Final Report

Team Blip

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Abstract

Build and design a radar system on a limited budget while maximizing accuracy, minimizing overall weight, and minimizing system power consumption.

Design Rules

- Budget of $300
- Target is a $0.3 * 0.3 \ m^2$ metal plate
- Be able to measure the target from 5 to 50 meters
- Only use commercially available technologies
- Allow for internal inspection of circuitry
- No external signal source (ie. local-oscillator or reference clock signals)
- Must operate at room temperature
- $\text{Score} = P_{DC} * W * \prod_{i \ = \ 1}^{N} \left(\frac{\hat{L}_i - L_i}{L_i} \right)$

Design Details

The design philosophy heading into this project was to base the quarter two radar system on the quarter one radar system and make simple but effective improvements. Simplicity of the system design was prioritized in the interest of good time management. Simplicity of the radar system minimizes the time required for the design phase without sacrificing quality which allows for a longer testing phase. A long testing phase allows for proper debugging and optimization of the radar system which ultimately has the largest impact on the competition score.

Component Selection

The component selection process of the radar system started with a systems level layout of the system in the form of a block diagram.
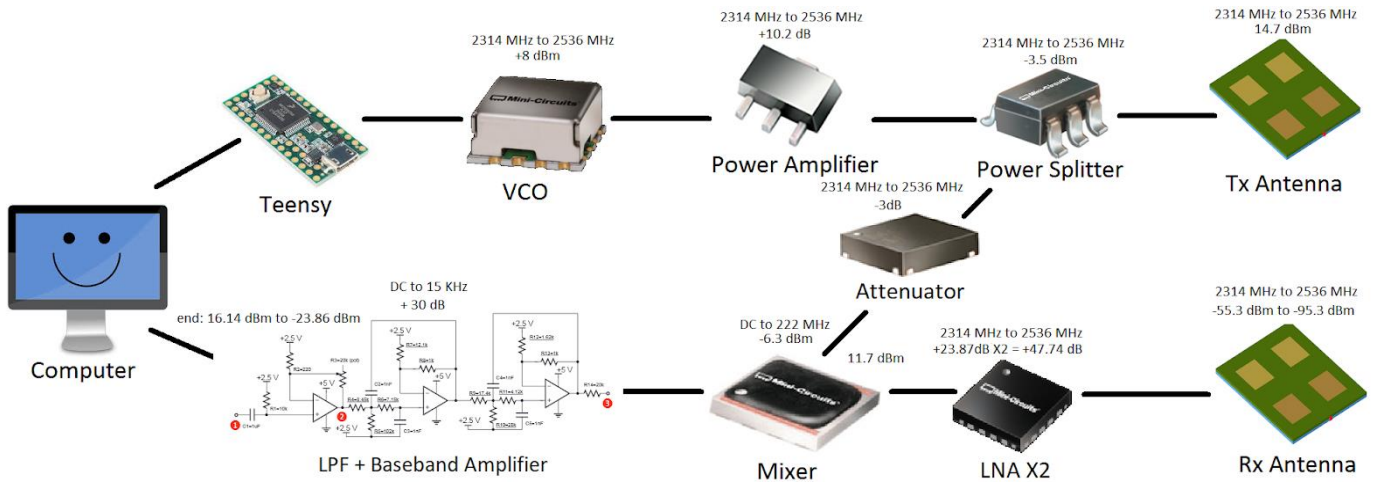
Fig 1. Radar System Block Diagram

To keep the radar system simple, the baseband portion of the radar system was kept the same as the quarter one system. The bulky SMA RF components from the quarter one radar system were replaced by surface mount equivalents, which drastically reduces the weight of the overall system. A RF block chain analysis program called ADIsimRF was utilized to calculate the power level at each stage as shown in the block diagram as well as other parameters.
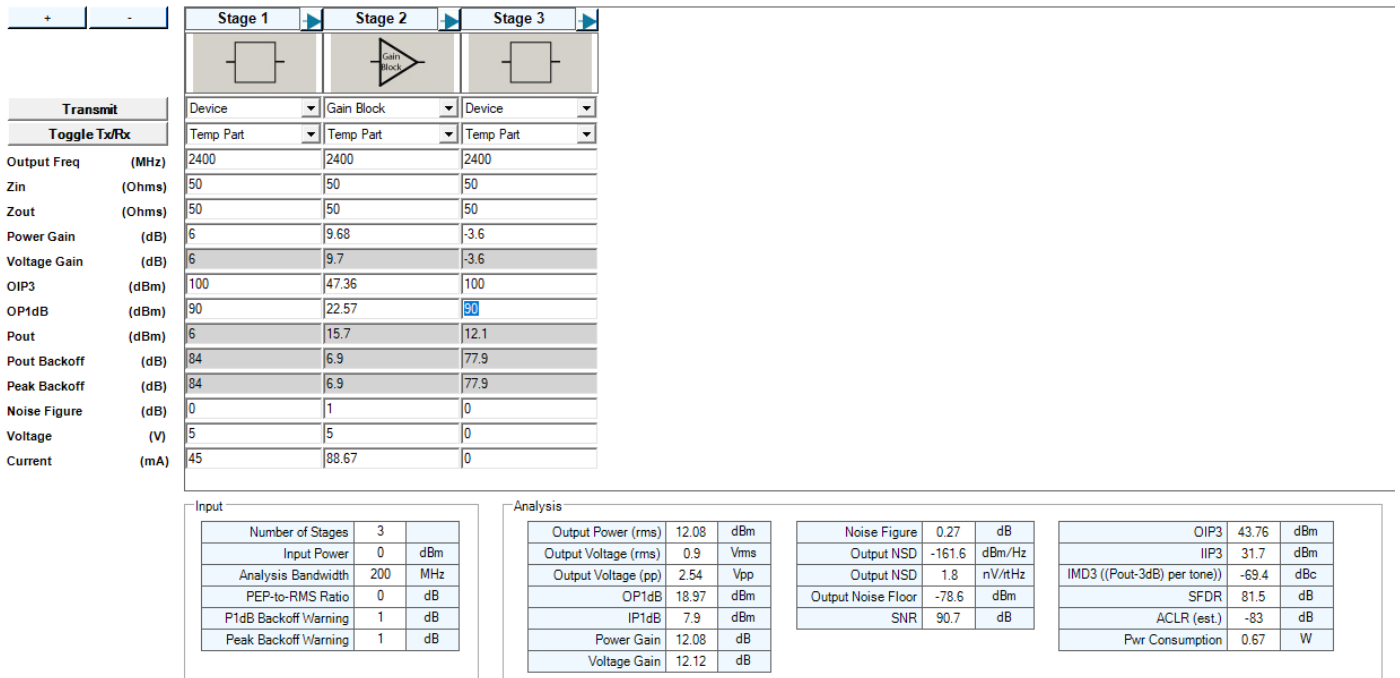

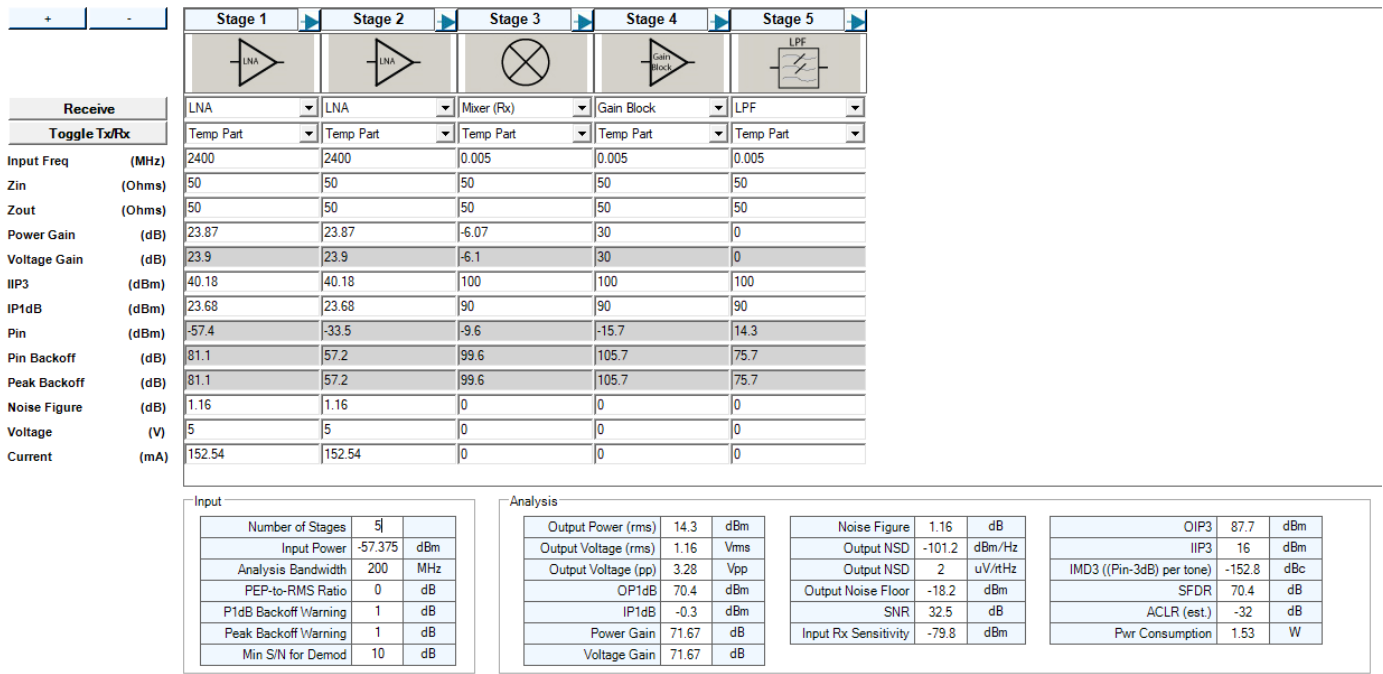
Fig 2. Transmitter ADIsimRF Analysis

Fig 3. Receiver ADIsimRF Analysis

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
		LNA	LNA	Mixer (Rx)	Gain Block	LPF
		Temp Part	Temp Part	Temp Part	Temp Part	Temp Part
Input Freq	(MHz)	2400	2400	0.005	0.005	0.005
Zin	(Ohms)	50	50	50	50	50
Zout	(Ohms)	50	50	50	50	50
Power Gain	(dB)	23.87	23.87	-6.07	30	0
Voltage Gain	(dB)	23.9	23.9	-6.1	30	0
IIP3	(dBm)	40.18	40.18	100	100	100
IP1dB	(dBm)	23.68	23.68	90	90	90
Pin	(dBm)	-57.4	-33.5	-9.6	-15.7	14.3
Pin Backoff	(dB)	81.1	57.2	99.6	105.7	75.7
Peak Backoff	(dB)	81.1	57.2	99.6	105.7	75.7
Noise Figure	(dB)	1.16	1.16	0	0	0
Voltage	(V)	5	5	0	0	0
Current	(mA)	152.54	152.54	0	0	0

Input

Number of Stages	5	
Input Power	-57.375	dBm
Analysis Bandwidth	200	MHz
PEP-to-RMS Ratio	0	dB
P1dB Backoff Warning	1	dB
Peak Backoff Warning	1	dB
Min S/N for Demod	10	dB

Analysis

Output Power (rms)	14.3	dBm
Output Voltage (rms)	1.16	Vrms
Output Voltage (pp)	3.28	Vpp
OP1dB	70.4	dBm
IP1dB	-0.3	dBm
Power Gain	71.67	dB
Voltage Gain	71.67	dB

Noise Figure	1.16	dB
Output NSD	-101.2	dBm/Hz
Output NSD	2	uV/rtHz
Output Noise Floor	-18.2	dBm
SNR	32.5	dB
Input Rx Sensitivity	-79.8	dBm

OIP3	87.7	dBm
IIP3	16	dBm
IMD3 ((Pin-3dB) per tone)	-152.8	dBc
SFDR	70.4	dB
ACLR (est.)	-32	dB
Pwr Consumption	1.53	W

Notable parameters that were of interest included the output power level of the receiver and the P1dB level. The output power level of the receiver was set to a level of approximately 1 Vpp at the 5 meter target range in order to keep within the 1 Vpp max line-in rating for most computer systems. The P1dB level was set to be well above the power level of the system to avoid non-linearity.

Component	Model
Attenuator	GAT-3+
Amplifier	PGA-103+
LNA	PMA4-33GLN+
VCO	ROS-2490+
Mixer	SIM-43LH+
Splitter	SP-2U1+
Bias Tee	TCBT-14+

Table 1. Final Component List

While the original design utilized the ROS-2536C-119+ VCO, it was discovered that the part was out of stock when the order was being placed. The ROS-2490+VCO was substituted in as a replacement. Due to the different power output level of the ROS-2490+ VCO, the GAT-5+ attenuator was replaced by the GAT-3+ attenuator.

Antenna Selection

Another area of improvement to the radar system was to replace the coffee can antennas from the quarter one system with lightweight PCB antennas. Two antenna types, the Yagi PCB antenna and Patch Array PCB antenna, were selected and ordered from Kent Electronics[1]. While both antennas have a similar gain, the Yagi PCB antenna has a higher directivity than the Patch Array PCB antenna. Two of each type of antenna was ordered to mix and match to see which combination of transmitting and receiving antenna produces the best result.
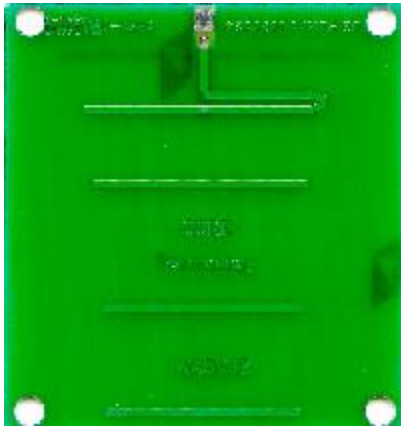
Fig 4. Yagi PC Antenna
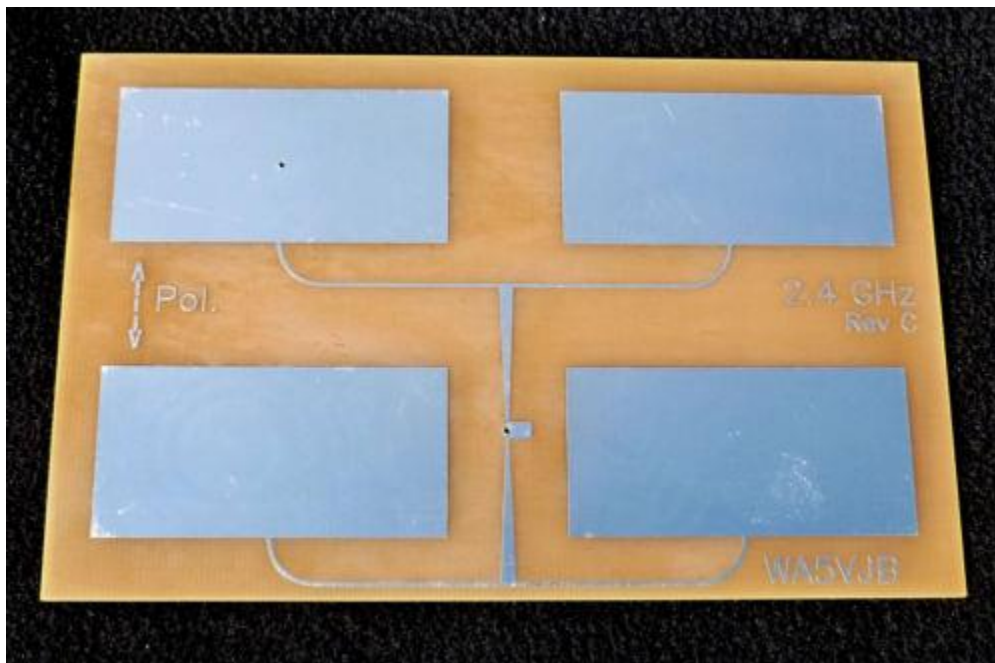
Fig 5. Patch Array PCB Antenna

PCB Design

The PCB was designed to have the baseband and RF subsystems on one board. This decision was made to reduce the profile and size of the overall radar system.
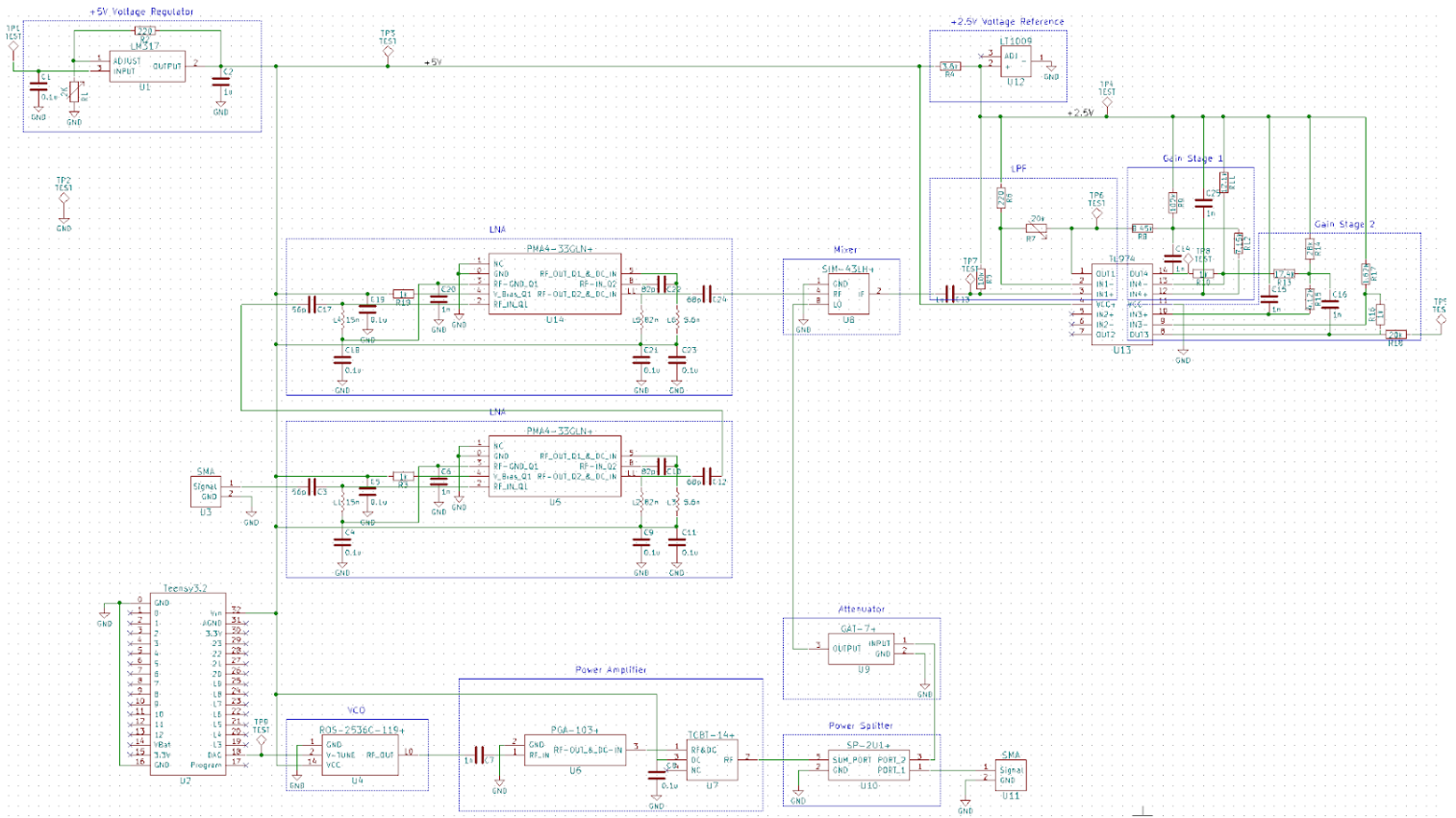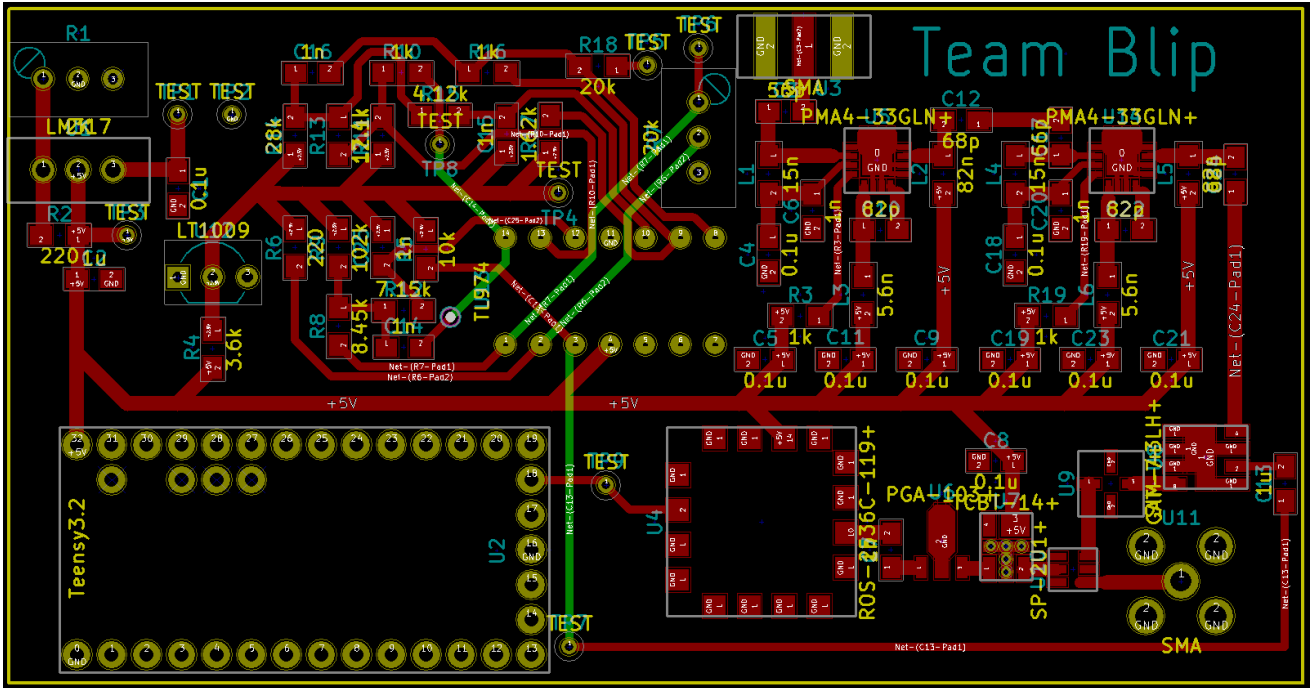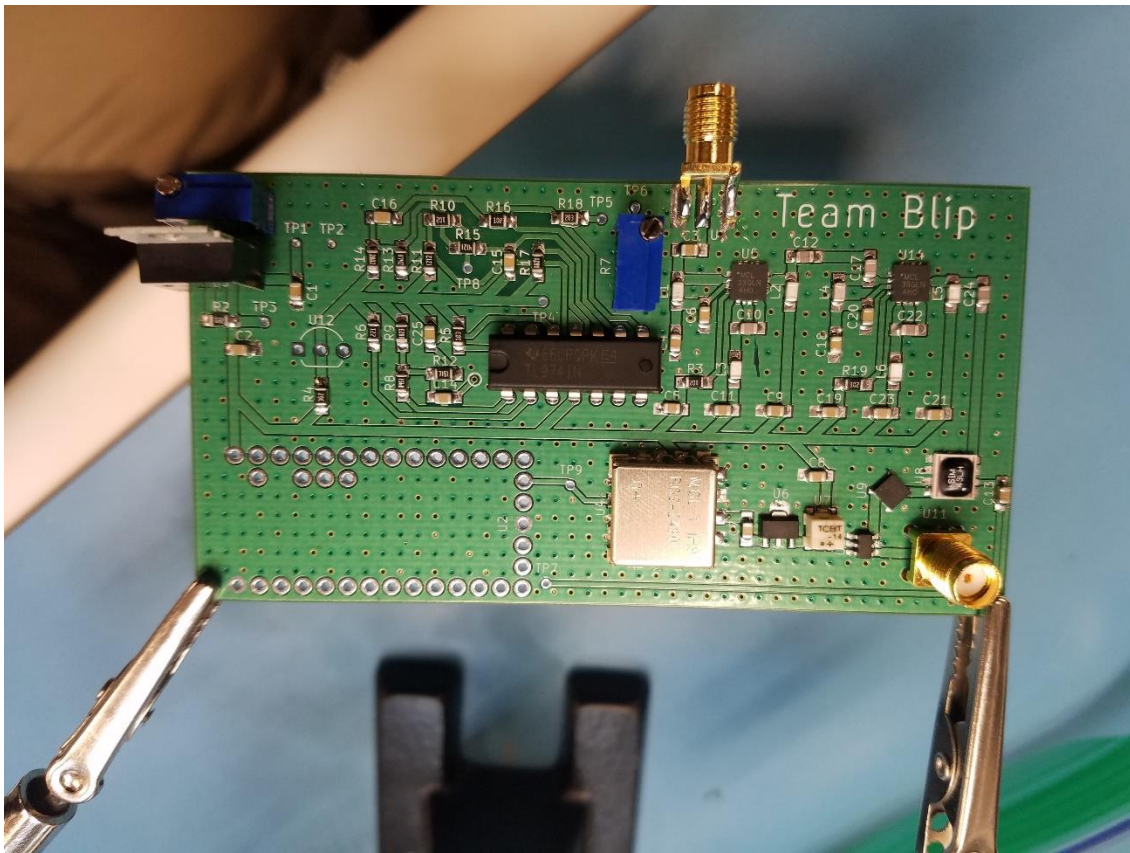
Fig 6. PCB Schematic

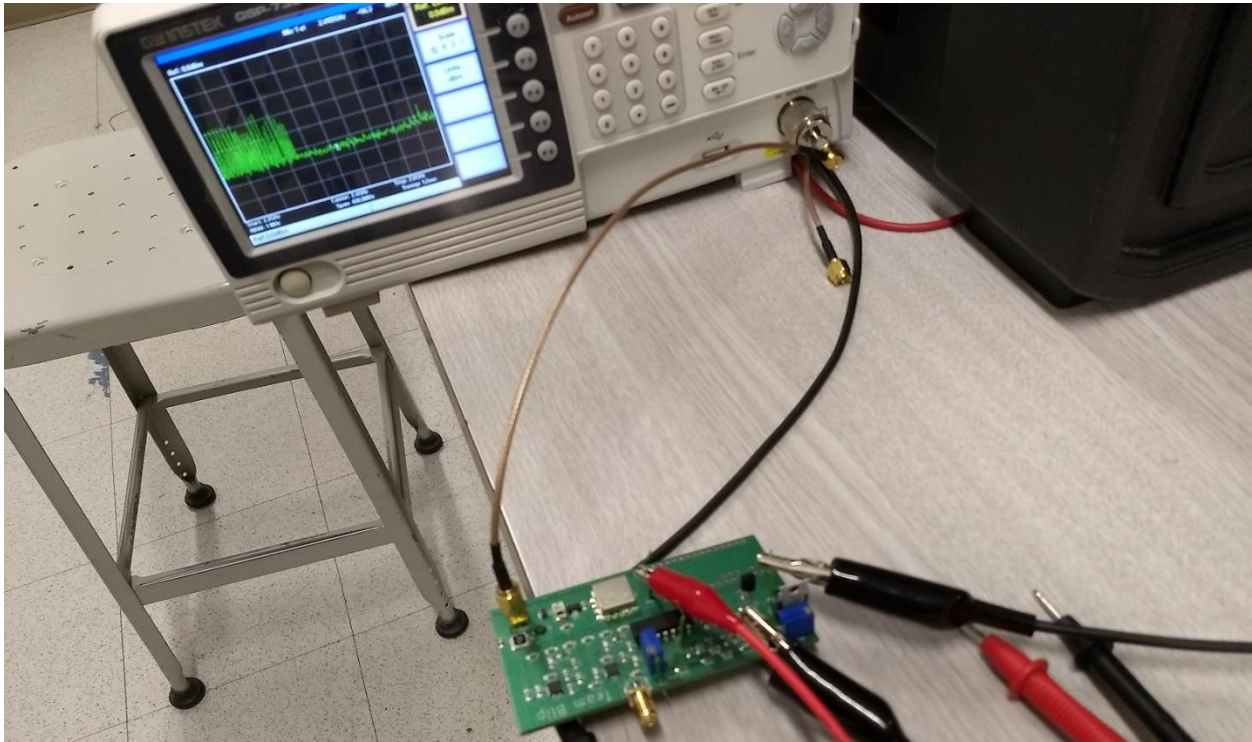Fig 7. PCB Layout

Fig 8. Assembled PCB

Testing
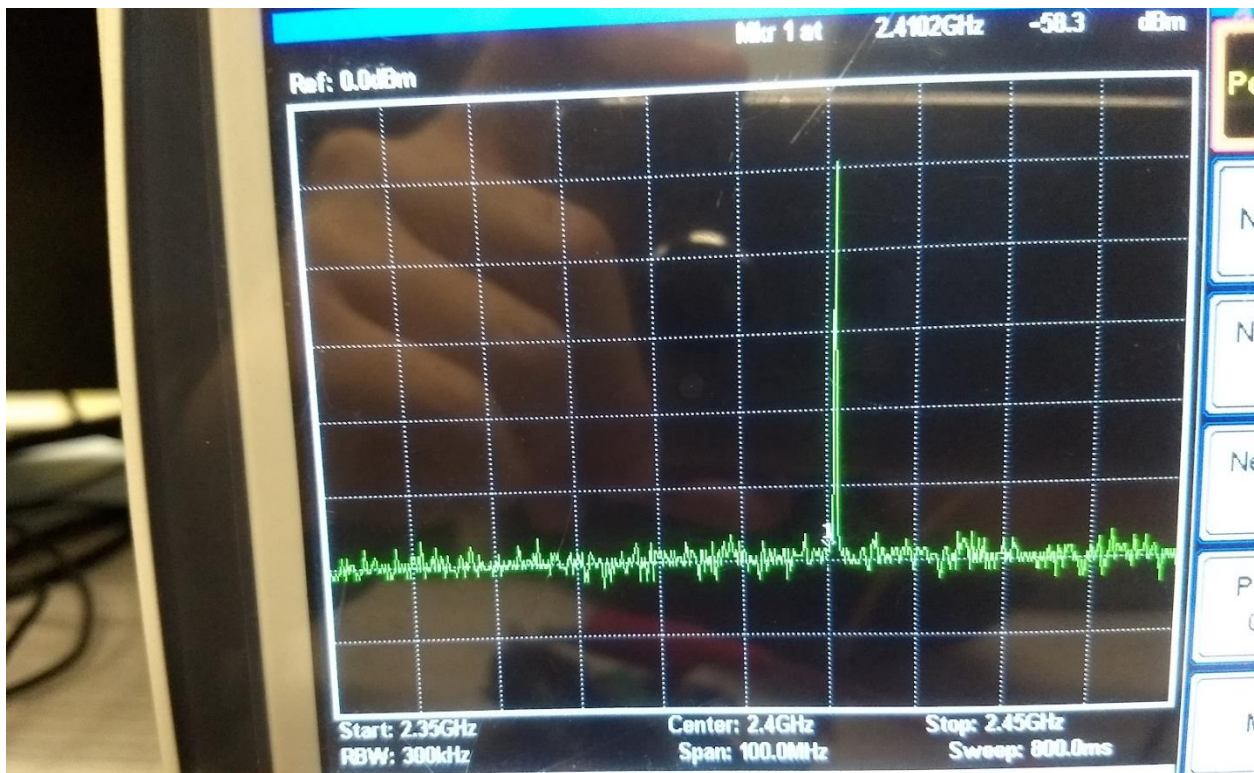

Fig 8. PCB Test Setup

Fig 9. Transmitter Test Results

After assembling the PCB and doing some preliminary testing, it was discovered that the transmitter was operating at the correct frequency but was outputting an incorrect power level of around -10 dBm compared to the expected 8 dBm. Initially, the problem was attributed to the assembly of the PCB. However after closer analysis, it was observed that the radar system was drawing the correct amount of power indicating that the components on the PCB were working and soldered correctly. Due to the complexity in diagnosing and addressing this problem and the competition being two weeks away, the decision was made to forgo the PCB and move on with the quarter one radar system.
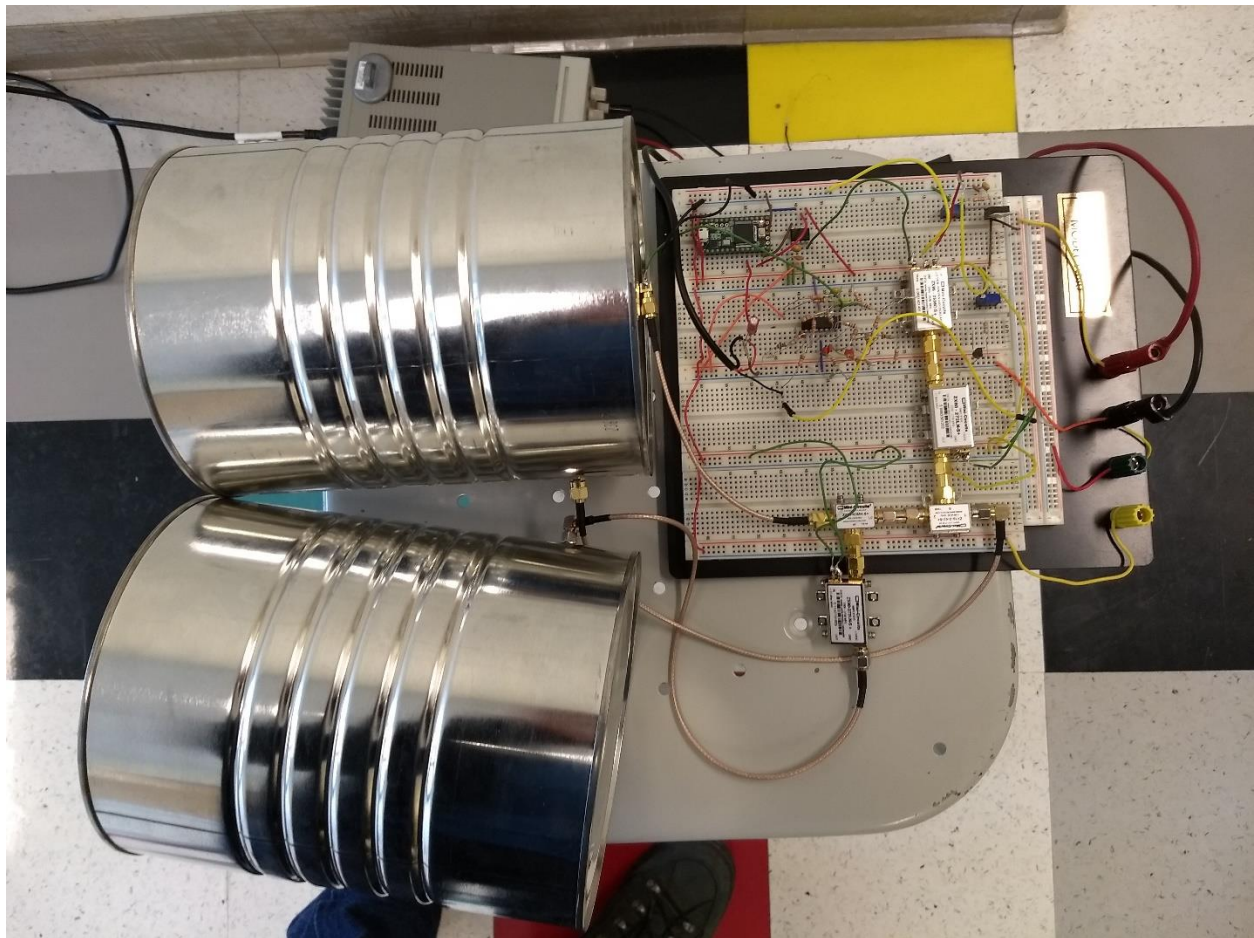

Fig 10. Assembled Quarter One Radar System

At this point, tests were conducted on the PCB antennas. The test results of the PCB antennas were inconsistent with the gain of the antennas fluctuating during the test. This issue was most likely caused by the shaky connection from the cable to the antenna. The 142 cable used for the antennas was heavy and the connection between the cables and the antennas were at singular points held by drops of solder. Any slight vibration would alter the connection point and affect the insertion loss of the cable, thus causing the gain fluctuations. Due to the

inconsistency of the PCB antennas, the coffee can antennas were selected to be used during the competition.

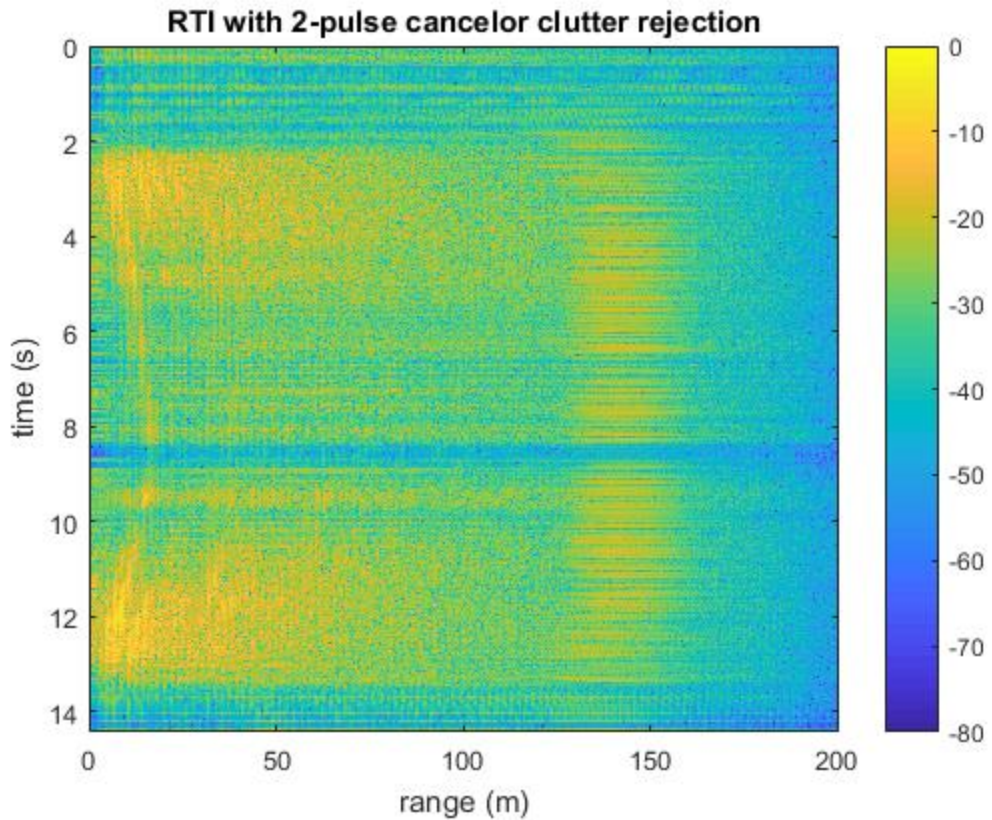Fig 11. Quarter One Radar System Testing

Fig 12. Indoor Testing Results

Tests were conducted indoor with the results displayed above. Due to the noisy environment with signals reflecting off the surrounding walls, the result was a very noise signal. However, a visible border line which indicates the location of the target can be seen. The signal processing was done using MATLAB [A1], which was tested to run faster than the python code.
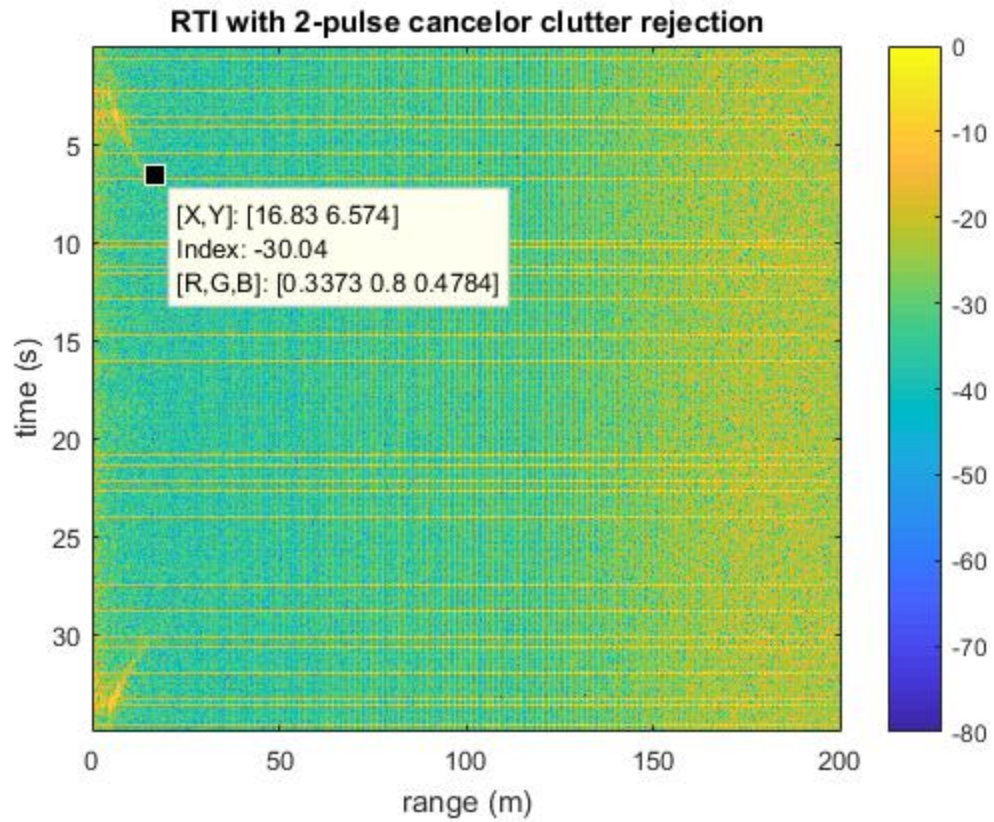
Fig 13. Outdoor Testing Results

Further tests were done after moving outdoors with the results displayed above. Due to the non-reflective environment a cleaner signal was able to be obtained and processed.
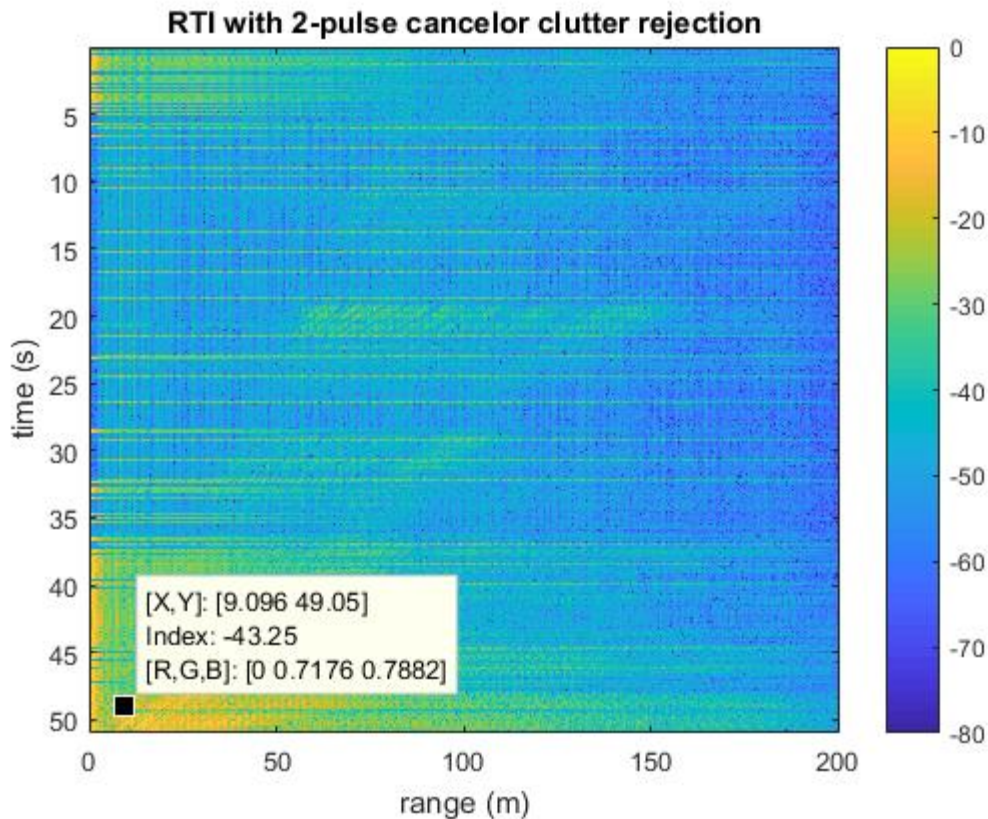
Competition

Fig 14. Competition Results

The competition results are displayed above. While the results were clearer for close distances, at longer distances the results start to fuzz out and was not as sharp as the outdoor testing results. However, values for the five measured distances were able to be obtained by observing the slope of the waveform and scaling the measurements off the closest measurement accordingly. The deviation from the competition and the data obtained during the tests may be attributed to reflection from water droplets as it was raining the day of the competition. Another possible reason would be water unintentionally getting into the system due to the rain and affecting the exposed electronics.

Conclusion

In conclusion, the radar design project was a educational course not only in the technical sense but also in the entire design process. The project taught the process of planning, designing, and testing. The planning process involved drafting a guideline on how to approach the design and covered component

selection. The designing process included the PCB as well as antenna design. Finally, the testing phase involved running the radar system through multiple trials and fixing any issues that came up as well as optimization. Getting familiar with this design process through this project was extremely beneficial as it provides a real life application very similar to that of the product design cycle in the industry.

Suggestions

- While our group designed one single PCB for both the RF and baseband subsystems, we highly recommend designing two PCBs for each subsystem. This would greatly help debug issues that will likely arise.
- Double check with the vendor to make sure that they carry all the components that you plan to use in your design. This would help save you time required should you need to backtrack in your design to make any adjustments.

BOM

Component	Description	Part	Value	Quantity	Unit Price	Total Price
1	Capacitor	C	0.1u	30	$0.028	$0.84
2	Capacitor	C	1000p	21	$0.036	$0.76
3	Capacitor	C	1u	10	$0.046	$0.46
4	Capacitor	C	56p	10	$0.057	$0.57
5	Capacitor	C	68p	10	$0.056	$0.56
6	Capacitor	C	82p	10	$0.057	$0.57
7	Inductor	L	15n	6	$0.16	$0.96
8	Inductor	L	5.6n	6	$0.16	$0.96
9	Inductor	L	82n	6	$0.16	$0.96
10	Resistor	R	1.62k	10	$0.022	$0.22
11	Resistor	R	102k	10	$0.022	$0.22
12	Resistor	R	10k	10	$0.017	$0.17
13	Resistor	R	12.1k	10	$0.022	$0.22
14	Resistor	R	17.4k	10	$0.022	$0.22
15	Resistor	R	1k	12	$0.017	$0.20
16	Resistor	R	20k	10	$0.017	$0.17
17	V Resistor	R_Variable	20k	3	$1.56	$4.68
18	Resistor	R	220	10	$0.017	$0.17
19	Resistor	R	28k	10	$0.022	$0.22
20	V Resistor	R_Variable	2K	3	$1.56	$4.68
21	Resistor	R	3.6k	10	$0.017	$0.17
22	Resistor	R	4.12k	10	$0.022	$0.22
23	Resistor	R	7.15k	10	$0.022	$0.22
24	Resistor	R	8.45k	10	$0.022	$0.22
25	Attenuator	GAT-3+	GAT-3+	3	$2.65	$7.95
28	Amplifier	PGA-103+	PGA-103+	3	$1.99	$5.97
29	LNA	PMA4-33GLN+	PMA4-33GLN+	6	$6.95	$41.70
30	VCO	ROS-2490+	ROS-2490+	3	$25.95	$77.85
31	Mixer	SIM-43LH+	SIM-43LH+	3	$8.05	$24.15
32	SMA Connect	Through Hole	Through Hole	3	$1.94	$5.82
34	Splitter	SP-2U1+	SP-2U1+	3	$0.96	$2.88
35	Bias Tee	TCBT-14+	TCBT-14+	3	$8.45	$25.35
38	Antenna	PCB Patch Array	PCB Patch Array	2	$10.00	$20.00
39	Antenna	Yagi	Yagi	2	$6.00	$12.00
40	Cable	142 Cable	142 Cable	1	$22.00	$22.00
41	Crimp	Cable Crimp	Cable Crimp	1	$8.00	$8.00
42	Battery Holder	8XAA Holder	8XAA Holder	1	$8.00	$8.00
43	SMA Connect	Right Angle	Right Angle	3	$0.00	$0.00
44	Regulator	LM317	LM317	3	$0.00	$0.00
45	2.5 V Reference	LT1009	LT1009	3	$0.00	$0.00
46	Op-Amp	TL974	TL974	3	$0.00	$0.00
47	Microcontroller	Teensy 3.2	Teensy 3.2	1	$0.00	$0.00
	Digikey Shipping+Tax					$7.17
					Total	$286.64

Acknowledgements

Professor Xiaoguang "Leo" Liu

TAs: Songjie Bi, Hind Reggad, Mahmoud Nafe

References

[1] http://wa5vjb.com/

Appendix

[A1] MATLAB Code

```
%MIT IAP Radar Course 20112.5
%Resource: Build a Small Radar System Capable of Sensing Range, Doppler,
%and Synthetic Aperture Radar Imaging
%
%Gregory L. Charvat

%Process Range vs. Time Intensity (RTI) plot

clear all;
close all;

% read the raw data .wav file here
% replace with your own .wav file
[Y,FS] = audioread('comp1.wav');
dbv=@(x) 20*log10(abs(x));

%constants
c = 3E8; %(m/s) speed of light

%radar parameters
Tp = 20E-3; %(s) pulse time
N = Tp*FS; %# of samples per pulse
fstart = 2260E6; %(Hz) LFM start frequency
fstop = 2590E6; %(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 input appears to be inverted
trig = -1*Y(:,1);
s = -1*Y(:,2);
clear Y;
```

```matlab
%parse the data here by triggering off rising edge of sync pulse
count = 0;
thresh = 0;
start = (trig > thresh);
for ii = 100:(size(start,1)-N)
    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
%check to see if triggering works
% plot(trig,'.b');
% hold on;si
% plot(start2,'.r');
% hold off;
% grid on;

%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);
v = dbv(ifft(sif,zpad,2));
S = v(:,1:size(v,2)/2);
m = max(max(v));
imagesc(linspace(0,max_range,zpad),time,S-m,[-80, 0]);
colorbar;
ylabel('time (s)');
xlabel('range (m)');
title('RTI without clutter rejection');

%2 pulse cancelor RTI plot
figure(20);
sif2 = sif(2:size(sif,1),:)-sif(1:size(sif,1)-1,:);
v = ifft(sif2,zpad,2);
S=v;
R = linspace(0,max_range,zpad);
for ii = 1:size(S,1)
    %S(ii,:) = S(ii,:).*R.^(3/2); %Optional: magnitude scale to range
end
S = dbv(S(:,1:size(v,2)/2));
m = max(max(S));
imagesc(R,time,S-m,[-80, 0]);
colorbar;
ylabel('time (s)');
xlabel('range (m)');
title('RTI with 2-pulse cancelor clutter rejection');
```