S-Band Radar Altimeter

Design Document

ECE 445: Senior Design
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1. Introduction

1.1. Problem

Consumer drones often rely on GPS or IR sensing for navigation and terrain avoidance. GPS, while reliable outdoors, requires line of sight to the sky and will not function properly in highly urban environments or indoor spaces. IR sensing reliably works indoors or in confined spaces, but its performance quickly degrades with increased distance, surface reflectivity, and drastic light changes [5], among other conditions commonly faced by pilots. Alternative sensor technologies such as lidar or mmWave radar improve on these issues to some degree, but are prohibitively expensive for consumers and suffer from low maximum range.

1.2. Solution

Our solution implements a radar altimeter operating in the S-band (2.25 GHz - 2.5 GHz), which can be mounted on large consumer drones. The radar will use an internal microcontroller and frequency modulator to generate FMCW (frequency-modulated continuous-wave) pulses of variable bandwidth for different distances. On the receiver side, the radar will use a LNA, a mixer, and op-amps for the IF filter. For transmission and reception, the radar will rely on two small antennas. All parts are off-the-shelf discrete amplifiers, passives, logic components, etc. Inside the radar, a mixer multiplies the transmitted and received signals to produce a difference signal, giving us information about the distance to the target (terrain). The distance is calculated using standard formulae for FMCW radars and is stored to an onboard SD card. To assess the precision and accuracy of the radar, an onboard barometric sensor will also be used and its data will be written to the SD card as well for post processing. Please note that the radar itself is a standalone system, and it will be tested as such. It does not connect electrically or physically to the drone; it can just be mounted on a drone via a housing.

1.3. Visual Aid

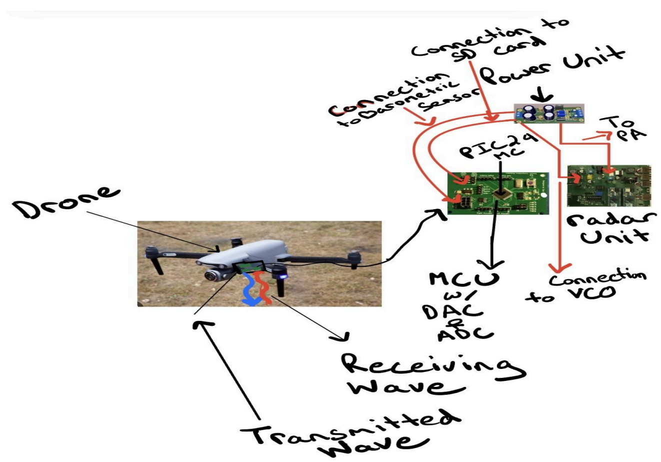

Figure 1: Visual Aid

1.4. High-Level Requirements

- The radar must have a maximum range greater than 20 m. This means that the lower bound on our maximum measurement range is 20 m, not including range resolution. To achieve this maximum range, we will use a power amplifier with high linearity until ~0.5W. This allows us to overcome any board or cable losses and provides the maximum range possible while avoiding the power consumption of a higher power part.
- The receiver noise figure must be less than 10 dB. This will more easily allow us to detect faint radar returns which undergo reflection and attenuation. To achieve this standard, we will use a low-noise amplifier with high gain and low noise figure. If necessary, we will cascade multiple LNAs to fix the system noise figure at that of the cascaded LNA combination.
- The radar must have a range resolution of 1.5m or better. Range resolution in FMCW radars is directly tied to the sweep bandwidth. Therefore, we will use a VCO with a sweep bandwidth of at least 100 MHz.

2. Design

2.1. Block Diagram

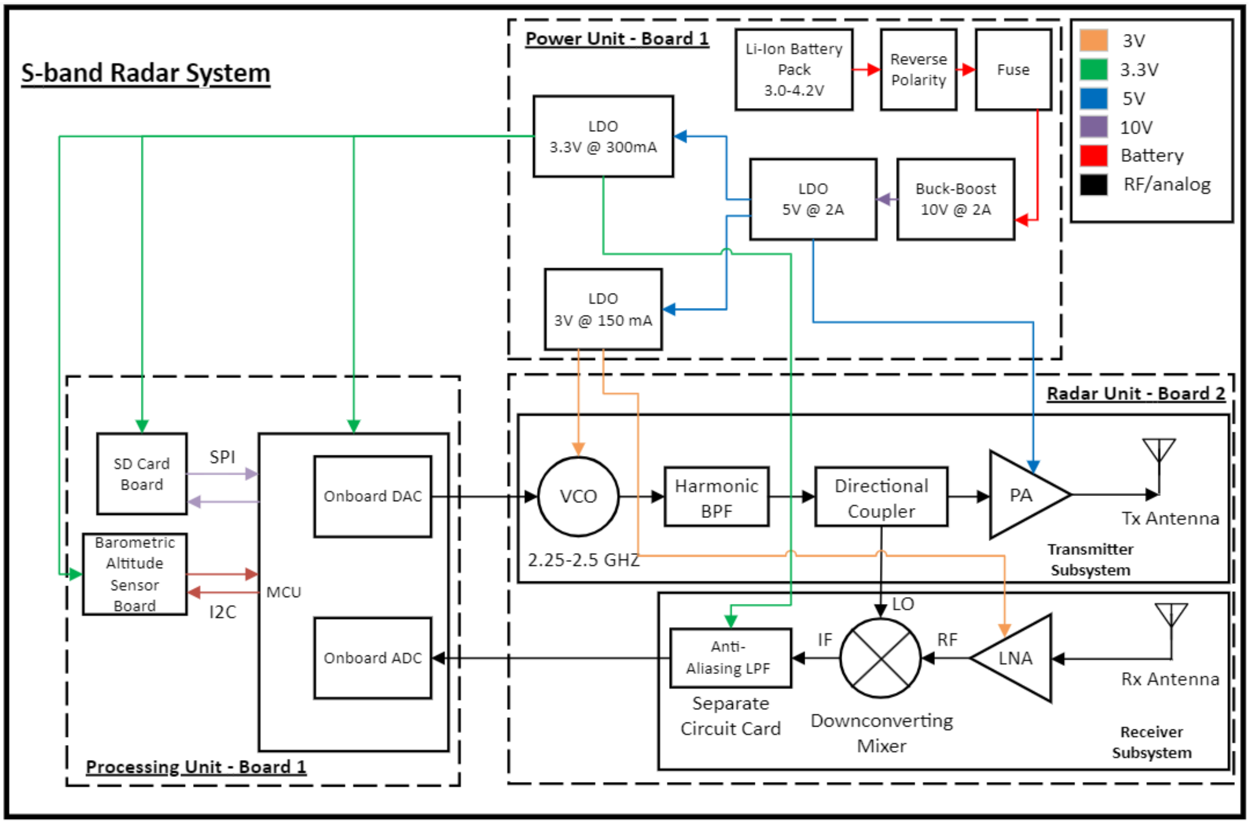

Figure 2: high level block diagram

Our design will consist of 3 subsystems: Processing Unit, Power Unit, and Radar Unit. The Processing Unit will be responsible for creating a triangle waveform that will be fed into the VCO input. This will allow for an FMCW wave to be created which is integral to the function of the radar unit. The Processing Unit will also record data coming through the Rx chain of the radar unit to be recorded for post processing to compare against the barometric readings. The Power Unit will be responsible for providing power to all active components of the design. This will include the various voltage inputs to the MCU, SD Card Board, Barometric Sensor, VCO, PA, and LNA. This will be done through the use of a Lithium Ion battery, 3 LDOs, and a Buck-Boost Converter. The Radar Unit Tx chain will be responsible for filtering and power amplifying the FMCW signal from the VCO that will lead into an antenna. The Rx chain will be responsible for amplifying the received signal and mixing it with the transmit signal. This mixing function will output a sum and difference signal that the LPF will only keep the difference. This process will allow us to determine the distance to the ground through the following equation:

$R = \frac{Tcf_r}{2(f_{max} - f_{min})}$ [14], where T is the time for the triangle waveform to reach a maximum value, c is the speed of light, f_r is the beat frequency, f_{max} is the maximum frequency of the

FMCW signal, and f_{min} is the minimum frequency of the FMCW signal. The beat frequency can be determined through the following relation: $f_r = \frac{|f_{bu} + f_{bd}|}{2}$ [14], where f_{bu} is the difference of the transmit at receive signal during the rising edge of the FMCW signal, and f_{bd} is the difference of the transmit at receive signal during the falling edge of the FMCW signal.

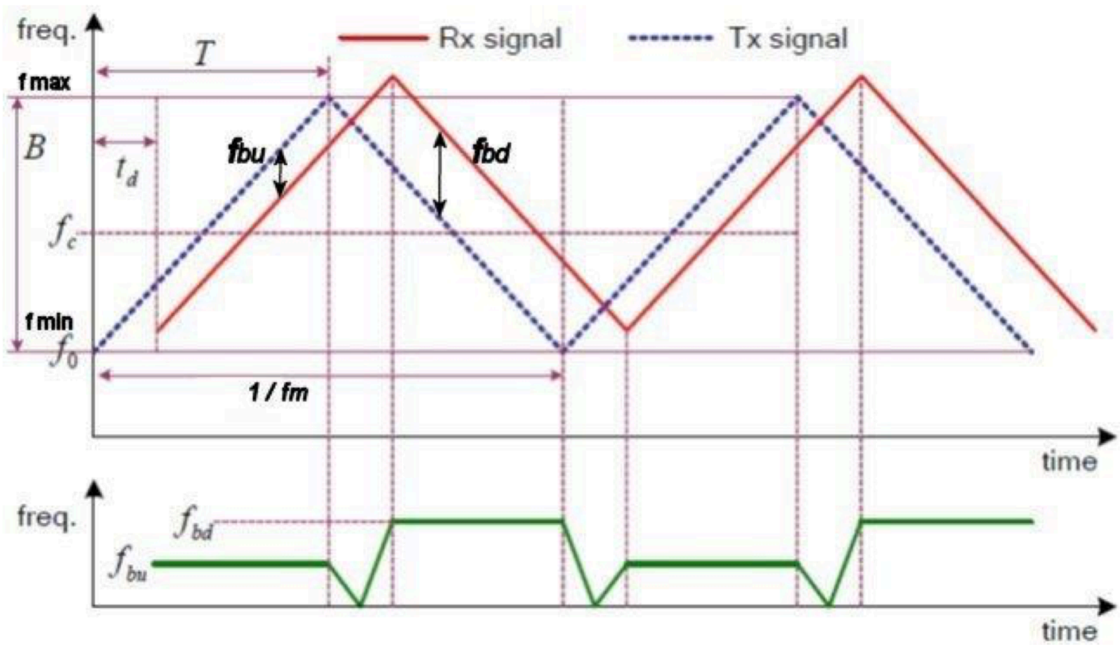

Figure 3: FMCW Radar signals using a triangle low frequency waveform

2.2. Physical Design

Our design consists of the radar unit, the processing unit, and the power unit. While the processing unit and the power unit reside on the same board, the radar unit is kept separate to minimize coupled noise due to digital signals and switching regulators. All of the boards will be mounted in one 3D-printed enclosure. Each board contains M2.5 mounting holes for connection to the enclosure.

The radar unit itself consists of a 4-layer RF board and a lower frequency 2-layer IF board. The IF board, which only contains analog filters and mates with the RF board via a 2.54mm 5-pin connector. This connector provides the IF board with power and the IF signal from the mixer on the RF board. Similarly, the RF board will use a different 2.54mm 5-pin connector to receive power and control signals from the processing and power board. The processing and power board will contain a 2-pin connector for the battery, and a 2.54mm 5-pin connector to provide power and control signals for the radar unit. All boards will be 100mm x 100mm at a maximum due to manufacturer restrictions.

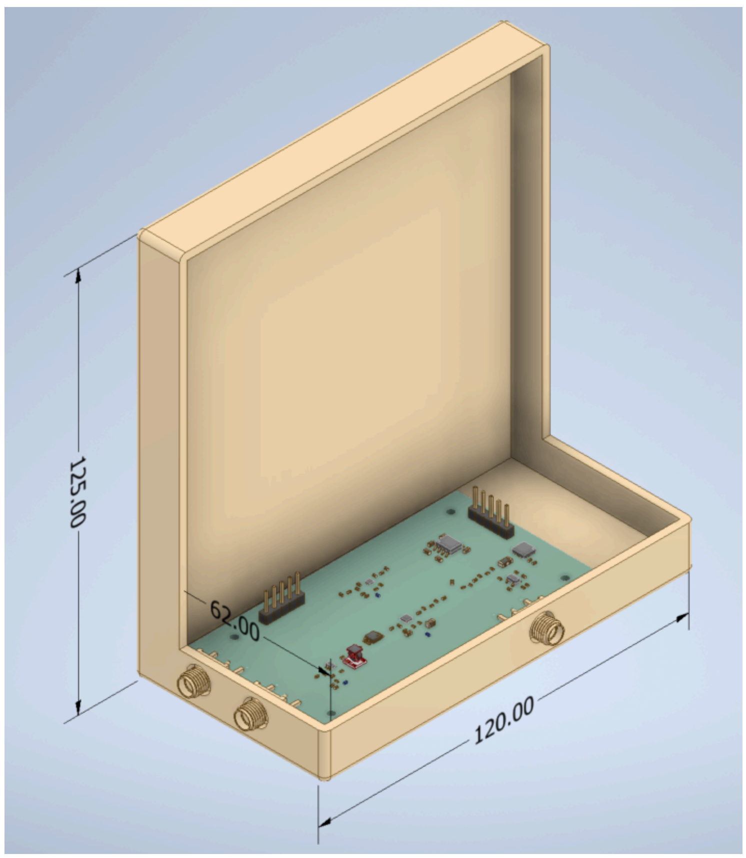

Figure 4: Draft of enclosure, with dimensions in mm. The RF board sits on the bottom; the processing and power board will sit on the large face on the left

2.3. Subsystem Overview

- **Complete Unit Overview**
  - Altogether, the radar system will function as follows: the power unit takes the 3.0-4.2VDC from the lithium battery and steps it up to 10V. This 10V is fed through a 5V LDO to produce a 5V rail from which we can create other voltages. On the power unit, this 5V LDO feeds a 3.3V LDO and a 3.0V LDO, creating secondary voltage rails. We use the latter LDOs to power the VCO and receiver on the radar board. At the same time, the 5V signal is used to power the transmitter on the radar board. The 3.3V is also used to power the microcontroller and associated peripherals in the processing unit.
  - Once it is powered, the radar board receives a control signal from the DAC on the processing unit. This control signal connects to the VCO and generates a FM sweep, which is used by the transmitter to send FMCW pulses. The receiver also uses this FM sweep as the LO for demodulating the FM pulses. The LO is fed into a mixer which creates a low-frequency IF signal. The IF signal is filtered, amplified, and connected back to the processing unit. Finally, the IF signal is sampled by the power unit to obtain range and velocity information. The range (altitude) is stored to the SD card for post processing.
- **Radar Unit**
  - **Transmitter Subsystem**
    - This subsystem is responsible for generating and transmitting FMCW waveforms used in the radar. A VCO (voltage controlled oscillator), driven by a triangle wave from the microcontroller, creates an FM signal over a specified bandwidth from 100 MHZ - 250 MHz. This waveform is split off by a directional coupler to be used as the LO (local oscillator) in the receiver subsystem. Finally, a PA (power amplifier) amplifies the signal to be transmitted by the antenna.

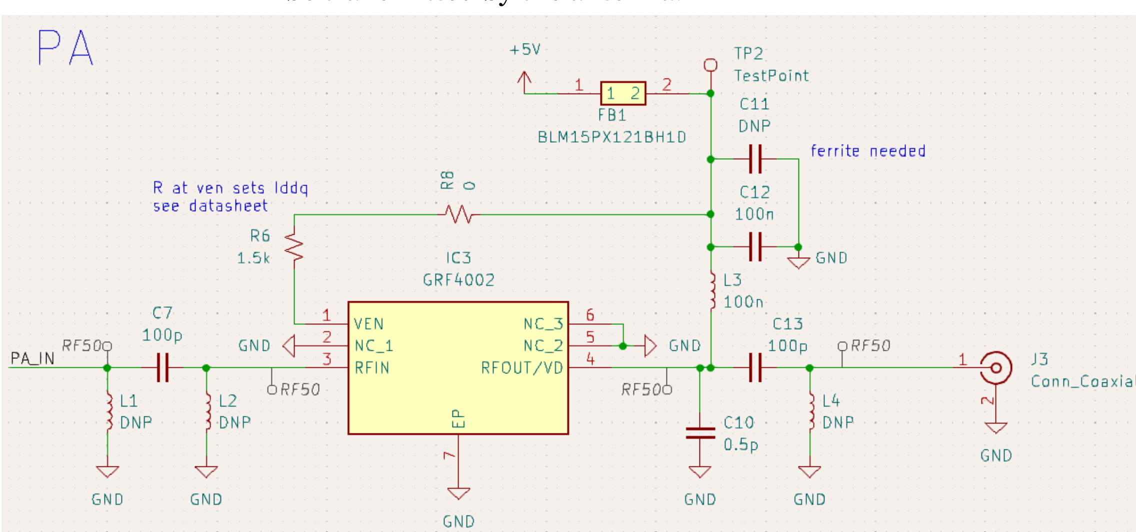

Figure 5: power amplifier schematic

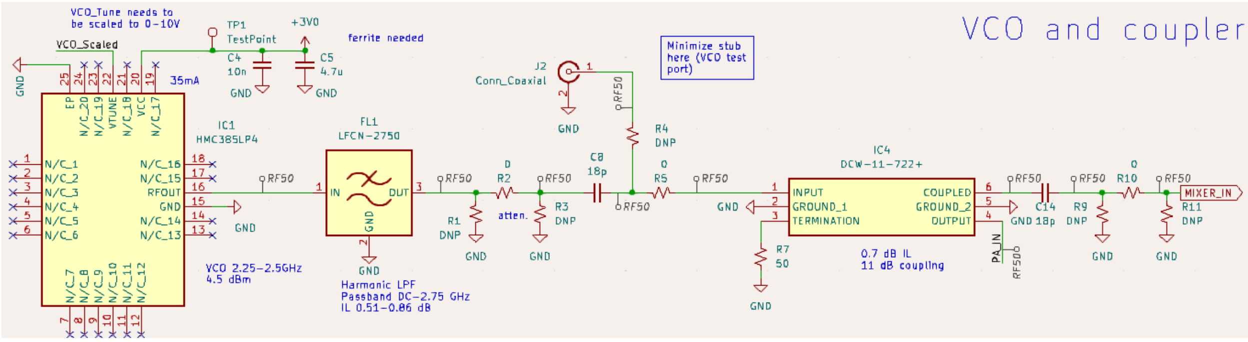

Figure 6a: FM modulator with VCO, harmonic filter, and directional coupler

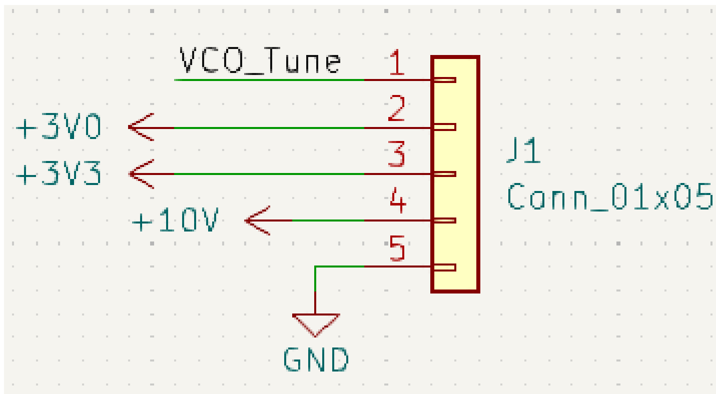

Figure 6b: Radar board interface connector with VCO tune pin and power pins

- ### Receiver Subsystem
  - This subsystem is responsible for receiving and demodulating the reflected FMCW signal from the target. It consists of a LNA (low noise amplifier), a mixer, and an active IF (intermediate frequency) filter. The mixer LO port is driven by the transmitted signal to produce small sum and difference frequencies used in range calculation. The IF filter cleans the demodulated signal so it can be sampled by the microcontroller ADC without aliasing. The IF filter itself is located on a small circuit card that mates with the radar board.

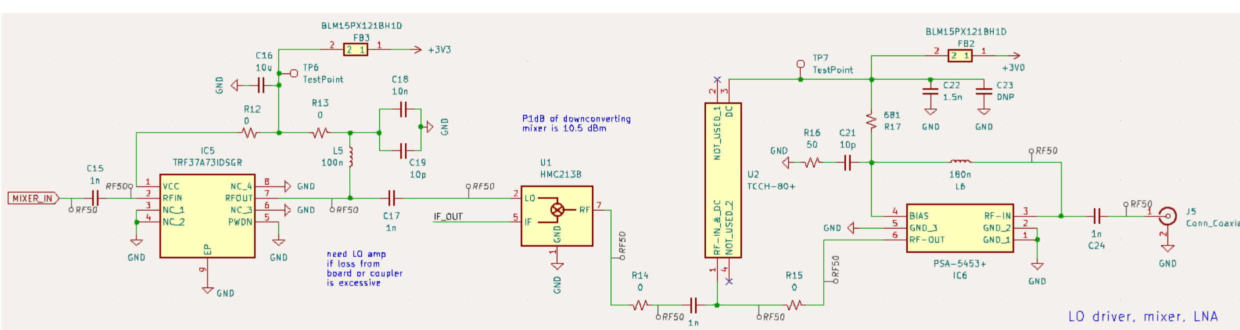

Figure 7a: LO driver (left), mixer (middle), and LNA (right) on the radar board

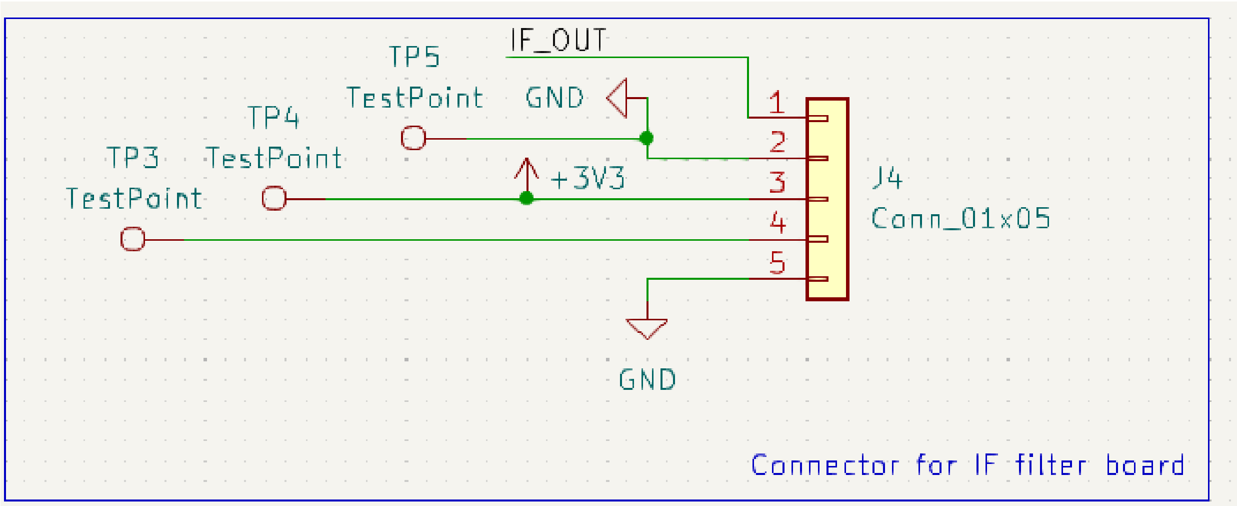

Figure 7b: IF circuit card connector on the radar motherboard

- Both of these subsystems are contained on a single radar board separate from the other units, although a small circuit card connected to the radar board holds the IF filter. Both Rx and Tx chains will use Yagi Antennas due to their simplicity and relatively high directivity.

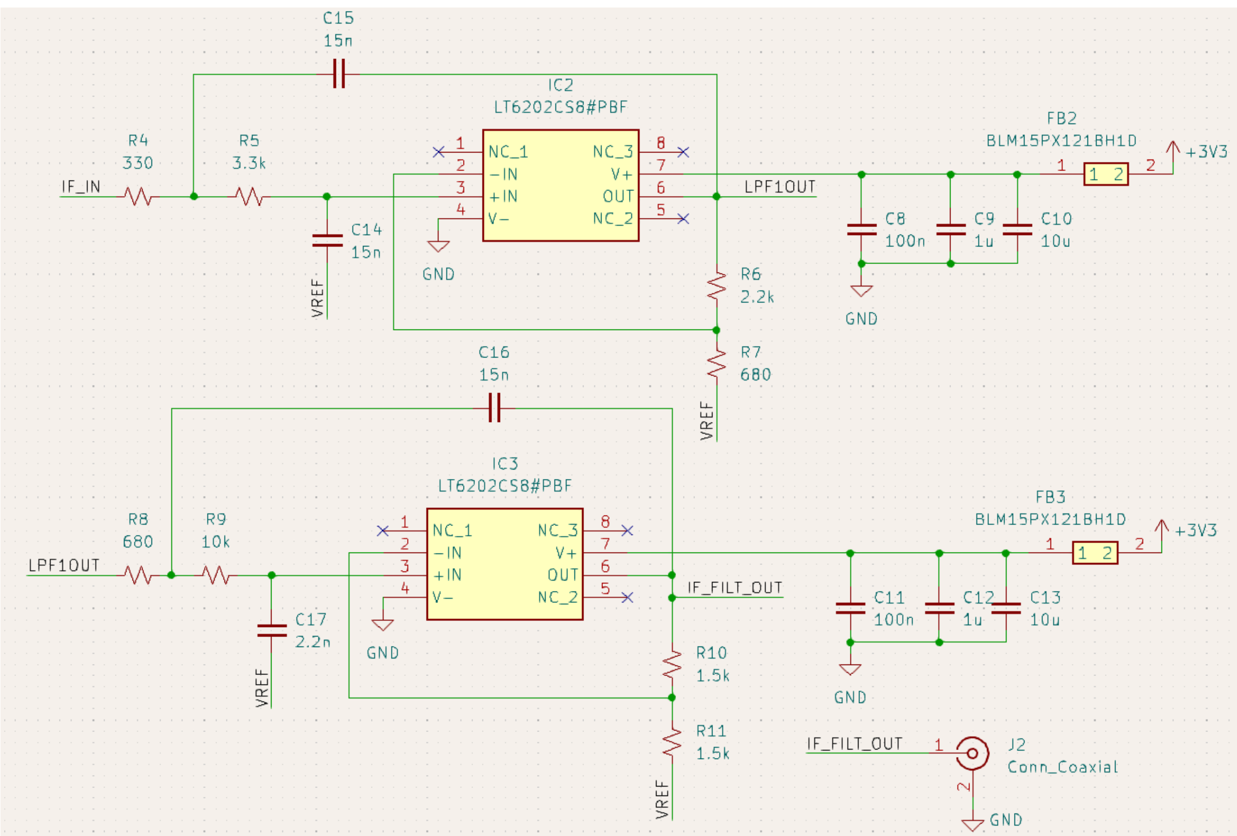

Figure 8a: IF filter on separate circuit card. This is a 4th-order anti-aliasing filter

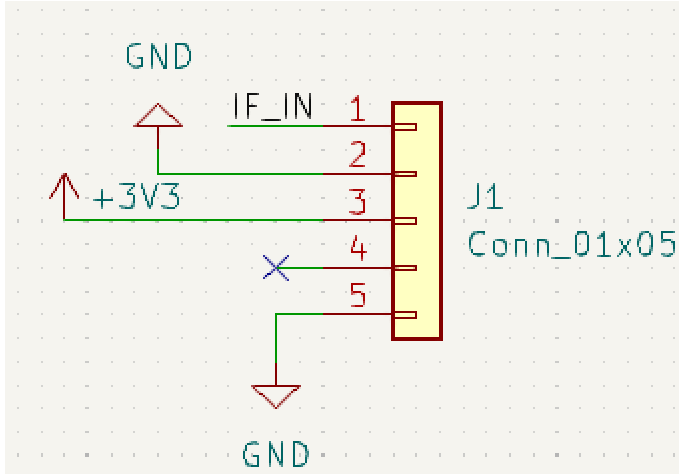

Figure 8b: IF circuit card interface connector on IF board. This mates with the corresponding connector on the radar board

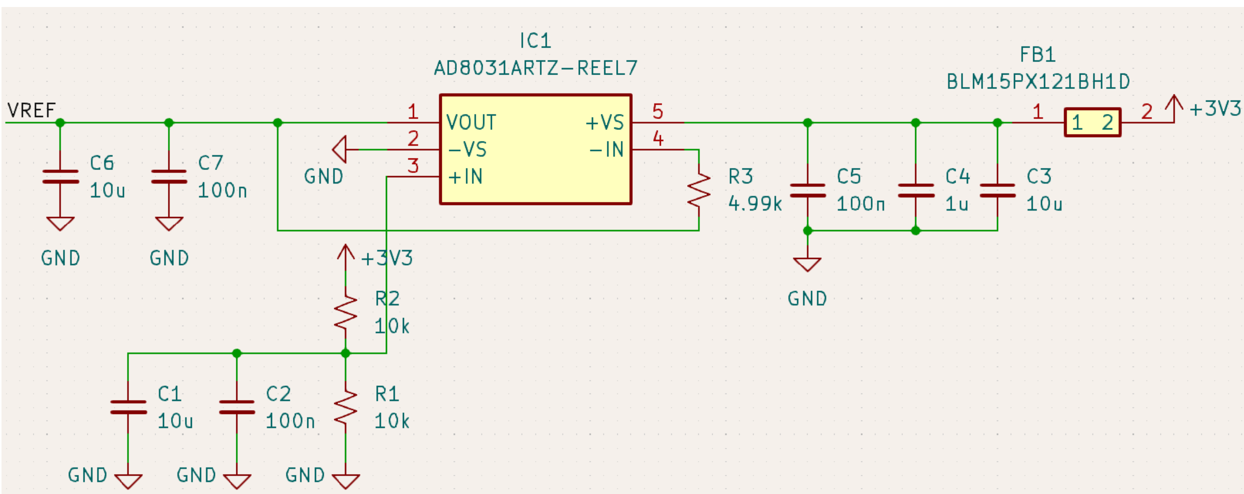

Figure 9: IF half-voltage reference generation, also on separate circuit card

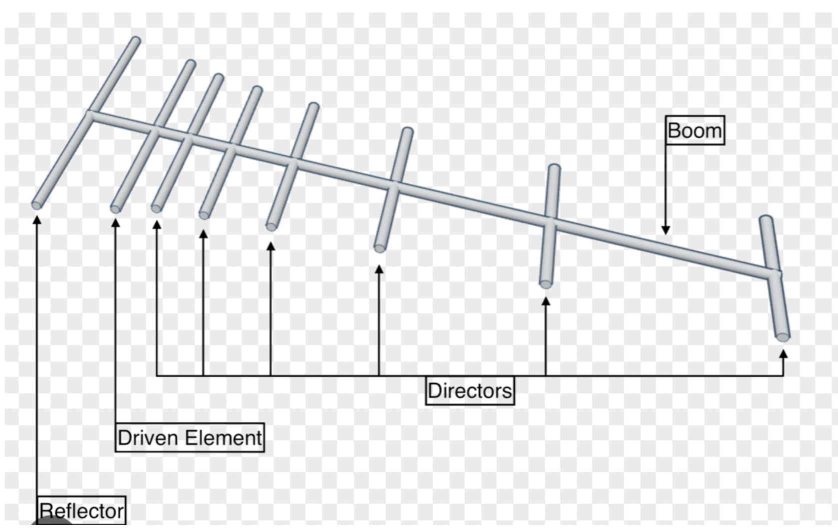

Figure 10: Yagi-Uda Antenna

- ## Power Unit
  - The power unit subsystem will be responsible for distributing necessary power to the radar and processing unit. A lithium ion battery will be used to supply power to the entire system. A Buck Boost converter will take the lithium ion battery as an input and up-convert to 10V. One LDO will step this 10V rail down to 5V, which can be fed to other LDOs as well as the transmitter on the radar board. We will take advantage of two LDOs (Low Dropout Regulator) to then deliver 3V at 150mA and 3.3v at 300mA to the radar receiver and the processing unit. There will also be reverse polarity protection and a fuse to provide protection to the circuit from the lithium ion battery.
  - Schematic for the Power Unit have not been completed.

- ## Processing Unit
  - This subsystem is responsible for receiving a signal from a low pass filter and going to a microcontroller. The microcontroller contains an analog-to-digital converter within the chip. After the signal becomes digital, it will be used to calculate the height from the ground using the time shift. This information will then be transferred to an SD card using the SPI communication protocol. Included is also a barometric altitude sensor which gives the true height of the radar. This information will be transferred to the microcontroller using the I2C communication protocol.
  - Schematic for the Processing Unit have not been completed.

2.4. Subsystem Requirements and Verification

Subsystem	Requirements	Verification
Radar Unit	• The radar unit must consume fewer than 2W when in operating mode. This means that, altogether, both the receiver and the transmitter must not consume over 2W of power. Parts should inherently be efficient enough to consume fewer than 2W, but the PA drive strength may vary as well. • The VCO second harmonic must not exceed -20 dBc. If the part does not nominally show this performance, we will use a harmonic filter to attenuate the second harmonic. This prevents a spur from being mixed into the received signal, interfering with range measurement. • The PA and LNA must be stable across the whole 2.25 GHz - 2.5 GHz operating band. We will achieve this by designing proper matching networks and traces. This prevents oscillation and destruction of parts. For this subsystem, there are no secondary requirements – the primary requirements enumerate the most important performance benchmarks that have not already been described in the high-level requirements.	• To test radar unit power consumption, while in operating mode, we will transmit enough power such that the PA will saturate, in order to find worst case performance, and measure the power being drawn from the Lithium Ion Battery with a power analyzer. This power level depends on the OP1dB of our PA, which is 23.5 dBm [15]. • To test VCO second harmonic dBc level, while in operating mode, we will connect a spectrum analyzer to the output of the VCO and measure the level of the second harmonic of the VCO relative to the fundamental. • To test the PA and LNA stability, while in operating mode, we will use a VNA to measure the S parameters of the PA and LNA to determine stability. We will ensure that the μ stability factor

			is > 1 for 2.25 - 2.5 GHz [7].
Power Unit	Primary Requirements:	Secondary Requirements:	
	• The power unit must include reverse polarity protection to prevent damage to power supplies, batteries, and other subsystems. • The power unit must contain a fuse which will open if over 2.5 A of current is flowing from the battery. • The power unit must contain undervoltage protection set at 3 V to prevent damage to the battery, which should nominally operate between 3 V and 4.2 V.	• The DC-DC converter must be able to supply 10V with < 0.2 Vpp ripple at 2 A maximum current, so as not to damage dependent parts. • The 3.3V LDO, the 5V LDO, and the 3V LDO must also be able to supply their respective voltages with < 0.1 Vpp ripple for sensitive analog parts.	• To verify reverse polarity protection, we will connect a power supply at 3.7V to the reverse polarity protection block in reverse to test if it behaves as an open circuit. • To test if the fuse blows at 2.5A, we will need to load the fuse fuse with > 2.5A so that it opens. This will be a destructive test of the fuse. • To test undervoltage protection, we will use a power supply to feed the power and processing board < 3V. We will observe whether the input behaves as an open circuit or draws current. • To verify the stability of the DC-DC converter, we will provide 3.7V to the DC-DC and attach a load such that 2A are drawn. We will use a multimeter or oscilloscope to measure the peak to

			peak ripple on the output and check for ripple < 0.2 Vpp. ● Similarly, to measure the 5V LDO stability, we will provide 10V as input to the LDO and load it such that 2A is drawn. We will use an oscilloscope or multimeter to check that the ripple is < 0.1 Vpp. ● For the 3.3V and 3V LDO, we will check power stability by providing 5V and loading each LDO with their maximum rated currents. We will observe the output voltage on a multimeter or oscilloscope and check that the ripple is < 0.1 Vpp.
Processing Unit	● The processing unit must have an error rate of less than 10% to be considered successful. An error will occur when the radar measurement is not within 5% of the barometric sensor reading. To realize this error rate, we will utilize a microcontroller with a high-resolution ADC to get the best sample approximation possible. If this is not adequate, we will use a discrete ADC instead. The ADC will be fast enough such that there is no aliasing in measurements. If the processor cannot compute distance fast enough in real time to keep up with the altimeter, we can buffer the ADC data to		● To verify the error rate is less than 10% we will save the data from the Altimeter and Barometric Sensor onto an SD card and determine the difference seen from the Altimeter and Barometer.

	compensate. We will use the SD card to read radar measurements and barometric measurements for post processing.	

Table 1: Requirements and Verification

2.5. Tolerance Analysis

Radar Noise and Range

The performance of the radar itself is limited by noise, antenna parameters, system losses, and radar cross sections, among other factors [4]. For this analysis, we will use the well-known radar equation [3], as well as system parameters, to construct a link budget for the radar.

$$P_r = P_t \frac{\lambda^2 G_t^2}{(4\pi)^3 r^4} \sigma_{RCS}$$

P_t : transmitted power
λ : wavelength
G_t : transmitting antenna gain (same as the receiving antenna gain)
r : range to target (same for transmit and receive)
σ_{RCS} : target radar cross section
We will rearrange this equation as follows [2], where P_r becomes P_{min} – the minimum detectable signal at the receiver. The antenna gains and operating wavelengths are assumed to be equal.

$$R_{\max} = \sqrt[4]{\frac{P_t G^2 \lambda^2 \sigma}{P_{\min} (4\pi)^3}}$$

To find P_{min} , we consider the receiver noise floor, principally consisting of thermal noise. This can be expressed as kTBF, where k is the Boltzmann constant, B is the noise bandwidth (of one FFT bin), T is receiver noise temperature, and F is the total noise figure. Using the Friis cascaded noise figure equation $F_{tot} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + ... + \frac{F_n - 1}{G_1 G_2 ... G_{n-1}}$ [7], we can calculate the total noise figure.

Component	
PSA-5453+ (LNA) [11]	Gain: 19.6 dB Noise figure: 0.7 dB
HMC213B (mixer) [10]	Conversion gain: -10 dB Noise figure: 10 dB
IF Amplifier/Filter [7]	Noise figure: 10 dB (conservative estimate based on thermal noise from input resistors)

Table 2: receiver component specifications

For an IF amplifier/filter noise figure of 10 dB, the total noise figure comes out to be ~3.76 dB using the Friis equation. An even more conservative estimate of 15 dB would yield a noise figure of ~6.76 dB, which still meets the spec. In this case, it would be beneficial to place another LNA in the receiver to minimize the impact of the op-amp [2], [8]. In total, the noise floor (from kBTF) evaluates to -147.2 dBm using the most conservative op-amp noise figure of 15 dB.

The maximum detectable range is then calculated with an antenna gain of 6 dBi (conservative for Yagi or horn) and a wavelength of 12.5 cm for 2.4 GHz. A table from [6] shows the RCS distribution in dB for linearly polarized radiation incident on soil and rock, which can be used to calculate the minimum range.

Statistical Distribution Table for **Soil and Rock Surfaces**

S Band, **HH** Polarization

Angle	N	σ^o_{max}	σ^o_5	σ^o_{25}	Median	σ^o_{75}	σ^o_{95}	σ^o_{min}	Mean	Std. Dev.
0°	264	20.1	16.7	7.2	1.7	-3.0	-8.1	-11.3	2.6	7.5
5°	186	12.4	7.5	4.0	0.3	-4.9	-10.1	-14.7	-0.4	5.7
10°	442	6.0	3.3	-0.5	-3.6	-7.2	-12.5	-16.0	-3.9	4.7
15°	361	5.3	-0.1	-2.6	-5.4	-9.5	-14.1	-19.4	-6.2	4.5
20°	442	0.9	-2.0	-5.8	-8.8	-12.0	-16.2	-21.5	-9.0	4.5
30°	264	0.8	-2.9	-8.8	-12.7	-15.4	-20.6	-25.5	-12.2	5.1
40°	82	-5.3	-9.0	-11.6	-14.3	-20.2	-26.0	-29.2	-15.8	5.7
50°	16	-15.0	-16.4	-18.0	-18.9	-21.3	-22.1	-22.4	-19.2	2.2

S Band, **HV** Polarization

Angle	N	σ^o_{max}	σ^o_5	σ^o_{25}	Median	σ^o_{75}	σ^o_{95}	σ^o_{min}	Mean	Std. Dev.
0°	258	-1.7	-5.2	-10.6	-14.8	-18.8	-22.9	-25.5	-14.5	5.5
5°	181	-6.7	-11.9	-14.0	-16.9	-22.1	-25.3	-28.8	-17.8	4.6
10°	311	-8.7	-14.1	-17.1	-19.8	-23.8	-27.3	-31.1	-20.3	4.2
15°	275	-14.5	-16.0	-19.2	-22.6	-25.5	-30.2	-36.0	-22.6	4.3
20°	393	-8.9	-15.6	-20.0	-23.2	-26.2	-30.2	-36.4	-23.1	4.6
30°	264	-8.7	-16.0	-19.7	-25.4	-28.6	-34.0	-38.6	-24.7	5.7
40°	80	-9.9	-15.6	-19.9	-23.8	-29.8	-36.1	-40.3	-24.9	6.7
50°	14	-25.9						-35.3	-31.7	2.7

S Band, **VV** Polarization

Angle	N	σ^o_{max}	σ^o_5	σ^o_{25}	Median	σ^o_{75}	σ^o_{95}	σ^o_{min}	Mean	Std. Dev.
0°	264	19.7	16.2	7.2	1.0	-3.1	-8.1	-11.7	2.4	7.5
5°	186	11.7	7.4	3.2	0.0	-5.6	-10.0	-14.2	-0.9	5.7
10°	441	6.2	3.1	-0.4	-3.8	-7.3	-12.5	-16.9	-4.0	4.7
15°	362	4.9	-0.1	-2.7	-5.4	-9.8	-14.3	-20.1	-6.4	4.7
20°	442	1.5	-1.9	-5.7	-8.6	-12.2	-16.6	-23.3	-9.0	4.6
30°	263	0.8	-3.1	-8.8	-13.5	-16.3	-20.3	-24.1	-12.6	5.2
40°	82	-3.4	-8.0	-10.4	-14.3	-17.6	-23.4	-26.0	-14.2	4.9
50°	16	-10.0	-13.5	-16.9	-18.5	-19.7	-20.8	-21.8	-17.8	3.0

Table 3: RCS [dB] model for S-band linearly polarized radiation incident on soil or rock

We will use an output power of 20 dBm (100 mW) which accounts for cable and PCB loss and can evaluate the minimum and maximum ranges for linear polarization (HH/VV) in Python.

```
max range hh:  166.2553229669458
min range hh:  25.87598040821954
max range vv:  162.47088978532884
min range vv:  25.28697118363547
system nf:  6.768685611440928
```

Figure 11: Python script output showing worst-case system NF and maximum ranges

The evaluated result shows that, for the worst RCS at 0° incidence and the worst op-amp noise figure of 15 dB, the minimum ranges for horizontal and vertical polarizations are 25.88m and 25.29m, respectively.

Radar Range Resolution

Our design specification stipulates that the range resolution of the radar must be 1.5m or better. Since our VCO can sweep from 2.25 GHz to 2.5 GHz, we can say that the best range resolution can be achieved with the maximum bandwidth of B = 250 MHz. We can use the FMCW range resolution equation $S_r = \frac{c}{2B}$ to verify this [1], [9]. With the maximum bandwidth, our range resolution is 0.6m. If we restrict the bandwidth to 100 MHz, the range resolution degrades to 1.5m – the worst allowable. We will operate the radar at ≥ 100 MHz bandwidth as a result.

3. Cost and Schedule

3.1. Cost Analysis:

A typical graduate student at the ECE department makes approximately $2,800 per month. Breaking this figure down even further this comes out to $700 per week. Since ECE graduates work part-time (20 hours per week), they make approximately $35 per hour. If we benchmark this number and say that each individual in our senior design group is getting paid $35 an hour, we can come up with a number for total labor cost.

So far this semester each group member has been working approximately 10 hours per week. We are assuming that this number will jump up 15 hours per week individually once we get more involved in the design process. This will occur for the last 6 weeks of the semester.

Total labor cost per person = $35/hour x 10 hours/week (first 8 weeks) x 8 weeks + $35/hour x 15 hours/week (last 6 weeks) x 6 weeks

Total Labor cost per person = $5,950

Parts:

Part #	Manufacturer	Description	Quantity	Cost per Unit
HMC213B*	Analog Devices	Mixer 1.5-4.5 GHz	1	$15.56
TCCH-80+	Mini Circuits	RF Choke	1	$4.91
BLM15PX121BH1D	Murata	100☐ ferrite	6	$0.31
LFCN-2750	Mini Circuits	Bandpass filter DC-2750 MHz	1	$2.97
HMC385LP4*	Analog Devices	VCO 2.25-2.5 GHz	1	$21.43
AZ1084CD-5.0TRG1	Diodes, Inc.	LDO 5V 5A	1	$0.56
GRF4002	Guerilla RF	RF Amp 0.1-3.8GHz	1	$2.56
DCW-11-722+	Mini Circuits	Directional Coupler	1	$4.17
TRF37A73IDSGR	Texas Instruments	RF Amp 0.001-6GHz	1	$1.44
PSA-5453+	Mini Circuits	RF Amp	1	$1.96
TS461CLT	STM	Op-Amp	1	$1.07
73251-1153	Molex	SMA Connector	3	$3.94
PH1-05-UA	Adamtech	CONN HEADER VERT 5POS 2.54MM	10	$0.099
LT6202CS8#PBF	Analog Devices	Op-Amp	2	$5.25
AD8031ARTZ-REEL7	Analog Devices	Op-Amp	1	$3.77
U.FL-R-SMT-1(80)	Hirose Electric	U.FL Connector	1	$0.22
TPS61230ARNSR	Texas Instruments	Buck-Boost Converter	1	$1.96
AZ1117CH2-3.3TRG1	Diodes Incorporated	LDO	1	$0.35
ADP150AUJZ-3.0-R7	Analog Devices	LDO	1	$1.43
MIKROE-698	MikroElektronika	3.7V Li-Ion Battery 1Ah	1	$8.90

DEV-13743	Sparkfun	SD Card Shield	1	$5.95
MPL115A2	Adafruit	Barometric Altimeter Shield	1	$9.95
PIC24FJ128GC010-I_PT	Microchip Technologies	MCU	1	$7.18
GRT155R60J106ME13J	Murata	0402 ceramic cap 10u	10	$0.223
GRM155D81A475ME15J	Murata	0402 ceramic cap 4.7u	10	$0.09
GRM155C71C105ME11D	Murata	0402 ceramic cap 1u	10	$0.05
GRM152R61A104KE19D	Murata	0402 ceramic cap 0.1u	20	$0.109
GRM1555CYA103GE01D	Murata	0402 ceramic cap 0.01u	10	$0.068
GRM155R71C153JA01D	Murata	0402 ceramic cap 0.015u	10	$0.034
GMD155R71H102KA01D	Murata	0402 ceramic cap 1n	10	$0.58
GRM155R61A222KA01D	Murata	0402 ceramic cap 2.2n	10	$0.016
GRM155R72A152KA01D	Murata	0402 ceramic cap 1.5n	10	$0.037
GRM1555C2A101GA01D	Murata	0402 ceramic cap 0.1n	10	$0.039
GRT1555C1E100JA02D	Murata	0402 ceramic cap 0.01n	10	$0.022
GJM1555C1H180FB01D	Murata	0402 ceramic cap 18p	10	$0.061
GRT1555C1H6R0DA02D	Murata	0402 ceramic cap 0.5p	10	$0.032
CRT0402-BY-1002GLF	Bourns	0402 thin film res 10K	10	$0.169
CR0402-FX-1501GLF	Bourns	0402 thin film res 1.5K	10	$0.007
CR0402-JW-681GLF	Bourns	0402 thin film res 680	10	$0.001

RP0402BRD074K99L	Yageo	0402 thin film res 4.99k	10	$0.307
CR0402-JW-331GLF	Bourns	0402 thin film res 330	10	$0.005
RP0402BRD073K3L	Yageo	0402 thin film res 3.3k	10	$0.307
RC0402FR-072K2L	Yageo	0402 thin film res 2.2k	10	$0.009
RT0603BRE0750RL	Yageo	0603 thin film res 50	10	$0.152
RR0510P-101-D	Susumu	0402 thin film res 100	10	$0.033
ERJ-2GE0R00X	Panasonic	0402 jumper 0 ohm res	25	$0.0184
0402HPH-R18XGRW	Coilcraft	0402 RF 100n inductor	2	$2.55
0402HPH-R18XGLW	Coilcraft	0402 RF 180n inductor	1	$2.08

Table 4: List of Parts and Unit Cost

* = Potential to order free sample of product

Total Cost = $153.75 ($116.76 with free samples)

3.2. Schedule:

Task	Member(s)	Description	Timeline
RF Board	Elliot	Design schematic and complete RF board layout	Complete by week of February 26th
IF Board	Elliot	Design schematic and complete IF board layout	Complete by week of February 26th
Power and Processing Board	Bobby Rayan	Design schematic and complete Power and Processing board layout	Complete by week of February 26th
Order PCBs	Bobby	Order PCBs from PCBway	Complete by March 5th
Order Individual Components	Elliot	Order all discrete components	Complete by March 5th
Simulations	Elliot Bobby	Conduct simulations in HFSS and ADS to assess expected performance	Complete during wait time of PCB delivery
MCU Analog Software Creation	Rayan	Start writing code to control ADC/DAC of MCU	Complete during wait time of PCB delivery
Soldering Components	Everyone	Solder all discrete parts onto each PCB	Complete by week of March 25th
Assemble Design	Everyone	Assemble all three PCBs and system chassis into one system	Complete by week of March 25th
Test Design	Everyone	Conduct tests on design and compare against simulations	Complete by week of March 25th
MCU SD Card/Barometer code	Rayan	Write code to interface with SD card and barometric altimeter	Complete by April 2nd
Modify and Reorder Design (if necessary)	Elliot Bobby	Modify and reorder design to improve performance	Complete by April 2nd
Test Design Again	Everyone	Conduct tests on design and compare against simulations	Complete by week of April 8th
Demo	Everyone	Demo final board	Complete by April 24th
Presentation	Everyone	Conduct final presentation	Complete by April 30th
Final Paper	Everyone	Turn in final paper	Complete by May 1st

Table 5: Schedule

4. Ethics and Safety

When developing an S-band radar altimeter for drone height detection, several ethical and safety considerations must be addressed. These considerations encompass both the development process and the potential misuse of the technology.

A significant concern relates to measurement accuracy, and the implications of the radar's measurements. Inaccurate height measurements could lead to dangerous decisions based on erroneous data. In extreme cases, inaccurate altitude data could cause injuries and destruction of both the radar and the drone. This is a potential conflict with section 1.2 in ACM's Code of Ethics [13], which mandates engineers to avoid harm wherever possible. To mitigate this, we will validate and calibrate the radar altimeter to ensure accurate height measurements. We will ensure that users understand that the altimeter may produce inaccuracies, and to use proper judgment when flying.

During our demonstration, we will verify that users and observers fully understand the altimeter's limitations. If the altimeter is tested on a drone, we will compare the measured altitude of the drone to that of the radar as a form of redundancy. That way, if the radar returns incorrect information, we will not cause injury to observers or irreparable damage to the drone.

Similarly, our use of a Lithium-based battery comes with safety implications. If users are harmed by a fault in the battery system, we would be in violation of section I-1 of the IEEE Code of Ethics [12], which mandates engineers to disclose hazards and protect the health of the public. Our design includes battery undervoltage and overcurrent monitoring so as not to cause dangerous damage to the battery or the radar itself.

A related safety issue pertaining to I-1 of [12] is that of thermal management. Power amplifiers can heat up significantly when saturated due to their relatively low efficiency. If both the battery and the PA heat up, thermal runaway can occur, causing a battery fire. A thermistor internal to the battery should prevent this, but a lithium battery bag will be used as well to contain any would-be fire.

Finally, in the development of prototypes or experimental hardware such as our radar, it is critical that our team is open to extensive review of our design. This is directly pursuant to section I-5 of the IEEE Code of Ethics, which mandates that we accept constructive feedback and make informed design choices based on all available data [12]. In order to stay in accordance with I-5, we will seek out design feedback from instructors, students, and professional connections. To make justifiable design decisions based on data, we will use simulation tools and academic resources to validate our design process.

5. References

[1]“Radar Basics,” Radartutorial.eu, 2019.
https://www.radartutorial.eu/02.basics/Frequency%20Modulated%20Continuous%20Wave%20Radar.en.html

[2]H. Forstén, “Third version of homemade 6 GHz FMCW radar,” Henrik’s Blog, Sep. 28, 2017. https://hforsten.com/third-version-of-homemade-6-ghz-fmcw-radar.html (accessed Feb. 08, 2024).

[3]E. Kudeki, “ECE 350 Lecture Notes,” https://courses.engr.illinois.edu/ece350/ece350lecture_notes_ver2024.pdf, 2023. https://courses.engr.illinois.edu/ece350/ (accessed Feb. 08, 2024).

[4]S. Frick, “RADAR ALTIMETERS OVERVIEW OF OPERATION, DESIGN, AND PERFORMANCE,” 2021. Accessed: Feb. 08, 2024. [Online]. Available: https://avsi.aero/wp-content/uploads/2021/12/Radar-Altimeter-Overview-of-Design-and-Performance.pdf

[5]“User Manual,” DJI. Available: https://dl.djicdn.com/downloads/DJI_Mini_2/20210630/DJI_Mini_2_User_Manual-EN.pdf

[6]F. Ulaby, M. C. Dobson, and J. L. Álvarez-Pérez, Handbook of Radar Scattering Statistics for Terrain. Artech 2019, 2019.

[7]S. Franke, “ECE 453 Wireless Communication Systems,” https://courses.engr.illinois.edu/ece453/fa2023/secure/supplementary_notes/ECE453Notes_SP19.pdf, (accessed Feb 08, 2024).

[8]J. Karki, “Calculating Noise Figure in Op Amps,” 2003. Accessed: Feb. 08, 2024. [Online]. Available: https://www.ti.com/lit/an/slyt094/slyt094.pdf

[9]I. Rosu and F. Rosu, “S-Band 2.4GHz FMCW Radar.” Accessed: Feb. 09, 2024. [Online]. Available: https://www.qsl.net/va3iul/Radar/S-Band_2.4GHz_FMCW_Radar/S-Band_2.4GHz_FMCW_Radar.pdf

[10]“HMC213B Datasheet,” Analog Devices, Feb. 2018. Accessed: Feb. 09, 2024. [Online]. Available: https://www.analog.com/media/en/technical-documentation/data-sheets/hmc213b.pdf

[11]“Monolithic Amplifier PSA-5453+,” Mini-Circuits. Accessed: Feb. 09, 2024. [Online]. Available: https://www.minicircuits.com/pdfs/PSA-5453+.pdf

[12]IEEE, “IEEE Code of Ethics,” ieee.org, Jun. 2020.
https://www.ieee.org/about/corporate/governance/p7-8.html

[13]ACM, “ACM Code of Ethics and Professional Conduct,” Association for Computing Machinery, Jun. 22, 2018. https://www.acm.org/code-of-ethics

[14] I. Rosu and F. Rosu, “S-band 2.4ghz FMCW radar,” S-Band 2.4GHz FMCW Radar, https://www.qsl.net/va3iul/Radar/S-Band_2.4GHz_FMCW_Radar/S-Band_2.4GHz_FMCW_Radar.pdf (accessed Feb. 22, 2024).

[15] “GRF4002 Data Sheet | Guerrilla RF,” *www.guerrilla-rf.com*, 2024. https://www.guerrilla-rf.com/products/DataSheet?sku=4002&file_name=GRF4002DS.pdf (accessed Feb. 23, 2024).