EEC 134 Final Report

Team TEAM

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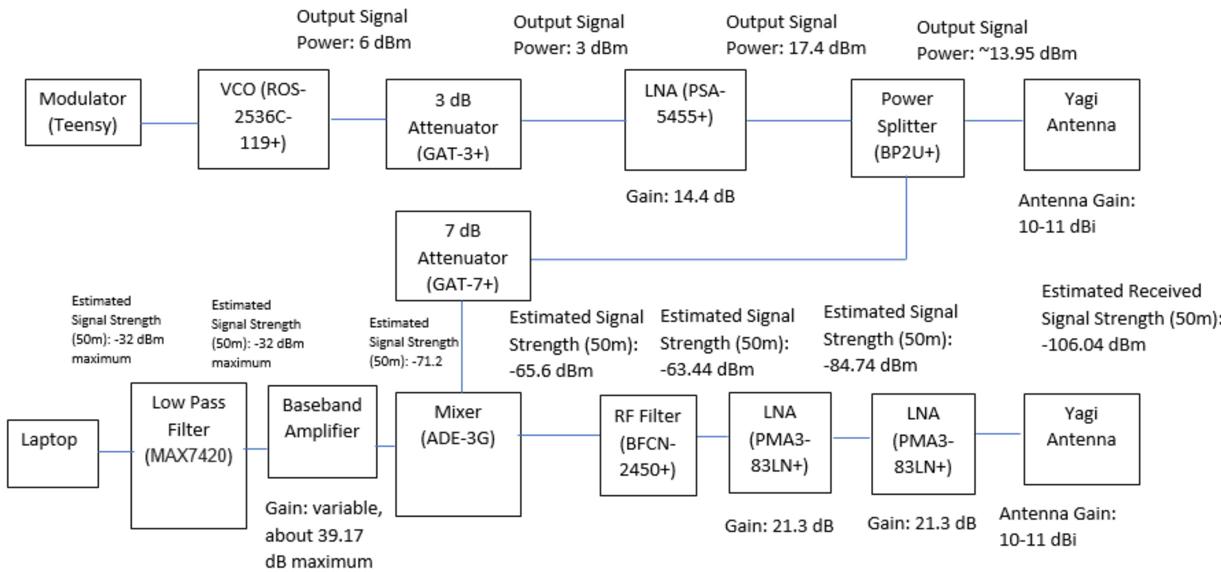
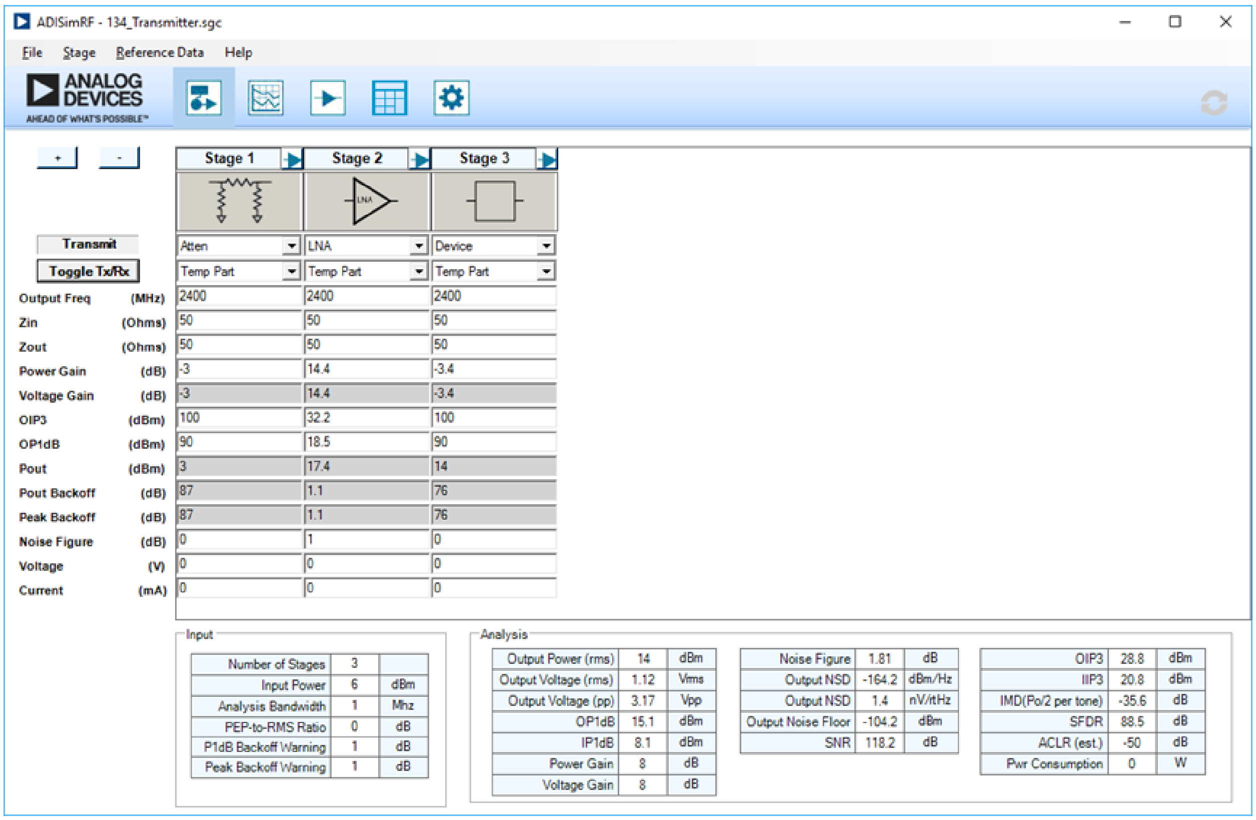
Abstract
This report details the design, implementation, and testing of a Frequency Modulated Continuous Wave (FMCW) radar system. This sort of radar system transmits a continuous signal and receives a reflection of the original signal which can then be used to determine either the position or speed of an object based on the difference in frequencies of the two signals. After building a radar system whose design was provided to us in the first quarter of the class, our goal was to improve upon this design in the second quarter. This was primarily done by selecting different components that we believed could improve upon the original design.

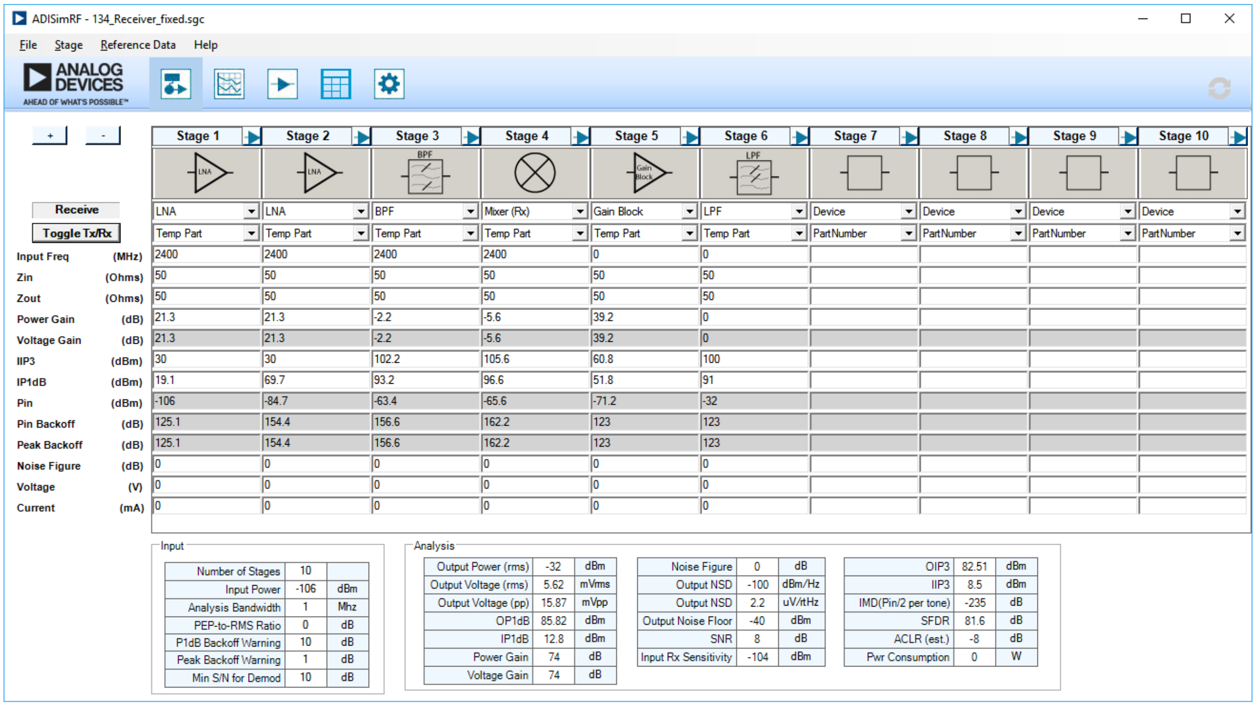
Design of the System
This system has two primary subsystems: a transmitting system, and a receiving system. The transmitter consists of a modulator, a voltage controlled oscillator (VCO), an attenuator, a low noise amplifier (LNA), a power splitter, and a transmitting antenna while the receiver consists of a receiving antenna, two LNAs, an RF Filter, a mixer, a baseband amplifier, a low-pass filter (LPF), and a computer for processing the final signal. Below is a block diagram of the system:



In regards to selecting the components, we had several desirable qualities we looked for. The first and most obvious is that the components used operated at the frequencies of the signals we would be using, which were 2.4 GHz for the transmitting portion and slightly higher than 2.4 GHz for the receiving portion depending on the position of the object being observed. Next, the supply voltage was a concern. Since we were only allowed to use one power supply, we wanted to have as many components as possible use the same supply voltage. Although we could build circuits that provided other biases other than the primary supply voltage such as a voltage regulator or a voltage reference circuit, we decided against this for providing power to components as it would require more circuitry and thus more things that could go wrong, a potentially harder time troubleshooting any problems, more power consumption, a higher cost, and a heavier system. As such, a supply voltage of 5 volts was selected for the whole system. Third, the power of the signal at different stages was looked at so that the signal did not clip and could be properly processed in the final stage of the receiving end. Using ADIsimRF to simulate the transmitting and receiving subsystems of the radar system, the components were tested to make sure that they would not distort the signals and that the computer would receive a sufficiently powerful but not to powerful voltage. Additionally, an equation that calculates the received power in a radar system was used along with some rough estimations for non-idealities in free-space to estimate the received signal strength. The ADIsimRF simulation for the transmitting side is below:



Similarly, the simulation for the receiving side is as follows:



The used received power equation for a radar system and the estimations for the received power using estimated non-ideal losses are as follows:

$$P_R = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R^4}$$

Additionally, the estimated loss from various sources was 21.1 dBm. From this, we made the following estimations for the received power:

Distance (m)	Power Received without Loss (dBm)	Power Received with Loss (dBm)
5	-41.06	-62.16
50	-84.94	-106.04

Moreover, other qualities used to determine the components used were the power consumption of the component, the cost of it, the weight of it, any loss caused by the component, and any noise associated with it. Also, we primarily selected components from

Minicircuits to simplify looking for parts and since we felt that Minicircuits had more detailed or clearer datasheets than some of the other manufactures.

Now, we will look at the transmitting end of the system. For the modulator, we used the Teensy 3.1 chip provided to us in the first quarter. Next, a ROS-2536C-119+ VCO from Minicircuits was chosen for the VCO. We found that the transmitted signal needed to be attenuated slightly to avoid distortion later in the LNA stage, so a GAT-3+ attenuator was used in the transmitting end. An LNA was needed in the transmitting side of the apparatus for which we chose a PSA-5455+ from Minicircuits as it provided what we believed would be adequate signal amplification and a high enough 1dB compression point to avoid distorting the signal. We also chose to use a TCCH-80+ RF Choke from Minicircuits as part of the recommended application circuit for the PSA-5455+ LNA to help filter any undesired signals interfering with the biasing of the LNA. A BP2U+ power splitter was chosen so that the transmitted signal could be used in the mixer in the receiving subsystem. Finally, a Yagi antenna found online was used for the transmitting antenna. We originally planned to fabricate our own antennas for the project; however, we decided that due to time constraints, it would be more effective to purchase a commercial product with desired qualities. For the antennas we selected, they operated at 2.4 GHz and had an antenna gain of 10 to 11 dBi.

For the receiving end of the system, we chose the following parts. Like the transmitting end, we used a Yagi antenna. Next, we used two PMA3-83LN+ LNAs to provide the gain that we believed would work for the receiver. TCCH-80+ RF Chokes were again used as suggested by the recommended application circuit. An RF filter was then chosen to remove any unwanted received signals. For this, we used a BFCN-2450+ filter. An ADE-3G mixer was used to mix the received and transmitted signals to get a low signal signal with the transmitted signal being the LO signal. Also, a 7 dB attenuator, specifically using a GAT-7+, was needed to match the power of the LO signal to the level of the mixer which was a level 7 mixer. The IF signal from the mixer was then processed by a baseband system modeled on the Quarter 1 baseband system.

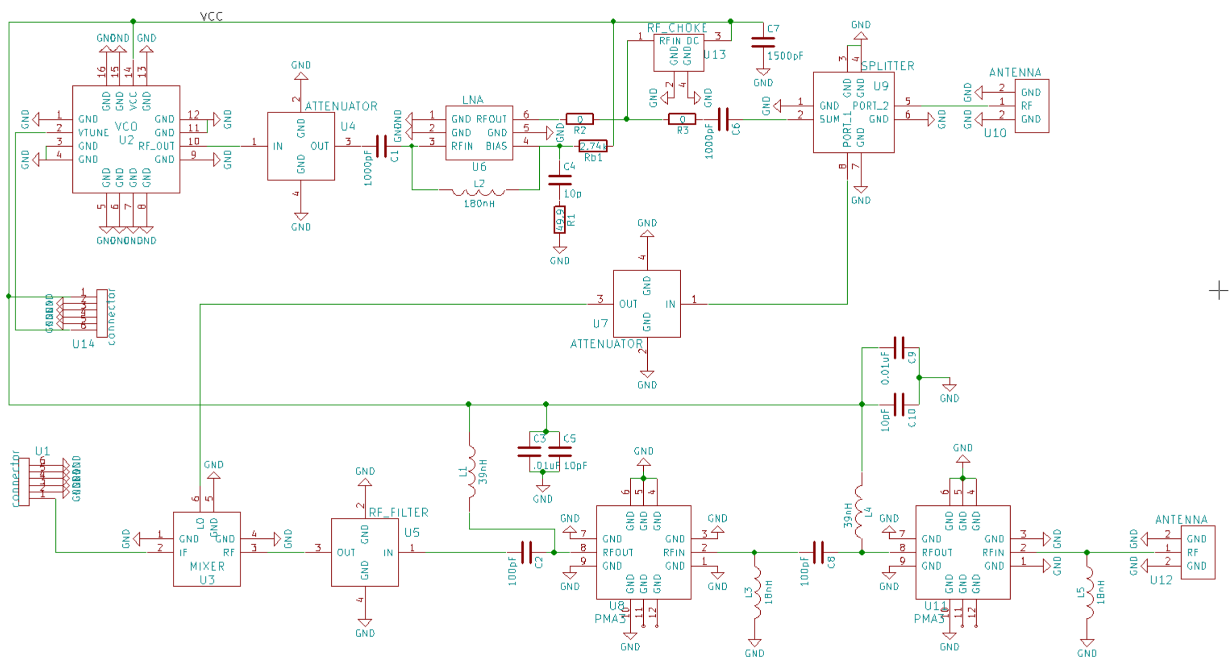
The other part of the system was the baseband amplifier. The baseband amplifier contained two parts. The first part was the LDO voltage regulator that maintained a constant voltage of 5V for the system. This LDO was the TPS737 and was used to create a constant voltage and had a voltage divider to create a 2.5V reference for the negative inputs of the amplifier. The Teensy 3.1 was used to produce a square wave of 2 Vp-p that went to the MCP4921 DAC to produce a triangle wave. That triangle wave goes to the V-tune of the VCO to produce the 2.4 GHz signal.

The IF signal of the mixer was amplified by one stage of the the TL974N. This amplified signal was amplified about 40 times and was then filtered by a MAX 7420 low pass filter. This filter is tuned by a clock tunable frequency to match the 15kHz that is expected to be filtered. This was tuned by the 73pF attached to the clock of the filter. This filtered signal was then recorded by Audacity and processed by Matlab.

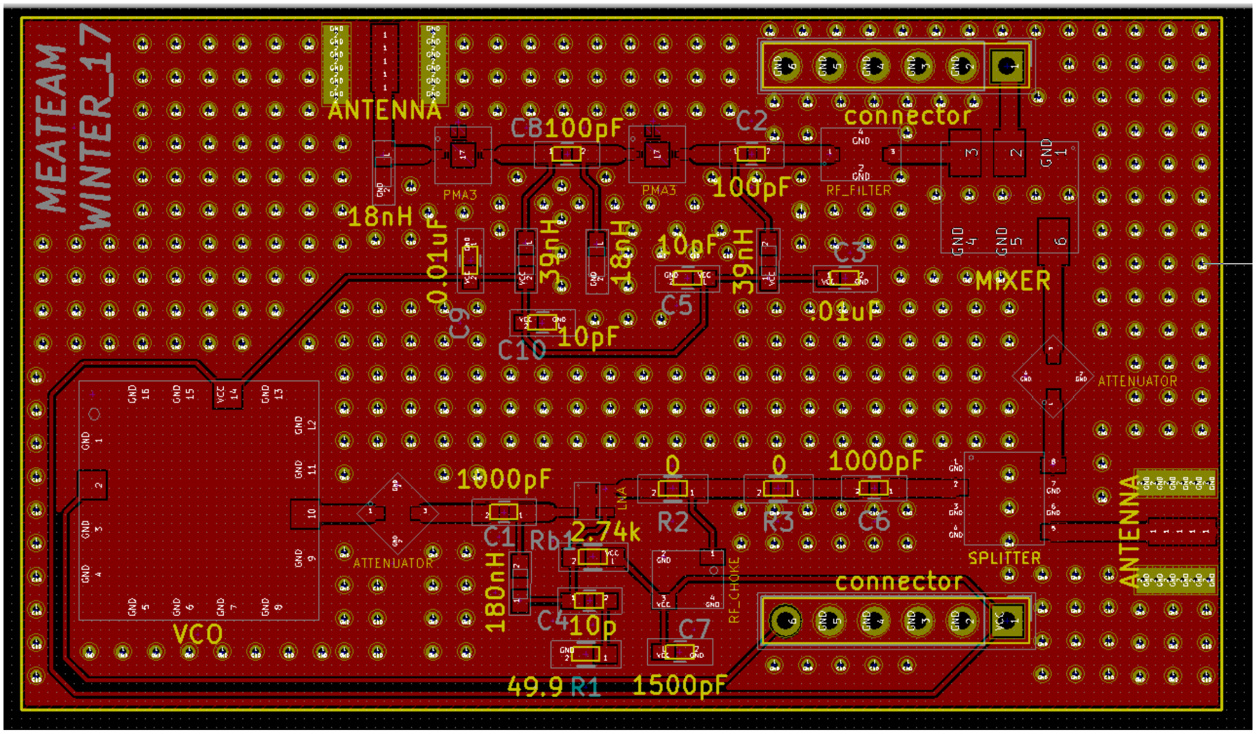
PCB Design

For the PCB design of the radar, we decided to make two separate PCBs, one PCB was for the RF sub-circuit and the other one was for the baseband sub-circuit. We planned to stack two PCBs using two sets of pin headers placed parallel with other to share the common signals such as voltage supply Vs, ground GND, and IF output. Additionally, we used the parallel structure to support the PCBs when we stacked them up, making the system more structurally stable. Separating the whole system into two sub-circuits helped simplify the circuit design since the RF and the baseband sub-circuits had different requirements and parameters that need to be concerned. For example, the RF board needed all the traces on the top layer of the PCB while this limitation was not extended to the baseband board. Also, the RF PCB dealt with transmission lines, so we needed to apply a via fence on the board to prevent any interfering signals from surrounding environment; however, the baseband PCB did not require this kind of work. Separating the circuit was also helpful for the testing purposes. We could put some test points on the baseband board to test the performance and function at critical points on the circuit; however, this was not possible on the RF board. KiCad was the software that we used to design the PCBs, its basic functions were introduced to us in the first quarter of the course and we had the chance to practice on several simple PCBs, giving us enough experience and knowledge to make our own designs.

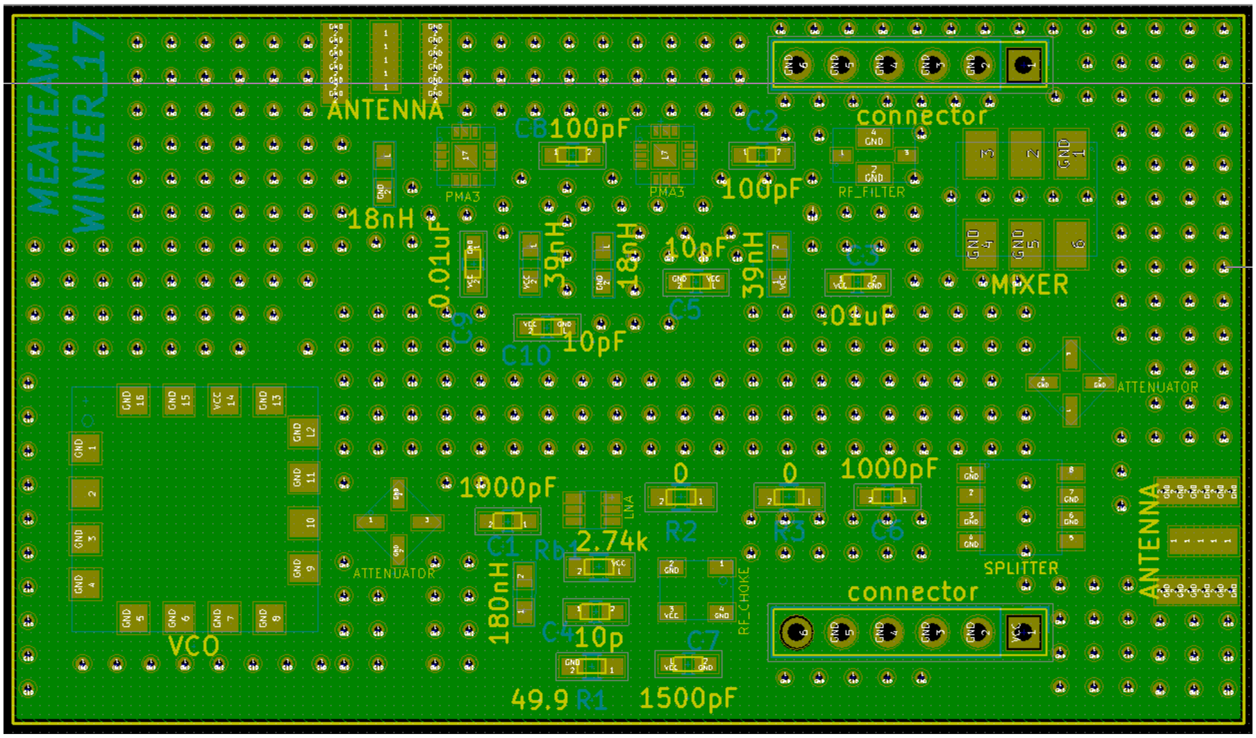
The RF PCB design is presented as follows. First, the schematic of the RF board:



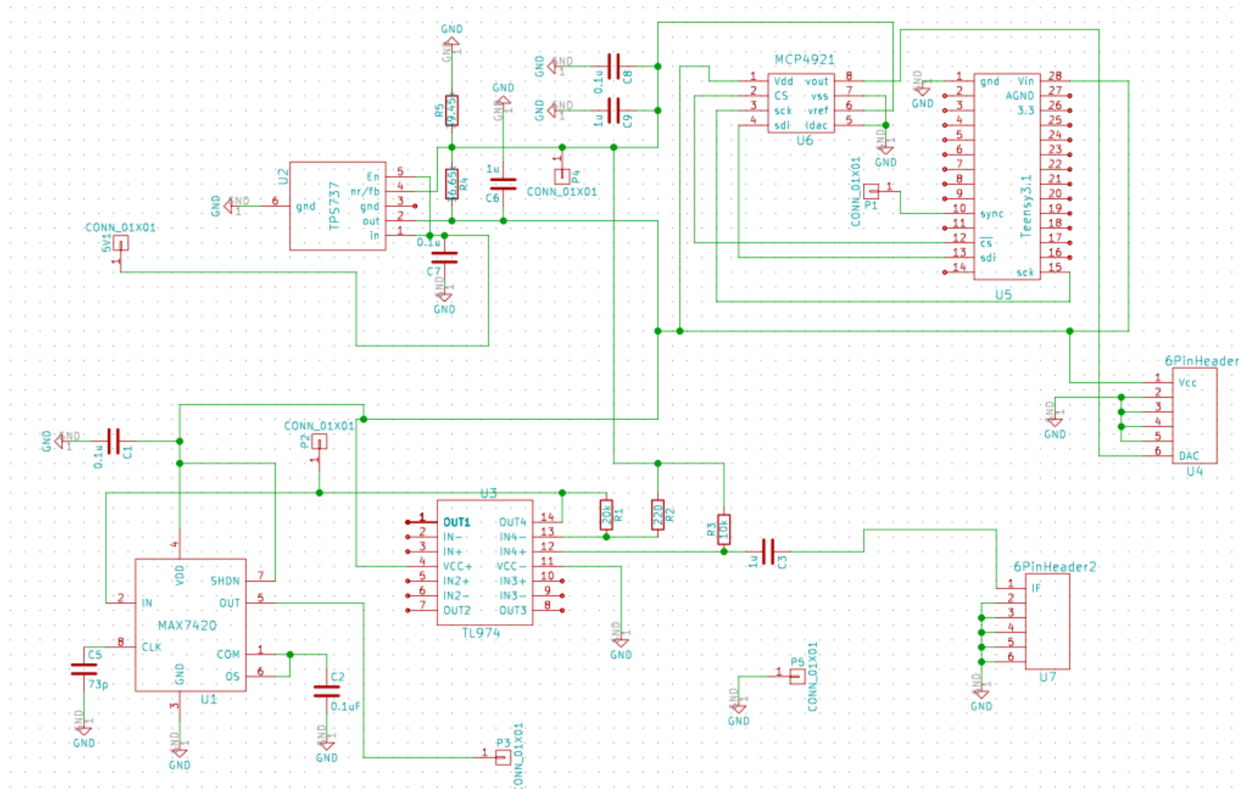
Next, the top layer of the RF board:



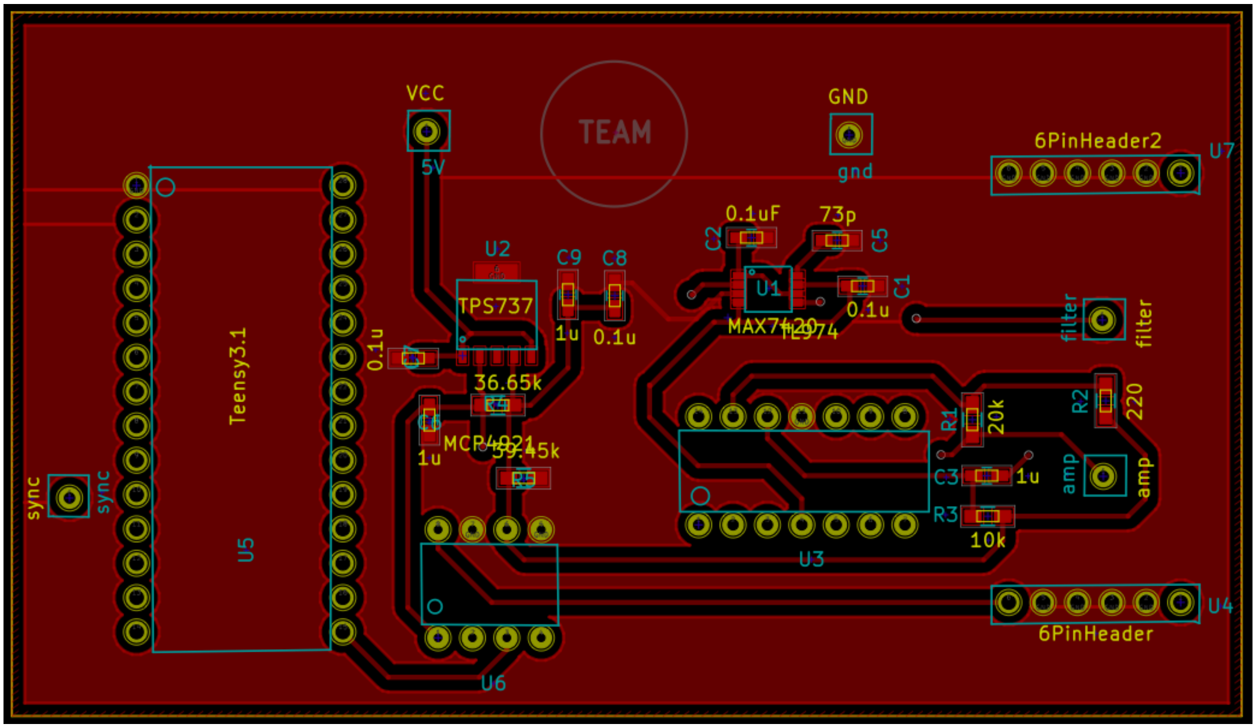
Finally, the bottom layer of the RF board:



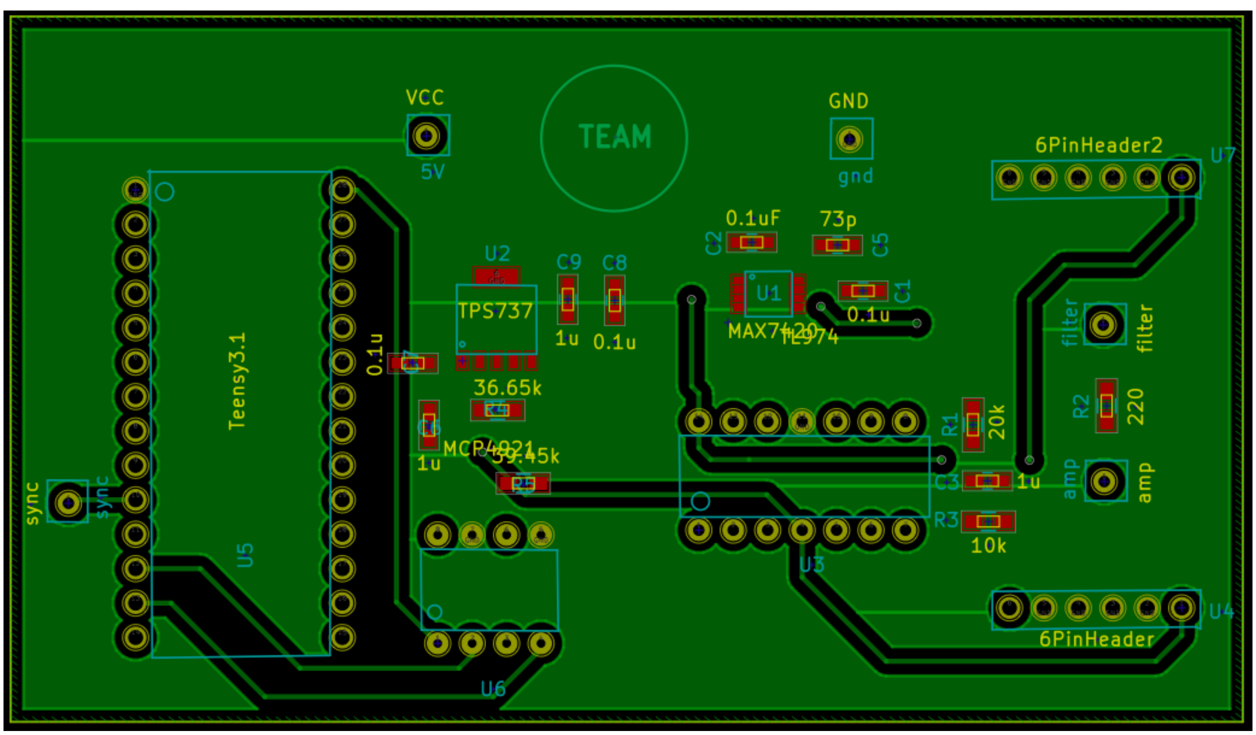
The Baseband Amplifier PCB design is presented as follows. First, the schematic of the RF board:



Next, the top layer of the Baseband board:



Finally, the bottom layer of the Baseband board:

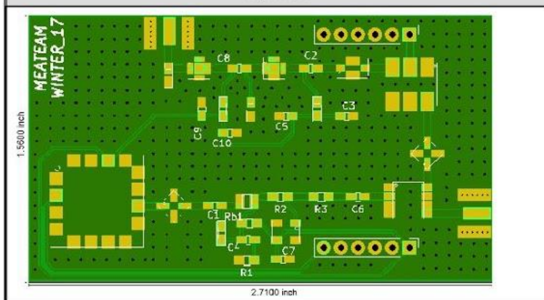
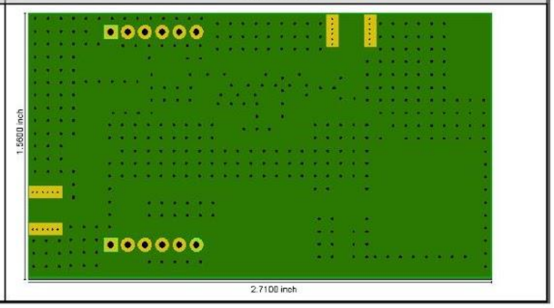


The DFM report of the RF board, as generated by Bay Area Circuits, is presented as follows:

QED Report Integr8tor

Name	3924k2q6.zip	Id.	8329 - QED With Image Data
Report Generated on	Feb 4, 2017 12:21:31 AM	Customer	InstantDFM
Board Id			

Single PCB View

Top View	Bottom View
	

Summary - General

PCB Size	2.7100 inch x 1.5600 inch	Copper Layers	2
PCB Thickness	62.00 mil	Solder Mask	Both
Customer Panel Size		Solder Mask Color	Green
SMD Pads Top	148	Legend	Top Only
SMD Pads Bottom	0	Legend Color	White
SMD Density Top	35 SMD/inch^2	Peeloff Mask	None
SMD Density Bottom	0 SMD/inch^2	Carbon Mask	None
Number of Nets	26	Drill Hole Density	103 Holes/inch^2
Electrical Test	Single Sided	Holes in SMD Pads	Yes
Max. Aspect Ratio on PTH	6.2	Edge Connectors	No

Summary - Copper Layers

Layer Type	Min. Line Width	Min. Ring	Min. Clr. to Copper	Min. Clr. to Plated Hole	Min. Clr. to NPTH	Min. Clr. to Outline
	mil	mil	mil	mil	mil	mil
Outer	[6] 9.00	[7] 12.00	[8] 5.32	[9] 18.00		[10] 8.95
Inner						

Summary - Sequences

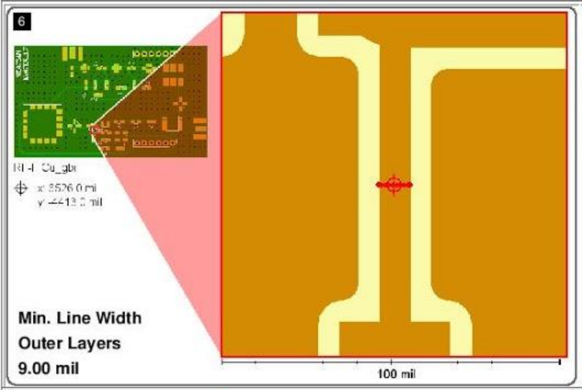
Type	Sequences	Tools	Min. End Dia.	Max. End Dia.	Holes	Min. Ring on Outer	Min. Ring on Inner	Min. Clr. Hole to Copper
			mil	mil		mil	mil	mil
Blind	0							
Buried	0							
PTH	1	3	10.00	39.00	434	12.00		18.00
Plated (Total)	1	3	10.00	39.00	434	12.00		18.00
NPTH	0							
Total	1	3	10.00	39.00	434	12.00		18.00

QED Report

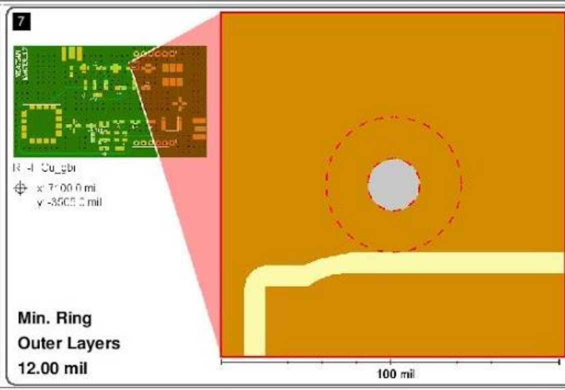
Integr8tor

Name	3924k2q6.zip	Id.	8329 - QED With Image Data
Report Generated on	Feb 4, 2017 12:21:31 AM	Customer	InstantDFM
Board Id			

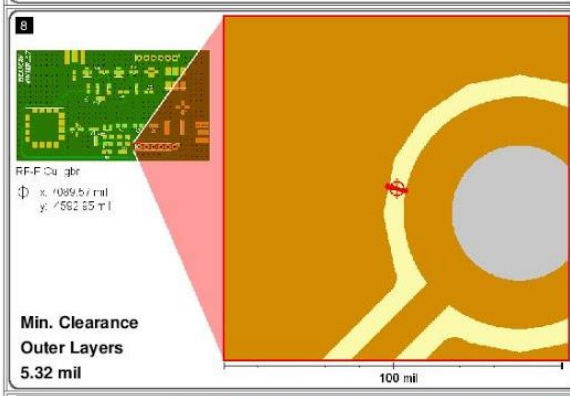
Summary Minimum Design Characteristics - Locations



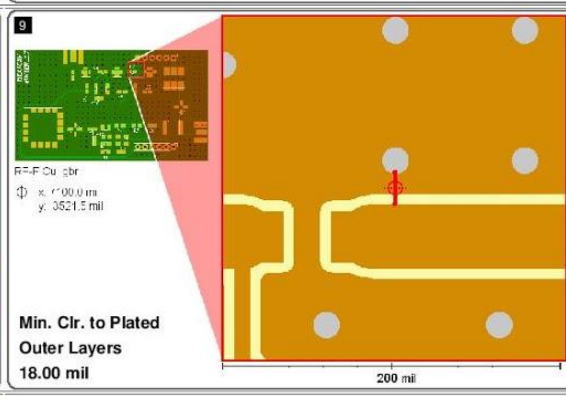
Min. Line Width
Outer Layers
9.00 mil



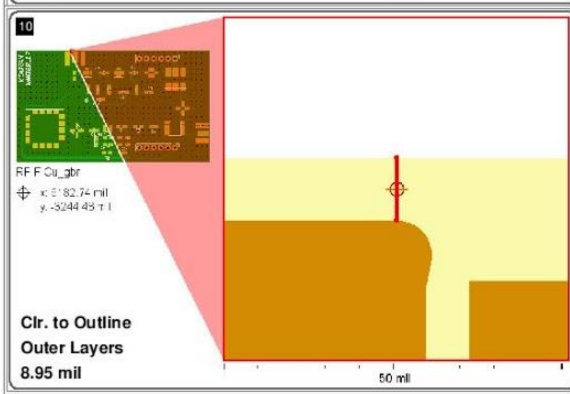
Min. Ring
Outer Layers
12.00 mil



Min. Clearance
Outer Layers
5.32 mil



Min. Clr. to Plated
Outer Layers
18.00 mil

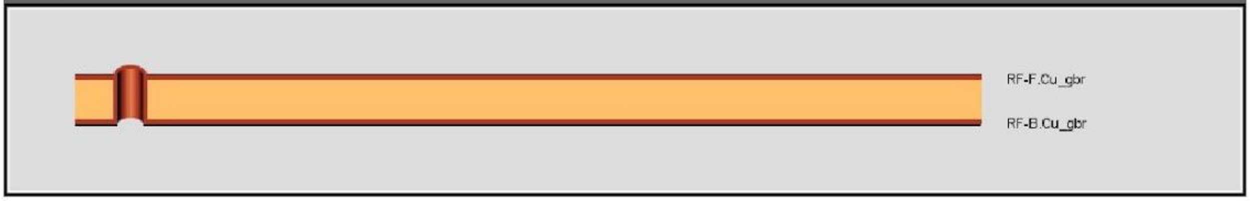


Clr. to Outline
Outer Layers
8.95 mil

QED Report Integr8tor

Name	3924k2q6.zip	Id.	8329 - QED With Image Data
Report Generated on	Feb 4, 2017 12:21:31 AM	Customer	InstantDFM
Board Id			

Stackup



Copper Layers

File	Pos.	Min. Line Width	Min. Ring	Min. Clr. to Copper	Min. Same Net spacing	Min. Clr. to Plated Hole	Min. Clr. to NPTH	Min. Clr. to Outline	Copper Area	
		mil	mil	mil	mil	mil	mil	mil	$inch^2$	%
RF-F.Cu_gbr	1	9.00	12.00	5.32	16.06	18.00		8.95	3.9465	93
RF-B.Cu_gbr	2	>16.00	13.55	5.32	>20.00	19.28		8.95	4.1462	98

Drill Tools

File	Tool Nr.	Span	Type	Method	FilledVia	Countered	End Dia.	Holes (in PCB)	Moves (in PCB)	Double Hits (in File)	Predrill Hits (in File)	Min. Ring on Outer	Min. Ring on Inner	Min. Pad Size
							mil					mil	mil	mil
RF_drl	1	1-2	PTH	unknown	unknown	unknown	10.00	24	0	0	0	16.05		42.10
RF_drl	2	1-2	PTH	unknown	unknown	unknown	15.00	398	0	22	0	12.00		39.00
RF_drl	3	1-2	PTH	unknown	unknown	unknown	39.00	12	0	0	0	13.96		66.92

Sequences

Span	Type	Tools	Min. End Dia.	Max. End Dia.	Holes	Min. Ring on Outer	Min. Ring on Inner	Min. Ring on Outer NPTH	Min. Ring on Inner NPTH	Min. Clr. Hole to Copper	Min. Clr. Hole to Outline	Min. Clr. Track to Outline
			mil	mil		mil	mil	mil	mil	mil	mil	mil
1-2	PTH	3	10.00	39.00	434	12.00				18.00	22.50	disabled
All	Plated	3	10.00	39.00	434	12.00				18.00	22.50	disabled
All	All	3	10.00	39.00	434	12.00				18.00	22.50	disabled

Rout Tools

File	Tool Nr.	Type	Tool Dia.	End Dia.	Draw Length	Nibble Count
			mil	mil	mil	

Routed Holes

File	Hole Nr.	Instances	X Size	Y Size	Draw Length	Nibble Count
			mil	mil	mil	

QED Report

Integr8tor

Name	3924k2q6.zip	Id.	8329 - QED With Image Data
Report Generated on	Feb 4, 2017 12:21:31 AM	Customer	InstantDFM
Board Id			

Solder Mask

Side	Min. Ring on Cu Defined Pads	Min. Ring on SM Defined Pads	Min. Clr. Mask to Mask	Min. Web	Min. Clr. Mask to Copper	Fully Covered Via Holes	Partly Covered Via Holes
	mil	mil	mil	mil	mil		
Top	7.87		3.25	1.75	6.63	Yes	No
Bottom	7.87		>10.00	>10.00	>10.00	Yes	No

Files

Initial	Renamed	Format	Function	Position	Color
RF-F.SilkS.gbr	RF-F.SilkS_gbr	ger274x	silk	top	white
RF-F.Mask.gbr	RF-F.Mask_gbr	ger274x	mask	top	green
RF-F.Cu.gbr	RF-F.Cu_gbr	ger274x	outer	1	
RF-B.Cu.gbr	RF-B.Cu_gbr	ger274x	outer	2	
RF-B.Mask.gbr	RF-B.Mask_gbr	ger274x	mask	bottom	green
RF.drl	RF_drl	excellon2	plated	1-2	
RF-B.SilkS.gbr	RF-B.SilkS_gbr	ger274x	empty	none	
RF-Edge.Cuts.gbr	RF-Edge.Cuts_gbr	ger274x	cad_outline	none	
report.txt		text	document		

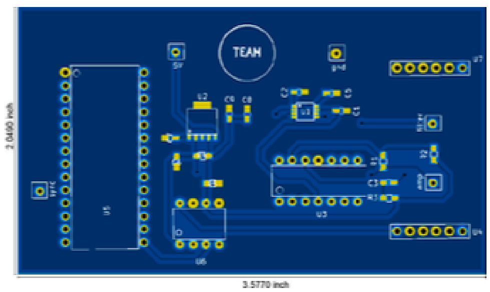
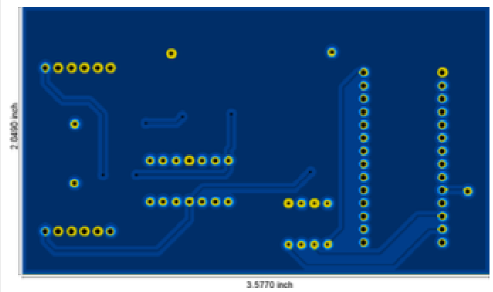
Comments

The DFM report of the Baseband board, as generated by Bay Area Circuits, is presented as follows:

QED Report — Integr8tor

Name	dkgm9f't5.zip	Id.	9132 - QED With Image Data
Report Generated on	Mar 5, 2017 12:19:33 PM	Customer	InstantDFM
Board Id			

Single PCB View

Top View	Bottom View
	

Summary - General

PCB Size	3.5770 inch x 2.0490 inch	Copper Layers	2
PCB Thickness	62.00 mil	Solder Mask	Both
Customer Panel Size		Solder Mask Color	Blue
SMD Pads Top	39	Legend	Top Only
SMD Pads Bottom	0	Legend Color	White
SMD Density Top	5 SMD/inch^2	Peeloff Mask	None
SMD Density Bottom	0 SMD/inch^2	Carbon Mask	None
Number of Nets	48	Drill Hole Density	10 Holes/inch^2
Electrical Test	Single Sided	Holes in SMD Pads	No
Max. Aspect Ratio on PTH	3.9	Edge Connectors	No

Summary - Copper Layers

Layer Type	Min. Line Width	Min. Ring	Min. Clr. to Copper	Min. Clr. to Plated Hole	Min. Clr. to NPTH	Min. Clr. to Outline
	mil	mil	mil	mil	mil	mil
Outer	[5] 15.00	[6] 3.81	[7] 6.00			[8] 32.95
Inner						

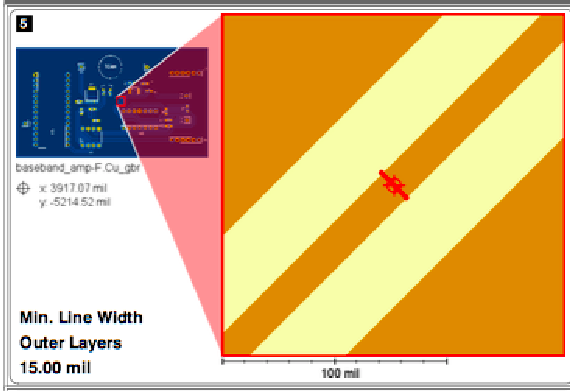
Summary - Sequences

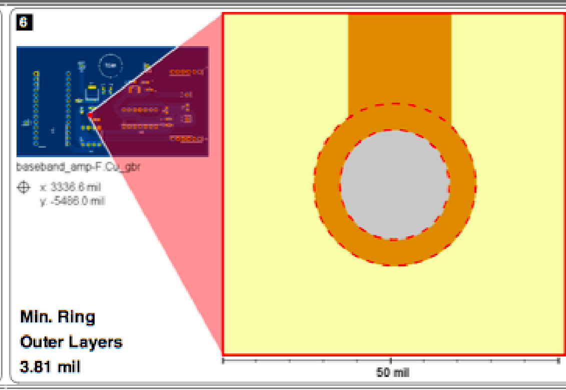
Type	Sequences	Tools	Min. End Dia.	Max. End Dia.	Holes	Min. Ring on Outer	Min. Ring on Inner	Min. Clr. Hole to Copper
			mil	mil		mil	mil	mil
Blind	0							
Buried	0							
PTH	1	4	16.00	40.00	73	3.81		unknown
Plated (Total)	1	4	16.00	40.00	73	3.81		unknown
NPTH	0							
Total	1	4	16.00	40.00	73	3.81		unknown

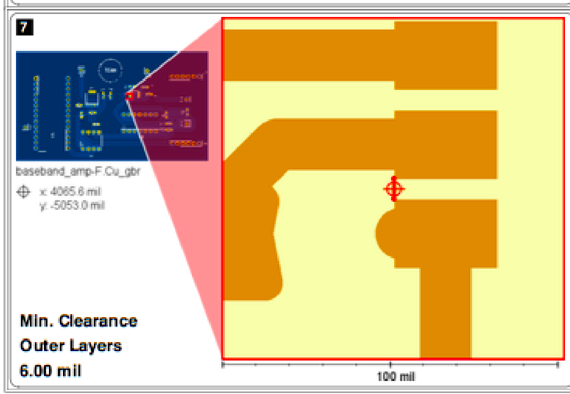
QED Report — Integr8tor

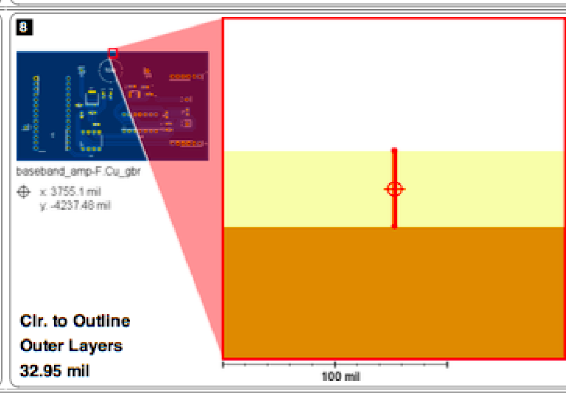
Name	dkgm9ft5.zip	Id.	9132 - QED With Image Data
Report Generated on	Mar 5, 2017 12:19:33 PM	Customer	InstantDFM
Board Id			

Summary Minimum Design Characteristics - Locations









Stackup

Copper Layers

File	Pos.	Min. Line Width	Min. Ring	Min. Clr. to Copper	Min. Same Net spacing	Min. Clr. to Plated Hole	Min. Clr. to NPTH	Min. Clr. to Outline	Copper Area	
		mil	mil	mil	mil	mil	mil	mil	$inch^2$	%
baseband_amp-F.Cu_gbr	1	15.00	3.81	6.00	>20.00	>32.00		32.95	5.6133	77
baseband_amp-B.Cu_gbr	2	15.00	3.81	29.18	>20.00	>32.00		32.95	5.9064	81

Name	dkgm9ft5.zip	Id.	9132 - QED With Image Data
Report Generated on	Mar 5, 2017 12:19:33 PM	Customer	InstantDFM
Board Id			

Drill Tools

File	Tool Nr.	Span	Type	Method	FilledVia	Countered	End Dia.	Holes (in PCB)	Moves (in PCB)	Double Hits (in File)	Predrill Hits (in File)	Min. Ring on Outer	Min. Ring on Inner	Min. Pad Size
							mil					mil	mil	mil
baseband_amp_drl	1	1-2	PTH	unknown	unknown	unknown	16.00	6	0	0	0	3.81		23.62
baseband_amp_drl	2	1-2	PTH	unknown	unknown	unknown	22.00	8	0	0	0	19.00		60.00
baseband_amp_drl	3	1-2	PTH	unknown	unknown	unknown	30.00	19	0	0	0	15.00		60.00
baseband_amp_drl	4	1-2	PTH	unknown	unknown	unknown	40.00	40	0	0	0	10.00		60.00

Sequences

Span	Type	Tools	Min. End Dia.	Max. End Dia.	Holes	Min. Ring on Outer	Min. Ring on Inner	Min. Ring on Outer NPTH	Min. Ring on Inner NPTH	Min. Clr. Hole to Copper	Min. Clr. Hole to Outline	Min. Clr. Track to Outline
			mil	mil		mil	mil	mil	mil	mil	mil	mil
1-2	PTH	4	16.00	40.00	73	3.81				>32.00	153.00	disabled
All	Plated	4	16.00	40.00	73	3.81				>32.00	153.00	disabled
All	All	4	16.00	40.00	73	3.81				>32.00	153.00	disabled

Rout Tools

File	Tool Nr.	Type	Tool Dia.	End Dia.	Draw Length	Nibble Count
			mil	mil	mil	

Routed Holes

File	Hole Nr.	Instances	X Size	Y Size	Draw Length	Nibble Count
			mil	mil	mil	

Solder Mask

Side	Min. Ring on Cu Defined Pads	Min. Ring on SM Defined Pads	Min. Clr. Mask to Mask	Min. Web	Min. Clr. Mask to Copper	Fully Covered Via Holes	Partly Covered Via Holes
	mil	mil	mil	mil	mil		
Top	7.87		>10.00	>10.00	>10.00	Yes	No
Bottom	7.87		>10.00	>10.00	>10.00	Yes	No

Files

Initial	Renamed	Format	Function	Position	Color
baseband_amp-F.SilkS.gbr	baseband_amp-F.SilkS_gbr	ger274x	silk	top	white
baseband_amp-F.Mask.gbr	baseband_amp-F.Mask_gbr	ger274x	mask	top	blue
baseband_amp-F.Cu.gbr	baseband_amp-F.Cu_gbr	ger274x	outer	1	
baseband_amp-B.Cu.gbr	baseband_amp-B.Cu_gbr	ger274x	outer	2	
baseband_amp-B.Mask.gbr	baseband_amp-B.Mask_gbr	ger274x	mask	bottom	blue
baseband_amp.drl	baseband_amp_drl	excellon2	plated	1-2	
baseband_amp-B.SilkS.gbr	baseband_amp-B.SilkS_gbr	ger274x	empty	none	
baseband_amp-Edge.Cuts.gbr	baseband_amp-Edge.Cuts_gbr	ger274x	cad_outline	none	

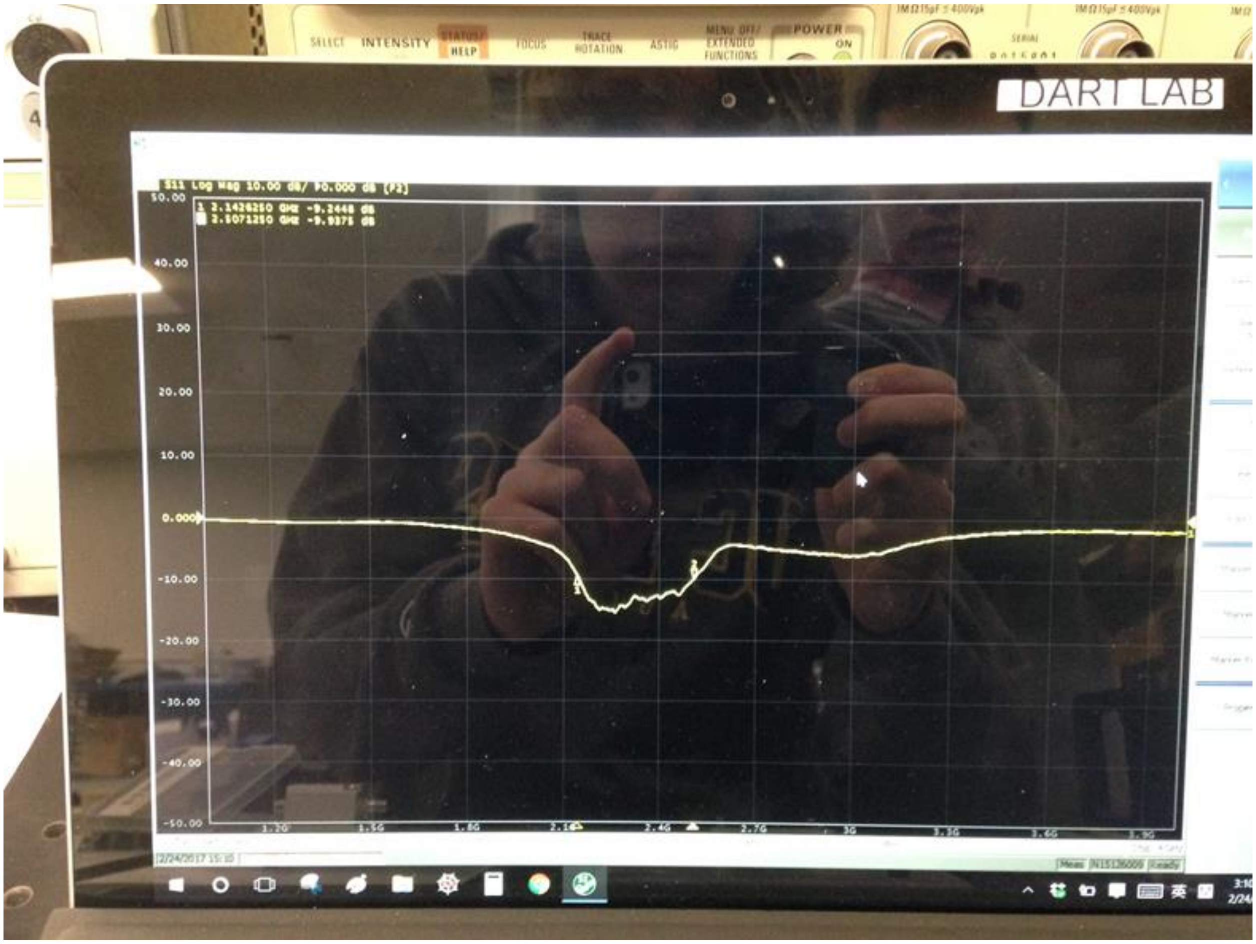
System Testing

Quarter 2 System Failure

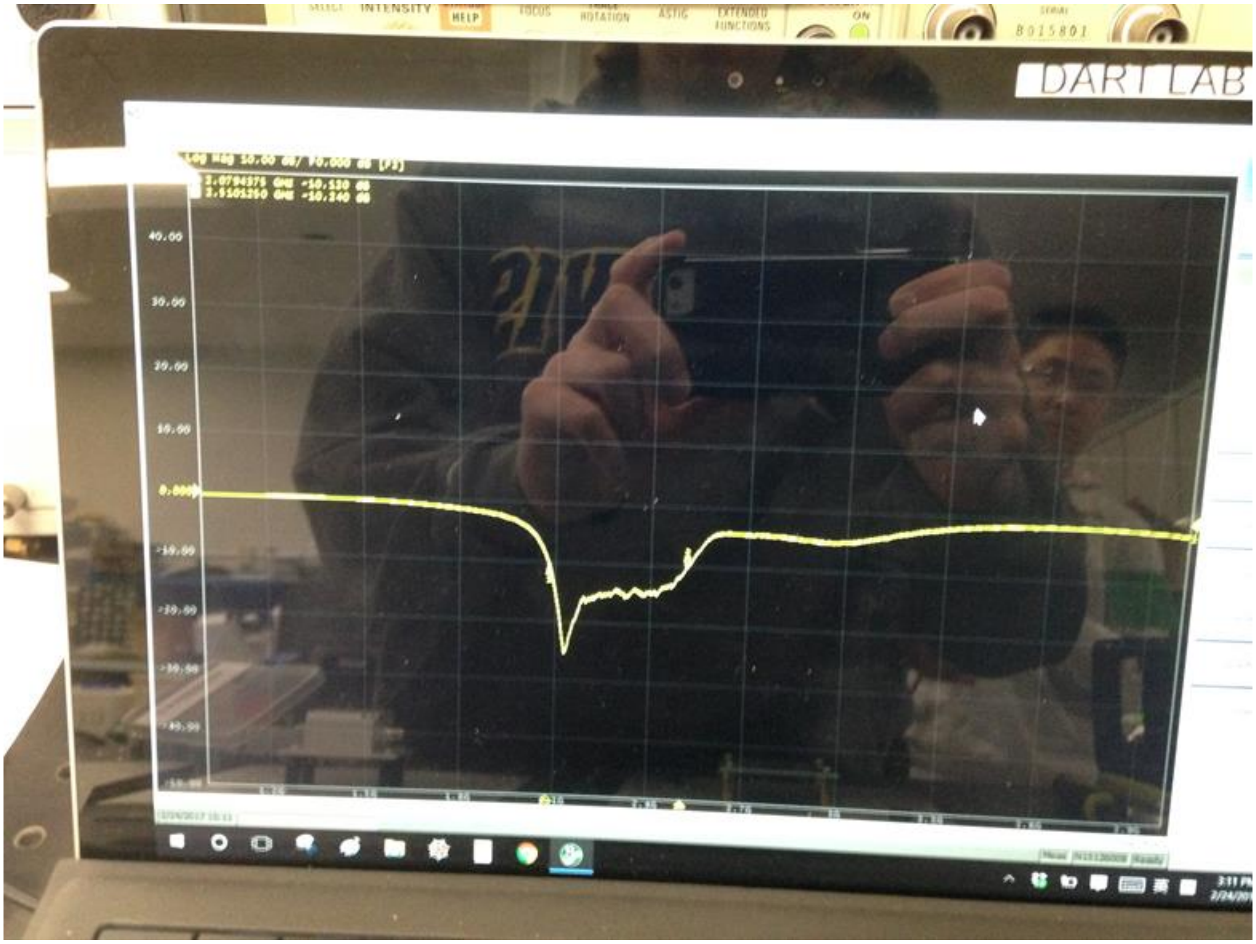
Unfortunately, the system that was designed for the second quarter did not properly operate. We believe that there may have been an error somewhere in the RF PCB, specifically the receiver. For some unknown reason, the two LNAs on the receiving side of the system failed to work and instead attenuated the signal. We thought the failure happened due to the soldering job. The amplifiers ICs were small and had pins at the bottom, so even with the optical equipment provided, it was really difficult for us to verify if we soldered the chips properly or not. Another problem we met is that the inputs of the amplifiers were connected to inductors which were grounded. Thus, we could not confirm whether or not these pins were shorted with the grounded pins nearby. Although the receiver did not work properly, we managed to get the transmitter work fairly well. The transmitting signal which was about 3 dB lower than the expected value, but we could pump that signal up a little higher by taking out the attenuator or adding a gain block. However, due to lack of time and difficulty in pinpointing the problem, we were unable to submit a revised RF PCB in time for the second PCB run.

The baseband PCB also suffered issues. In the first design, there were some issues with some of the connections being wrong as well as some component values that were possibly incorrect. It appeared that pins 5-7 were all grounded and only 5 and 7 should be grounded but pin 6 should receive 2.5V from the voltage divider. The other issue that we saw was that the floor for the amplifier was elevated to 5V so that it appeared to be all DC and no room for amplification of the IF signal. Although we were able to fix the perceived errors in a revised PCB, we did not have time to solder components onto the new PCB as by this point in the quarter, we had moved to focusing solely on rebuilding and improving where we could on the quarter one system.

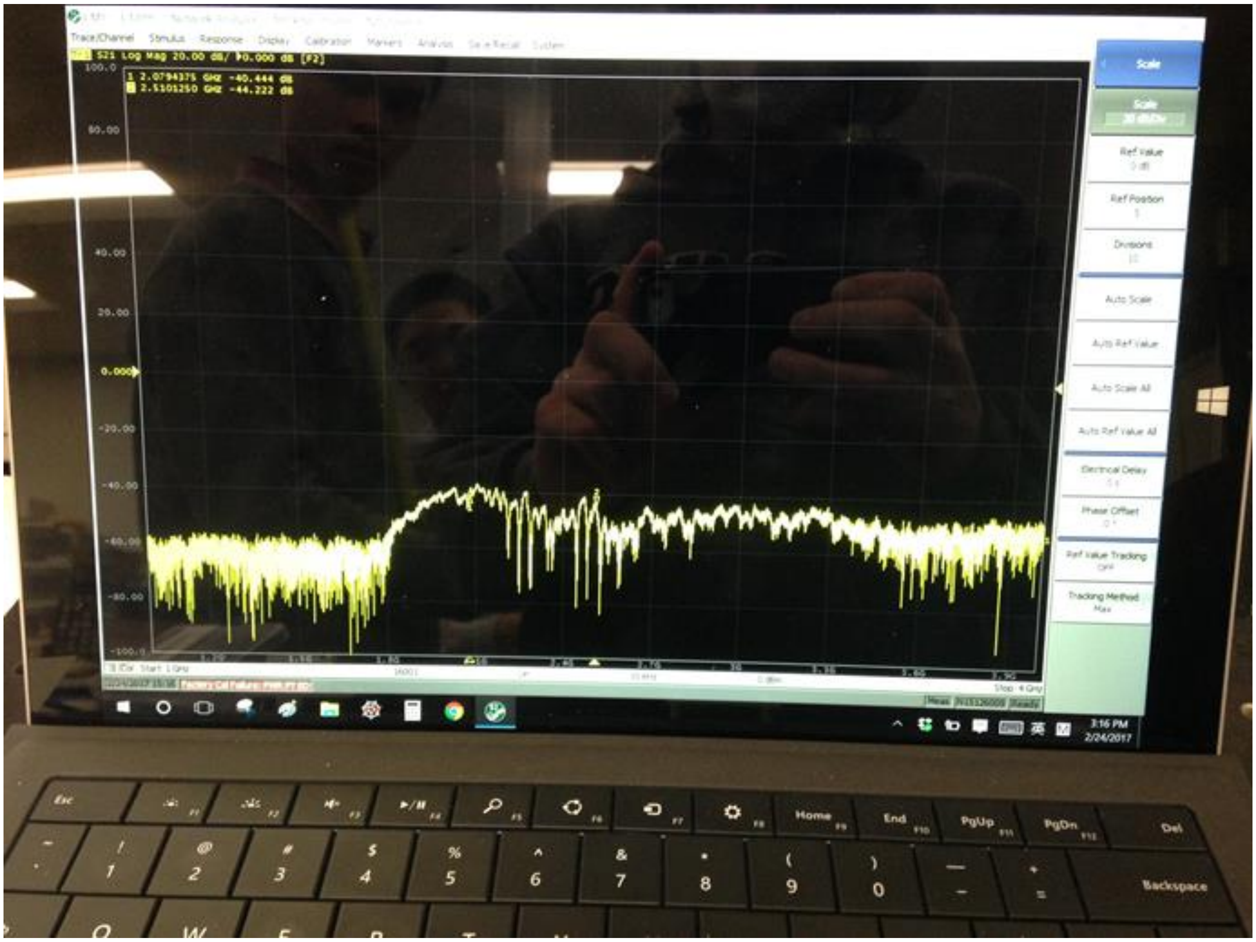
However, we did get proper results for the Yagi antennas we purchased. First, we tested the S11 scattering parameter of each antenna and got an antenna gain of roughly 10 to 11 dBi over the band of frequencies that we were working with. The results are below for the first antenna:



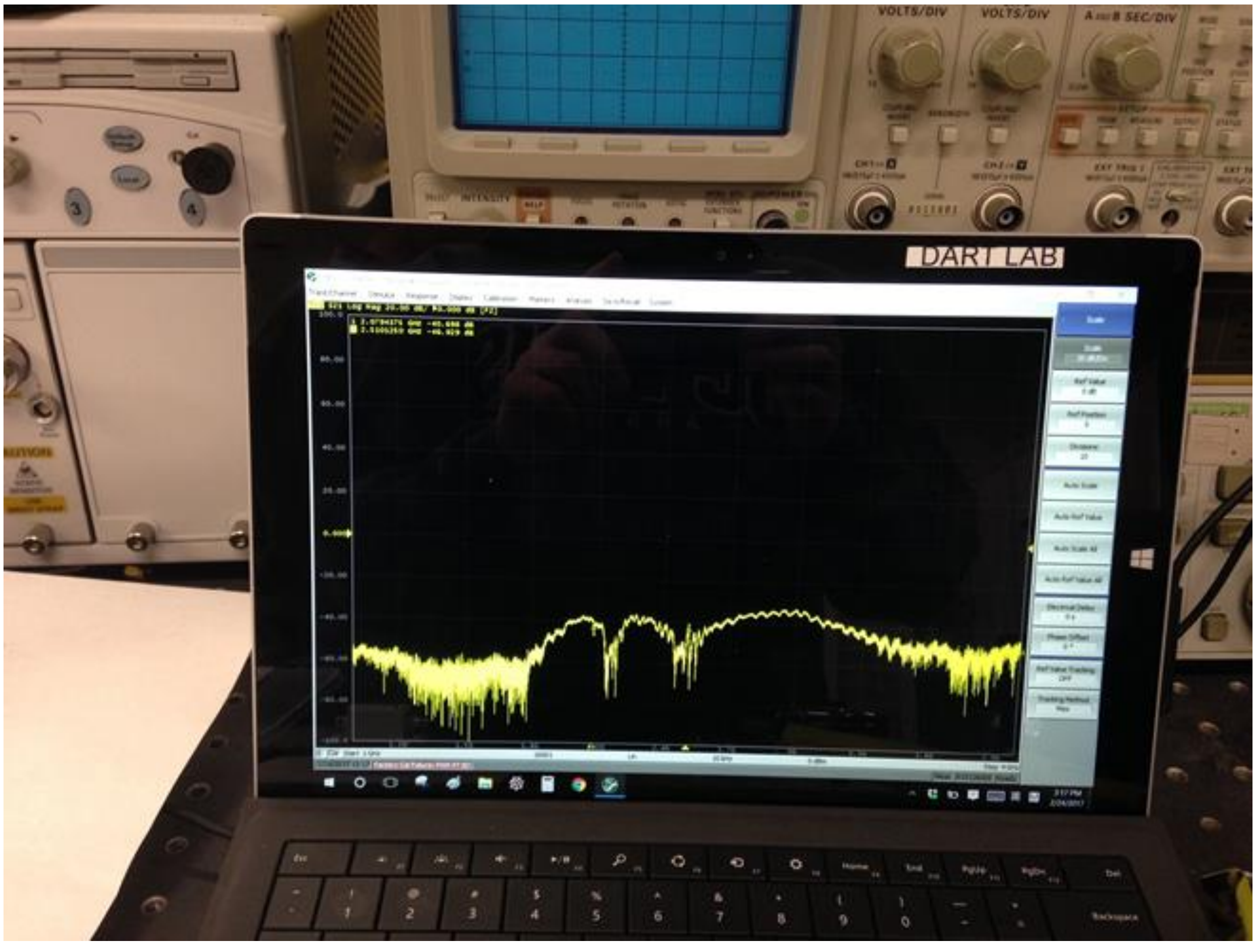
And, for the second antenna:



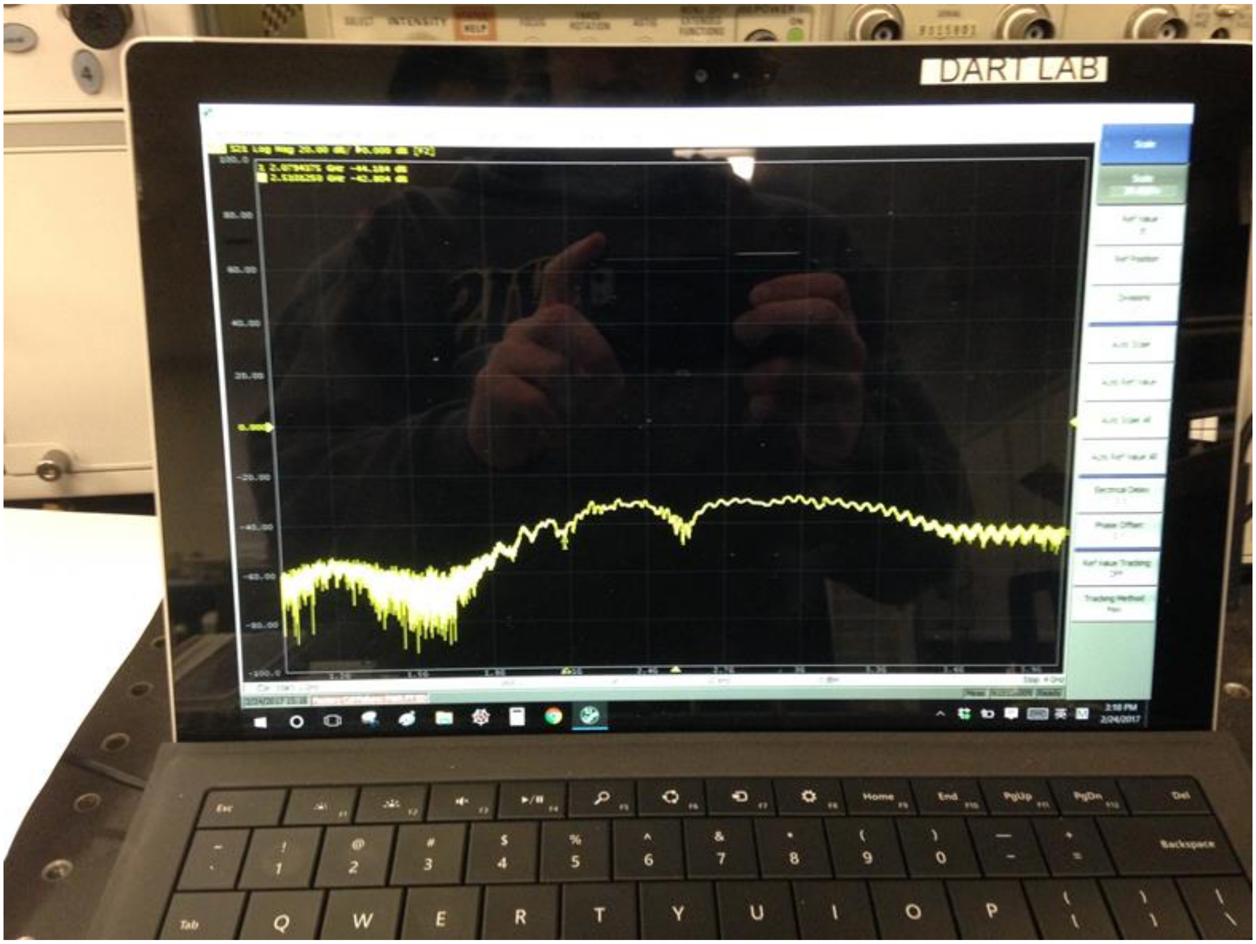
Additionally, we tested the crosstalk of the two antennas to find a good distance to separate them by. We found that having them greater than or equal to a foot apart had crosstalk at a minimum. However, this measurement was not in an anechoic chamber and may not be entirely accurate. First, the antenna S21 with the antennas separated at 12 inches with the two antennas on the same plane:



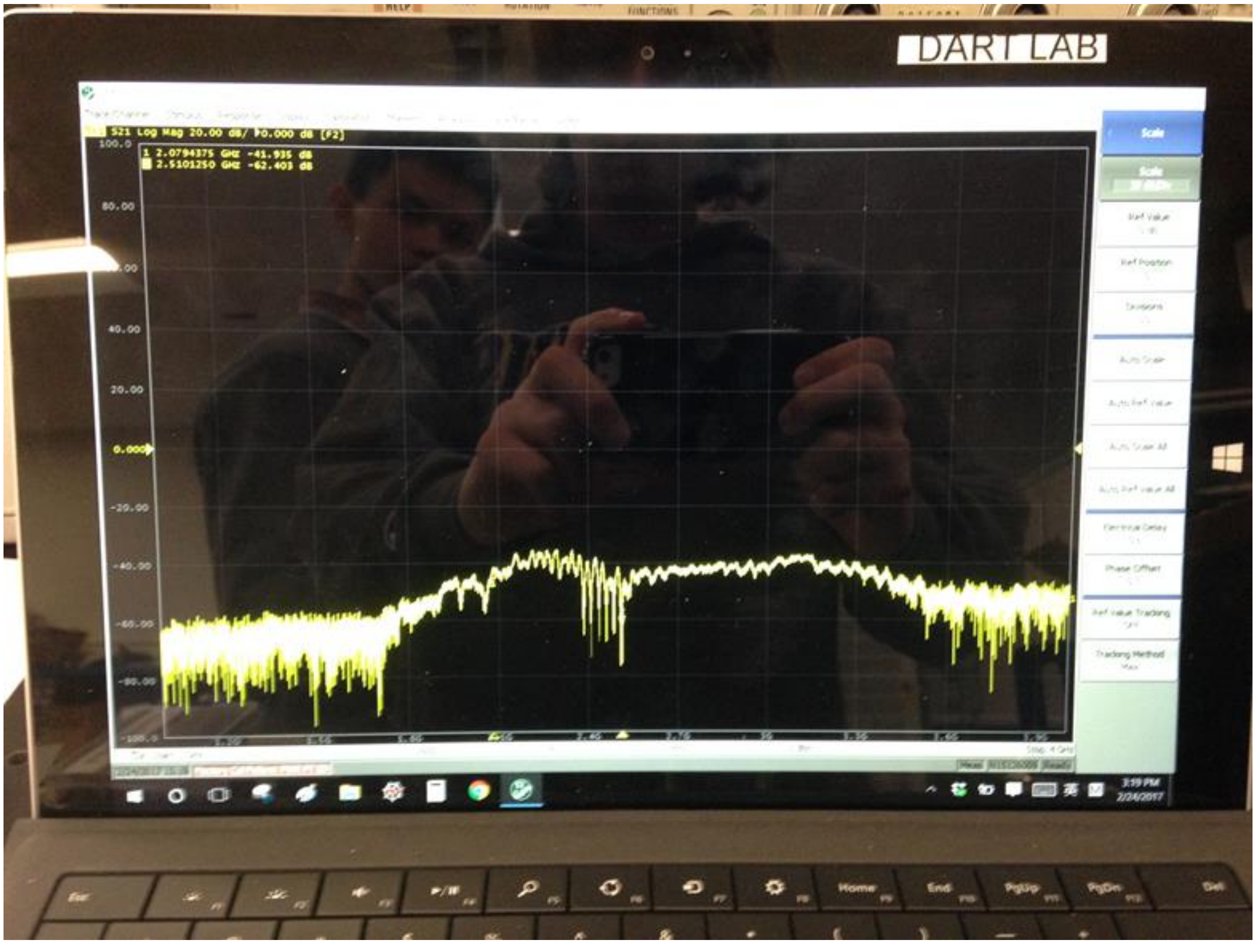
Next, the antennas 12 inches apart with them on parallel planes:



Now, the antennas on parallel planes with them separated by 10 inches:

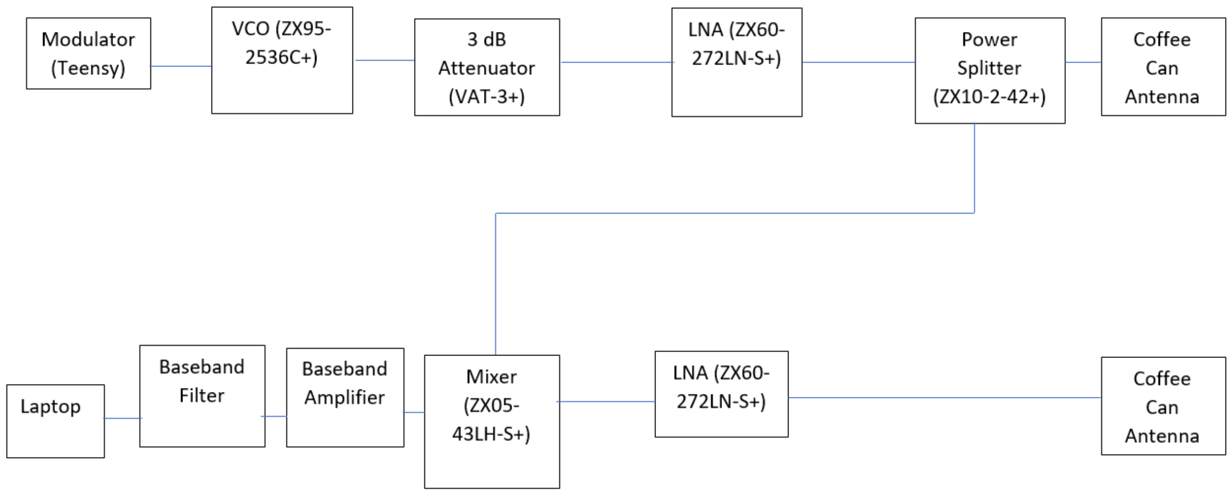


Finally, the antennas separated by 14 inches with them on parallel planes:

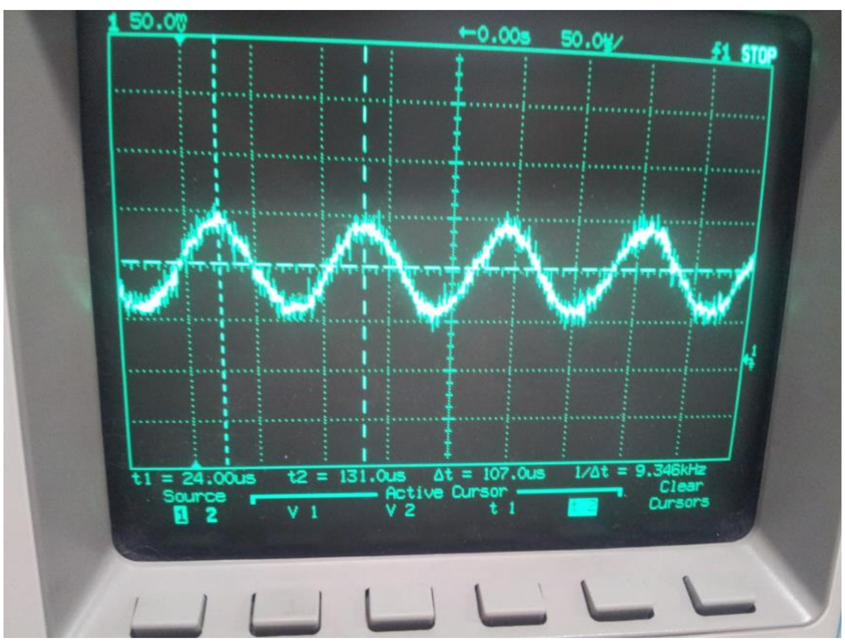


From these measurements, it becomes apparent that the antennas' crosstalk is approximately at a minimum when the two antennas are at least 12 inches apart. As such, we chose to have the antennas separated by at least this distance when assembling the final system.

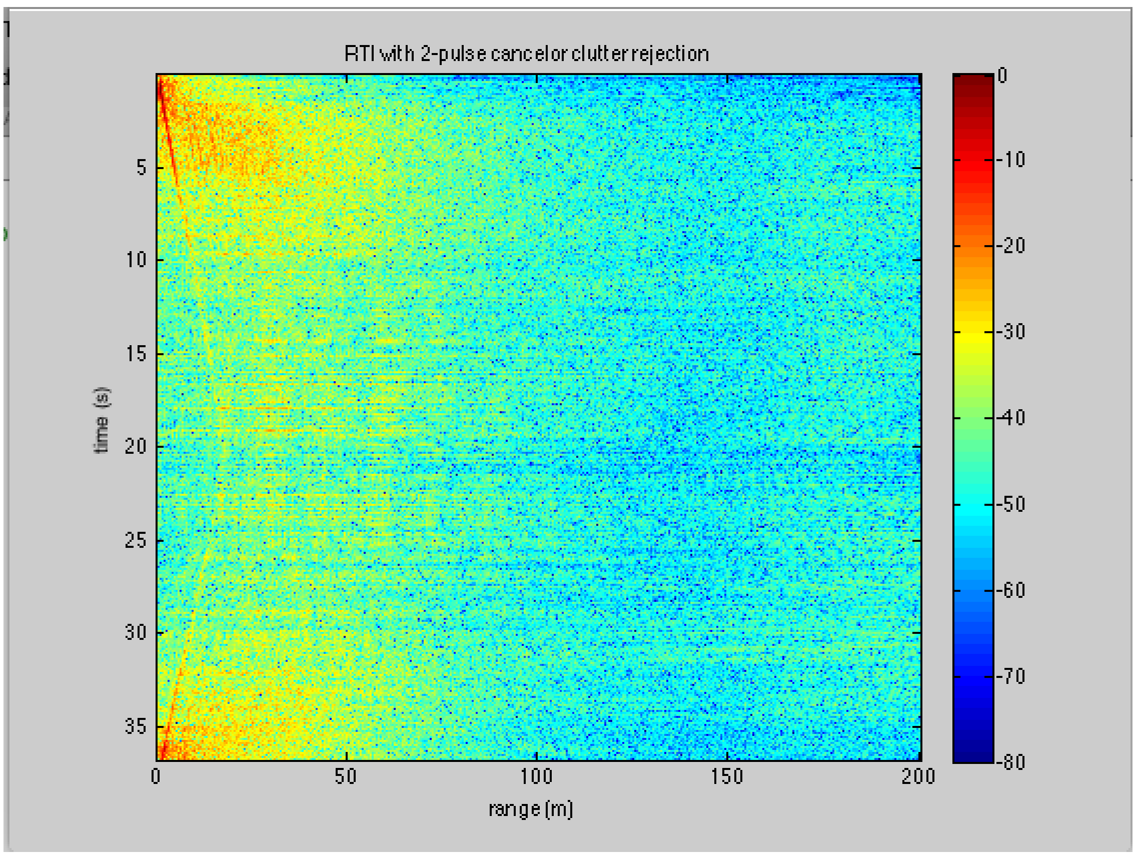
Quarter 1 System Rebuilding, Modifying, and Testing
After the failure of our quarter two design, we went with our backup: rebuilding and modifying our system from quarter one. The block diagram of the original quarter one design is as follows:

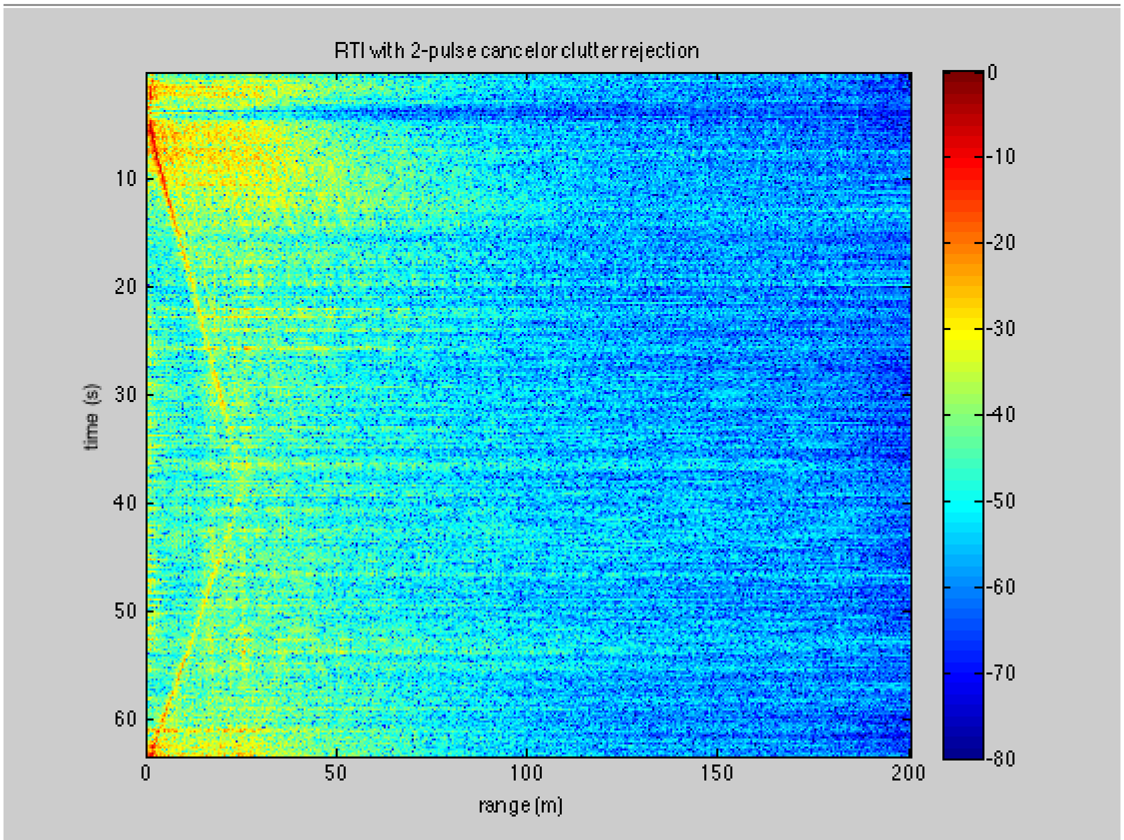


After reconstructing the original design, we tested it by using two TPI synthesizers with one in place of the VCO and the other sending a signal to the receiving end of the system. The first synthesizer was set at 2.4 GHz and the other was set at 2.40001 GHz. This test was done to ensure that we were getting the correct frequency out of the system, and to find the best possible mixer for our system. We obtained a signal with the proper frequency after the mixer as seen below:



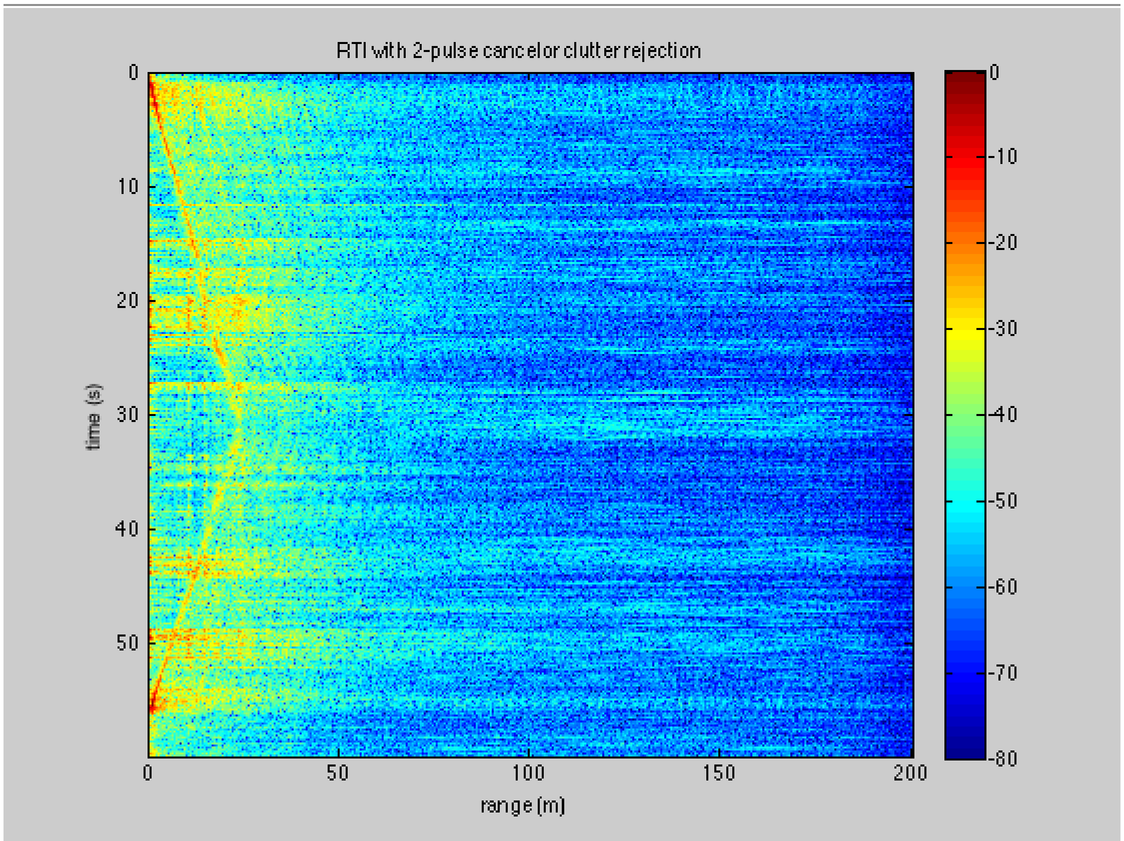
Next, we began making any modifications to improve the system. First, we tested several mixers to replace our original mixer as our original one had an output power that was smaller than anticipated possibly due to some internal problem with it. Next, we added one more LNA. The additional LNA was placed in cascade with the existing LNA of the receiving end right before the mixer to boost the gain of the received signal. Adding the LNA increases the amplitude of the receiving signal, so it is easier to discern the signal with background noise and collect the data needed for processing. Additionally, we removed the 3-dB attenuator in order to maximize the gain in the transmitting side of the system despite the risk of the signal becoming distorted. Also, we compared using the coffee can antennas used in quarter one and the Yagi antennas we purchased in quarter two. We found that using two coffee cans seemed to yield the best results as the Yagi antennas seemed to require being very precisely aimed at the target object. We tested the system indoors in a corridor that was slightly less than 30 meters long. We obtained the following two sets of data with coffee can antennas:





From this data, it is evident that we were able to obtain a signal from approximately 30 meters away.

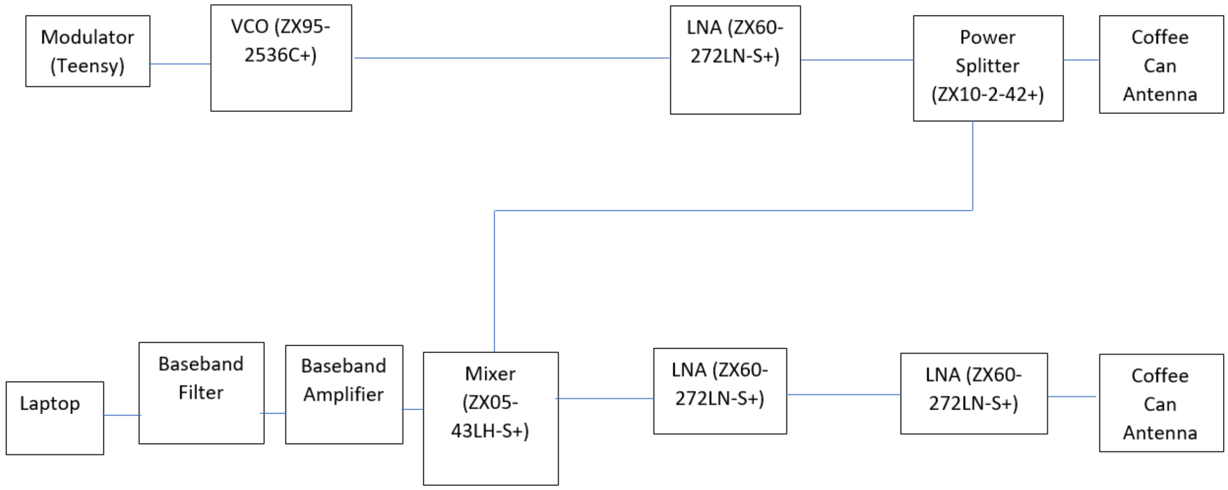
We also tested the system using a Yagi antenna as a transmitting antenna and a coffee can antenna as a receiving antenna. However, we felt that this run produced inferior results compared to the previous run. The result from this trial is below:



While this test produced similar results, we saw some distortion in the signal. As such, we elected to use coffee can antennas for both antennas.

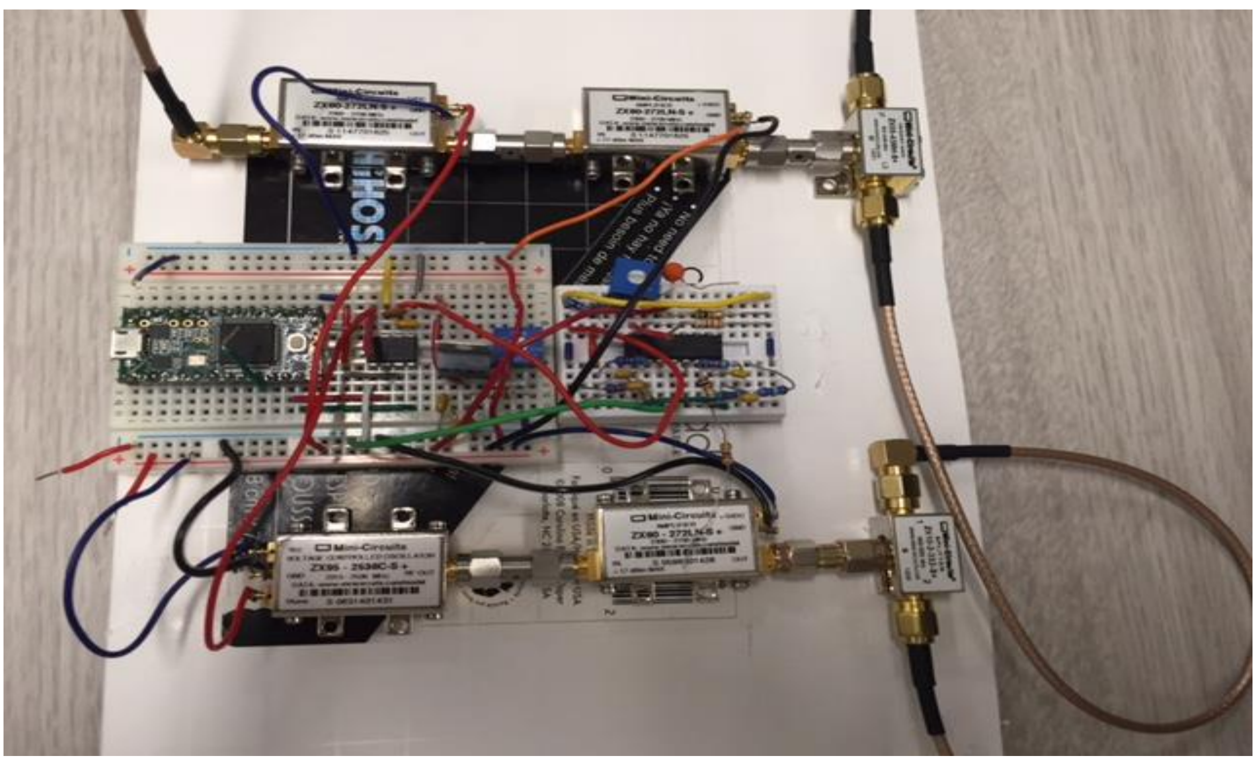
Unfortunately, we were unable to perform a proper outside test with the system because of difficulty obtaining a computer to run the tests on and rain.

The final block diagram of our system is below:

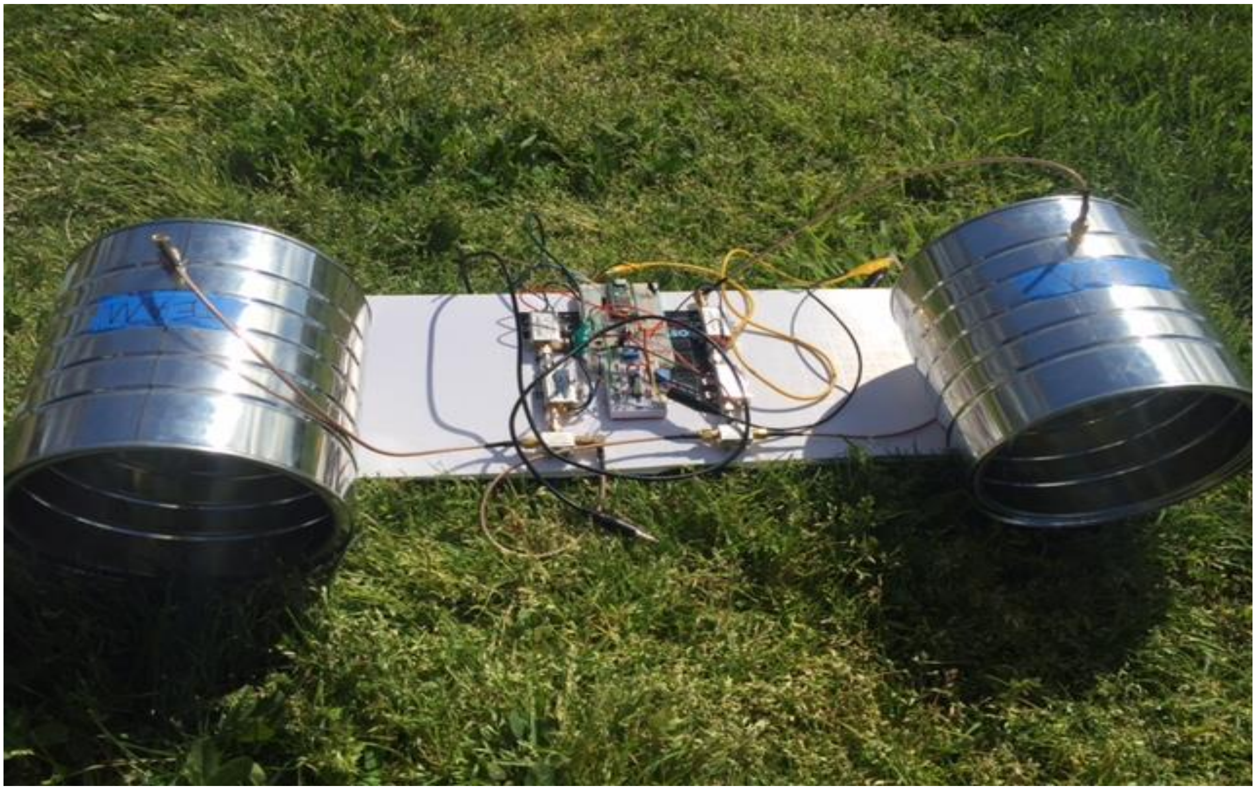


Pictures of our system are presented below:

Close-view of the final system:

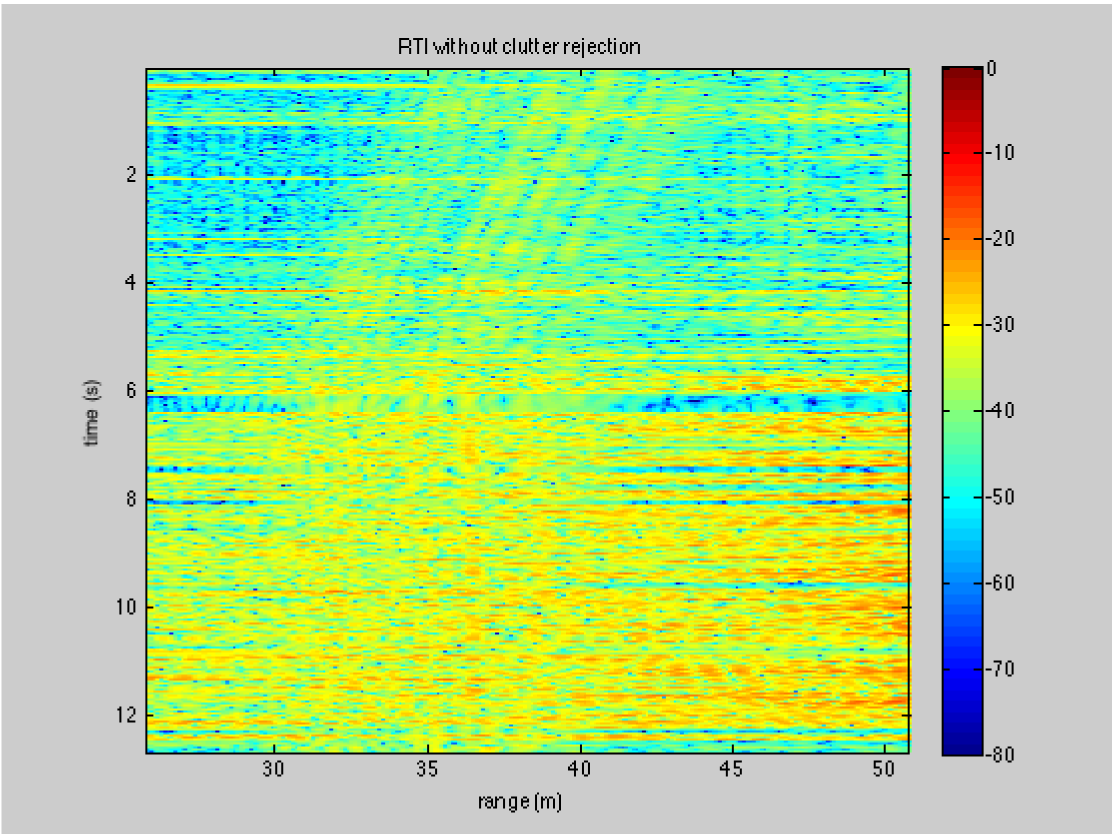


The complete system:

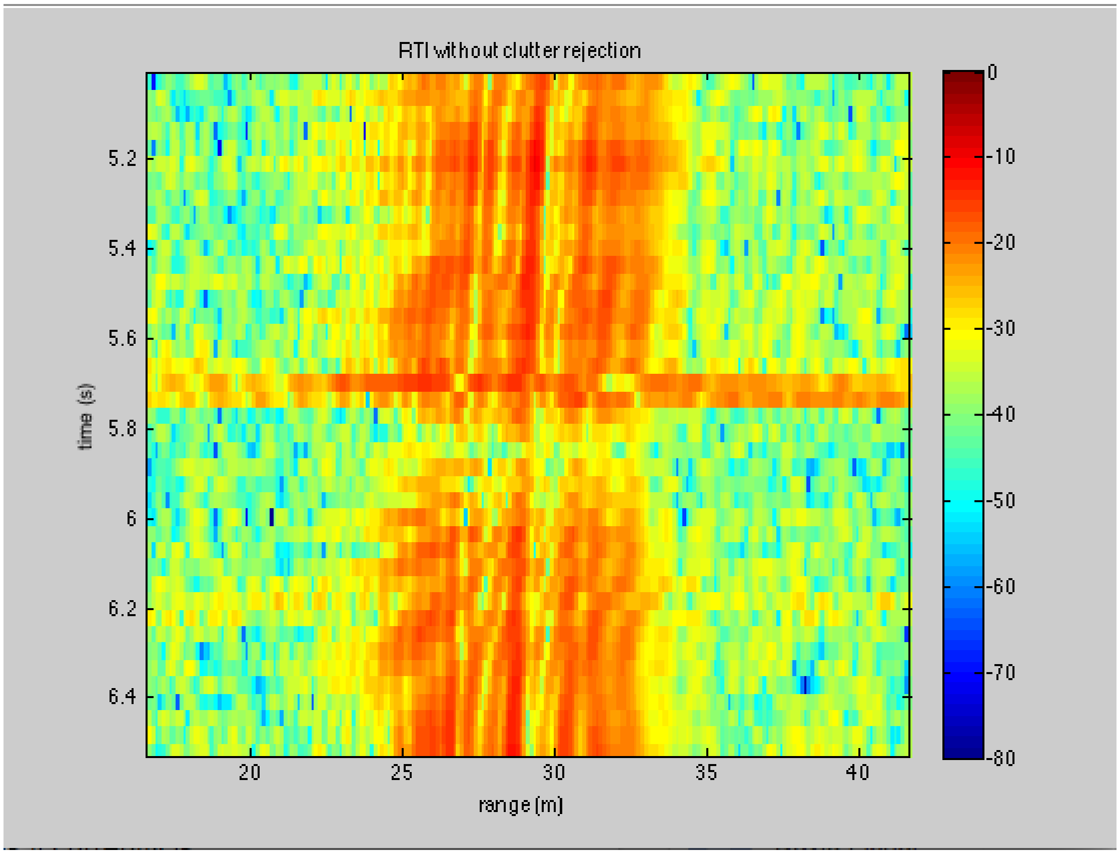


Competition Results
Using our rebuilt and modified Quarter 1 system, we obtained the following results in the radar competition: 36m, 29m, 24m, 19m, and 11m, respectively. The graphs were zoomed in to get the most precise value and are presented as follows:

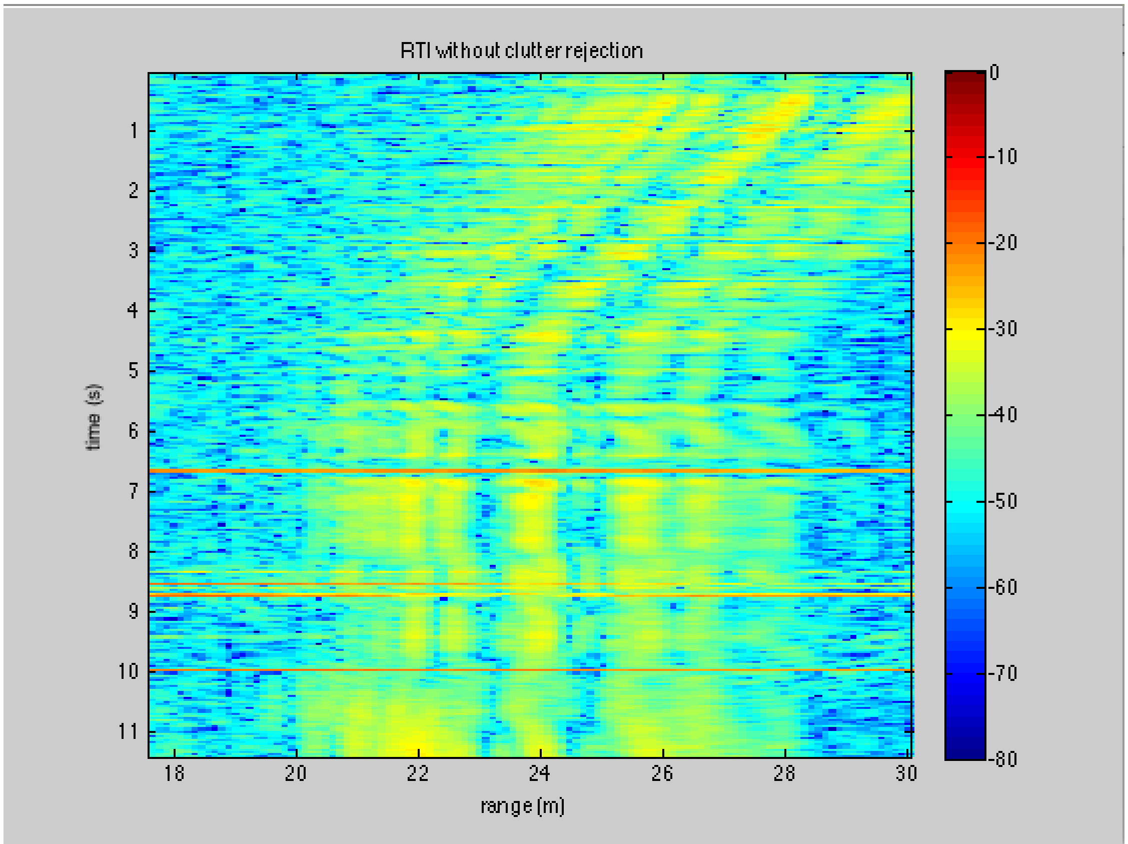
First position:



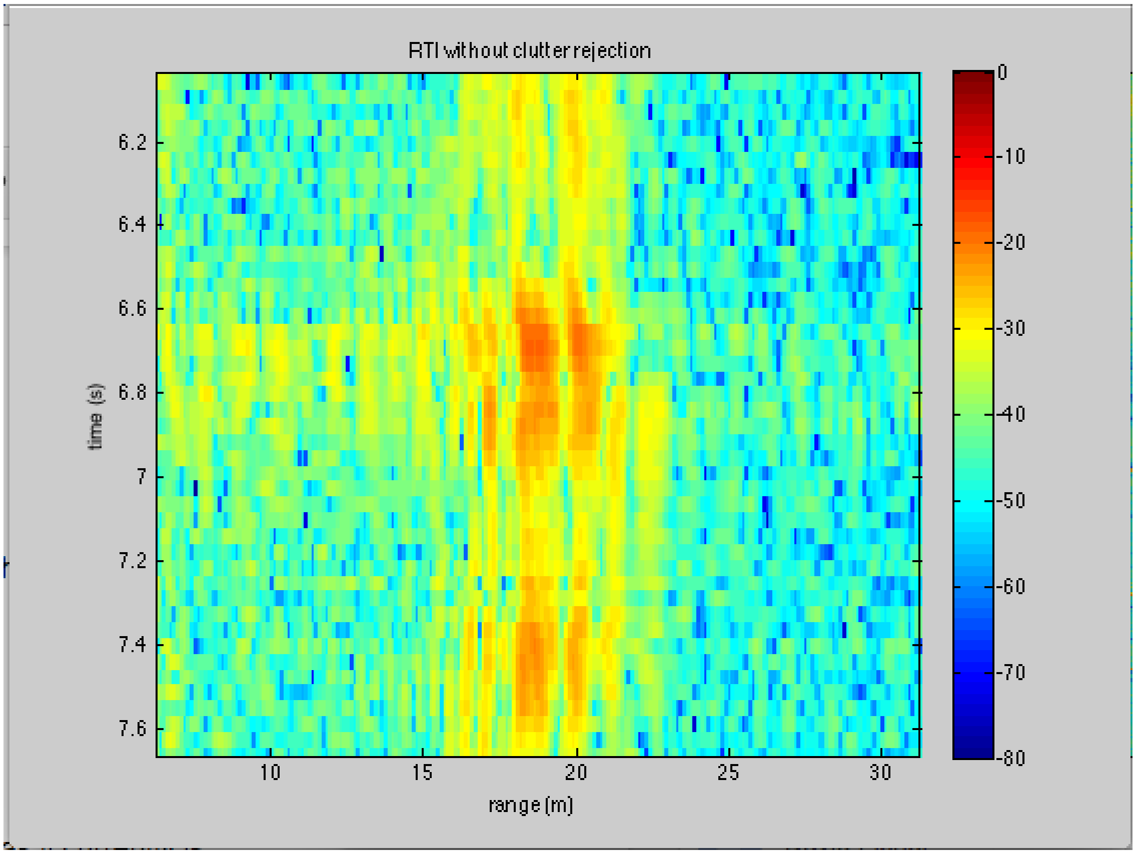
Second position:



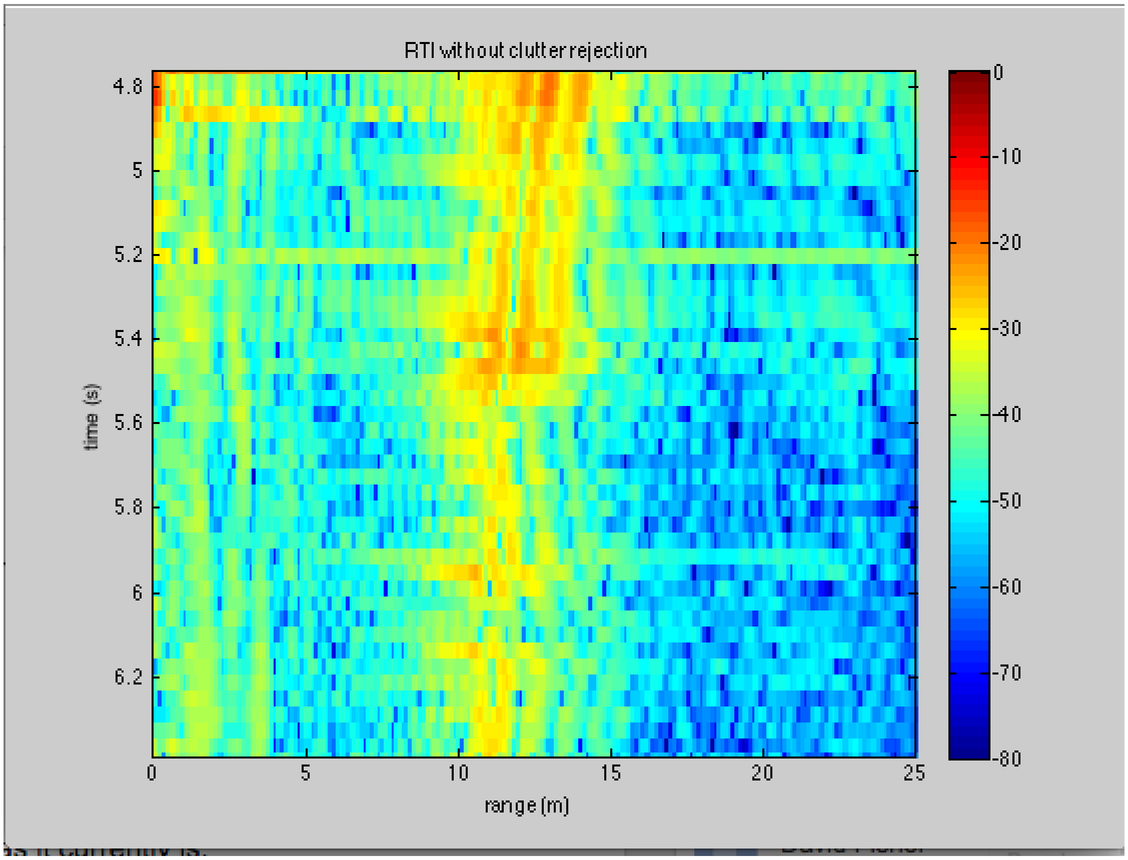
Third position:



Fourth position:



Fifth position:



Although we were able to identify a signal in the received data, the data had much more noise than previously. It's possibly that some part of the circuitry such as the potentiometer in the baseband system was altered when the system was transported to the field where the system was tested, leading to the system not being properly calibrated. Additionally, there may have been noise introduced by the different surroundings. For example, when testing indoors, the system was placed in front of a wall. This placement may have provided less variable interference from objects behind the system, resulting in a more readable result than what was obtained in the final competition.

Discussion

Unfortunately, we were unable to get our second design working. This was most likely due to some error with the PCB design. However, we were able to reconstruct our Quarter 1 system and have it function.

By reusing and modifying the system from the first quarter, we were able to build a working system. We were able to build a system that could detect objects approximately 50 meters away and roughly discern their location.

However, we did experience a large amount of noise in our radar competition results for an unknown reason. Despite this, we were still able to obtain understandable data for the test. Because of these shortcomings, there are certainly ways that we could improve upon the system and the results that we were able to obtain.

Possible Improvements For the System

Although we were able to yield proper data with our system, there is always room for improving it. Several ways in which we could improve the system are discussed as follows.

The first way is to move both the baseband and RF systems to PCBs. Although this was attempted, there were issues with the assembly and testing of the PCBs. Having individual modules for each stage would be helpful in the debugging process since it is unclear which stage is having the issue. This problem could be overcome by having additional time as well as having more PCB prototypes.

Next, better antennas could be used for the system. The coffee can antennas were able to get results; however, the antennas themselves are crude. Using a better commercial antenna set could improve results.

Third, we could have used better components than what our final design used. Since we resorted to resurrecting our Quarter 1 system, the components used were not what we ideally wanted to use. As such, results could improve if we were not limited to these reused components. Additionally, some of the components that we had did not necessarily function as ideally as indicated on their respective datasheet. For instance, we used several mixers before we were able to find one that gave us usable results as the other ones we tested had a much larger loss than what was indicated on the datasheet for the part.

Suggestions For Improving the Class

One suggestion that we have for the class is to possibly merge a couple of the labs in the first quarter. Specifically, we felt that Lab 3 and Lab 4 were very quick and simple labs and could easily be lumped into one lab. We feel that this could benefit future students as it would allow for an extra week in the quarter that could be used to work on Lab 6 as that lab seemed like it was crammed into the end of the quarter.

Additionally, for the second quarter, there could be a better system for getting access to the Fujitsu laptop for testing purposes. For instance, there could be a form for reserving the computer at a certain time for testing or a checkout sheet.

Another suggestion could be having PCB 1 due right from the start of the second quarter since there was a lot of wait time when ordering the PCB. Since the PCB 1 return and PCB 2 design submission were fairly close in timeline, this didn’t allow enough time for testing between PCBs.

Conclusion

In conclusion, we were able to build a working FMCW radar system that could detect objects approximately 50 meters away. Although we needed to scrap any design plans that we had made during the second quarter due to problems with assembling the new system, we still managed to built something that provided results. Moreover, this project has given each of us insight into the operation of a radar system and the general design process for designing a system in Electrical Engineering. Some general notions of system design that this project exposed us to were selecting components to meet specifications, budgeting a system, designing PCBs, and prototyping and debugging a system.

Bill of Materials

The Bill of Materials for the Baseband Amplifier:

Part	Value	Quantity	Description	Price
C_0603_HandSoldering	0.1 u	4	C1, C2, C7, C8	Acquired
C_0603_HandSoldering	1 u	3	C3, C6, C9	Acquired
C_0603_HandSoldering	73 p	1	C5	$0.10
R_0603_HandSoldering	20 k	1	R1	Acquired
R_0603_HandSoldering	220	1	R2	Acquired
R_0603_HandSoldering	10 k	1	R3	Acquired
R_0603_HandSoldering	36.65 k	1	R4	$0.10
R_0603_HandSoldering	39.45 k	1	R5	$0.10
MAX7420	MAX7420	1	U1	$4.54
TPS737	TPS737	1	U2	$1.59
1x6 Pin Header	N/A	2	U4, U7	Acquired
pin	pin	5	VCC, sync, amp, filter, GND	Acquired
Teensy	Teensy 3.1	1	U5	Acquired
TL974	TL974	1	U3	Acquired
MCP4921	MCP4921	1	U6	Acquired
Total				$6.43

The Bill of Materials for RF board:

Part	Value	Quantity	Description	Price
C_SMD_HandSoldering	1000pF	2	C1, C6	Acquired
C_SMD_HandSoldering	100pF	2	C2, C8	Acquired
C_SMD_HandSoldering	0.01uF	1	C3, C9	Acquired
C_SMD_HandSoldering	10pF	3	C4, C5, C10	$0.29 (each)
C_SMD_HandSoldering	1500pF	1	C7	$1.50
R_SMD_HandSoldering	49.9	1	R1`	Acquired
R_SMD_HandSoldering	0	2	R2, R3	Acquired
R_SMD_HandSoldering	2.74K	1	Rb1	$0.10
L_SMD_HandSoldering	180nH	1	L2	$0.11
L_SMD_HandSoldering	18nH	2	L3, L5	$0.44 (each)
L_SMD_HandSoldering	39nH	2	L1, L4	$0.10 (each)
MIXER	ADE-3G	1	U3	Sampled
SPLITTER	BP2U+	1	U9	Sampled
VCO	ROS-2536C-119+	1	U2	Sampled
3dB_ATTENUATOR	GAT-3+	1	U4	Sampled
7dB_ATTENUATOR	GAT-7+	1	U7	Sampled
LNA	PSA-5455+	1	U6	Sampled
POWER AMP	PMA3-83LN+	2	U8, U11	Sampled
SMA CONNECTOR	N/A	2	U10, U12	Acquired
1x6 Pin Header	N/A	2	U1, U14	Acquired
RF_CHOKE	TCCH-80+	1	U13	Sampled
RF_BPF	BFCN-2450+	1	U5	Sampled

Total				$3.66

Other parts:

Part	Quantity	Price
Yagi Antenna	2	$9.99
Total		$19.98

Acknowledgements
We would like to acknowledge Minicircuits for providing parts for our project through both sampling components through their website and through contacts at the company. Specifically, we would like to mention the representative that came to one of the Friday meetings and Janet Hunn.

Additionally, we would like to acknowledge both Professor Leo and the three teaching assistants for the course, Songjie Bi, Daniel Kuzmenko, and Hao Wang, for providing us with an opportunity to work with and understand the development of this sort of system.