

University of California, Davis

EEC 193 Final Project Report

Radar Shield System Design

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Abstract

Our Radar Shield system is an independent and portable radar system that users can plug in any compatible antennas and read the real-time object distance on the microcontroller's on-board OLED. We think this is interesting to the general public because it can be mass manufactured as a plug-and-play product that can possibly implement many interesting applications, such as motion sensing, remote vital sign monitoring, robotic vision, and collision avoidance.

Introduction

Our system uses the frequency difference between the transmitting signal and the receiving signal to calculate the distance of an object. The frequency of the transmitting signal is changing linearly over time. As shown in figure 1. After the signal transmitted a distance of $2d$, the travelling time will be $2d/c$, and there is a frequency difference Δf between the transmitting and the received signal. Based on the relation of Δf and transmission time of the signal, the distance of the object can be calculated by:

$$d = \Delta f * c * T / 2$$

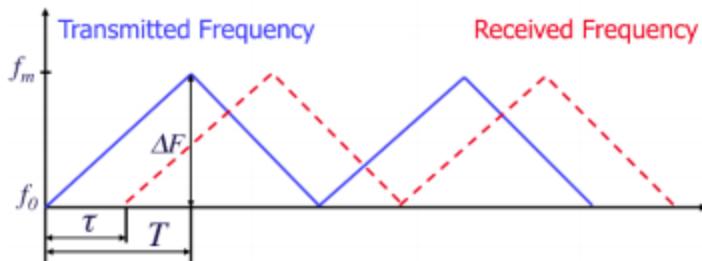


figure-1

Goals

- Make the system compact by putting all the components on PCB
- Increase the resolution
- Use microprocessor for real time signal processing
- Display the distance on the screen of the microprocessor

Description of the project

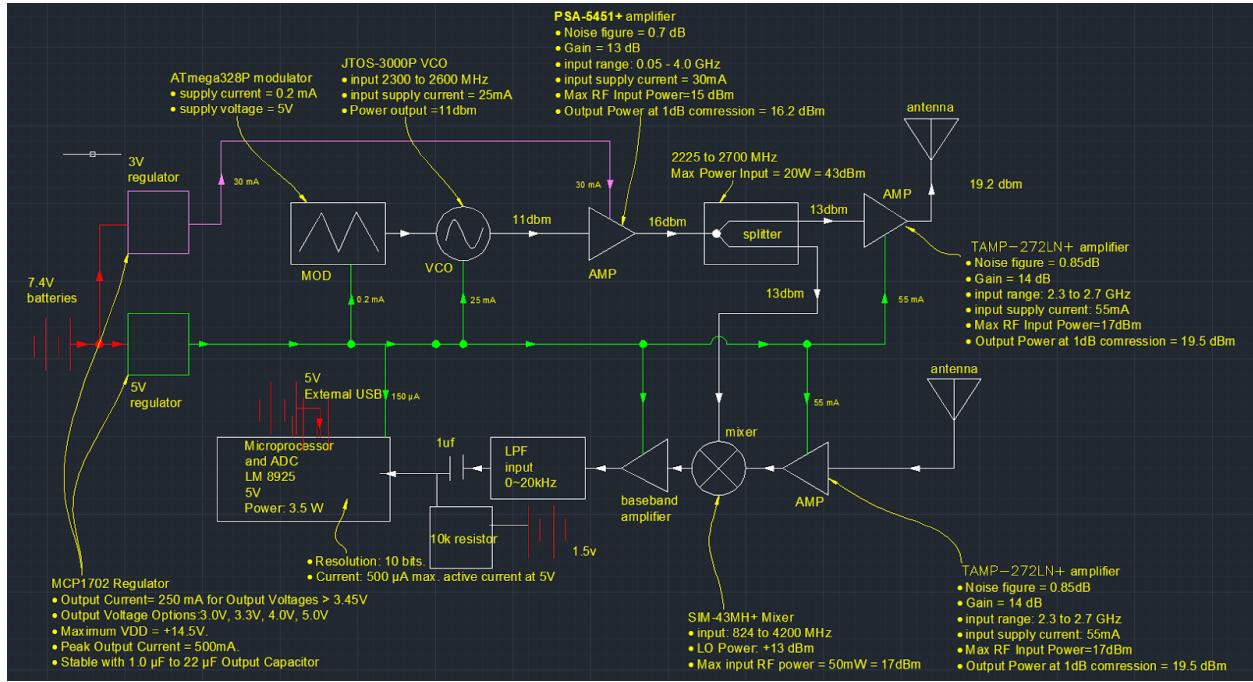
This project consists of three major parts.

The first part is the quarter one design -- the signal generation, transmission, and detection. We need to generate the FM signal, amplify it, and split the signal into two branches. In one branch, we amplify the signal again and transmit it out through an antenna. In the other branch, we feed it into a mixer which mixes it with the received signal from the receive antenna. The mixed signal will then go through an active low-pass filter before it goes into an ADC.

The second part is signal processing with microcontroller Stellaris LM3S8962 Evaluation Board. Real-time analog signals will go into the microcontroller's ADC. And then the digitized signals will be Fourier transformed. The output frequency with the greatest magnitude will be used to compute for the object distance. The real-time object distance will then be displayed on the on-board OLED of the microcontroller.

The third part is the PCB implementation of the circuit in part one. The PCB will be implemented onto a 4-layers board base on the quarter one design. We kept using the through hole chip for the modulator to generate an input for the VCO. For all the RF components, we decided to use surface mount components to minimize the size of our design. The amplifier in the active low pass filter will be replaced by a surface mount chip instead of the through hole chip. Width of the transmission line is calculated to satisfy 50 ohm impedance. There will be some test point around the input, output, and regulator in order to make sure each part works properly.

Design Details



We use a 7.4V rechargeable to power up the system. there are three 5V regulators to supply the VCO, 3 amplifiers and modulator. there is a 3V regulator to give the offset of the baseband amplifier. To increase the resolution of the radar, we increase the bandwidth of the VCO from 200MHz to 300 MHz. The frequency range of the VCO is from 2.3to 2.6Ghz, and it has output power of 11dbm. We use a level 13 mixer for signal demodulation, which needs 13 to 16dbm power for the local oscillator . The amplifier after the VCO increases the power to 19dbm and the splitter reduces the power to 16dbm before the mixer.

Surface Mount Voltage Controlled Oscillator

5V Tuning for PLL IC's 2300 to 2600 MHz

Features

- low phase noise
- 5V tuning voltage range
- linear tuning characteristics
- aqueous washable

Applications

- PLL circuitry
- measurement instrumentation
- frequency synthesizers

JTOS-3000P+
JTOS-3000P



CASE STYLE: BK377
PRICE: \$21.95 ea. QTY (5-49)

+RoHS Compliant

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

Electrical Specifications

FREQUENCY (MHz)		POWER OUTPUT (dBm)		TUNING VOLTAGE (V)		PHASE NOISE (dBc/Hz) SSB at offset frequencies:				PULLING pk-pk @ 12 dB _r (MHz)	PUSHING (MHz/V)	TUNING SENSITIVITY (MHz/V)	HARMONICS (dBc)	3 dB MODULATION BANDWIDTH (MHz)	POWER SUPPLY	
Min.	Max.	Typ.	Min.	Max.	1 kHz	10 kHz	100 kHz	1 MHz	Typ.	Typ.	Typ.	Typ.	Max.	Typ.	Voltage (V)	Current (mA) Max.
2300	2600	+11	0.5	5.0	-65	-92	-112	-132	50.0	5.0	120-160	-22	-12	20	5	25

Ceramic Surface Mount

Frequency Mixer WIDE BAND

Level 13 (LO Power +13 dBm) 824 to 4200 MHz

Maximum Ratings

Operating Temperature	-40°C to 85°C
Storage Temperature	-55°C to 100°C
RF Power	50mW
For extended temperature range, consult factory.	
Permanent damage may occur if any of these limits are exceeded.	

Features

- wide bandwidth, 824 to 4200 MHz
- low conversion loss, 6.1 dB typ.
- excellent L-R isolation, 35 dB typ.
- LTCC double balanced mixer
- tiny size, low profile, 0.08"
- useable as up and down converter

SIM-43MH+



CASE STYLE: HV1195
PRICE: \$7.45 ea. QTY (10)

+RoHS Compliant

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In order to maximize the power of the transmitting signal, we add an amplifier before the antenna with output power of 19.5 dbm.

Low Noise Amplifier

50Ω 2300 to 2700 MHz

TAMP-272LN+

The Big Deal

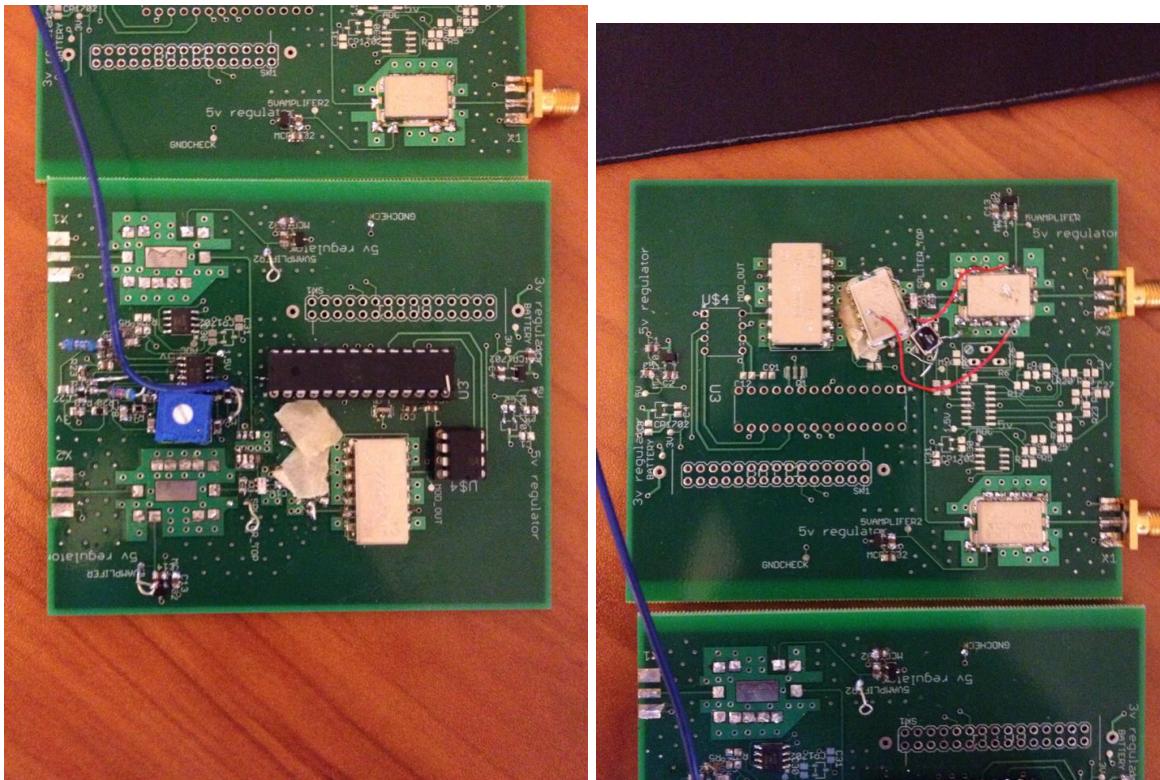
- Ultra Low Noise Figure, 0.85 dB typ.
- High Output Power, +19.5 dBm typ.
- High Output IP3, 30 dBm typ.
- Integrated Bias Matching and Stabilization Circuits



CASE STYLE: JQ1382

The baseband amplifier has a 3V offset and 7V voltage swing. The voltage range of the ADC is 3V. In order to maximize the usage of the ADC, we give the received signal a 1.5V offset.

PCB



Design Goal

The first goal of making a PCB is to create a more compact design of our radar car parking sensor. We want to have a lighter and thinner device. For our second goal, we want to have a low distorted device by minimizing noise and improve from our breadboard design. One of the solutions that we will try is to provide our system by having better impedance matching (50ohms) on our PCB. By manufacturing two designs on one board, we can test both designs and see which design can perform better and more reliable results.

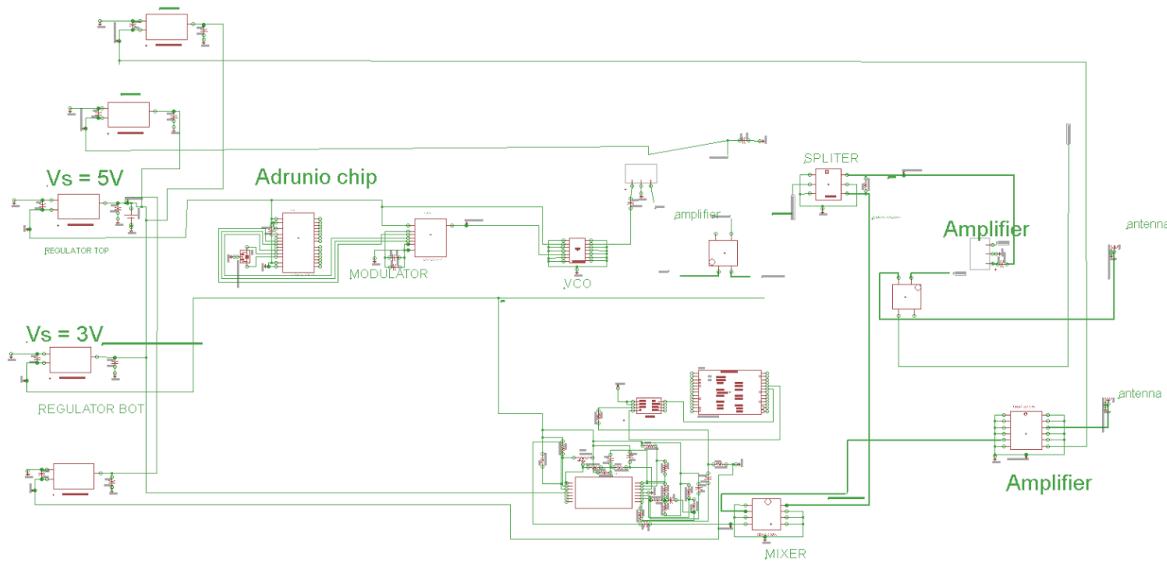
Schematic

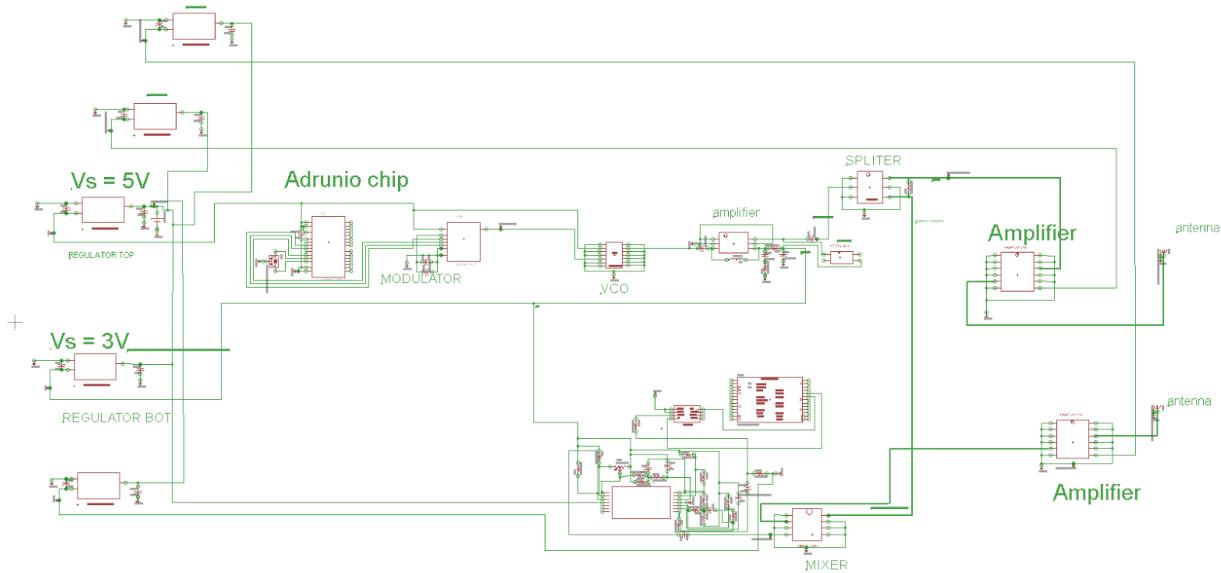
Schematic is a crucial part of the layout process because all the wiring and the connections on the layout interface will be heavily depend on the design on the schematic. It is very important to double check and make sure that all the pins of the components are

connected and wired to the right position. Some of the components might not be able to find in the library, then you will need to stick closely to the datasheet of the component and create a library for it. Our group researched on tutorials that are available on the internet to guide us to through making our PCB.

Before we create our component, we first have to decide on rather if we can copy the suggested PCB layout onto Eagle. For the amplifier, we tried to look for packaged “all in one” components instead of using the ones that we have to follow the datasheet and create an application circuit in order to have the component function as it described, because they are more complicated to create and it may result in impedance mismatching. We also kept checking the stock of the components for our PCB, because we want to make sure these components are available when the PCB arrives.

When we make our components for the schematic , we want to label our input and output carefully to make sure that the component pins between the schematic and the board are the same. We want to make sure that the pads for our surface mount components are exactly the same size as the suggested layout because if we make a mistake on the board side of our design then we might face trouble in soldering the components onto the PCB.





Layout

Since we are working on a 4-layers PCB design. The stack-ups of our design are signal layer, ground layer, power layer, signal layer (as shown below)

4 Layer Foil Lamination - .062				
				Thickness
TOP	L1	Foil	H oz	0.0007
Prepreg	2116		1	0.0045
Prepreg	1080		1	0.0030
L2		Foil	1 oz	
	Core Thickness		0.040	0.0428
L3		Foil	1 oz	
Prepreg	1080		1	0.0030
Prepreg	2116	No. of pcs.	1	0.0045
BOTTOM	L4	Foil	H oz	0.0007
Total Thickness				0.0592

The 4-layers PCB is commonly used in the industry.

Sending out the PCB

After completing the PCB, we must convert our PCB design into Gerber files for the manufacturer. For our four layer systems, we opened our layout design and we go into CAM processor and start a new job. Instead of manually fill in the layer functions. Eagle has a preset cam file for four layer boards, so we look for the “Open for Job” tab and we select the gerb274x-4layer.cam. we make sure all the layers are correct, for example, for our board, we want to make sure that when the layers are being processed, our top signal layer is with 17 pad layer, 18 Vias layer and 20 dimension layer in the .CMP file, etc.

PCB Soldering

Good soldering is a must for a good design. Good soldering can ensure each component is well placed and make good contact with the pad on the board. Too much solder might lead to short circuit and the design cannot work as expected. Always have a DMM to test after soldering each components can save time and reduce the chance of having error in the design. Desoldering skill might be needed to fix errors and misplace components. This class gave us a good opportunity to practice and utilize our soldering skills.

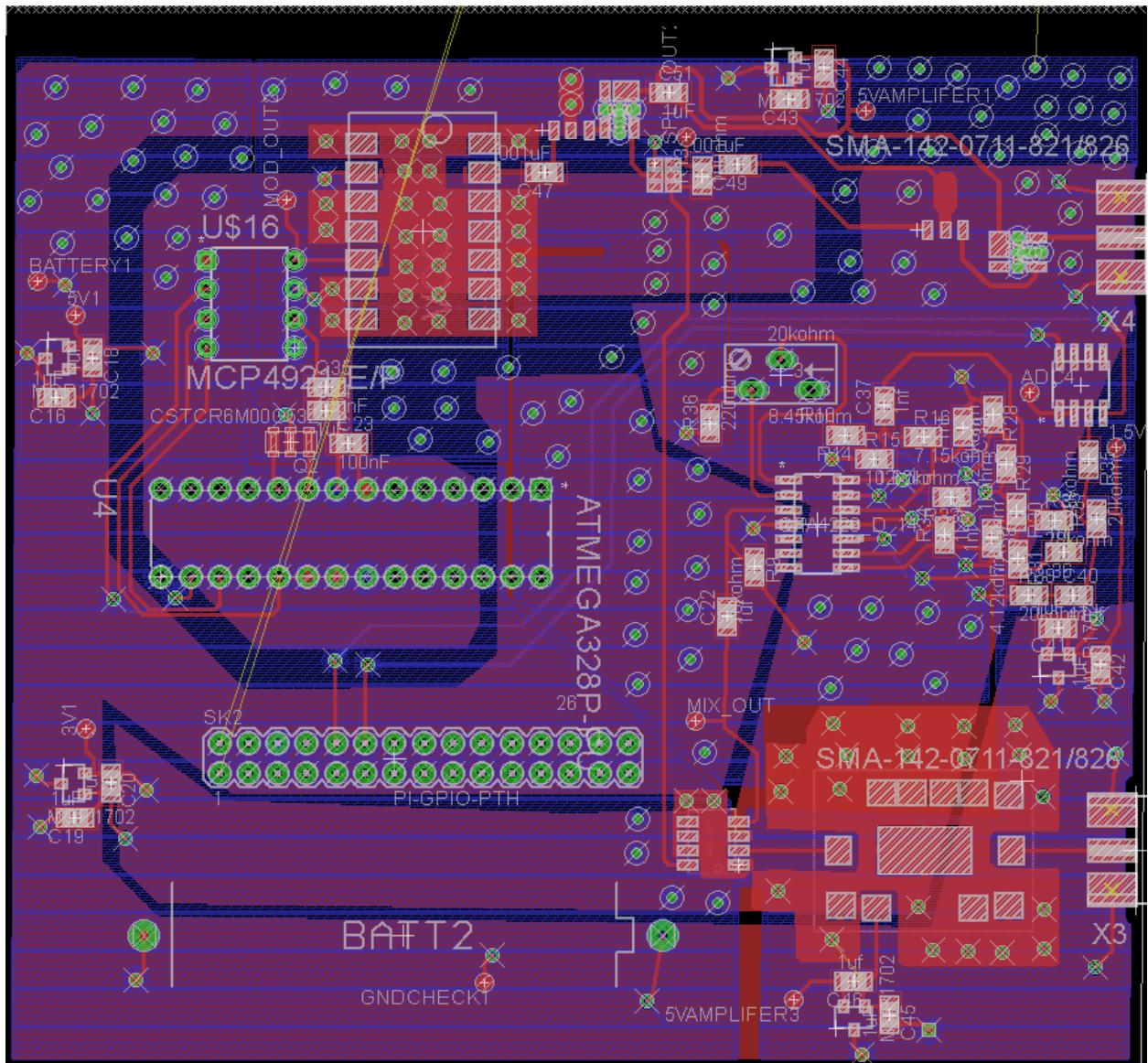
PCB difficulty

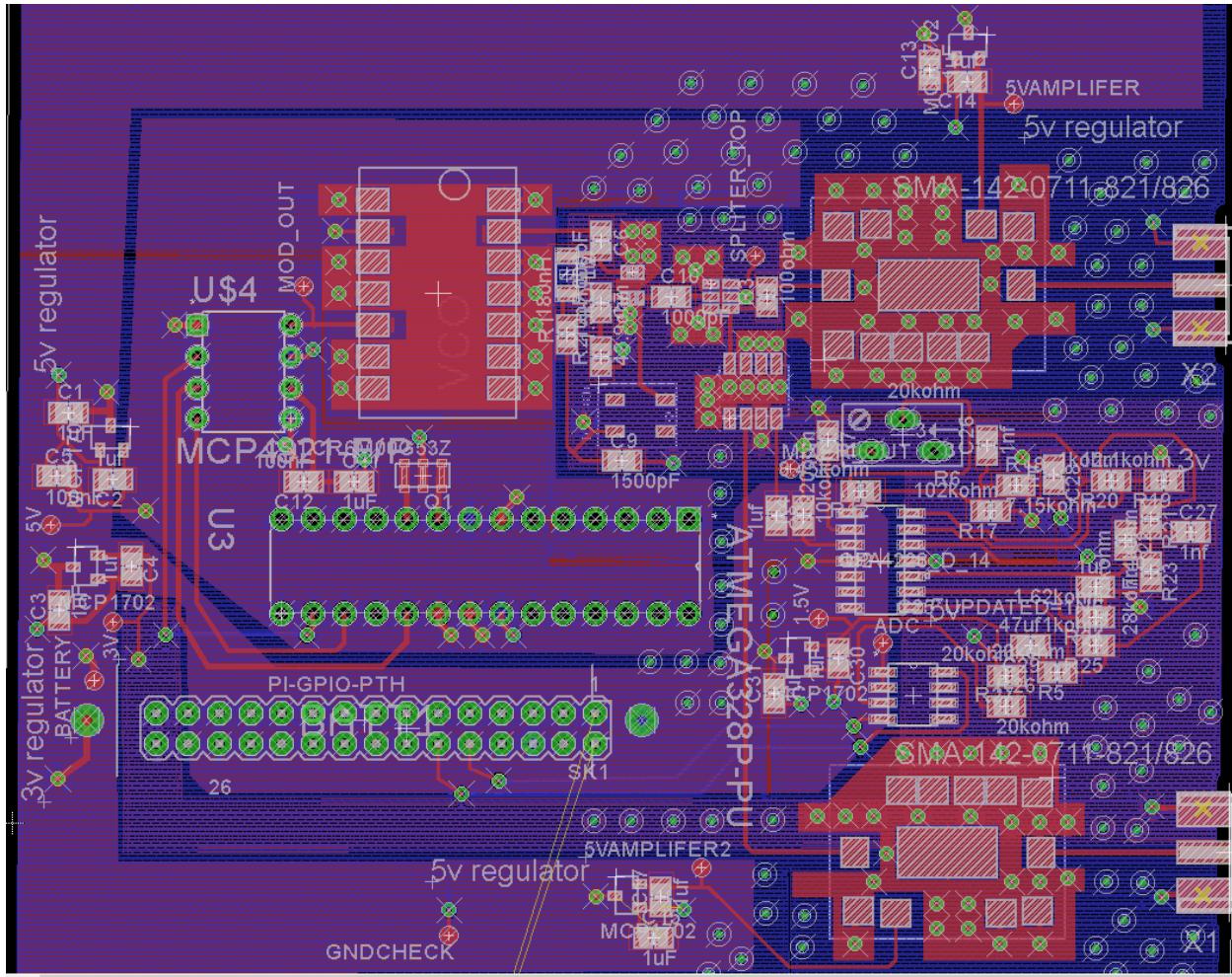
When we made our design, we fail to create one of the amplifier (PSA-5451+) because of mismatching. One of the reason would be some of the components within the amplifier are connected with 50 ohms. The solution that we used to solve this problem is by using another packaged (TAMP-272+) and solder the input and output of the older amplifier pads.

Another problem that we faced when we received our PCB was that one of the input and output of the mixer are switched. To solve this problem, we tried to add wires to correct this mistake. Unfortunately, one of the input signal is part of RF, so we gain a lot of noise after we wired them. In the end, we notice that the mixer's output is also connected to the ground, so we turned our mixer component (SIM-43MH+) by 45 degree angle and place them on the correct pads, then add extra wire from the ground of the mixer and connect it to our low pass filter.

PCB results

We have completed in turning our design into a compacted form, however, we made a few mistakes that ultimately reduced the effectiveness of the system. However, we only used one try on the PCB and after we have test all of our other components by parts and they all are working properly.





Microcontroller Coding

We studied the matlab program that was given to us in quarter one of this course. We found out that the sync line of the audio cable does not matter that much since it only helps to take samples in when it is at positive edge. Then we figure out the algorithm of the rest of the code. It follows the steps shown below:

1. Take multiple data at two different time
2. Subtract the old data from the new data
3. Store the result into a new group of data
4. Plot the amplitude of the data.

The subtracting helps to eliminate random noise to get a much better and cleaner signal. Plotting the amplitude helps us identify where the signal is located. For example, (figure of a matlab result) the result of the matlab code is shown in Figure #. The first plot is the one

without subtract and the second plot is the one with subtract. The red line indicates our signal.

We used the same idea on our LM3s8962 board to implement our signal processing. We first use an add-on library to do FFT on our ADC signal. Then we have a time delay (one second) for taking samples. So we have two groups of data at different time. After that, we subtract the old data from the new data to eliminate noise in the system, store the result in a new buffer. Then we find the frequencies at which the amplitude is the highest in the buffer that consists of multiple columns of array. We then compare those frequencies to see if there are close by. If they are close, we take the average of the frequencies and take the result to be our final frequency that shows where the signal is located. If they are not close by, then we can just ignore those frequencies. This method helps us find an accurate frequency of our signal.

Another programmed feature of our microcontroller board is that with a single button press, the OLED display could switch to become a real-time spectrum analyzer. All FFT result frequency components will be graphically displayed in real time. Pressing that button again will switch the OLED back to displaying computed distance.

Test/Measurement results

Detection refreshing rate = 1Hz

Detection range = 0 to 5 meters

Radar resolution = 0.3 meters

The three youtube links below are our successful test results with the bread-board prototype.

object departing: <https://www.youtube.com/watch?v=g9FnICcHuS4>

object approaching: <https://www.youtube.com/watch?v=2uyk-n8H818>

spectrum analysis: <https://www.youtube.com/watch?v=Bdx1nQ3C664>

This video below is our test result with the combination of a few PCBs. There are some errors on each individual PCB so for time's sake we combined a few boards to make a working system. For some reason, the noise is greater than we expected. The system only has a detection range up to about two meters as the video shows.

PCB implementation: <https://www.youtube.com/watch?v=2znEmWlbERo>

Possibility for future extension

Our current design works only from range up to 5 meters (approximately 1000Hz). We believe that we can further improve our result by changing our specifications. One of the problem we having in our system is that our signal will be covered by noise once we get pass 5 meters. So by changing our current amplifier to a stronger amplifier, our dbm at the receive end and transmit end of the system will also increase. That way, our signal will be stronger and can detect further in distance.

Second possible extension is to have higher precision on our reading. This goal can be achieve by using a higher bit resolution ADC. Our current ADC is only 10 bit precision. So we can only divide our signal into 1024 parts. By using a higher bit resolution ADC, we can have more precise results of our frequency reading.

Suggestions to this class

Overall, this class is fun due to it is challenging. Coming up with a design and implement it is not a simple or easy task. It actually requires a lot more time than expected. One of the suggestion to this class is that to have more design options provided by the instructor. That way, instructor can know the progress of each group and give them warnings if they are not on schedule. Also, instructor can give them hints on how to improve the design. Another suggestion is that to have the class compete with each other. If students are under pressure, we believe that they will work harder and try to be the best in the class to show off their cool design.

Conclusion

In quarter one, our bread-board system can detects objects up to 100 meters. However, our Radar Shield System can correctly detect objects up to 5 meters. We have concluded a few causes of our Radar Shield System's short detection range.

1. Our microcontroller's on-board ADC only has 10-bit resolution. So as the object goes farther, the returned signal will be too weak to be distinguished with 10-bit resolution.
2. Our imported FFT code will only allow the system to produce 64 frequency elements. This limits the sampling rate, frequency resolution, and frequency range.

3. Our microcontroller can only output a real-time result to show the object distance, while our quarter one design used matlab to record massive amount of results over a long period of time with a graphical output. The graphical output is not real time but the statistic-like graphic presentation can tolerate a few error data points without undermining the overall trace of the signal.

4. Our microcontroller has significantly less computing power (Cortex M3 single core 50 MHz) than a laptop computer (i7 4-core 2.4GHz). So the data mining approach is not really an option. Therefore random error cause by noise is a significant threat to our perception of data correctness.

Acknowledgement

Mini-Circuits

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Thanks for her helping on getting the components very quick. She was able to give us student discount on our order and waive the minimum quantity requirements for the components. As long as the website says it is available for free sampling, she can help you to generate the order for free samples and make a quote for the rest of the components you need. We got our mixer, splitter, bias tee, attenuator and some of the amplifier for free. The quantities can be vary depends on different components.

Microchip, Texas Instruments, Atmel

Thanks for their education program for students. All of them are providing samples on many of their chips as long as you have an email with .edu. They do provide free ground shipping (4~5 days) for the samples. However, they only allow us to get small quantities each time for each account. I encourage each team member should create an account in order to have enough samples for testing.