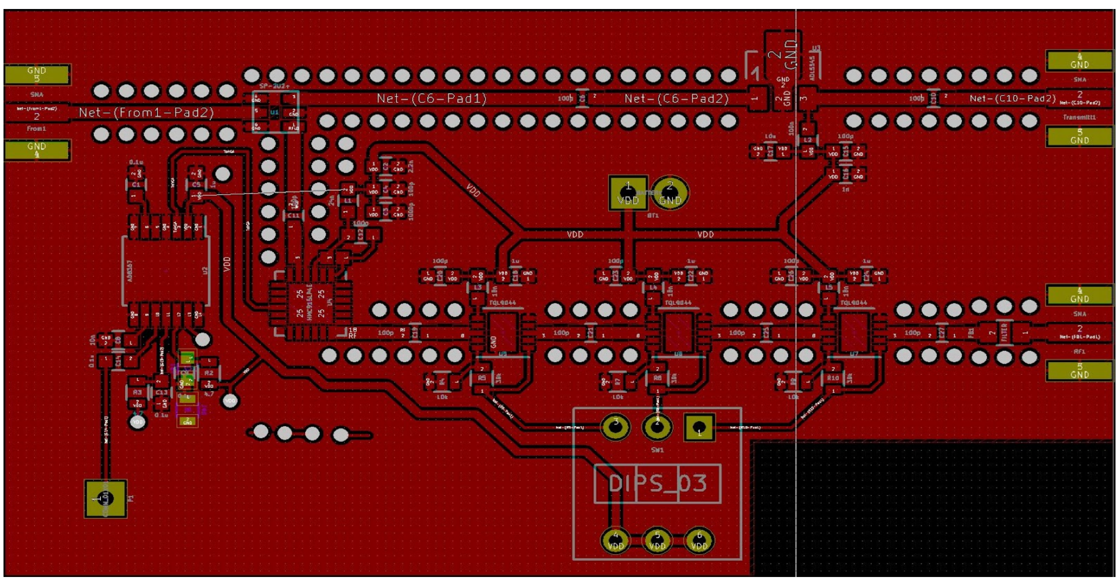

Figure 3 - Prototype

To achieve PCB design goal, we decided to separate RF module and IF module. RF module (Figure 4) and IF module (Figure 5) showed the result. Module separation gave us benefits. One is that signal trace reduced dramatically and there was only minimized empty space. Moreover, we could manage bottom surface of PCB to be GND surface. Two PCB modules are isolated by GND plane. Therefore, IF module could be more safe from RF module noise **(noise performance is much better than protytype)**. We built PCB with recommendation layout from each component's data sheet. As you can see, **almost all component has GND in their base plane.** Also, GND was placed next to signal trace to reduce noise. Power trace is much thicker than signal trace to handle high power consumption. Voltage regulator was in RF module and it PCB layout is slightly larger than recomendation size for heat dissipation.

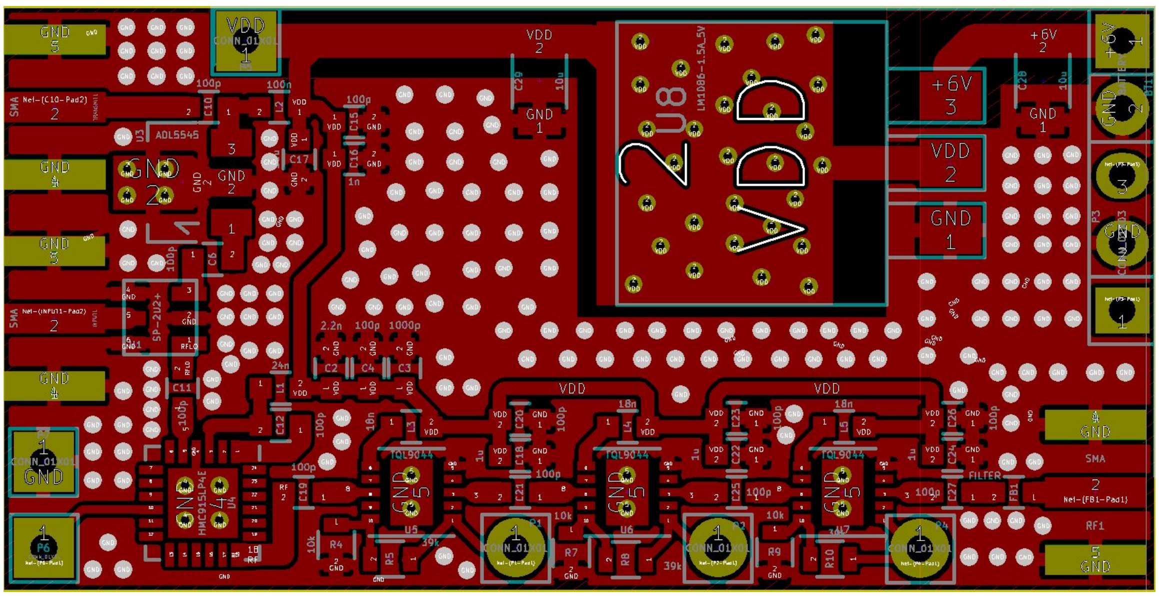

Figure 4 - RF module

IF module has connection pins for Teensy module. The IF signal from RF module amplified by VGA to V_{p-p} 1V and filtered out through LPF with gain 4.5 and cutoff frequency 10 KHz. After that, clean 4.5V_{p-p} IF signal injected to DSP process

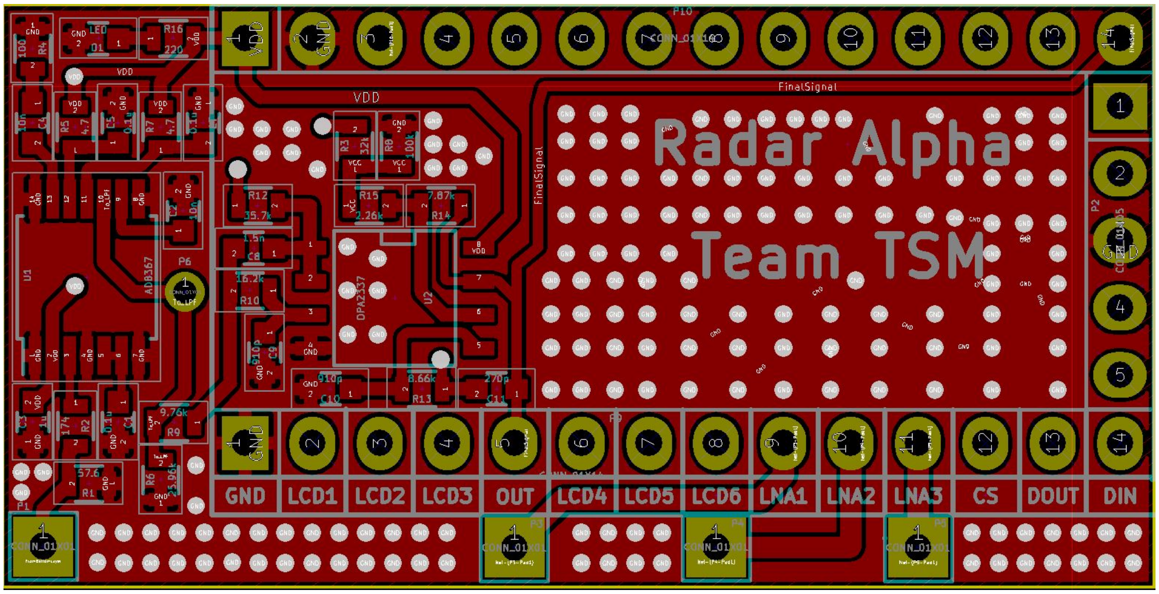

Figure 5 - IF Module

FIgure 6 is VCO module. We didn't put VCO in either RF module and IF module. We hope it will provide stable VCO output.

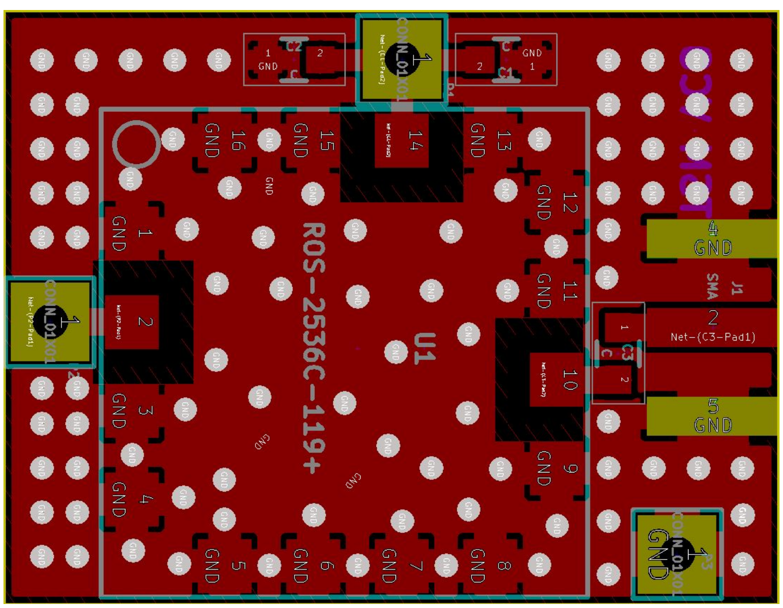

Figure 6 - VCO

Figure 7 is manufactured RF module. As you can see, This PCB module minimized well. PIN headers placed for module connection.

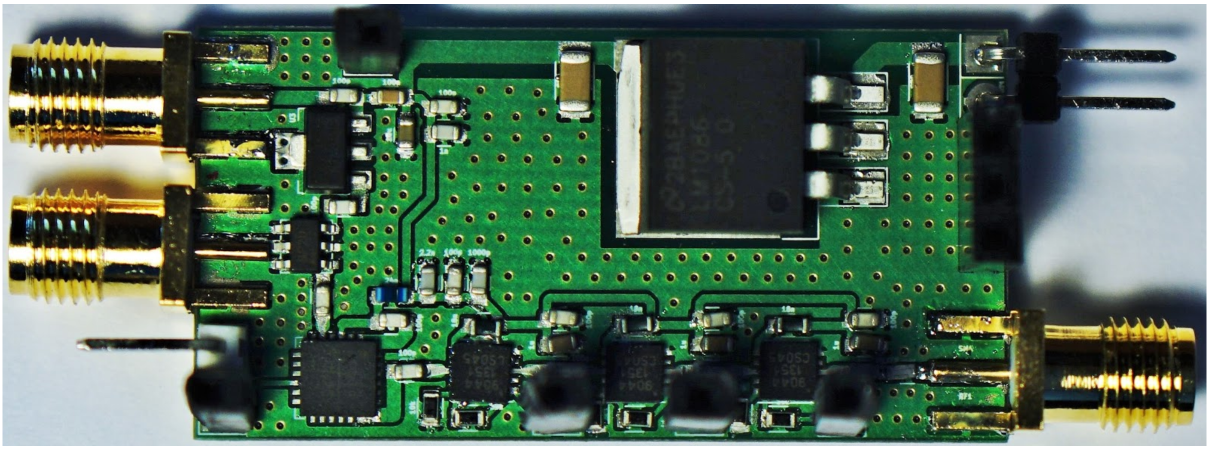

Figure 7 - RF PCB

Figure 8 is manufactured IF module.

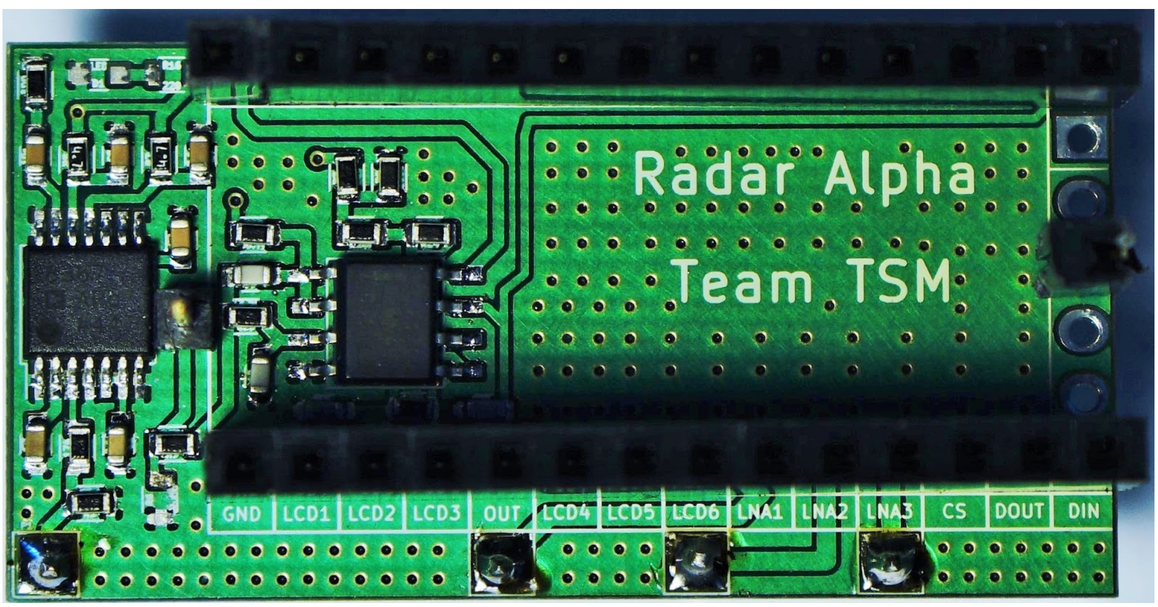

Figure 8 - IF PCB

Figure 9 is manufactured VCO PCB. I didn't place capacitor for Vdd. Since it shows pretty stable output.

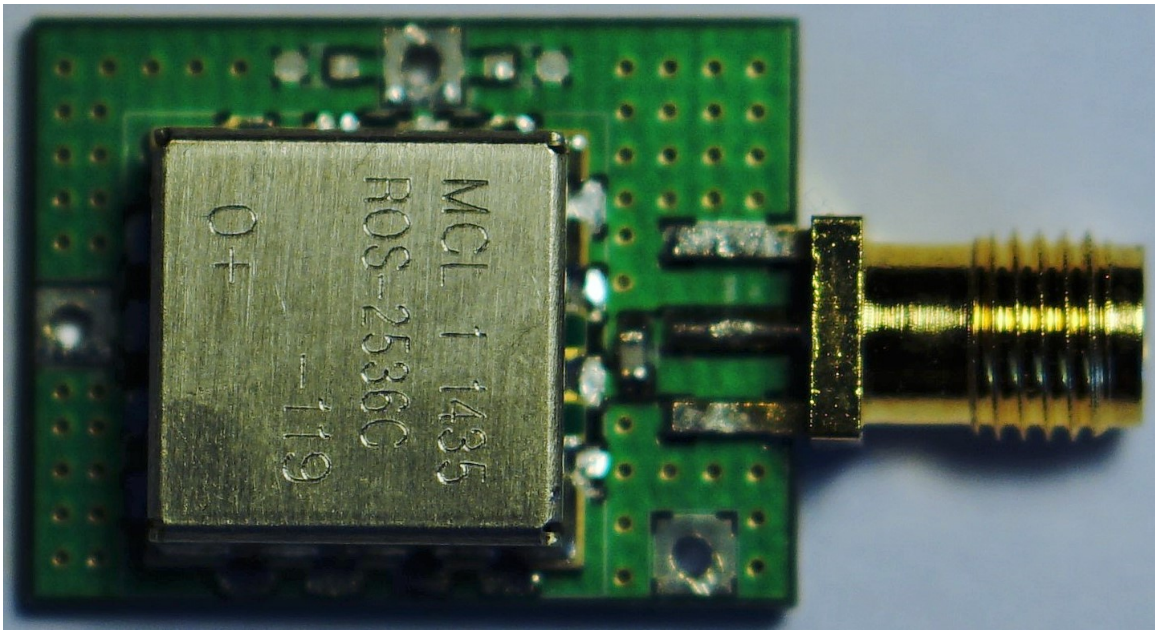

Figure 9 - VCO PCB

Figure 10 shows how those two board are stacking up. The quality of PIN header was horrible. There was lots of connection problem.

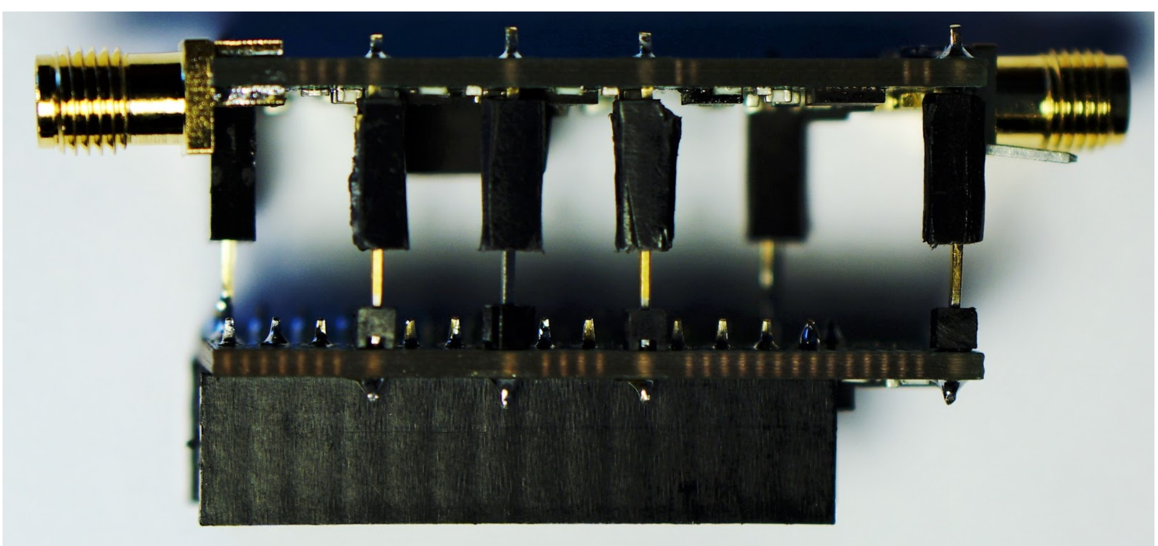

Figure 10 - Two board Connection

Antenna Choice

We didn't design antenna for our project because the frequency range was between 2.45Ghz - 2.55Ghz. Those frequency ranges are popular for wifi router. Therefore it is easy to find an antenna which works well for our project. Moreover, commercial antenna is cheap and well-designed due to the mass production. We bought two patch antennas for $20. Figure 11 and 12 are characteristics of Patch antenna for our project. **The S11 and Radiation pattern are good enough for our project.**

Speciation	
Type	Directional
Gain	7dBi
S11	-17.442 dB
Bandwidth	0.15 GHz

Table 2 - Specification of Antenna

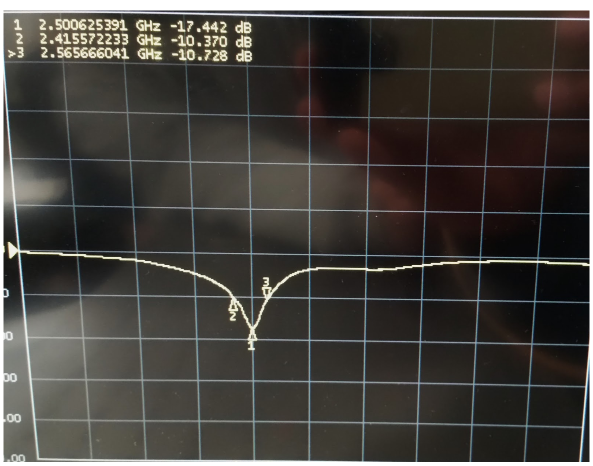

Figure 11 - S11 Data

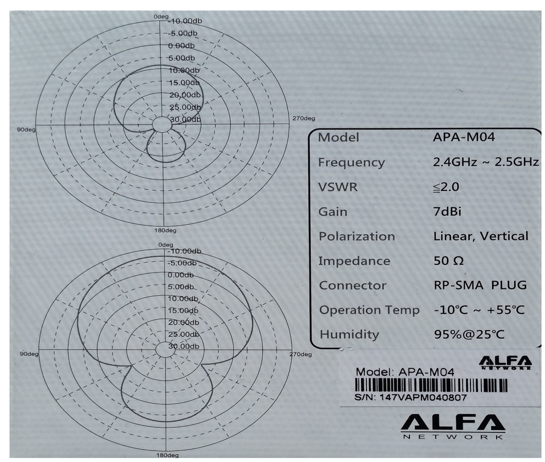

Figure 12 - Radiation Pattern

Test and Result for Individual Parts:

VGA Test:

We pick the AD8367 AGC amplifier which has variable gain from -2.5dB to +42.5 dB. Ideally, it should work for DC to 500MHz. VGA could replace multiple normal active amplifiers due to its huge gain range. Therefore, we could minimize our PCB. We need to detect various distance of objects. AD8367 has AGC function which could vary the gain by itself to create consistent output voltage even the power of input signal is varying. After soldering the PCB, we had run several tests on our VGA, and observed the output frequency and output voltages when the input voltage are set as 100 mV and 200 mV. During the test, the range of the input frequency was set from 10 Hz to 5 MHz, and we found out that the output frequency were close to the input frequency. The output voltage Vp-p looks normal at the frequency around 1 KHz to 5 MHz, VGA keeps the output voltage as 1Vp-p at higher frequency. However, Vp-p of VGA has distortions at very low frequency, and Figure 15 shows the wired graph of Vp-p with input frequency of 10 Hz at Vin = 200 mV. As a result, AD8367 AGC amplifier we chose for VGA did not work at low frequency.

Vin = 100 [mV]				**Vin = 200 [mV]**		
Input freq [Hz]	**Output Freq [Hz]**	**Output voltage [V]**		**Input freq [Hz]**	**Output freq [Hz]**	**Output voltage [V]**
10	**10.05**	**0.2480**		**10**	**None**	**None**
100	**100**	**0.3312**		**100**	**100**	**1.5470**
200	**200**	**0.5531**		**200**	**201**	**1.0500**
300	**301.2**	**0.7938**		**300**	**299**	**1.0500**
390	**390.6**	**1.0000**		**400**	**400**	**1.0310**
1K	**1K**	**0.9875**		**500**	**500**	**1.0310**
100K	**100K**	**0.9582**		**10K**	**10K**	**0.9625**
300K	**301.2K**	**0.9250**		**100K**	**10K**	**0.9625**
1000K	**1000K**	**0.7250**		**500K**	**503K**	**0.9063**
5000K	**5000K**	**0.2156**				

Table 3 - Input Freq Vs. Vout for VGA

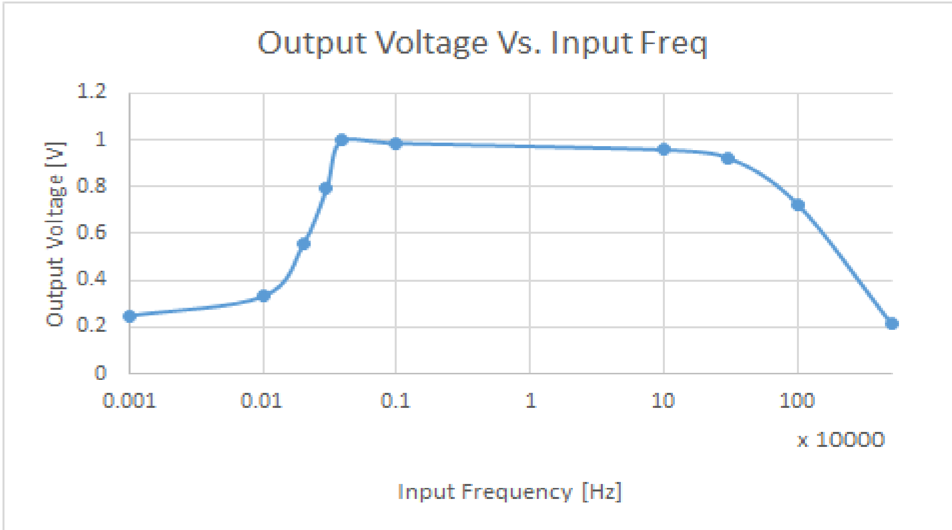

Figure 13 - Vin = 100mV

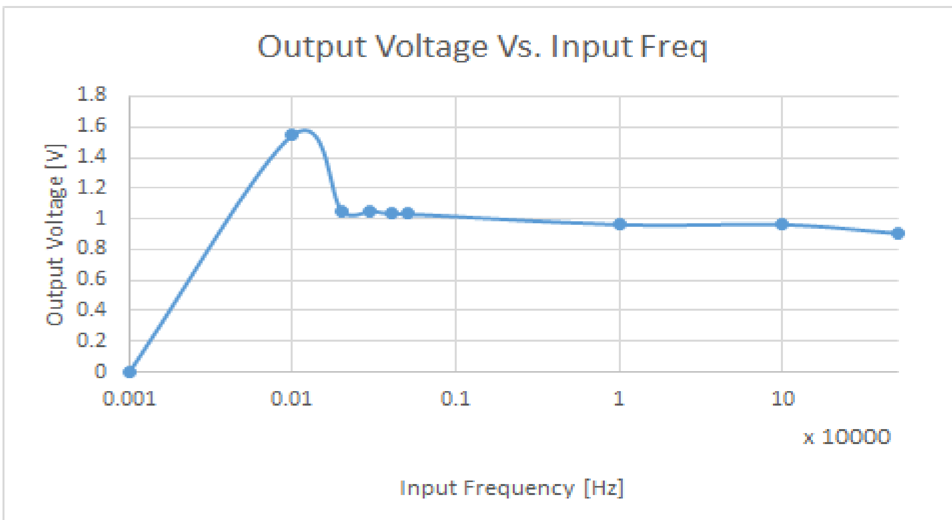

Figure 14 - Vin = 200 mV

Figure 15 - VGA at Low Frequency

VGA with LPF Test:

LPF has cutoff frequency 10Khz and 4.5 gain. We run the test on the board with 100 mV_{p-p}, and Input frequency from 100Hz to 10 KHz. and We found out the cutoff frequency at -3db is around 7400 Hz. Surprisingly, even VGA has some distortion at low frequency range, all distortion is disappear after LPF. **Therefore, overall IF module works perfectly.**

Vin			100[mV]		
$Freq_{in}$ (Hz)	Vout[V]	Gain[dB]	$Freq_{in}$ (Hz)	Vout[V]	Gain[dB]
100	4.36	32.78973	4900	3.88	31.77663
500	4.56	33.1793	6000	3.8	31.59567
600	4.56	33.1793	6100	3.72	31.41086
900	4.44	32.94766	6800	3.56	31.029
1000	4.44	32.94766	7600	3.48	30.83158
2100	4.36	32.78973	7700	3.32	30.42276
3800	4.1	32.25568	8200	3.16	29.99374
3900	4.1	32.25568	9100	3.08	29.77101
4400	4.04	32.12763	10000	2.84	29.06637
4800	3.96	31.9539			

Table 4 - IF Module Data

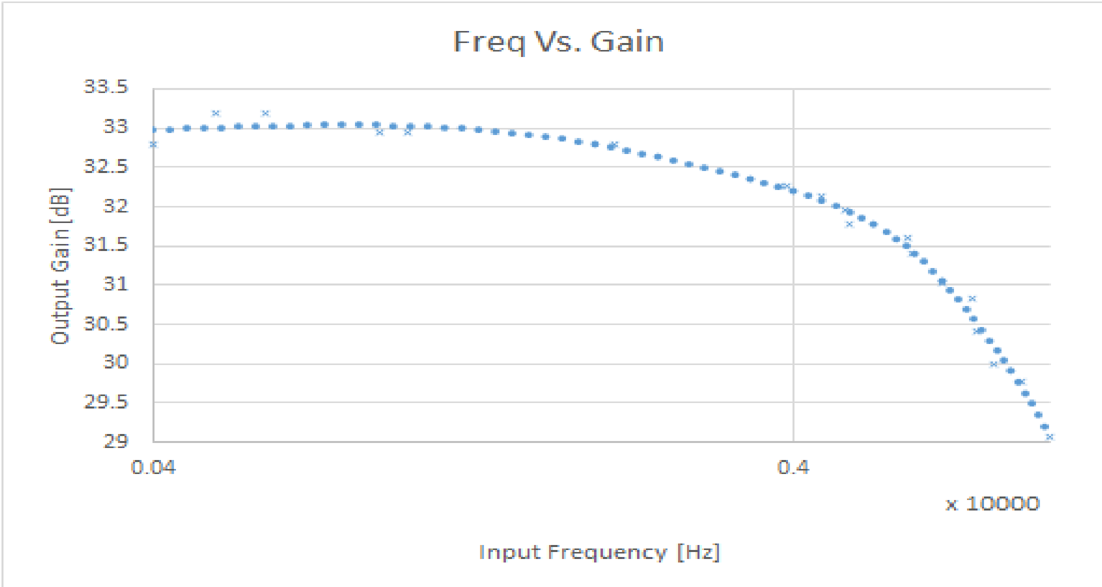

Figure 16 - LPF Gain

Regulator (LM1086) Test:

The following data is for regulator LM1086. As a result, we found out the output voltage will consistently remained as 4.99V after the input voltage became 6V. Furthermore, based on the datasheet, When the input voltage is between 6.5V and 20V, the typical values of the output voltage is 5V, and the range of the output voltage is between 4.9V and 5.10V. **Hence the result of testing the regulator is consistent with the datasheet and satisfied our requirement.**

Vin [V]	Vout [V]	Vin [V]	Vout [V]
1.33	0.49	5.06	4.05
2.48	1.49	6.03	4.99
2.73	1.73	7	4.99
3.55	2.55	7.5	4.99
4.91	3.89		

Table 5 - Regulator Test

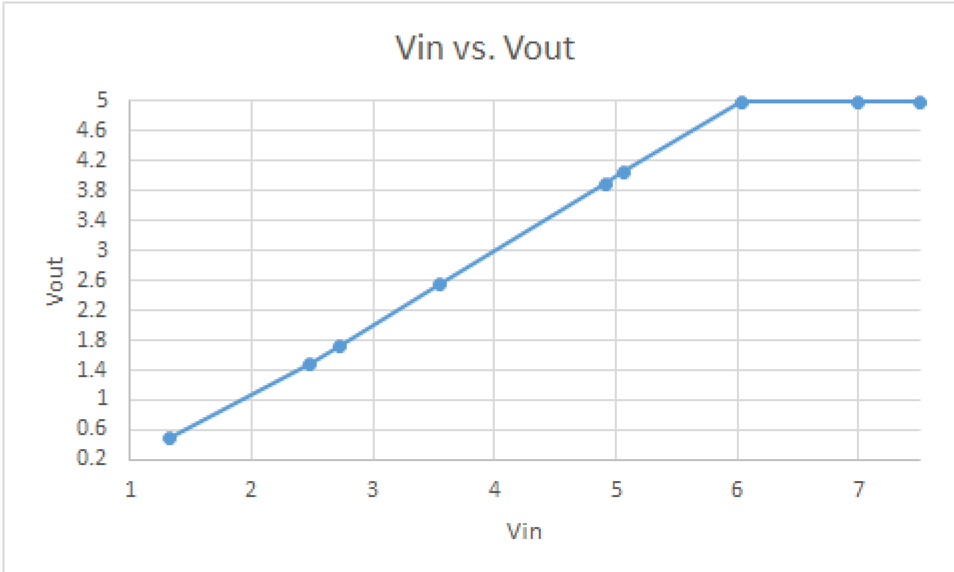

Figure 17

VCO Test:

We run the test on the VCO. According to the performance data on the datasheet, the range of the V_{tune} is between 0V and 5V. First of all, we connected the 5V power to the VCO as a constant Vdd, and then connect it to another power supply as V_{tune}. So we modified the V_{tune} with the corresponding center frequency, and observed the output on the spectrum analyzer. Table 6 shows experimental data. As a result, at the room temperature of 25°C, the center frequency can be modified from 2254.84Hz to 2598.44Hz. Figures 18 and 19 compare spec from data sheet and experimental data. However output power doesn't follow spec. Especially, when the V_{tune} is low, the output power is way too smaller than the spec value. In fact, the range of the Vtune we are going to use for our radar system is from 2.75V to 3.5V. **Therefore performance of VCO will be fine even it has low output power at low Vtune. Overall, we are going to use VCO frequency between 2.45784 GHz and 2.51 GHz. As a result, we found out that the bandwidth of the design is approximate 52.16MHz.**

Vtune (V)	Output (dBm)	Center freq (MHz)	Vtune (V)	Output (dBm)	Center freq (MHz)
0	-1	2254.84	2.75	5.7	2457.84

0.5	3.8	2292.12	3	5.7	2499.48
0.75	4.9	2309.76	3.25	5.7	2493.44
1	4.3	2327.52	3.5	5.9	2510
1.25	5.6	2346.6	3.75	6.2	2527.04
1.5	5.7	2364.92	4	5.6	2543.16
1.75	5.7	2382.76	4.25	5.7	2558.64
2	4.7	2401.65	4.5	5.6	2572.8
2.25	4.7	2421.04	4.75	5.6	2586.3
2.5	5.7	2439.16	5	5.5	2598.44

Table 6 - VCO Test

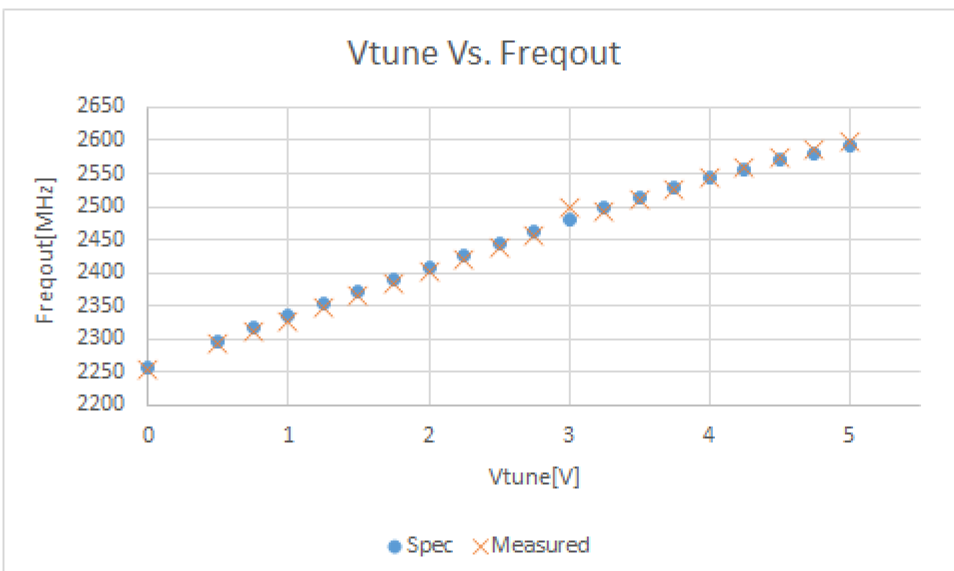

Figure 18 - Frequency Output with Vtune

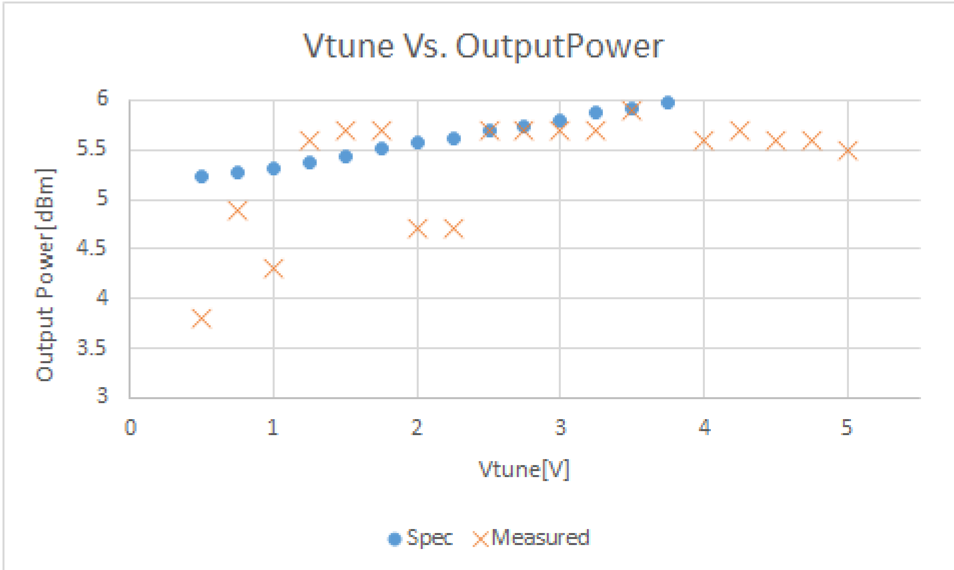

Figure 19 - Output Power with Vtune

Receiving Module test.

Receiving module is consisted with Splitter, RF Amp(for transmitting), RF Amps(for receiving), and mixer. Each receiving RF Amp have switch to control two states which are by-pass, and amplifier. As you can see the Table 7, the receiving module works. Since synthesizers are not calibrated correctly, even frequency of two synthesizer are the same, IF signal is around 1KHz. Vp-p for IF signal is way too high than I expected. To reduce IF signal power, I should turn off one of the receiving amp. However, when I turn off all three receiving amps, IF signal is just vanished. Moreover, when If signal is less than 100mV, we can boost IF signal by turning on one more receiving amp. However, when we turn on three receiving amp, IF signal also vanished or IF signal Vp-p isn't increased correctly. Figure 20 shows one of data.

Receiving AMP			**Synthesizer 1**		**Synthesizer 2**		**IF Signal**	
1	**2**	**3**	**Freq (Khz)**	**Power (dbm)**	**Freq (Khz)**	**Power (dbm)**	**Freq (hz)**	**Vp-p (mV)**
off	**off**	**on**	**2500**	**5**	**2500**	**8**	**939.2**	**962**
off	**off**	**on**	**2500**	**5**	**2500**	**7**	**945.2**	**1002**

off	off	on	2500	5	2500	6	912.8	1004
off	off	on	2500	5	2500	5	909.6	1004
off	off	on	2500	5	2500	4	920	1009
off	off	on	2500	5	2500	3	919	1008
off	off	on	2500	5	2500	2	909	984
off	off	on	2500	5	2500	1	927	928
off	off	on	2500	5	2500	0	931.5	846
off	off	on	2500	5	2500	-1	920	768
off	off	on	2500	5	2500	-2	932	528
off	off	on	2500	5	2500	-3	909	292
off	off	on	2500	5	2500	-4	670	272
on	off	off	2500	5	2500	-5	951	436
on	on	off	2500	5	2500	-6	876	300
on	on	off	2500	5	2500	-7	855	300
on	on	off	2500	5	2500	-8	922	264
on	on	off	2500	5	2500	-9	875	240
on	on	off	2500	5	2500	-26	Unstable	50
on	on	off	2500	5	2500	-27	Unstable	36.4
on	on	off	2500	5	2500	-28	Unstable	28
on	on	off	2500	5	2500	-29	Unstable	20
on	on	on	2500	5	2500	-30	Unstable	90
on	on	on	2500	5	2500	-31	906	82

Table 7 -Receiving Module Test

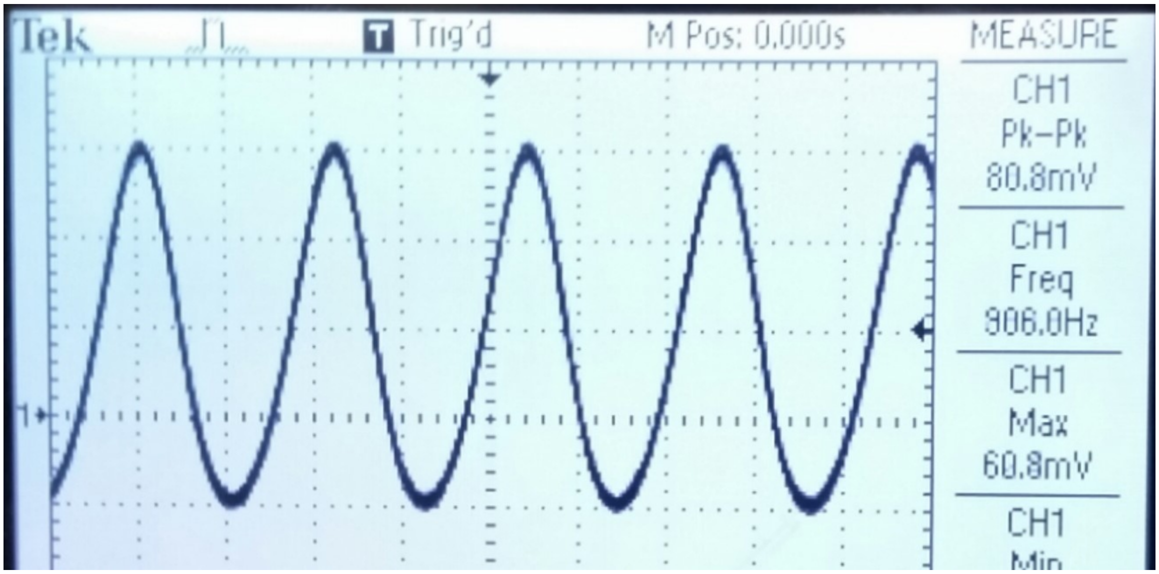

Figure 20 - 3 Amps on

Power Dispassion Analysis:

Since our voltage regulator can handle up to 3A, our PCB design works fine consider of power consumption.

Components	Internal Power Dispassion (W)
Low noise amplifiers, TQL9044	70 mA
Power amplifier ADL5545	56 mA
RF mixer, HMC915LP4	117 mA
VGA AD8367	250 mA
Low Pass Filter OPA2337	10 mA
Teensy 3.1	50 mA
Total	720 mA

Table 8 - Power consumption

Microcontroller Test

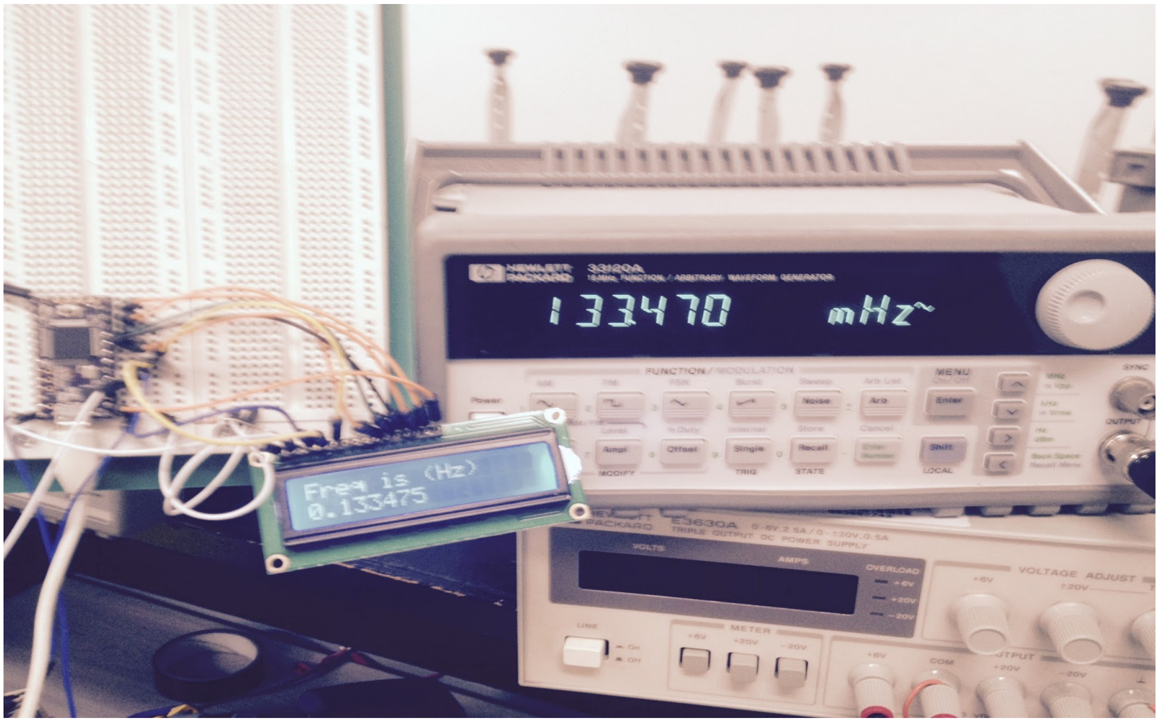

Figure 21 - The result of Teensy

The digits can be displayed is six decimal place. The FreqMeasure library works well for sine, triangle, and square wave. To process DSP, the analog signal IF signal from LPF need to be at least 3.5 $V_{p\text{-}p}$. We collected three different frequency input signals. The datas we measure are shown below. Figures 22, 23, and 24 shows DSP processing.

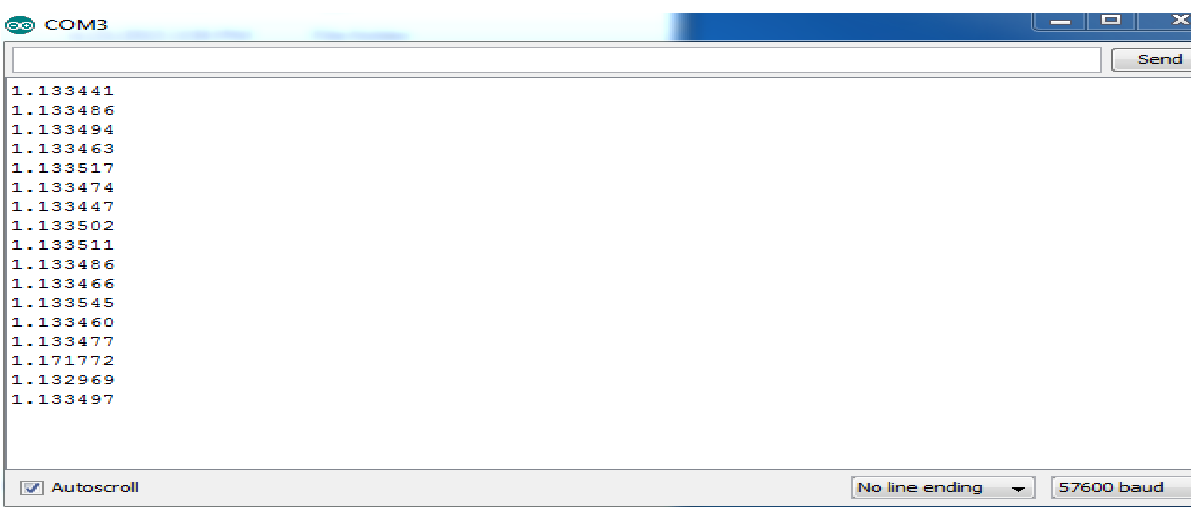

Figure 22 - 1.13347 Hz; 3.5 $V_{p\text{-}p}$ sine wave

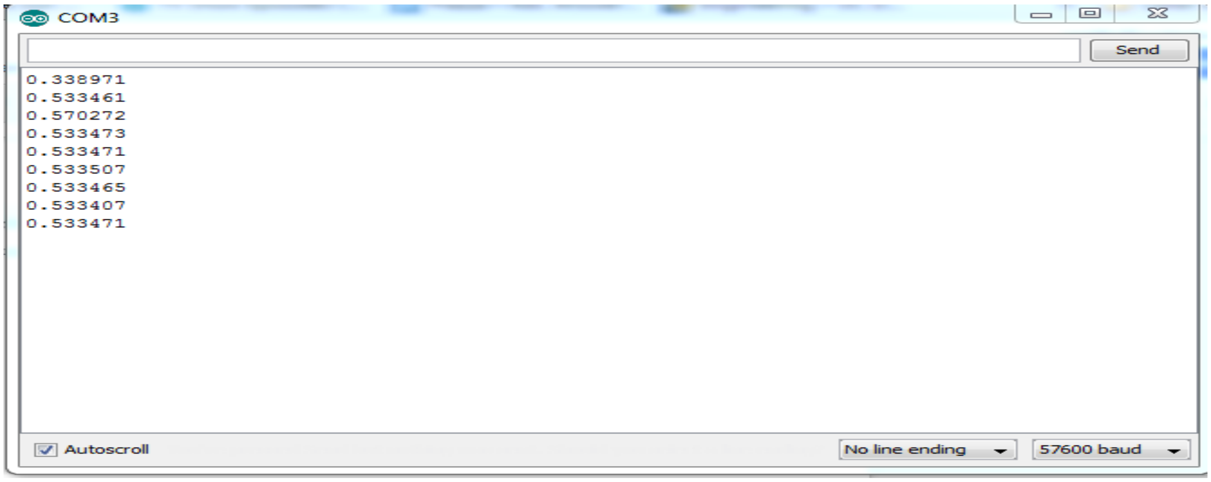

Figure 23 - 0.533470 Hz; 3.5 V_{p-p}; square wave

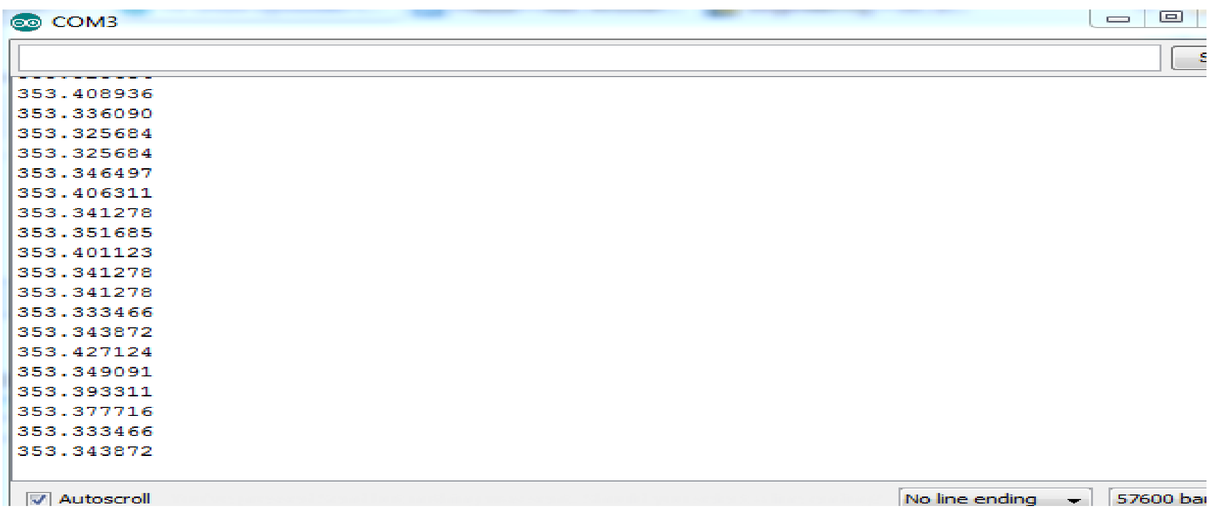

Figure 24 - 353.347 Hz; 3.5 V_{p-p} triangle wave

Also, Teensy 3.1 has 12 bits DAC. We used it to generate the triangle wave. The maximum output voltage is created by the stable reference voltage (3.5 V), so it's doesn't vary if your power supply voltage changes slightly. The maximum frequency of the triangle wave is 222.23 kHz. The minimum frequency is 68.32 Hz.

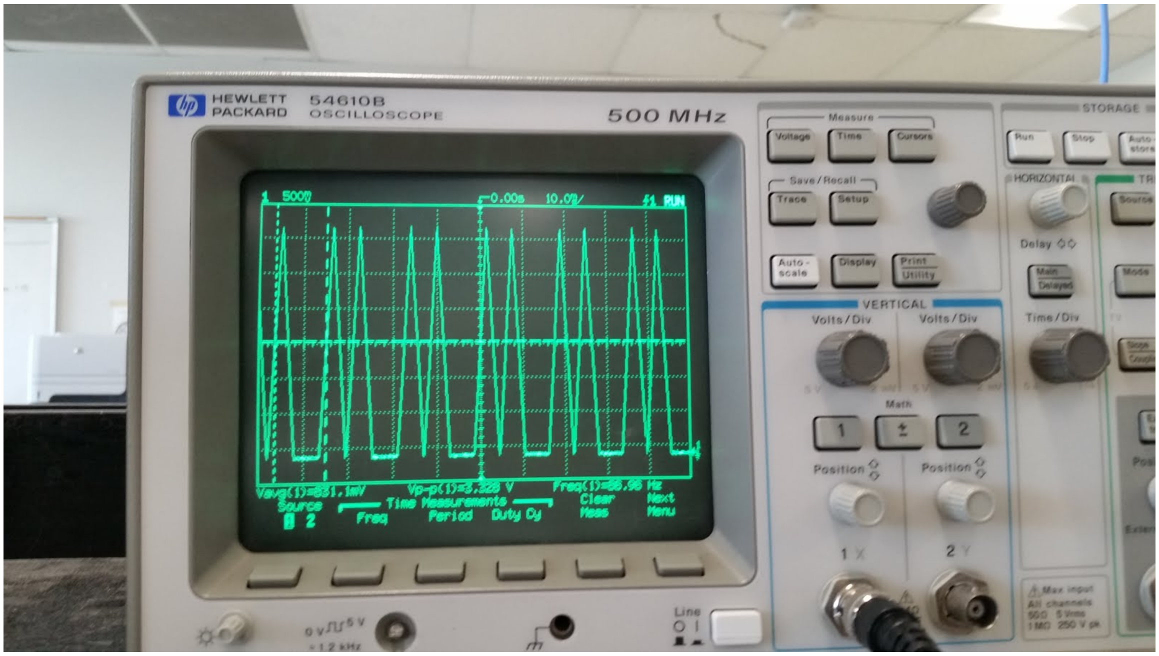

Figure 25- 3.5 V; f_{min} = 66.32Hz; triangle wave

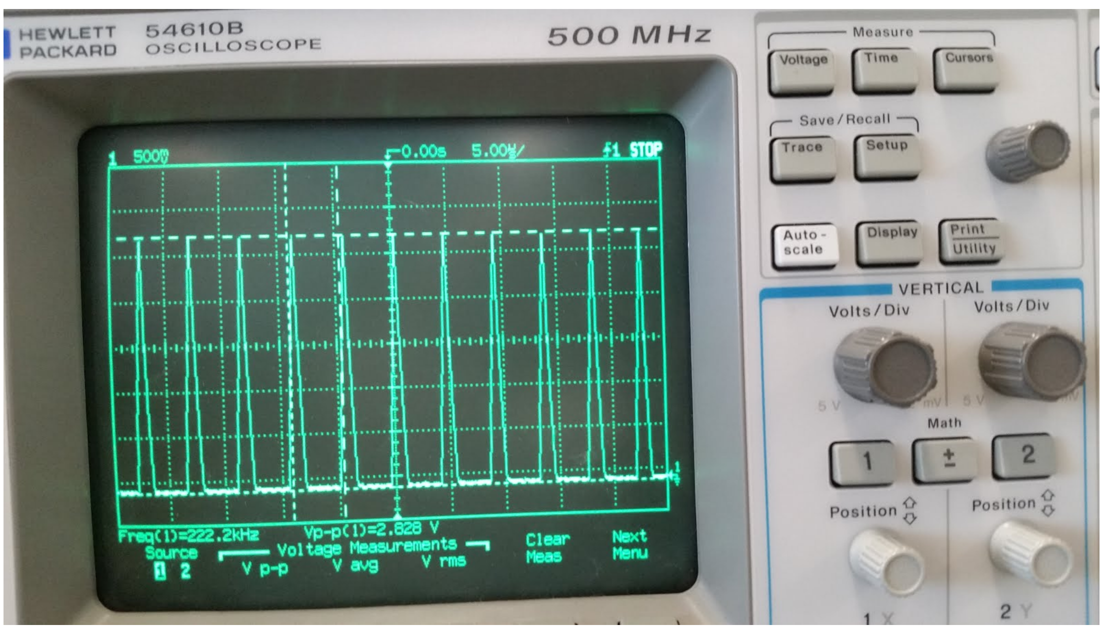

Figure 26 - f_{max} = 222.2kHz triangle wave

The analysis of code

We used a loop to generate a continuously triangle wave. The variable "val" can determine the resolution of the triangle way. Since the analog output of teensy 3.1 has 12 bits DAC, the maximum value of "val" is 2^12 = 4096. When the increment of "val" is one, the board can generate a minimum frequency 68 Hz. As we increase the increment of the “val”, the frequency of the triangle wave will be increased as the resolution of the triangle wave decreases.

This is an example of the code for generating the triangle wave.

“void loop() {   for (int val = 0; val < 4096;){
  val = val + 128;
analogWrite(A14, (int)val);}
for (int val = 4096; val >0;){
  val = val - 128;
analogWrite(A14, val);}”

When we set the increment of the “val” equal to 128, the frequency of triangle wave is 20 kHz. We used the library named “FreqMeasure” of Teensy 3.1 to processing the input signal. The library requires the input frequency as a digital level signal on the pin 3. The reliable interval of frequency which can be measured is within 0.01 Hz to 100 kHz. After we included the FreqMeasure library, we used a while loop to keep this program work continuously. The command “FreqMeasure.read()” can read frequency of the input signal. In order to improve the accuracy of the result, the variable “ sum” is used to cumulate 30 datas. The average frequency of the 30 datas will be displayed on the LCD.

```
while (FreqMeasure.available()) {
  // average several reading together
  sum = sum + FreqMeasure.read();
  count = count + 1;
  if (count > 30) {
    float frequency = FreqMeasure.countToFrequency(sum / count);
    sum = 0;
    count = 0;
    lcd.setCursor(0,0);
    lcd.print("Freq is (Hz)");
    lcd.setCursor(0,1);
    lcd.print(frequency,6);
    delay(1000);
```

Figure 27 - Code for Frequency Measure

As Figure 25 and Figure 26 shows above, there are straight lines between two triangle waves. Because, the triangle wave and frequency measure were written into the same loop. the straight line demonstrates the gap of processing time between the triangle wave and frequency measure. If we increase the increment of the “val”, the triangle wave will be generated faster. Hence, the straight line will be longer. Even though there are gaps exit, the triangle wave still can use as an output signal. Because the method of the teensy 3.1 for measuring frequency is counting the average frequency of one cycle of the signal. The gap didn't affect the result much. Hence, we still can use one teensy board to measure.

Overall Test Result

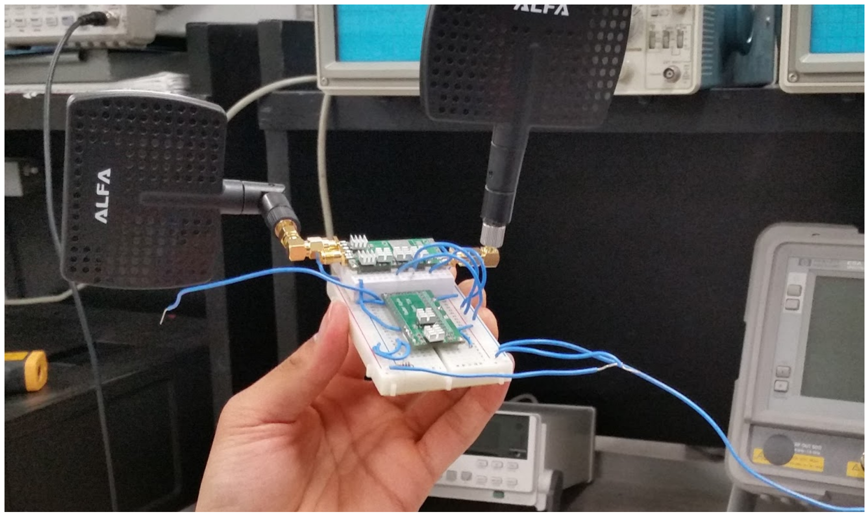

Figure 28 - Full Demonstration of the Design

After running several tests on individual module, we connect two module(RF module and IF module) and Teensy 3.1. Figure 28 shows complete system of radar. One time, overall system looks like work. Especially, doppler effect test was shows some clean sinusoidal wave when we move object in front of antenna. However result is not good enough to test field test. For distance detection, the system has problem. Somehow our IF signal contain triangle signal from Teensy instead of signal from antenna. To debug this problem, we look at the spectrum analyzer of VCO signal. When IF signal is in working range(It means that IF signal is less than 10 KHz), VCO get some feedback signal from circuit. This unwanted feedback causes output frequency VCO too noisy.

Improvement

VCO

To get accurate IF signal, VCO should have minimum noisy. Using PLL is best for reducing noise from anywhere. Also to isolate feedback from RF module it would be better to use circulator.

2. RF AMP

Using 3 amplifier in a row was mistake. The reason is that it is hard to debug. and the amplifier we used in our design was too small to place correctly. To educational purpose it would be better use IC chip with leg. Also make independent PCB. It will be easy to debug.

3. Power AMP

Our output power was lower than our expected. It might be due to signal loss on PCB board. To educational purpose, there is no restriction for output power. Therefore, it would be better to use super high gain Power amp for transmitting signal.

4. Directional Antenna

Even though our antenna is directional and good S11 spec, there is always better to use antenna with more directional and better S11 spec. Also using small IC, overall PCB is small. Then some signal from transmitting antenna could straight back to receiving antenna instead of bouncing from the object. Therefore, high directional antenna is necessary when PCB is getting smaller.

5. Passive Parts

I should pay attention to quality of Passive part. Especially, Female pin header cause lots of problem while we test design. Also, soldering with cheap quality passive parts was digester. We should buy high quality component for removing frustrating problem. It makes us waste too much time.

Conclusion

It was a very good opportunity and experience to work on a big project. Most things we touched were new to us, such as PCB design, PCB review, datasheet review, teensy coding, and choosing and buying components. Within all the discussions and problem solving, we overcame the difficulties that came to us and learned the lessons to move on for more challenges. Although our final project was not working as it should be, the effort and time we spent on this project were not a waste. Indeed, by working on this project, every member in our group had gained knowledge and skills in engineering.

Bill of Materials

	Manufacturer Part #:	Mouser Part #:	Description:	Price($)	na	Price
Capacitor	06035A101JAT2A	581-06035A101J	100pF 5% C0G	0.01	100	1
Capacitor	GRM188R61E105KA12D	81-GRM188R61E105KA12	1uF 25volts X5R 10%	0.026	10	0.26
Capacitor	GRM188R71E104JA01J	81-GRM188R71E104JA1J	SMD/SMT 0.1uF 25Volts X7R 5%	0.047	10	0.47
Capacitor	GRM1885C1H271JA01D	81-GRM39C271J50	SMD/SMT 0603 270pF 50volts C0G 5%	0.05	10	0.5
Capacitor	GRM1885C1H911JA01D	81-GRM1885C1H911JA1D	SMD/SMT 910pF 50Volts C0G 5%	0.067	10	0.67
Capacitor	GRM1885C1H152JA01J	81-GRM185C1H152JA01J	SMD/SMT 0603 1500pF 50volts C0G 5%	0.045	10	0.45
Capacitor	GRM188R71H103JA01D	81-GRM18R71H103JA01D	SMD/SMT 0603 0.01uF 50volts X7R 5%	0.031	10	0.31
Capacitor	GRM319R6YA106KA12D	81-GRM319R6YA106KA2D	SMD/SMT 1206 10uF 35volts X5R + - 10%	0.145	10	1.45
Capacitor	GRM188R61A106KE69D	81-GRM188R61A106KE9D	SMD/SMT 0603 10uF 10volts X5R + - 10%	0.125	10	1.25
Capacitor	GRM1885C1H102JA01D	81-GRM39C102J50	SMD/SMT 0603 1000pF 50volts C0G 5%	0.025	10	0.25
Capacitor	GRM1885C1H222JA01J	81-GRM1885C1H222JA1J	SMD/SMT 2200pF 50Volts 5%	0.084	10	0.84
Inductor	ELJ-RE18NGFA	667-ELJ-RE18NGFA	Fixed Inductors 0603 18nH 2% 450mohm 350mA	0.122	10	1.22
Inductor	LQW18AN24NG00D	81-LQW18AN24NG00D	Fixed Inductors 0603 24nH +/-2% DCR 0.21ohm	0.252	10	2.52
Inductor	LQG18HNR10J00D	81-LQG18HNR10J00D	Fixed Inductors 0603 AIR CORE .1uH 5% TOL	0.17	10	1.7
Resistor	ERJ-3EKF3902V	667-ERJ-3EKF3902V	Thick Film Resistors - SMD 0603 39Kohms 1% Tol	0.009	100	0.9
Resistor	ERJ-3EKF1002V	667-ERJ-3EKF1002V	Thick Film Resistors - SMD 0603 10Kohms 1% Tol	0.009	100	0.9
Resistor	ERJ-3EKF2612V	667-ERJ-3EKF2612V	Thick Film Resistors - SMD 0603 26.1Kohms 1% Tol	0.008	100	0.8
Resistor	ERJ-3EKF1003V	667-ERJ-3EKF1003V	Thick Film Resistors - SMD 0603 100Kohms 1% Tol	0.009	100	0.9
Resistor	ERJ-3EKF3242V	667-ERJ-3EKF3242V	Thick Film Resistors - SMD 0603 32.4Kohms 1% Tol	0.008	100	0.8
Resistor	ERJ-3EKF57R6V	667-ERJ-3EKF57R6V	Thick Film Resistors - SMD 0603 57.6ohms 1% Tol	0.009	100	0.9
Resistor	ERJ-3EKF1740V	667-ERJ-3EKF1740V	Thick Film Resistors - SMD 0603 174ohms 1% Tol	0.008	100	0.8
Resistor	ERJ-3GEYJ4R7V	667-ERJ-3GEYJ4R7V	Thick Film Resistors - SMD 0603 4.7ohms 5% Tol	0.008	100	0.8
Resistor	ERJ-3EKF1000V	667-ERJ-3EKF1000V	Thick Film Resistors - SMD 0603 100ohms 1% Tol	0.009	100	0.9
Resistor	ERJ-3EKF9761V	667-ERJ-3EKF9761V	Thick Film Resistors - SMD 0603 9.76Kohms 1% Tol	0.008	100	0.8
Resistor	ERJ-3EKF1622V	667-ERJ-3EKF1622V	Thick Film Resistors - SMD 0603 16.2Kohms 1% Tol	0.008	100	0.8
Resistor	ERJ-3EKF3572V	667-ERJ-3EKF3572V	Thick Film Resistors - SMD 0603 35.7Kohms 1% Tol	0.008	100	0.8
Resistor	ERJ-3EKF2261V	667-ERJ-3EKF2261V	Thick Film Resistors - SMD 0603 2.26Kohms 1% Tol	0.008	100	0.8
Resistor	ERJ-3EKF7871V	667-ERJ-3EKF7871V	Thick Film Resistors - SMD 0603 7.87Kohms 1% Tol	0.008	100	0.8
Resistor	ERJ-3EKF8661V	667-ERJ-3EKF8661V	Thick Film Resistors - SMD 0603 8.66Kohms 1% Tol	0.008	100	0.8
Antenna			ALFA 2.4HGZ 7DBI	10	2	20
LCD			16 X 2, 1602 WHITE ON BLUE	10	1	10
RF Adapter			RIGHT ANGLE RP-SMA Adapter	11	1	11
RF Adapter			Right Angle RF Adapter	10	1	10
Heat Sink			20 PCS HEATSINKS	7	1	7
MCU			TEENSY 3.1 WITH PINS	30	1	30
Filter	FI168B250065-T	963-FI168B250065-T	BANDPASS FLTR HI FREQ MULTILYR	0.71	1	0.71
IC	TQL9044	772-TQL9044	RF Amplifier 1.5-4.0GHz LNA NF .6dB Gain 19.4dB	6.64	12	79.68
IC	HMC915LP4E	584-HMC915LP4E	RF Mixer mix DBL LO Amp 0.5-2.4GHz	15.53	4	62.12
IC	OPA2171AIDR		IC OPAMP GP 3MHZ RRO 8SOIC	1.72	3	5.16
Adapter	132171RP	523-132171RP	RF Adapters	5.82	2	11.64
Pin	22-28-8020	538-22-28-8020	Headers	0.24	1	0.24
Pin	4-644456-4	571-4-644456-4	Headers	0.93	2	1.86
				Total($)		274.8
Sample		LM1086CS-5.0	Regulator			
Sample		OPA2337EA	LPF			
Sample		SP-2U2+	SPLITTER			
Sample		AD8367	VGA			

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