Field Radio

Group 5
Noah Madison, Brian Taylor, Elier Bermudez, Daniel Sypioe

Meet the team

Electrical Engineers:

Noah Madison

Brian Taylor

Computer Engineers:

Elier Bermudez

Daniel Sypioe

Introduction/Motivation

We are working on this project because there is currently no open-source design for a modular, portable, low-cost, and user-friendly SDR available to the HAM radio community. The available handheld radios have closed-source designs, and are often made below FCC EMI/EMC standards.

At the request of our sponsor the Amateur Radio Club, we aim to use the LIMESDR to develop a baseline that future hobbyists, developers, and students can build off of to add additional features to. The main goal of our project is to meet all technical requirements while still allowing for expandability and community reproducibility.

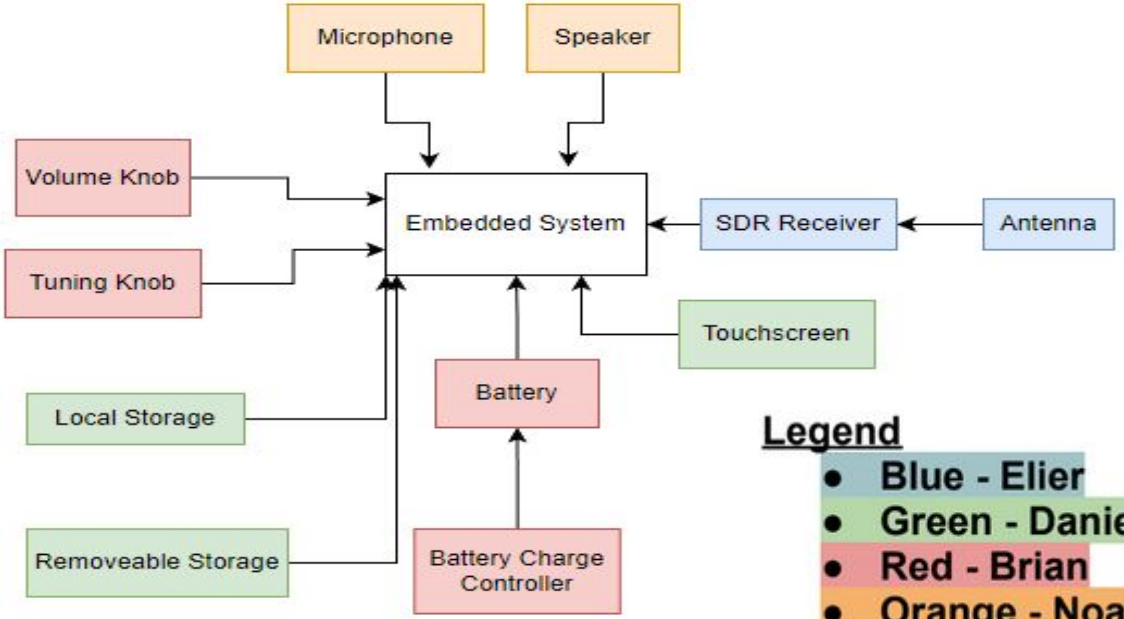
Goals/Objectives

- Transmit and receive FM signals
- Touch-Screen display to show the user interface
- External controls in the form of either buttons or the touch-screen
- Open-source software design hosted on GitHub
- Long battery life to support mobile use
- Low cost to increase reproducibility
- Easy to use to encourage expanded features

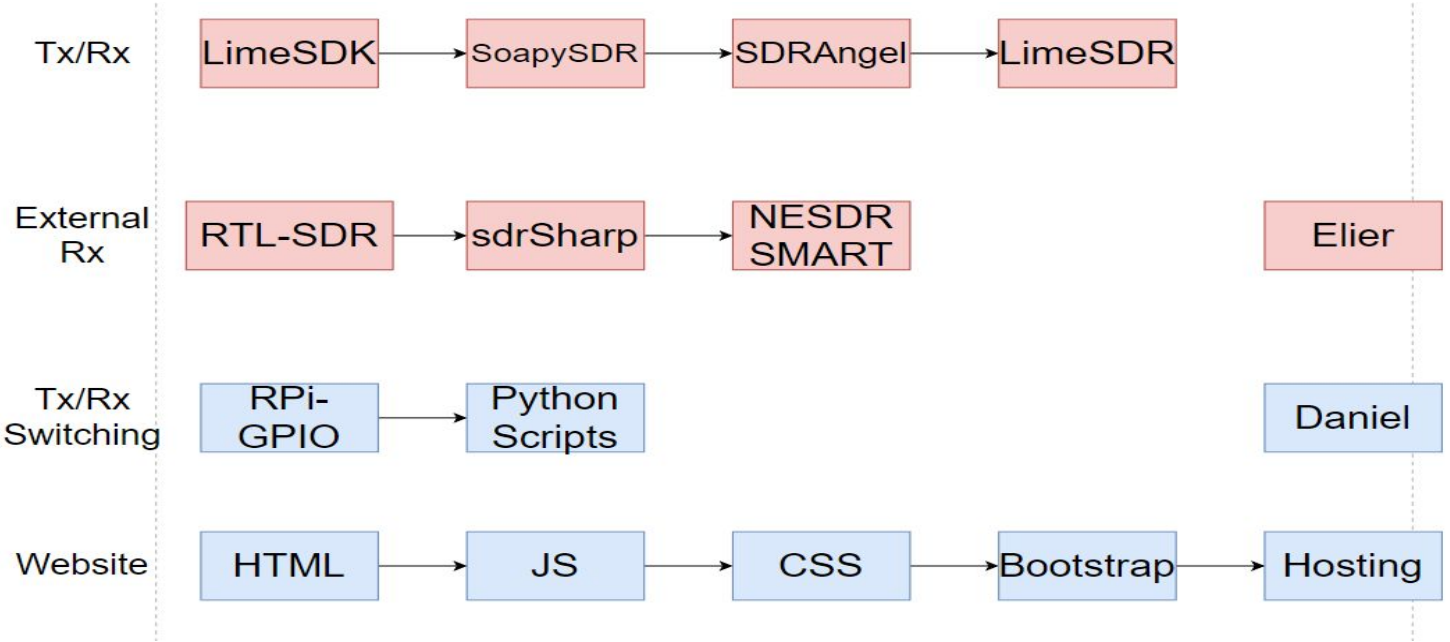
Specifications/Requirements

Transmission Delay	< 5 Seconds
Transmission Shutdown Delay	< 5 Seconds
Receive Delay	< 2.5 Seconds
Receive Shutdown Delay	< 2.5 Seconds
Output Power	5 Watts FM; 3 Watts AM
Repeater Functionality	CTCSS standard subaudible tones (88-200hz)
Battery Life	3 hrs FM standby

System Block Diagram

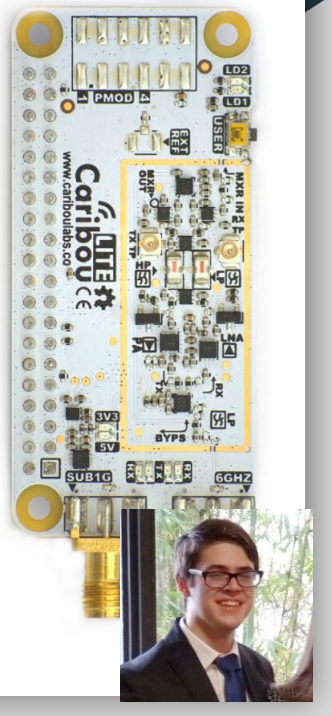


Software Block Diagram



SDR Receiver Part Selection

Feature	LimeSDR Mini	CaribouLite (MHz)
Frequency Range	10MHz - 3.5 GHz	Channel 1: 779-1020 or 389.5-510 Channel 2: 3-6(GHz)
RF Bandwidth	30.72 MHz	2.5 MHz
Sample Rate	30.72 MSPS	4 MSPS
TX/RX Channels	1	2
Transmit Power	10 dBm	14 dBm
Interface	USB 3.0	SMI (GPIO powered)



Supply chain Issues

- Both SDR were supposed to be available by Summer. Further issues in FPGA supply lines have pushed these dates back to Fall.
- We will be using a full-size LimeSDR as a replacement

CaribouLite

A 6 GHz RaspberryPi SDR HAT, with two TX/RX PMOD header.

$138 $8 US Shipping / $18 Worldwide

Orders placed now ship Sep 30, 2022.

Pre-order

LimeSDR Mini 2.0

$399 $8 US Shipping / $18 Worldwide

Orders placed now ship Oct 15, 20

Back This Project 192 claim

Embedded System Part Selection

	Raspberry Pi Zero W	Raspberry Pi Zero 2W	Omega2
CPU	Single-core Arm11 @ 1 GHz	Quad-core Cortex-A53 @ 1 GHz	Single-Core @ 580MHz
Memory	512MB DDR2 PoP	512MB DDR3 wire-bond	16MB Flash 64MB DDR2 DRAM
Storage	MicroSD Card	MicroSD Card	Supports MicroSD or USB Swap
USB	Micro USB OTG port	Micro USB OTG port	USB 2.0
Expansion	40-pin GPIO header	40-pin GIP header	32-pin GPIO header
Power Supply	5V/1.2A	5V/2.5A	3.3V/240mA
Dimensions	65 x 30 x 13 mm	65 x 30 x 13 mm	42.9 x 26.4 x 9.9 mm
MSRP	$10	$15	$25

Low Level Software Selection

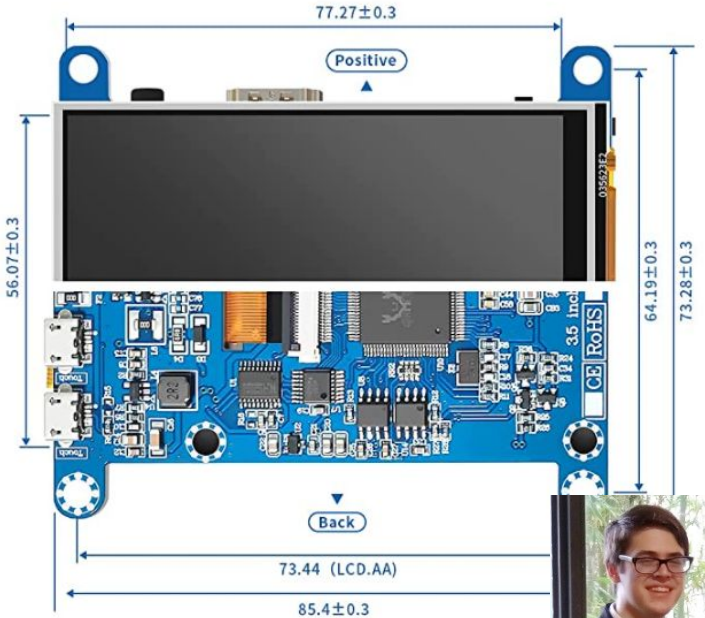
	Windows 10	Raspberry Pi OS	Raspberry Pi OS Lite
Weight	Heavy	Medium	Light
Ease of Use	Very easy	Medium	Difficult
Ease of Development	Difficult	Easy	Medium
Open-Source	No	Yes	Yes
Size	32GB	8GB	4GB
Virtual-Machine Friendly	Yes	Yes	Yes
GUI	Yes	Yes	No

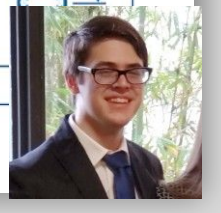
High Level Software Selection

	C++	Java	Python
Speed	Fast	Slow	Slow
Ease of Use	Difficult	Medium	Easy
Community Support	Low	Medium	High
Memory Usage	Low	Medium	High
Developer Familiarity	Medium	Medium	High

Touchscreen Part Selection

	JniTyOpt 3.5 inch Display	iUniker Raspberry Pi Screen
Refresh Rate	60Hz	60Hz
Resolution	480x320	480x320
Video Support	HDMI	GPIO
Audio Support	3.5mm Jack	None
Touchscreen	Resistive	Capacitive
Power	Micro Usb 5V	GPIO 5V
Weight	9.1 oz	2.12
Dimensions	3.46x2.99x0.47 in	3.94x1.97x1.18 in
Price	$28.99	$29.99





Speaker Part Selection

	GPIO	Bluetooth	HDMI	USB	3.5MM
Price	$13	$16	$30	$20	$8
Size	Medium	Medium	Very Large	Medium	Small
Availability	None	Average	Average	Average	Average
Ease of Use	Medium	Difficult	Difficult	Easy	Easy
Power Source	Pins	Independent	HDMI Port	USB Port	3.5MM Port

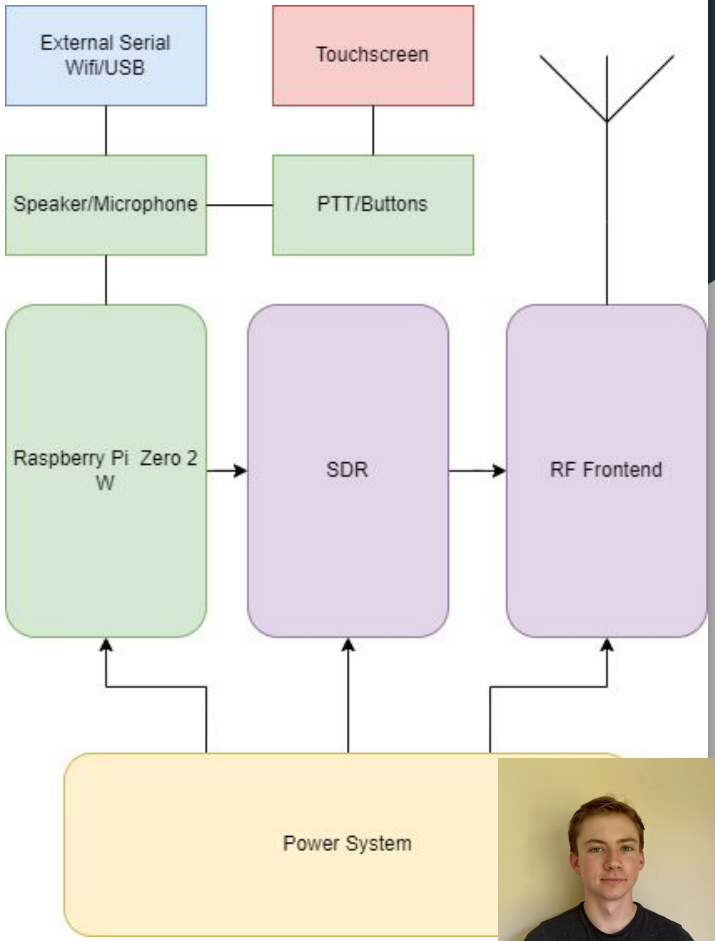
Microphone Part Selection

	GPIO	USB	3.5MM
Price	$7	$4.50	$8
Size	Small	Tiny	Tiny
Availability	Low	High	Average
Ease of Use	Medium	Easy	Easy
Power Source	Pins	USB Port	3.5MM Port

Electronic Design

System overview

- The Pi functions as the main control system and point of user interaction
- The SDR is controlled by the PI and receives streamed audio data from the Pi
- The SDR sends and receives low power rf using the RF front end



Amplifier comparison

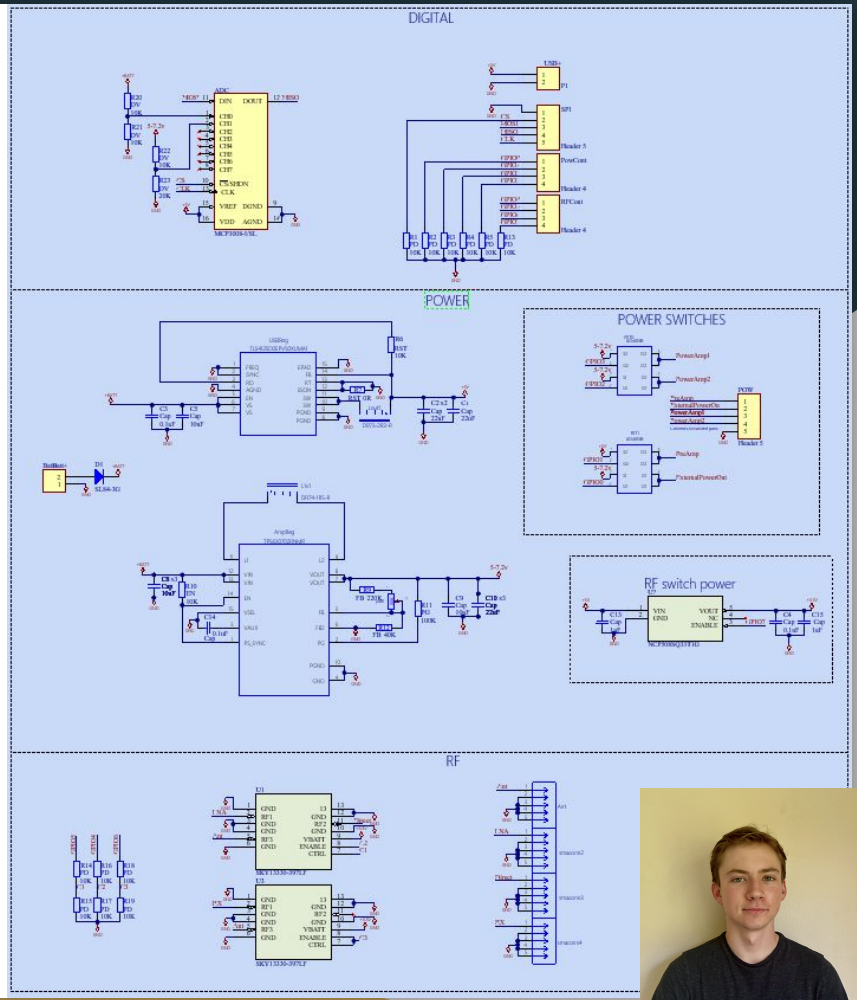
- Wide band amplifiers although possible will amplify everything in its bandwidth (the entire SDR bandwidth) allow for less power and more overall distortion
- Single band tuned amplifiers allows for a hot swappable high performance option

Amplifier comparison table

Option:	RF Power Amplifier 20M-512MHz	5W 433MHz Metal RF Power Amplifier Module
Type	WideBand untuned	Switch Single Band
Heat Dissipation	Heat Sync	Heat Sync
Impedance	50 ohm	50 ohm
Filter necessary?	Needs additional filter for each band	Has built in Filters
Price (USD)	36.88 without filter	Around 45 for all bands covered
Bands	20M-512MHz	70 cm

Schematics

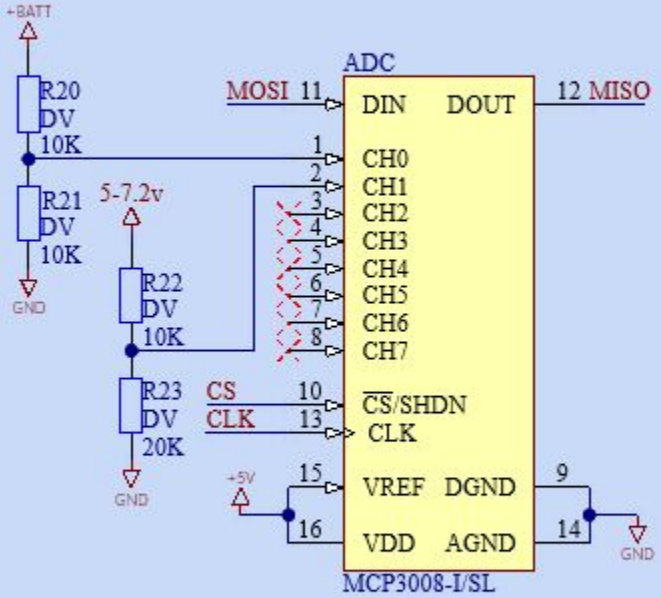
- Broken up into Digital, RF and Power
- Digital provides control capabilities from our raspberry pi
- RF allows for switching to multiple single band amplifiers

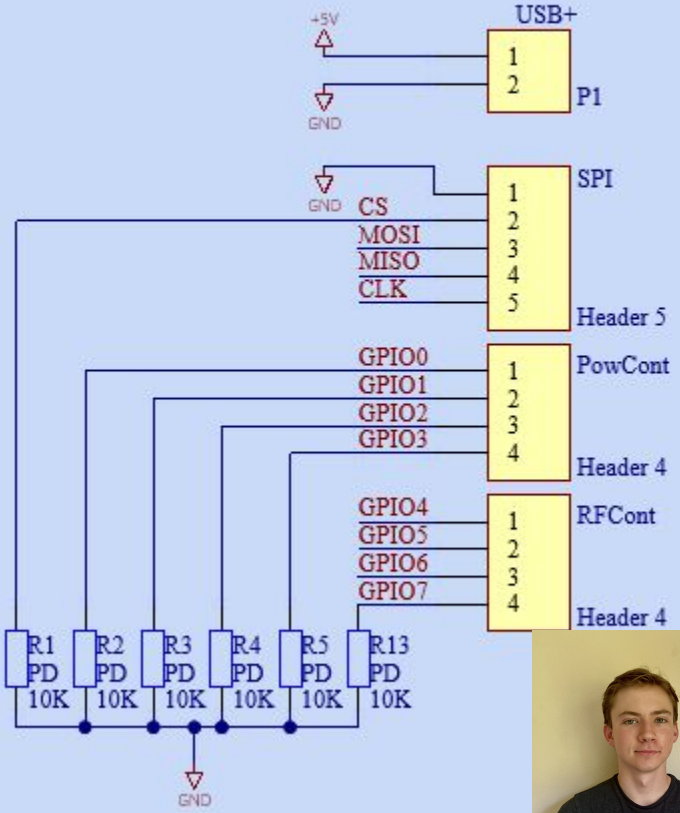


T/R Switch

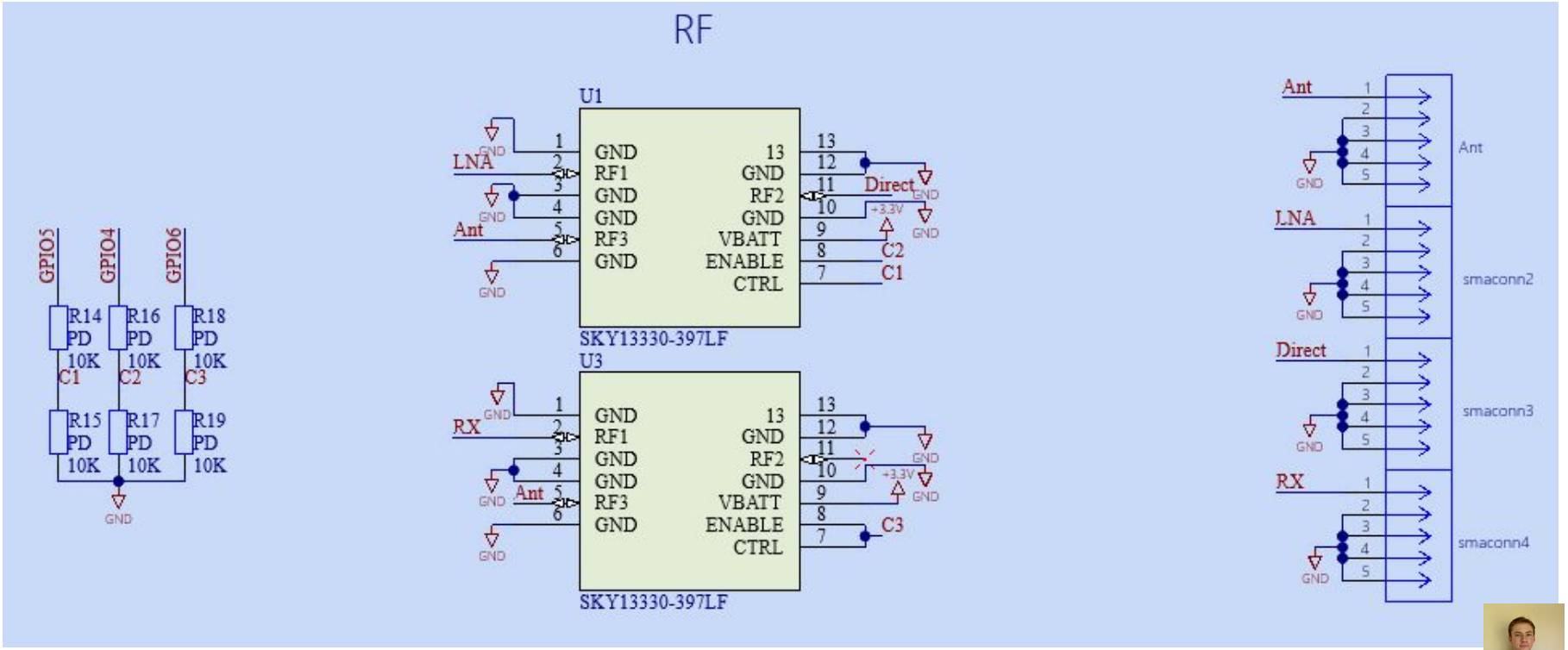
	SKY13414	SKY13330	MASW-008955-TR3000
Type	SP4T	SPDT	SP3T
Max RF reverse power	DigiKey Says 70 dBm but the datasheet says 33dBm	39dBm	42dBm
Max RF power Throughput	DigiKey Says 37 dBm but the datasheet says 27dBm	39dBm	35dBm
Isolation	31dB	40dB	20dB
Insertion Loss	0.45dB	0.45dB	0.6dB
Frequency Range	100MHz-3.8GHz	100MHz-6GHz	DC-3.5GHz
Technology	Absorptive and Reflective	Reflective	Reflective
Price	1.35	1.24	1.74

DIGITAL


+BATT
R20
DV
10K
R21
DV
10K
GND
5-7.2v
R22
DV
10K
R23
DV
20K
GND
ADC
MOSI 11
DIN
DOUT
12 MISO
1
CH0
2
CH1
3
CH2
4
CH3
5
CH4
6
CH5
7
CH6
8
CH7
CS 10
CS/SHDN
CLK 13
CLK
+5V
15
VREF
DGND
9
16
VDD
AGND
14
GND
MCP3008-I/SL

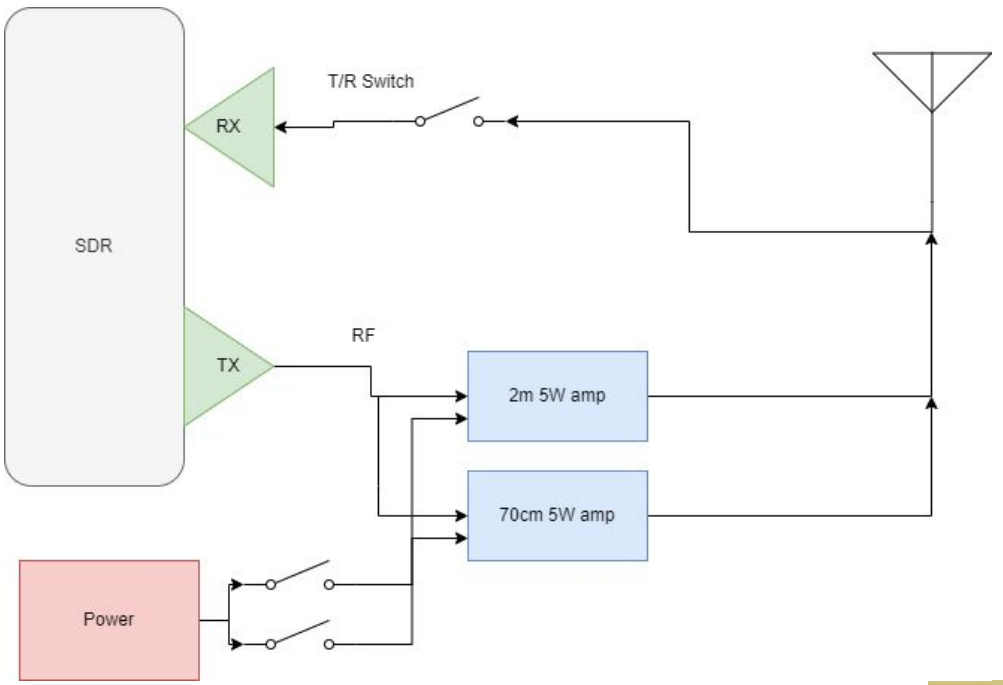

+5V
GND
USB+
1
2
P1
GND
CS
MOSI
MISO
CLK
SPI
1
2
3
4
5
Header 5
GPIO0
GPIO1
GPIO2
GPIO3
PowCont
1
2
3
4
Header 4
GPIO4
GPIO5
GPIO6
GPIO7
RFCont
1
2
3
4
Header 4
R1
PD
10K
R2
PD
10K
R3
PD
10K
R4
PD
10K
R5
PD
10K
R13
PD
10K
GND

- 3.3v logic resistor divided to 1.6v
- All rf lines 50 ohms

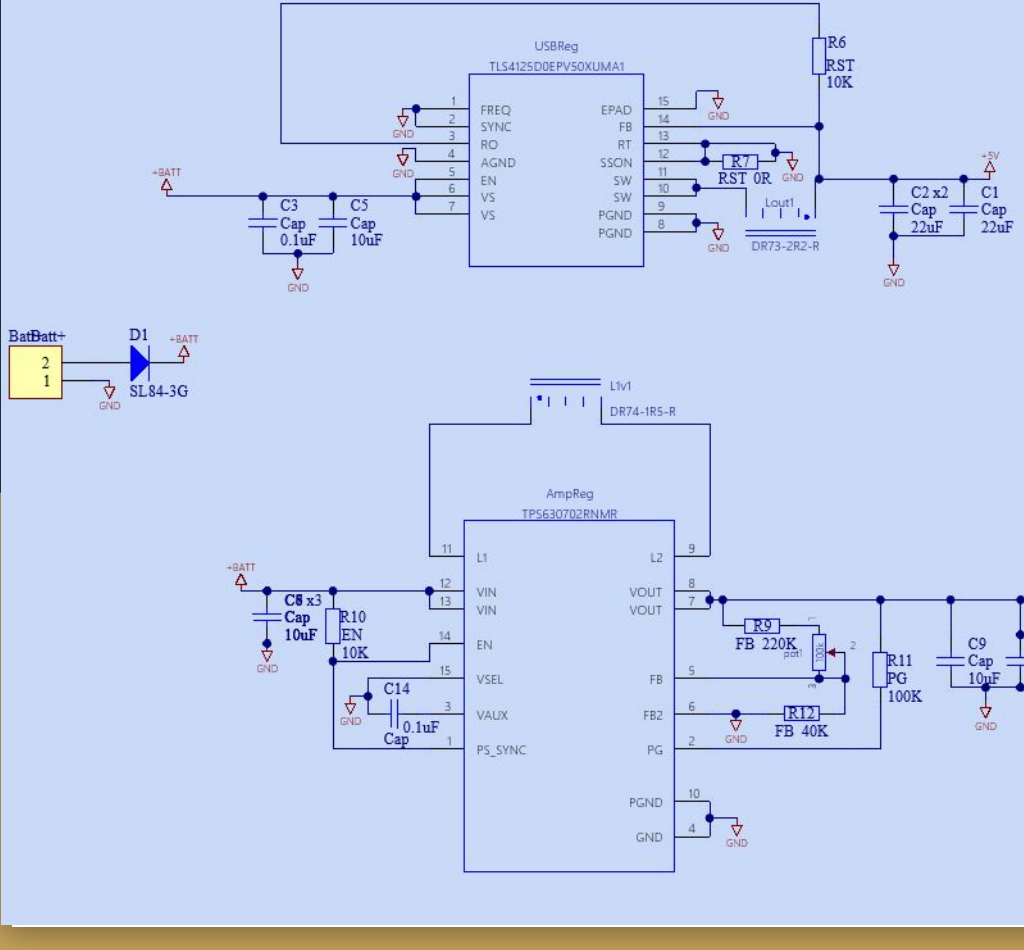


RF control

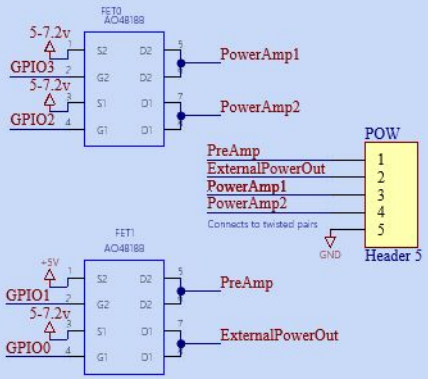
- The RF amplifiers are controlled with a combination of 2 methods
- The actual power supplied to the amplifiers can be disabled allowing for power saving
- Or the output for the lower power rf section can be switched directly to the Antenna
- This allows us to have a high output power while protecting the SDR



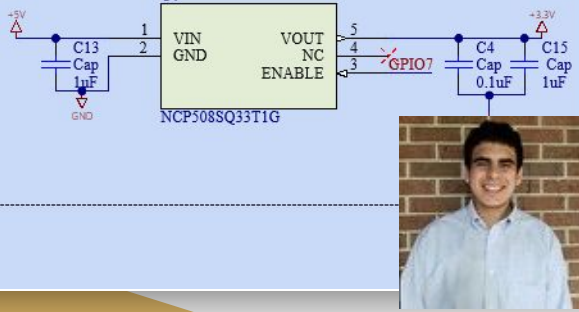
POWER

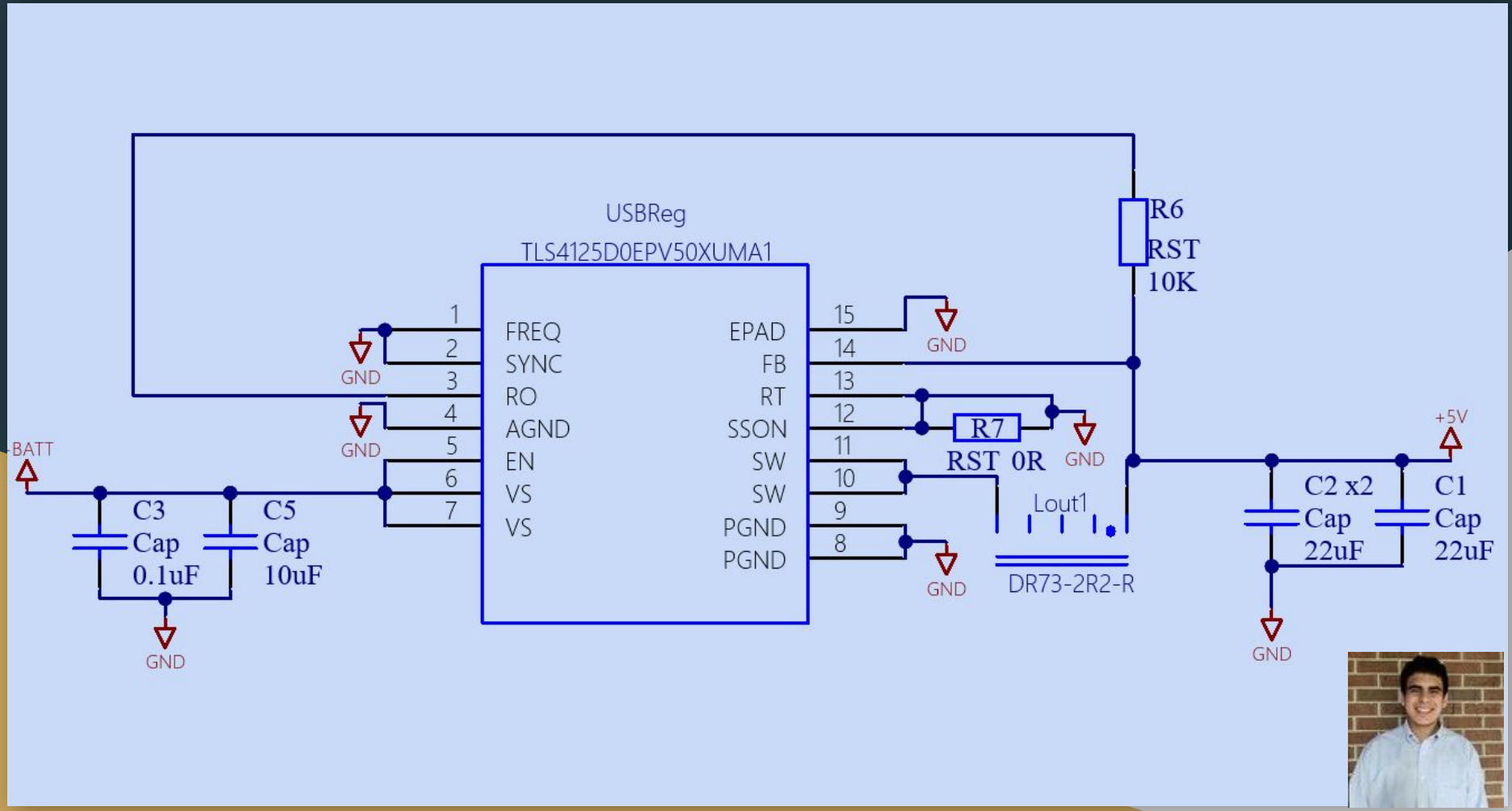


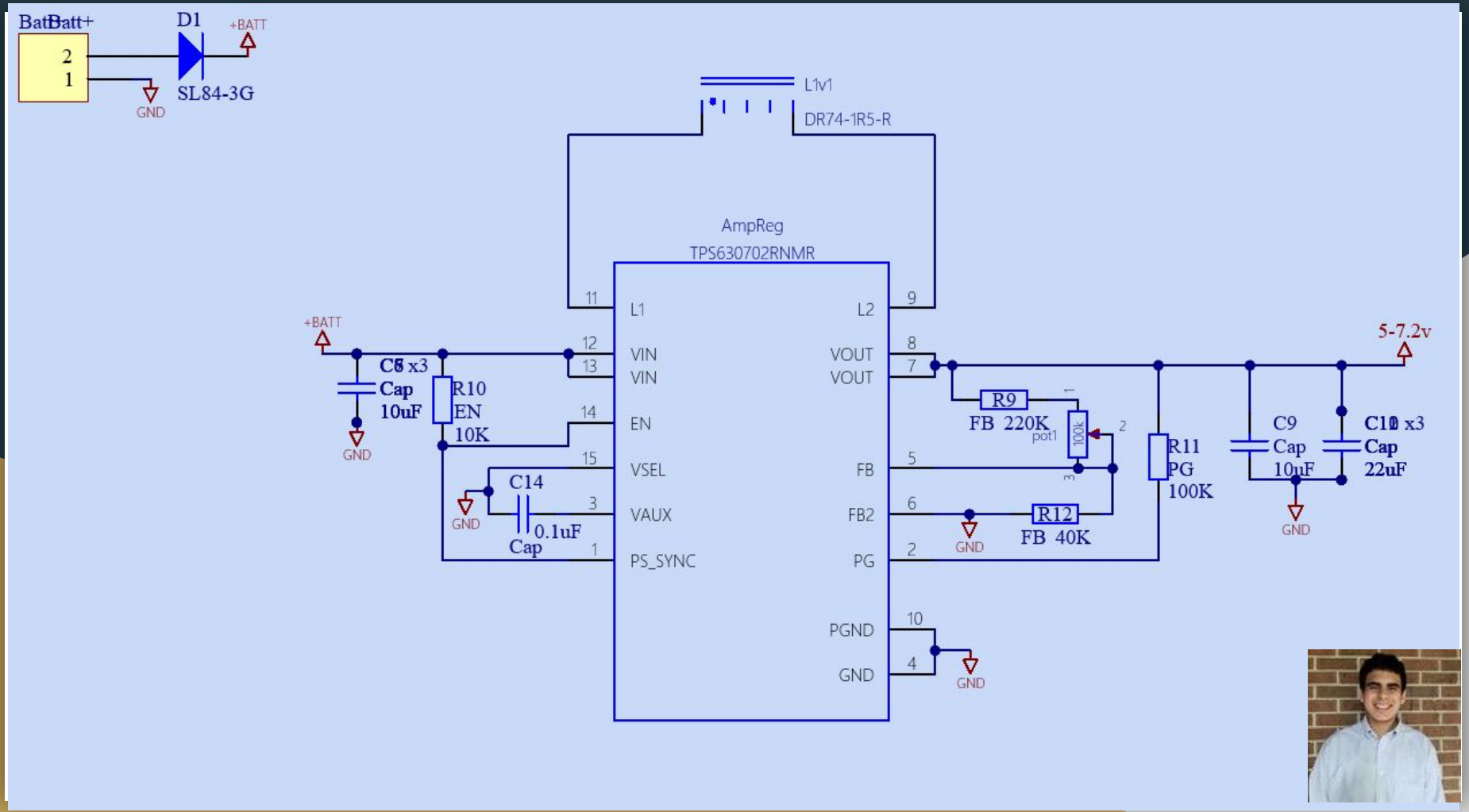
POWER SWITCHES



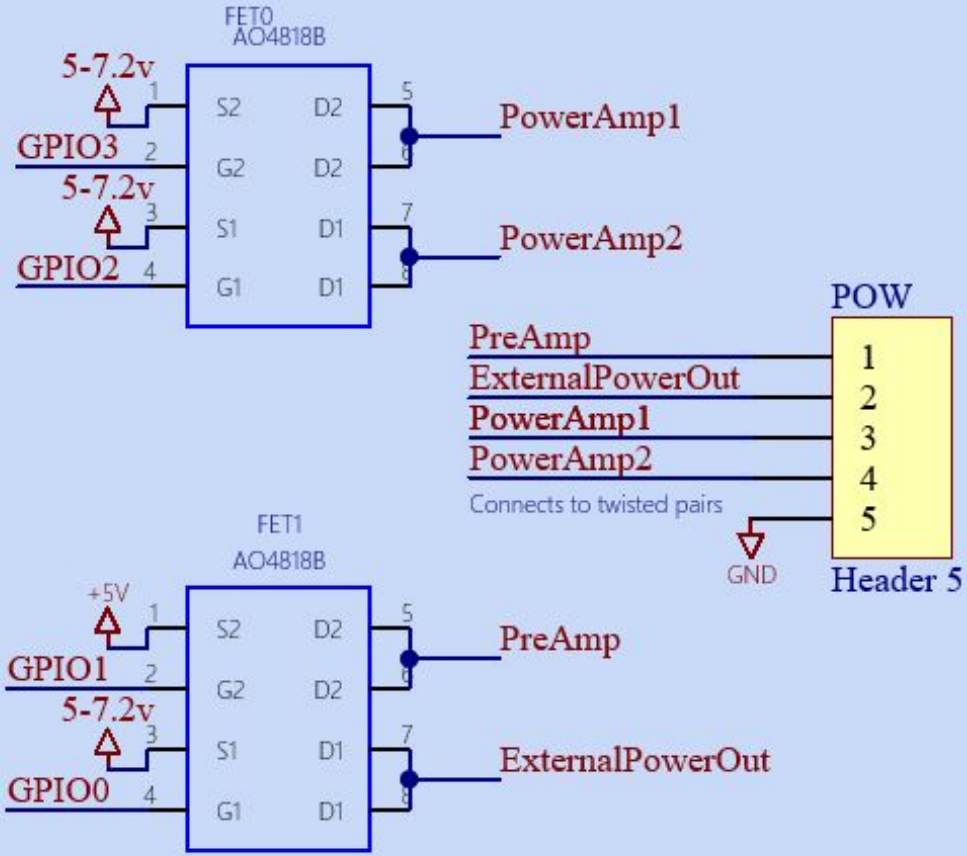
RF switch power

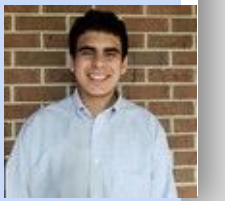



USBReg
TLS4125D0EPV50XUMA1
1 FREQ
2 SYNC
3 RO
4 AGND
5 EN
6 VS
7 VS
15 EPAD
14 FB
13 RT
12 SSON
11 SW
10 SW
9 PGND
8 PGND
GND
GND
GND
GND
GND
R6
RST
10K
R7
RST 0R
Lout1
DR73-2R2-R
BATT
C3
Cap
0.1uF
C5
Cap
10uF
C2 x2
Cap
22uF
C1
Cap
22uF
+5V

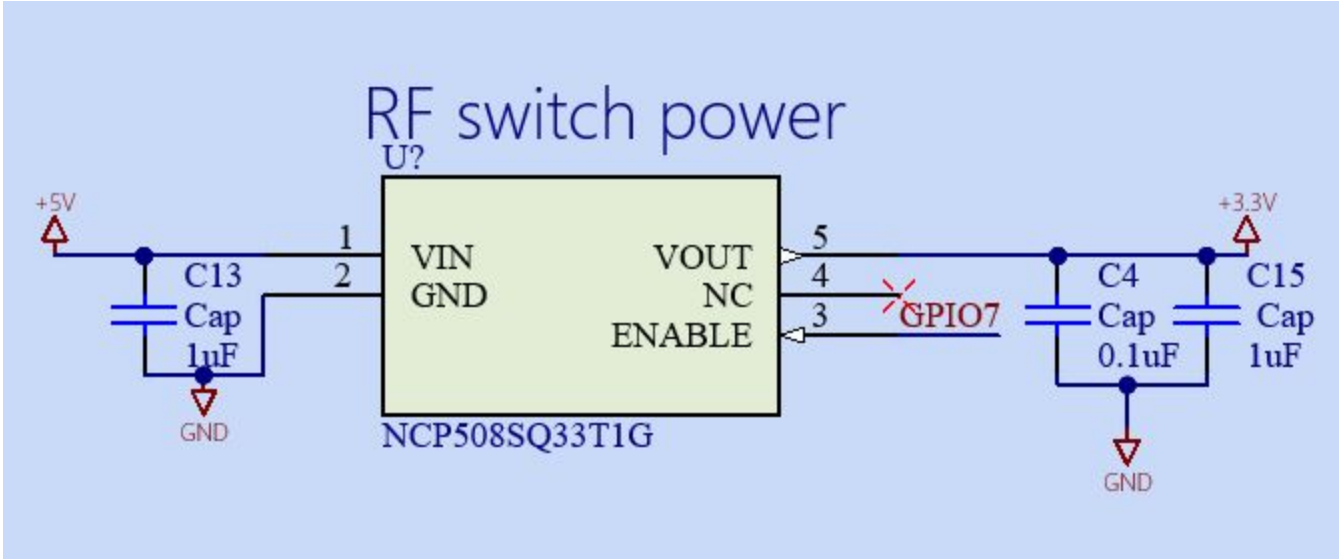

BatBatt+
2
1
D1
SL84-3G
+BATT
GND
L1v1
DR74-1R5-R
AmpReg
TPS630702RNMR
L1
L2
VIN
VIN
VOUT
VOUT
EN
VSEL
VAUX
PS_SYNC
FB
FB2
PG
PGND
GND
+BATT
C5 x3
Cap
10uF
GND
R10
EN
10K
C14
0.1uF
Cap
GND
R9
FB 220K
pot1
100k
R12
FB 40K
GND
R11
PG
100K
C9
Cap
10uF
GND
C10 x3
Cap
22uF
5-7.2v

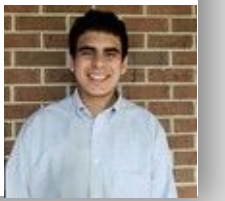
POWER SWITCHES





RF switch power





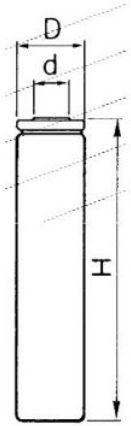
Batteries
Lithium Ion Composition

- Lithium Ion batteries boast significantly higher power density and specific energy compared to other battery compositions
- Notably lighter than other compositions.
- Fast Charging capabilities
- Longevity
- Stable

Characteristic	Lithium Ion Batteries	Other types (Lead Acid)
Longevity	Extreme longevity, very low self-discharge rate with relatively low maintenance	Does not require any maintenance at all, and is very reliable. Long life cycle, and can withstand inactivity but lower overall lifespan due to a very limited cycle life.
Charging speed	Extremely fast in comparison to other battery types. Can fully charge in 2.5 hours.	Extremely slow charge rate. Full saturation can take up to 16 hours.
Voltage Capacity	Boasts a very high voltage capacity, meaning it will last longer when charged.	Low specific energy, and low power density. Poor weight to energy ratio.
Stability	Environmentally friendly and generally more stable. It is not temperature restricted and can be stored both uncharged or charged. Long periods of use will not generate heat.	It is not environmentally friendly and must be stored in a charged condition to prevent sulfation. Different versions have different restrictions, flooded versions require watering.
Weight	About 70% lighter than lead based batteries. Weight to energy ratio is extremely favorable for handheld products such as this project.	Lead is heavier in comparison to alternative elements (even nickel iron cells) and due to its low specific energy has little to show for its higher weight.
Cost	Has become cheaper with time, but originally was more expensive. Averaged $132 per KWH in 2021 and $101 per cell.	Simple and inexpensive to manufacture. Low cost per watt-hour, best value power per KWH. Lead can be recycled and reused in new batteries.

Batteries

- Utilization of 18650 Lithium Ion Batteries
- 2 x 3.7V, 3400mAh
- Multiple characteristics must be maintained for safety, such as:
  - Heat
  - Severe Over and Under Voltage
  - Short-Circuits
  - Cannot charge above 4.25V
  - Cannot discharge below 2.5V



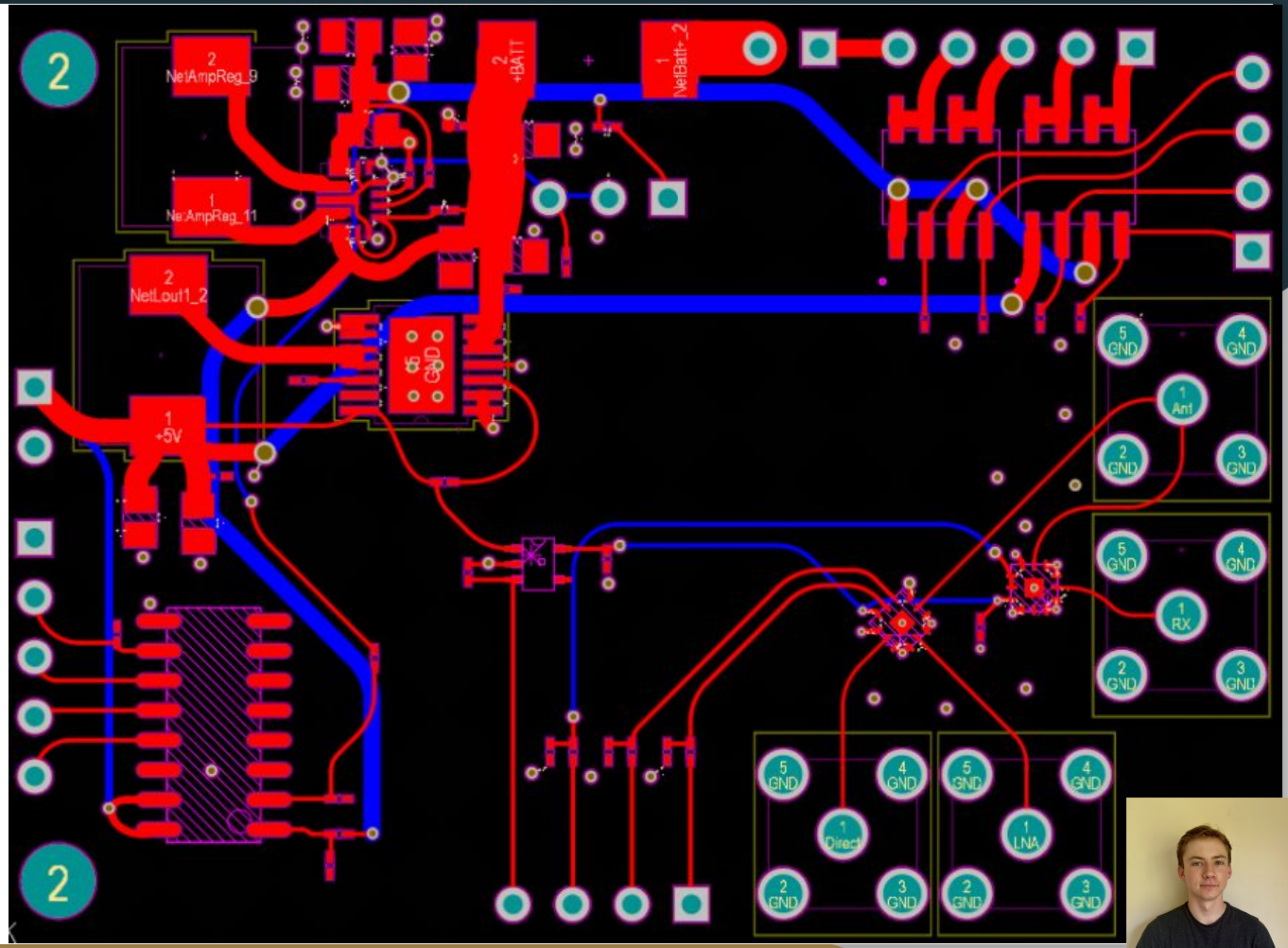
Dimensions(Typ.) of Bare Cell	H	64.93mm
	D	18.2mm
	d	7.9mm

Ambient Temperature	Charge	+10～+45℃
	Discharge	-20～+60℃
	Storage	-20～+50℃

PCB Design

PCB Layout

- Switching regulators and inductors furthest from rf section
- Shared ground plane across noise planes preventing EMI
- RF switch 50 ohm impedance matched



PCB Manufacturer

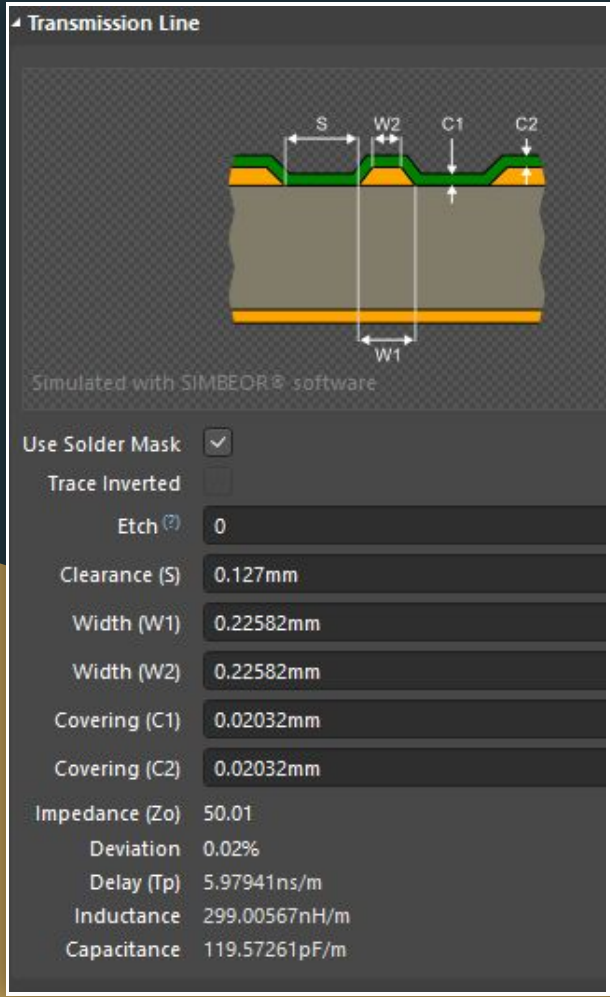
- Chose OSHPark
- Started with 2 layer but switch to 4 layer for lower cost and better impedance control

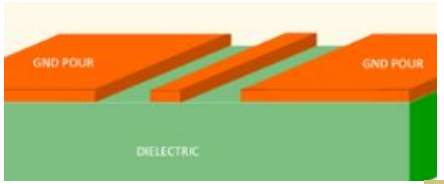
Layer	Material Type	Thickness	
Top Layer1	Copper	0.035 mm	
Prepreg	7628*1	0.2 mm	
Inner Layer2	Copper	0.0175 mm	1.1mm (with copper core)
Core	Core	1.065 mm	
Inner Layer3	Copper	0.0175 mm	
Prepreg	7628*1	0.2 mm	
Bottom Layer4	Copper	0.035 mm	

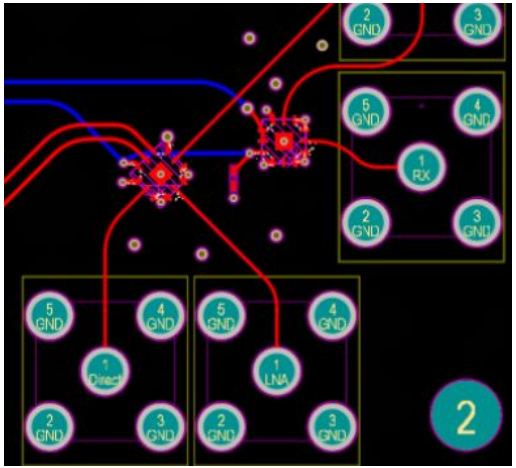
Impedance

- Coplanar waveguide for QFN pad size matching while within manufacturer capabilities for trace size

- 37 dbm at 50 ohm gives a peak voltage of 15.830v pk

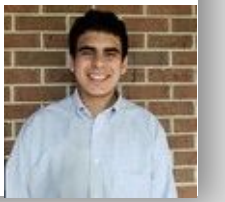






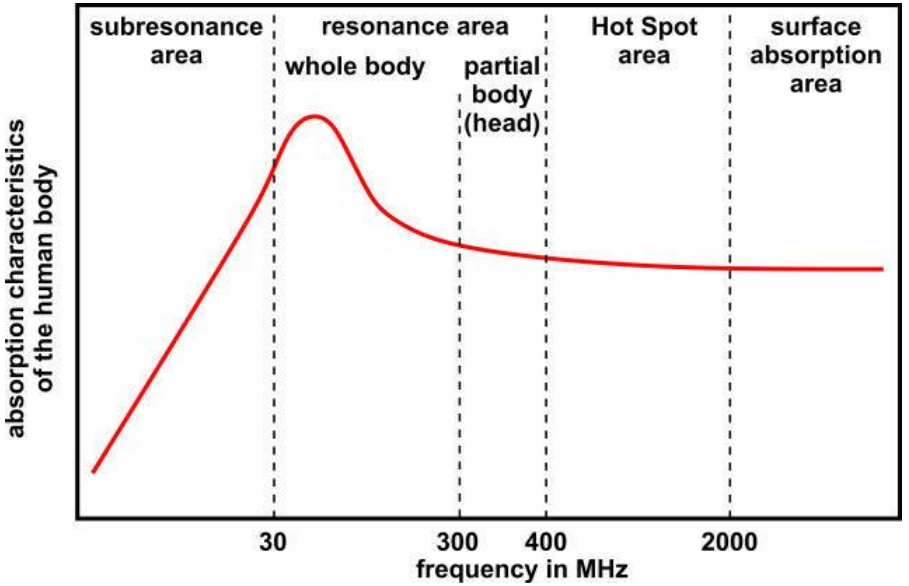
Accessibility

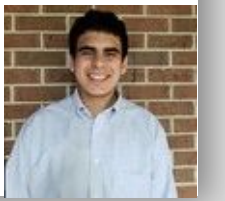
- Code will be open source
- Code will utilize well-documented languages (C, C++, Python)
- Batteries easily removable and accessible
- Batteries easily charged with any universally standardized battery charger



Heat & Radiation

- The FCC determines electromagnetic energy absorbed by the body in a measurement named SAR
  - FCC 47 C.F.R. Sections 1.1307b, 1.1310, 2.1091, 2.1093
- Must be determined in instances where device is 0.2m or less in contact with body
- Cannot exceed 1.6 watts per kilogram of tissue
- Device can burn user or components with lack of heat dissipation
- Device must stay between -4 and 113 degrees Fahrenheit.





Project Successes and Difficulties

Successes

- Timely completion of work
- Effective collaboration despite remote work
- Successful interfacing to the LimeSDR
- Device capable of outputting sound
- Device capable of recording audio
- System is able to switch from tx to rx and vice versa.

Difficulties

- Manufacturers delayed shipping on parts
- Microchip shortage
- Three different power requirements
- Limited budget
- Voltage Regulation System overcurrent
- RF components are extremely sensitive
- Limited Hardware Resources for Program
- Touchscreen power draw

Budget and Financing

Budget: $500

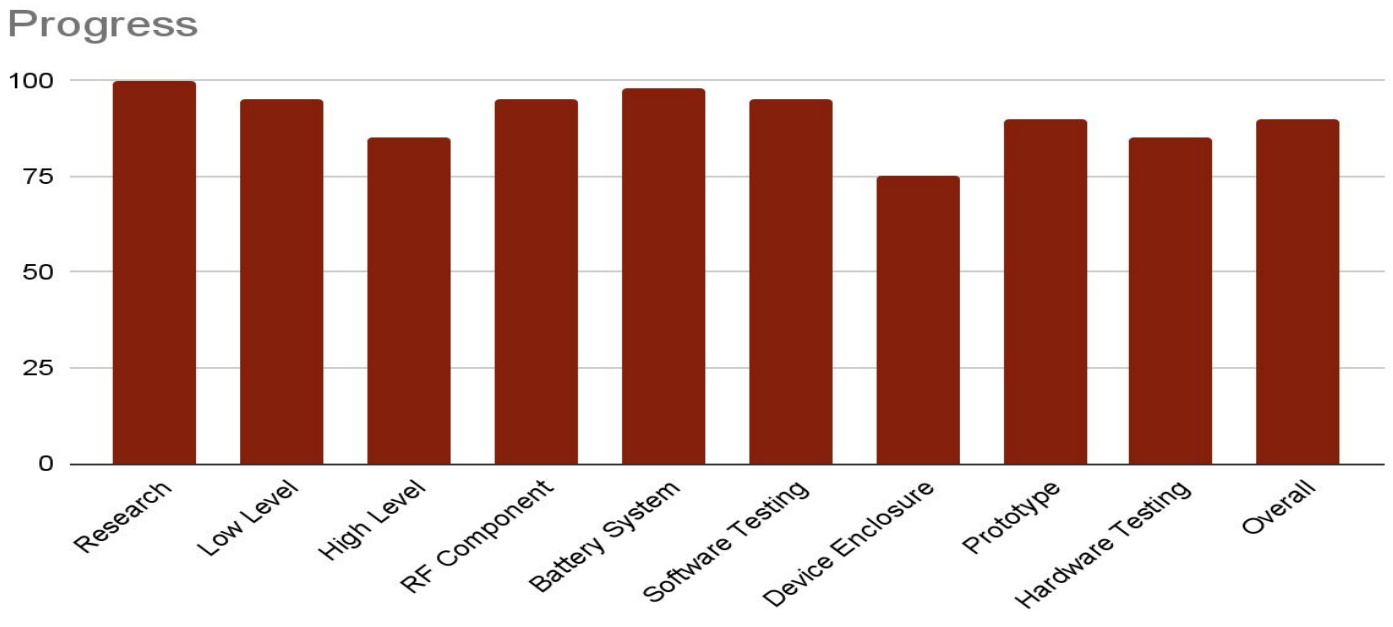
Sponsor: University of Central Florida Amateur Radio Club

Amount Used: ≈$475

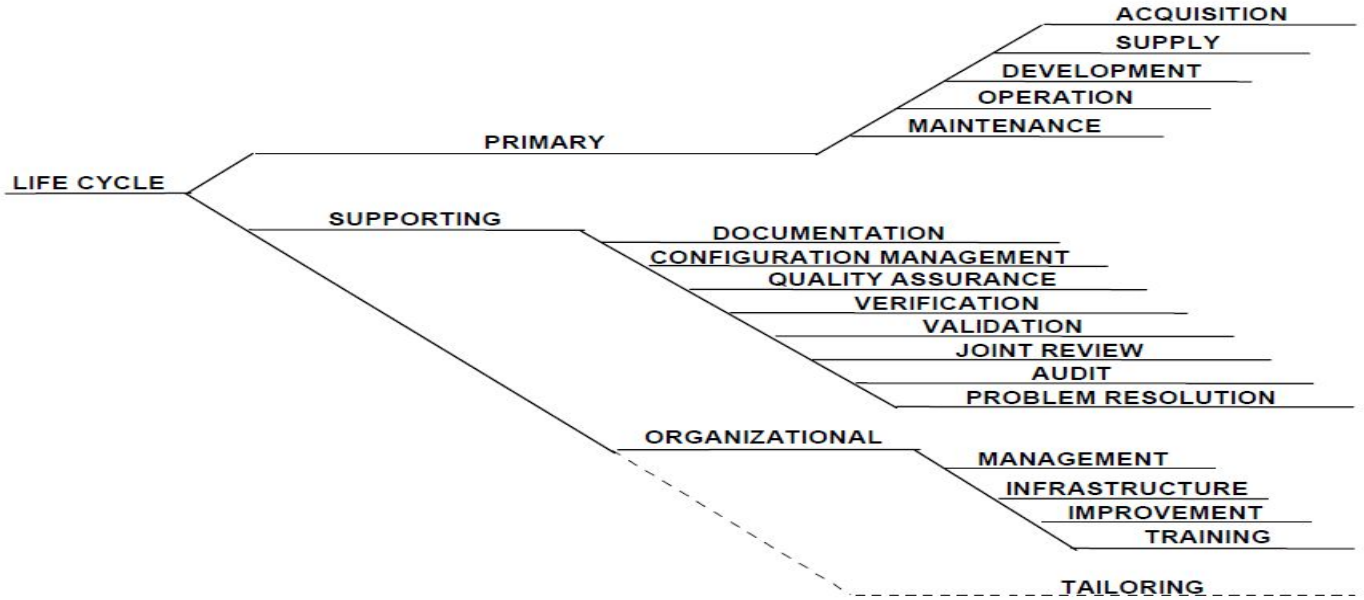
Budget and Financing

Component	Quantity	Vendor(s)	Estimated Cost
LimeSDR Mini	1	Limemicro LLC	$199
Raspberry Pi Zero 2 W	1	iUniker (Amazon)	$10
144MHz Amplifier	1	eBay	$20
433MHz Amplifier	1	eBay	$12
Antenna	1	Luiton	$20
Touchscreen Display	1	JniTyOpt	$30
Battery Controller	4	Mab	$7.49
Battery Charger	1	EBL	$7.99
MCP3008	1	Digikey/AdaFruit	$3.50
Misc		Various Vendors	$85.5
Total Estimated Cost	$395.50		

Statement of Progress



Plans for Project Completion



EIA/IEEE 12207 process tree