

# **RF Waveform Generator**

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## **CONCEPT OF OPERATIONS**

REVISION – Draft  
06 February 2024

CONCEPT OF OPERATIONS  
FOR  
RF Waveform Generator

TEAM <10>

APPROVED BY:

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Project Leader                          Date

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Prof. Kalafatis                          Date

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T/A                                  Date

## Change Record

Rev	Date	Originator	Approvals	Description
-	2/6/2024	Sandia National Labs		Draft Release
1	2/24/2024	RF Waveform Generator		Revision 1
2	4/27/2024	RF Waveform Generator		Final Report - ECEN 403
3	11/24/2024	RF Waveform Generator		Final Report - ECEN 404

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## 1. Executive Summary

One of the fundamental pillars that make up the field of RF communications and designs is frequency synthesis and modulation. To transmit radio signals and implement them in various applications, an RF signal must first be generated, preferably at a low cost and complexity. Therefore, Sandia National Labs has requested an RF waveform generator design focusing on low SWAP-C (minimal size, weight, power, and cost). This generator will produce a sawtooth waveform from 1.6-3.2GHz and should be robust to an increasing chirp rate without significant waveform degradation. While this is entirely exploratory research and development with no direct application in mind, this project aims to help reduce the cost and resources as much as possible to optimize the mass production of frequency synthesis.

## 2. Introduction

Frequency synthesis is the process of producing radio frequency signals with varying frequencies. It allows communication systems to tune to different frequencies quickly and precisely, thus forming the building blocks for RF communication and circuit designs. Practically anything that requires a stable RF source uses frequency synthesis, hence its wide variety of applications from Bluetooth transmitters to Wi-Fi routers and mobile phones. With such a pivotal role in RF communication, simpler and more economical designs of frequency synthesis would allow RF applications to be manufactured quickly and optimally.

### 2.1. Background

RF waveform generators, more generally recognized as RF frequency synthesizers, are the most essential part of any RF device. They directly generate a wide range of high frequencies from a single, lower reference frequency and are responsible for generating signals in the RF domain. Therefore, they are used in a variety of wireless applications, from Bluetooth transmitters/ receivers to Wi-Fi routers and communication systems. Generally, any device that transmits signals that require a stable RF source has some form of a frequency synthesizer.

Figure 1 below is an example block diagram for a frequency synthesizer. It contains a Voltage-Controlled oscillator which transforms a signal into an RF signal, with some components around it that keep the phase fixed to the reference signal known as a Phase-Locked Loop. For the scope of this project, the Phase-Locked Loop is not required as mentioned by our sponsor, just the reference signal and VCO.

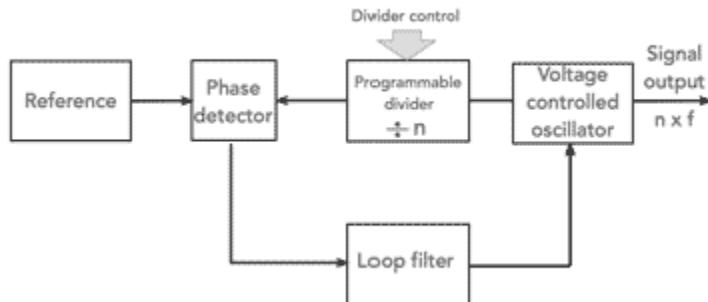


Figure 1. Example RF Frequency Synthesizer Block Diagram

Despite its wide use in the RF industry, most RF synthesis devices are costly, ranging well above \$2,000 per device which drives production costs in manufacturing. Therefore, this project is exploratory research and development, which aims to create an RF waveform generator in low SWAP-C (Size, weight, power, and cost). By minimizing costs and complexity, mass production would be easier to realize while still meeting the same specifications as the current ones used in the industry. For this project, our primary focus will be minimizing SWAP-C. While the original concept was to generate a higher waveform from 6-8GHz, due to the limited testing equipment provided as well as the budget of the project, a compromise was made to lower the frequency range to 1.6 to 3.2 GHz to fit all of our project constraints.

## 2.2. Overview

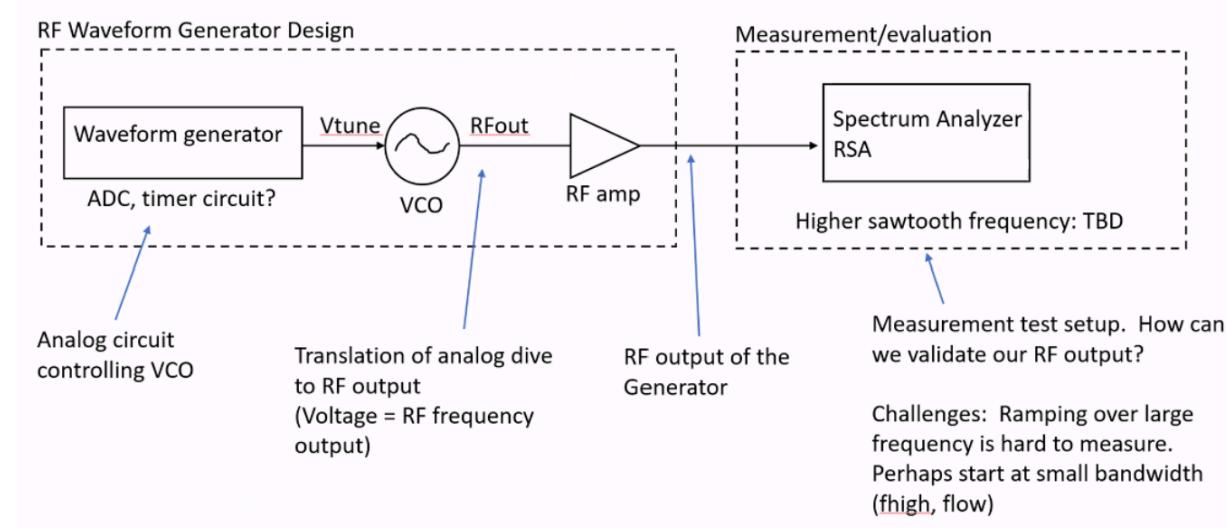


Figure 2. RF Waveform Generator Block Diagram

Drawing from the block diagram above, a waveform generator will produce the tuning voltage. A digital-to-analog converter (DAC) will be implemented to produce a periodic, tuning voltage. This tuning voltage acts like a dial for the Voltage Controlled Oscillator (VC), which produces an RF waveform. Changing the tuning voltage changes the frequency of the RF signal. The RF output would then be amplified to a magnitude that can be seen by an oscilloscope or spectrum analyzer for testing.

## ***2.3. Referenced Documents and Standards***

1. For the article "Synthesizer Types - Introduction" from Electronics Notes:  
[1] Author(s), "Synthesizer Types - Introduction," Electronics Notes, Available: [Online]. URL:  
<https://www.electronics-notes.com/articles/radio/frequency-synthesizer/synthesizer-types-introduction.php>. [Accessed: Feb 10, 2024].
2. For the article "The Basics of Voltage Controlled Oscillators (VCOs)" from Digi-Key:  
[2] Author(s), "The Basics of Voltage Controlled Oscillators (VCOs)," Digi-Key, Available: [Online]. URL:  
<https://www.digikey.com/en/articles/the-basics-of-voltage-controlled-oscillators-vcos>. [Accessed: Feb 10, 2024].
3. For the Surface Mount (SMT) Voltage Controlled Oscillator (VCO) product page from Pasternack:  
[5] Author(s), "Surface Mount (SMT) Voltage Controlled Oscillator (VCO) 3.2 GHz," Pasternack, Available: [Online]. URL:  
<https://www.pasternack.com/surface-mount-smt-voltage-controlled-oscillator-vco-3.2-ghz-pe1v14003-p.aspx>. [Accessed: Feb 13, 2024].
4. For the product page of TQL9093 from Qorvo:  
[6] Author(s), "TQL9093," Qorvo, Available: [Online]. URL:  
<https://www.qorvo.com/products/p/TQL9093>. [Accessed: Feb 28, 2024].

## **3. Operating Concept**

### ***3.1. Scope***

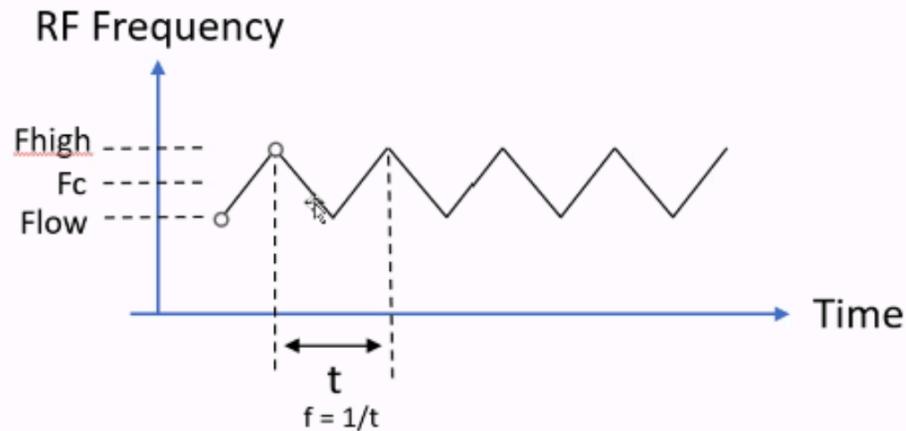
The RF waveform generator will be used for research and development purposes. The end goal is to demonstrate the function of the design on a singular PCB with all parts fully integrated. This will provide a proof of concept for the design and demonstrate the capability of a low SWAP-C (Size, Weight, Power, and Cost) waveform generator. This project is aimed towards achieving the minimum size, complexity, and cost.

### ***3.2. Operational Description and Constraints***

The RF generator described in this document will be used to investigate the capabilities of a low SWAP-C waveform generator. Our team is trying to push the boundaries by producing a product that is low in size, weight, power, and cost. This waveform generator will be designed to operate with the following specifications:

- Frequency range from 1.6GHz-3.2GHz
- Output power of +20dBm
- Small size and weight - 2x2 inch, 200g PCB board
- Low power consumption only using 2 AA batteries

The design will be oriented towards expanding what one can do with RF waveform generation. This means that as the project progresses, our team and Sandia National Labs might find it fit to change the specifications of this system to explore other areas of interest.



*Figure 3. RF Frequency Output*

One constraint of this waveform generator is maintaining stability and linearity despite a constantly changing frequency. To do so, the RF output signal must reflect and mimic the tuning voltage. If the tuning voltage is a periodic sawtooth waveform, so is the RF signal with an IF frequency equivalent to the frequency of the the tuning voltage modulating. This proves that the RF signal has a constant chirp rate (rate of change of frequency), is linear when it oscillates, and thus proven a sawtooth signal.

### **3.3. System Description**

The RF waveform generator will consist of several components that will be integrated into a single PCB board. These components are broken up into 4 different subsystems: Power Regulation, Analog Drive, VCO & RF Amplifier, and Testing/Signal Mixing. These systems are described below:

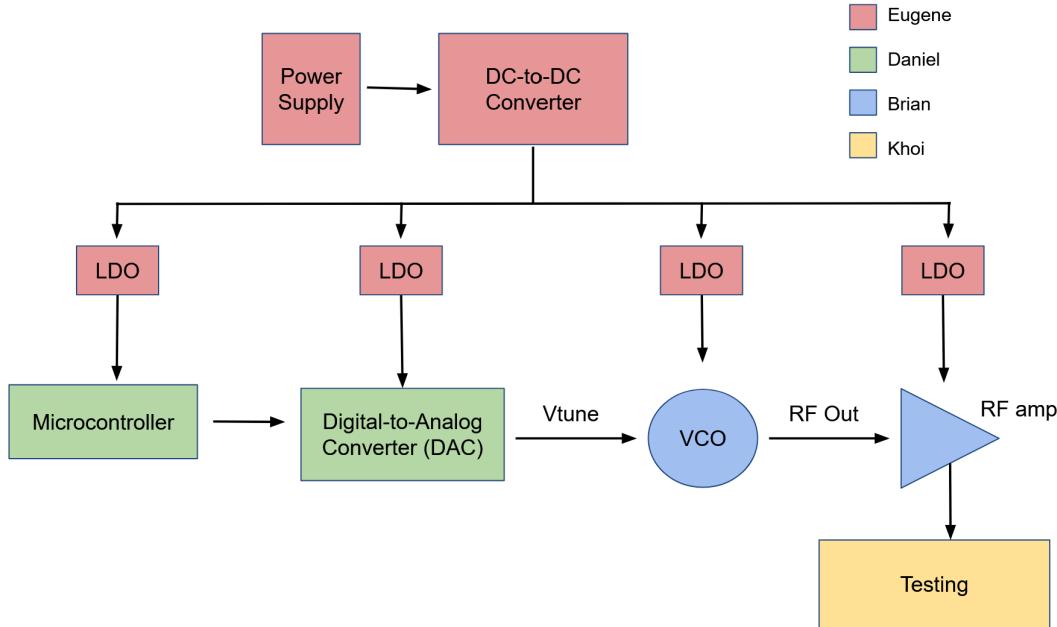


Figure 4. Subsystem Block Diagram

**Power Regulation Subsystem:** Power is a very important system of the waveform generator. It is necessary to regulate the power of each component to decrease the overall noise of the output. This means that our system must have a stable and reliable power supply with a simple and practical power source. Our team has chosen to use two double A batteries to comply with the low SWAP-C goal. To provide the necessary voltage to the other parts of the system we will use a DC-DC boost converter. To regulate the power these batteries provide, our team will implement a linear voltage regulator. This will provide a constant voltage to each part while also decreasing the noise that will be generated from the DC-DC boost which will help keep the waveform generation stable.

**Analog Drive:** The analog drive subsystem is what controls the waveform generation of the device. This portion of the waveform generator is controlled by a microcontroller that will be programmed to control the output of digital to analog converter (DAC). This DAC will be used to control the voltage-controlled oscillator (VCO) and in turn, produce the RF output signal. This subsystem is integral to the success of the waveform generator because it acts as the brains of the design. It will be responsible for controlling the modulation of the waveform and providing the different modes of operation. It is important to note that the microcontroller will control a voltage from the battery supply which will be amplified to match the tuning voltage range of the VCO. To meet our requirements of producing a frequency range from 1.6GHz to 3.2GHz, this subsystem must be able to produce voltage signals that modulate from 0 to 20V, since the tuning voltage is directly proportional to the RF signal frequency..

**VCO/ RF Amplifier:** Once the DAC and Microcontroller drive a tuning voltage, the Voltage Controlled Oscillator will take that as an input to create a waveform in the RF domain. The magnitude of the tuning voltage will directly affect the frequency of the RF signal produced. As previously mentioned, the signal frequency will oscillate from 1.6 to 3.2GHz, and the goal is to prevent any waveform degradation from the changing frequency (also known as

chirp rate). From there, an RF amplifier with an intended output power of 20 dBm will increase the voltage of the signal for adequate testing. To satisfy the specifications, our current decision is to use a PE1V14003 chip as the VCO, and TQL9093 as the RF amplifier.

**Testing/Signal Mixing:** Once the system is all integrated, testing will be performed. Our team decided to perform pulse compression techniques to test our system. A mixer (manually designed for exploring low-cost and ZX05-83LH-S+ sponsor provided) and a signal splitter (ZFRSC-42-S+) will be used to drive the RF signal from our generator to an oscilloscope to observe the IF output signal of the mixer. The sinusoidal waveform shown on the oscilloscope will tell how well our system is performing by comparing the calculation results and MATLAB simulation to the real measurement.

### **3.4. Modes of Operations**

The RF waveform generator is designed to be simple and robust. This means that the operation modes will be limited to 8 different types. The first (aka off) to fifth modes being DC (single frequency signal), and the fourth to 7th setting will be in modulation mode. These will provide an adequate range of operations for the user.

Once the user turns the generator on, the RF waveform Generator will begin to produce a waveform of constant frequency at either 1.6, 2, 2.4, 2.8, 3.2 GHz. This means tuning voltage will either be in 0, 4, 7, 10, or 20 V, spanning across the entire range that the VCO can output.

The final 3 modes are the modulation modes. This will allow the user to modulate the frequency output of the RF generator at a rate of 1kHz, 5kHz, or 10kHz. This output will also be in the form of a sawtooth waveform and will continue to output this waveform until the user switches modes.

Mode	Mode Type	Input Tuning Voltage (V)	Output Rf Frequency (GHz)
1	DC	0 (OFF)	1.6
2	DC	4	2
3	DC	7	2.4
4	DC	10	2.8
5	DC	20	3.2
6	Modulation	Mod at 1kHz	1.6 - 3.2
7	Modulation	Mod at 5kHz	1.6 - 3.2
8	Modulation	Mod at 10kHz	1.6 - 3.2

Table 1. Modes of Operation

### **3.5. Users**

Due to the research and development nature of the project, the RF waveform generator itself will not be used by end-users. However, this project will be useful to Sandia National Labs in providing knowledge about the capabilities of a low SWAP-C RF waveform generator design. With this knowledge, one can implement this design into many practical systems such as communications.

The user of this device will require minimal training. However, since there are 7 modes to this system, some basic knowledge in RF and frequency synthesis is required to understand all the modes and what they do.

### **3.6. Support**

Operational assistance will be provided through the use of documentation and user manuals. This will include the details of how to navigate the different modes of operation and operate the system. Troubleshooting information will also be provided in the documentation.

## **4. Scenario(s)**

### **4.1. Research and Development**

The design will determine what minimum size, complexity, and cost of this type of RF waveform generation because of designing for SWaP-C (Size, Weight, Power, and Cost). Our miniaturized and battery-operated RF waveform generators will be an achievement of compact designs, minimizing power consumption, and promising construction to space-constrained installations. Furthermore, the RF generator demonstrates its function on a path forward on size reduction into a single small PCB.

### **4.2. Mass Production**

Mass production is effective for many goods due to standardized processes, technology, and supply chain optimization. Since designing for SWAP-C, one of the features of our RF waveform generator is to fit on a 2 in. x 2 in. circuit board. With these benefits of minimal space and power consumption leading to low costs, this waveform generator can be implemented in practically any RF device and application potentially becoming the standard waveform generator when mass-producing RF devices.

## **5. Analysis**

### **5.1. Summary of Proposed Improvements**

- Since we are designing for SWAP-C the design would take up minimal space and power with the low cost. This would make mass production easier, resulting in further cost reductions in quantity.
- The design will have a minimal amount of parts to meet the proposed size of a 2x2 in board.

- The waveform generator will operate on 2 AA batteries.

## **5.2. Disadvantages and Limitations**

The RF Waveform Generator will have some limitations which would include:

- The sawtooth will only be for a range of 1.6 to 3.2 GHz.
- The sawtooth signal produced will be transmitted over only a short distance or short periods due to the low power.
- Waveform generator can only transmit RF signals through cables, rather than wirelessly.
- Due to budget constraints, the quality of the RF parts will be limited.
- Due to the high frequency nature of this project, system testing will be difficult to conduct due to limited testing equipment that can handle this frequency range.

## **5.3. Alternatives**

Since the RF waveform generator that we are designing is focused more on research and development to find the most optimal design to maximize SWAP-C there are a few other ways to complete the design.

- One way to help tune the voltage of the VCO is to use a timer circuit instead of a DAC to reduce the complexity of the current-voltage drive system.
- Since size is also a factor, some alternative, smaller parts for DC Regulation could also be implemented but the trade-off could be costs, so in this case cost has a higher priority than size.

One additional note on this project is that there may be limitations on lab equipment in measuring the RF waveform. The school currently has a Spectrum Analyzer that could go up to 3GHz, the capabilities of producing a spectrogram/ waterfall plot of that high frequency are unknown. Therefore, in the case that it doesn't, either the project sponsors will provide adequate lab equipment.

## **5.4. Impact**

- Since we are generating an RF waveform the general concerns that come from radio waves apply here.
- Exposure to very high RF intensities can result in the heating of biological tissue and an increase in body temperature.
- At relatively low levels of exposure to RF radiation, the effects have been referred to as "non-thermal" effects. Research into this needs to be conducted to determine the generality of such effects and their possible relevance, if any, to human health.

# **RF Waveform Generator**

Brian Chau  
Daniel Hickl  
Eugene Asare  
Khoi Le

## **FUNCTIONAL SYSTEM REQUIREMENTS**

**FUNCTIONAL SYSTEM REQUIREMENTS  
FOR  
RF Waveform Generator**

**PREPARED BY:**

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Author                              Date

**APPROVED BY:**

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Project Leader                      Date

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John Lusher, P.E.                      Date

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T/A                                      Date

## Change Record

Rev	Date	Originator	Approvals	Description
-	02/22/24	RF Waveform Generator		Draft Release
1	04/24/24	RF Waveform Generator		Revision 1
2	04/27/24	RF Waveform Generator		Final Report - ECEN 403
3	11/24/24	RF Waveform Generator		Final Report - ECEN 404

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## 1. Introduction

### 1.1. Purpose and Scope

Especially in the high RF domain, components for frequency synthesis are expensive and complicated which leads to increased resources in manufacturing even the most basic RF devices. Therefore, this project is entirely exploratory research and development, aiming to generate a sawtooth RF signal from 1.6-3.2 GHz with the lowest SWAP-C possible. Because this is R&D with no restrictions or restraints, our primary focus will be meeting the frequency specifications with a budget of \$500 and the ideal size on a 9 x 3-inch PCB (excluding the user interface and battery power supplies). Our system will provide a baseline for simplifying RF waveform generation, which could then be implemented to cut costs and materials in mass production.

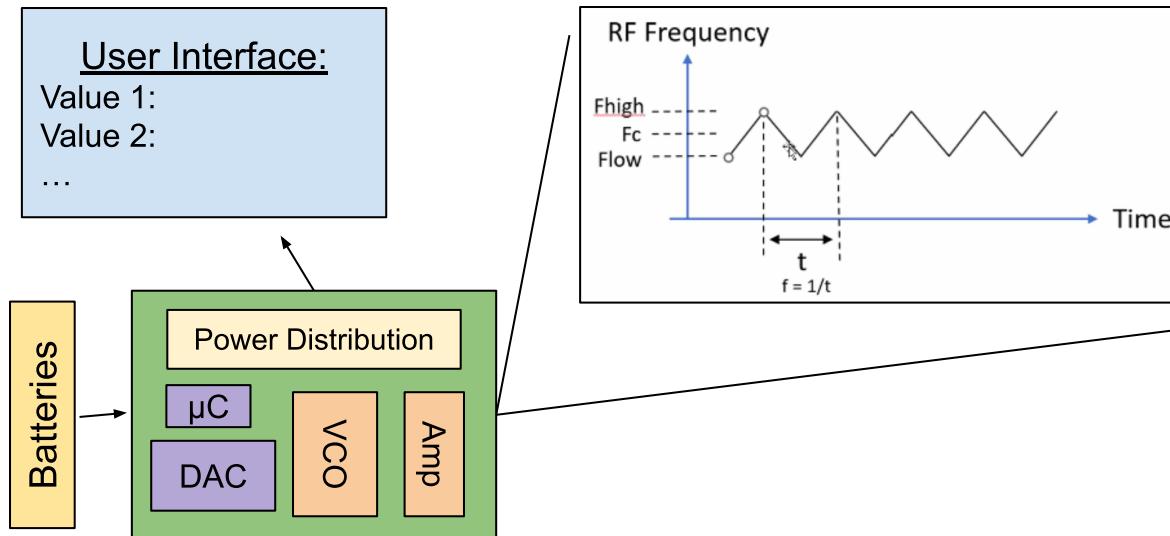


Figure 1. Project Conceptual Image

## ***1.2. Responsibility and Change Authority***

The team leader, Daniel Hickl, will be responsible for making sure all project requirements are met. Those requirements can only be changed with the approval of the team leader and Professor Stavros Kalafatis.

Subsystem	Responsibility
DC Power Regulation	Eugene Asare
Analog Drive	Daniel Hickl
VCO and RF Amplifier	Brian Chau
Testing/Signal Mixing	Khoi Le

**Table 1. Subsystem Assignments**

## 2. Applicable and Reference Documents

### 2.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
IEEE PC95.1-2345	05/21/2019	Force Health Protection Regarding Personnel Exposure to Electric, Magnetic, and Electromagnetic Fields, 0Hz to 300 GHz
ANSI C63.10-2013	12/10/2013	American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices
IEEE 1057-2007	12/05/2007	IEEE Standard for Digitizing Waveform Recorders

**Table 2. Applicable Documents**

### 2.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
IEEE C95.7	11/08/2010	IEEE Recommended Practice for Radio Frequency Safety Programs, 3kHz to 300 GHz
IEC 610004-4	06/06/2023	Electromagnetic Compatibility Testing And Measurement Package

**Table 3. Reference Documents**

### 2.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

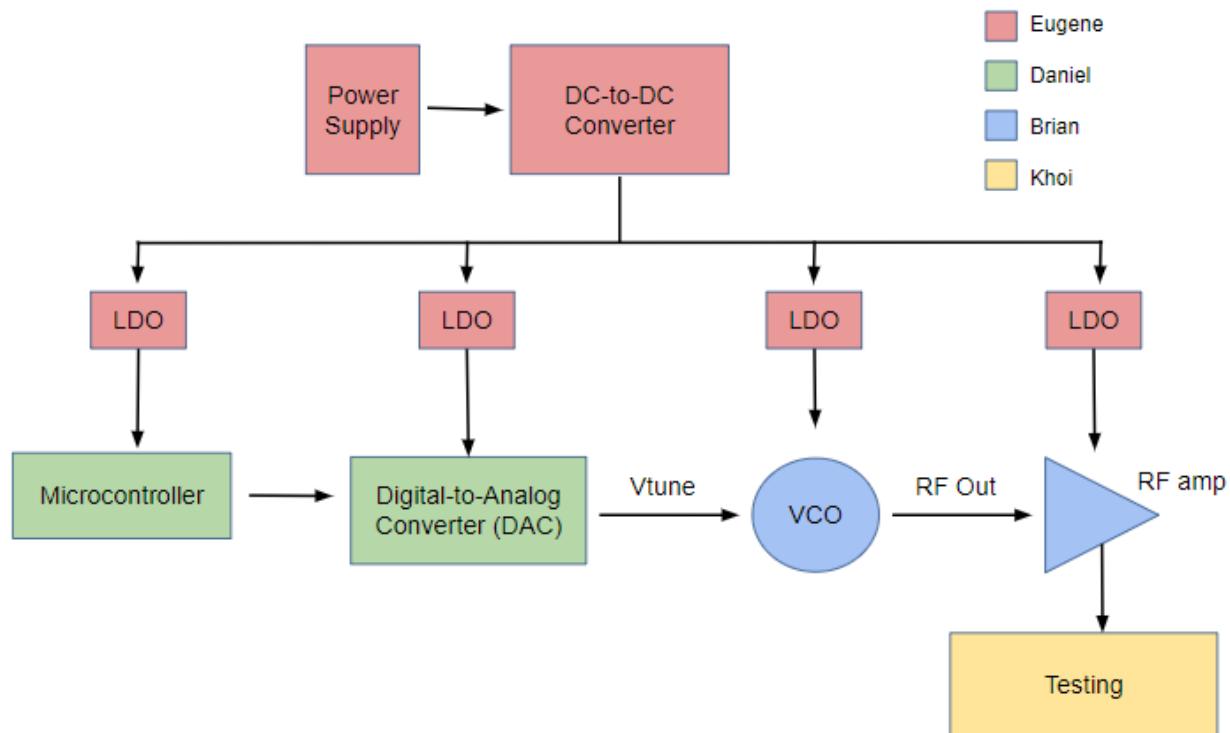
All specifications, standards, exhibits, drawings, or other documents that are invoked as "applicable" in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

### 3. Requirements

In developing the RF waveform generator, an RF signal will be produced that has a frequency range from 1.6 to 3.2 GH (1.6 GHz bandwidth). Despite the changing frequency, the signal should still be robust and not degrade with an increasing chirp rate. Its input, the tuning voltage, must be a periodic signal that oscillates between 0-20 volts as specified by the VCO component. The RF waveform generator has four subsystems: Analog Drive, VCO/ RF, Testing/Signal Mixing, and DC Power Distribution.

#### 3.1. System Definition

An Analog Drive consisting of a microcontroller and DAC will first create a sawtooth voltage signal. That will then be taken as an input for the VCO, Which will convert that tuning voltage into a sawtooth signal in the RF domain. An RF amplifier will increase the magnitude of the RF signal for adequate testing. A testing/signal mixing board that is used to measure the output of the VCO. Lastly, a power distribution subsystem will supply power to each component, stepping up/down with a series of LDOs.



**Figure 2. System Block Diagram**

In the block diagram, a power supply will consist of two or three AA batteries. Using a series of DC-DC boost converters and LDOs, that battery voltage will be stepped down to the specific needs of each component. A microcontroller will be used in conjunction with the DAC to create a tuning voltage signal digitally. That tuning voltage will be the direct input for the VCO, generating an RF waveform. Because the VCO produces a higher output power than what the RF amplifier can produce, a power attenuator will be installed between the

VCO and the amplifier. The testing/signal mixing board will be used to see the output of the VCO.

## 3.2. Characteristics

### 3.2.1. Functional / Performance Requirements

#### 3.2.1.1. User Interface

The RF Waveform Generator shall be controlled by a DIB Switch which shall be capable of controlling all the modes of operation.

*Rationale: This is the core system performance requirement. This is a requirement by our sponsor. This will allow us to have different functions for the RF generator, as well as monitor the status.*

#### 3.2.1.2. Modes of Operation

The RF Waveform Generator shall have three main modes of operation which include an on-state, off-state, and 3 modulation modes. These modes will allow the user to modulate the frequency output of the RF generator at a rate of 1kHz, 5kHz, or 10kHz.

*Rationale: This is the core system performance requirement. This is a requirement by our sponsor to perform optimally.*

#### 3.2.1.3. Range of RF Frequencies

The RF Waveform Generator shall have a range of 1.6GHz - 3.2GHz. The modulation mode shall span across this range. The “On” state shall choose constant frequencies in this range.

*Rationale: This is the core system performance requirement. This is a requirement by our sponsor to perform optimally.*

#### 3.2.1.4. Accuracy of Measurements

The RF Waveform Generator shall provide voltage and currents of certain components through the user interface and collected from the microcontroller. While frequency is variable in modulation mode, the output power should be 20 dBm +/- 3 dBm. Voltage and current readings of components are as follows in the table below:

Part	Description	Target Voltage	Target Current
PE1V14003	VCO	4.5 - 5V	16 mA
TQL9093	RF Amplifier	4.5 - 5V	120 mA
PIC32MK	MCU with DAC	3.3 V	200mA

LM358DR	Power Op Amp	24 V	20 mA
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Table 4. Target Voltage/ Currents for Each Component

*Rationale: This is a requirement specified by our sponsor due to the low SWAP-C constraints of their system in which the RF Waveform Generator is integrating. Also, this is for checking the performance of the RF Waveform Generator.*

The modulation mode and “On” state shall span across this range within a tolerance of 3%.

### 3.2.2. Physical Characteristics

#### 3.2.2.1. Mass

The mass of the RF waveform generator will be no more than 200g.

*Rationale: This is a requirement specified by our sponsor due to the low SWAP-C constraints in which the RF Waveform Generator is integrated.*

#### 3.2.2.2. Volume Envelope

The volume envelope of the Search and Rescue System shall be less than or equal to 2 inches in height, 3 inches in width, and 9 inches in length.

*Rationale: This is a requirement specified by our sponsor due to the low SWAP-C constraints in which the RF Waveform Generator is integrated.*

#### 3.2.2.3. Mounting

The RF Waveform Generator will have no mounting but instead it will be on a PCB.

*Rationale: The RF Waveform Generator has no mounting capabilities or functions.*

### **3.2.3. Electrical Characteristics**

#### **3.2.3.1. Inputs**

The only inputs the RF Waveform Generator is designed to handle are the power from the AA batteries and the tuning voltage to the VCO. The tuning voltage of the VCO will be controlled by the microcontroller. The DIP Switch connected to the microcontroller will control the state of the system. The switch is used as a hardware connection to control the RF waveform generator.

*Rationale: This is a requirement specified by our sponsor due to the low SWAP-C constraints in which the RF Waveform Generator is integrated.*

##### **3.2.3.1.1 Power Consumption**

The maximum peak power of the system shall not exceed 5 watts.

*Rationale: This is a requirement specified by our sponsor due to the low SWAP-C constraints in which the RF Waveform Generator is integrated.*

##### **3.2.3.1.2 Input Voltage Level**

The input voltage level for the RF waveform generator shall be +2.8 VDC to +3.6 VDC. This will be stepped up with a DC-DC boost converter that will give input voltages of 24 VDC, 5.5 VDC, and 5 VDC to individual LDOs. Those LDO will drop the voltage to the voltage input required for certain components. All voltage values will have an appropriate tolerance within +/- 5%.

*Rationale: This is a requirement specified by our sponsor due to the low SWAP-C constraints in which the RF Waveform Generator is integrated.*

##### **3.2.3.1.3 Input Noise**

The input noise for the RF Waveform Generation shall operate at the lowest possible with our design due to operating at high frequency. Operating at these high frequencies any additional noise that is generated from the voltages will disrupt the RF signal produced. The LDOs in the system are used to lower the noise generated by the DC-DC boost converters.

*Rationale: This is the core system performance requirement. This is a requirement by our sponsor to perform optimally.*

### **3.2.3.2. Outputs**

Essentially, there will be two outputs. One is voltage output of all monitored components. The other output will be the RF output that came out from the VCO.

#### **3.2.3.2.1 RF Signal Output**

The primary output of the system, which will be measured using an oscilloscope and spectrum analyzer provided in the lab. The maximum range of the RF output will be 1.6 GHz.

*Rationale: Primary purpose/result of the project. This is a requirement by our sponsor to indicate project functionality.*

### **3.2.4. Environmental Requirements**

The RF Waveform Generation shall be designed to withstand laboratory tests and be used in various R&D tests.

*Rationale: Since this project is R&D oriented there isn't much need to have our system withstand any other environmental situations.*

### **3.2.5. Failure Propagation**

The RF Waveform Generator shall not allow propagation of faults beyond the RF Waveform Generator user interface.

#### **3.2.5.1. Fault Detection**

The sensors are going to give inputs to the microcontroller with data on the voltages and currents and will be connected to the GUI and this user interface will display any errors in the power system distribution.

*Rationale: The data will help to ensure all components are supplied with proper power*

## **4. Support Requirements**

For this project, there are two supporting equipment, an RF signal mixer and signal splitter, that is required to adequately test and validate the system.

### **4.1. Necessary Technology**

#### **4.1.1 Mixer & Signal Splitter**

The signal mixer, with some calculations and processing, will decrease the frequency of the RF signal down to a range that current lab equipment can be used. For the purpose of this project, this signal mixer will also require a signal splitter, a device which splits the RF signal into two separate connections.

*Rationale: During the development of the project, one key issue that was brought up was whether the school had proper equipment to test our system. Because the RF waveform generator is operating at such high frequencies, there wasn't any equipment in the Electromagnetics lab that could properly measure the signal. This method was the most cost-effective solution without additional resources outside the scope of the project.*

## Appendix A: Acronyms and Abbreviations

RF	Radio Frequency
GHz	Gigahertz (1,000,000,000 Hz)
SWAP-C	Size Weight and Power - Cost
R&D	Research and Development
VCO	Voltage-Controlled Oscillator
DAC	Digital to Analog Converter
LDO	Low Dropout Regulator
PCB	Printed Circuit Board
VDC	Volts Direct Current
DIP	Dual In-Line Package

## Appendix B: Definition of Terms

DC-DC Boost Converter	A device with a higher output voltage than input voltage. AKA a step-up converter because it “steps up” the voltage.
Digital to Analog Converter	A device that translates digitally stored information from a computer or phone into an analog sound that we can hear.
DIP Switch	Consists of a small block of switches mounted on a dual in-line package. Each switch corresponds to a specific binary digit. Using the switch on the PCB provides flexibility in configuration.
Low Dropout Regulator	A device that takes an input voltage from a power supply and uses that input to output a steady voltage.
Voltage-Controlled Oscillator	An RF oscillator circuit whose frequency can be controlled by a DC input voltage.

# **RF Waveform Generator**

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## **INTERFACE CONTROL DOCUMENT**

**INTERFACE CONTROL DOCUMENT  
FOR  
RF Waveform Generator**

PREPARED BY:

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Author                                  Date

APPROVED BY:

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Project Leader                        Date

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John Lusher II, P.E.                Date

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T/A                                    Date

## Change Record

Rev	Date	Originator	Approvals	Description
-	02/23/2024	RF Waveform Generator		Draft Release
1	04/27/2024	RF Waveform Generator		Final Report - ECEN 403
2	11/24/2024	RF Waveform Generator		Final Report - ECEN 404

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## 1. Overview

The document describes the interface between the DIP Switch, microcontroller, and the LEDs in our RF waveform generator. The DIP Switch and the LED's are what the user will interact with on our board. A user interface for a microcontroller involves using binary configuration on the switch that allows users to interact with the microcontroller's functionalities such as changing the mode of operations or changing the frequency generated by the microcontroller. The LEDs are used to show the user what state the machine is in and verify that the board is powered on. Below is a block diagram of the user interface system.

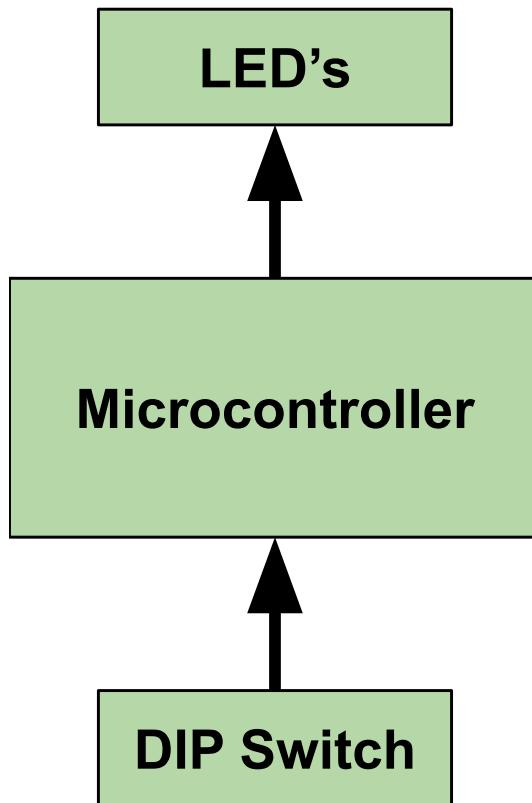


Figure 1. User Interface Block Diagram

## 2. References and Definitions

### 2.1. References

Document Name	Revision/Release Date/Version	Publisher
MPLab IDE User's Manual	2021	Microchip

**Table 1. User Interface References**

### 2.2. Definitions

DIP: Short for Dual In-line Package, consisting of a small block of switches mounted on a dual in-line package. Each switch corresponds to a specific binary digit. Using the switch on PCB provides flexibility in configuration.

### 3. Physical Interface

Component	Dimension (cm)	Weight (g)
DIP Switch	2.2	3
PCB	5 x 5	100
LEDs	0.13	1

**Table #2 : Items for Interface**

#### **3.1. Weight**

The device shall have the ability to be powered and controlled through a DIP switch, without the computer GUI connected.

The microcontroller and PCB board will weigh no more than 200g.

#### **3.2. Dimensions**

The dimensions of the RF generator PCB shall be no more than 5cm x 5cm. This is important for our goal of having a low SWAP-C for the system. If possible, we shall decrease the dimensions of this board even further.

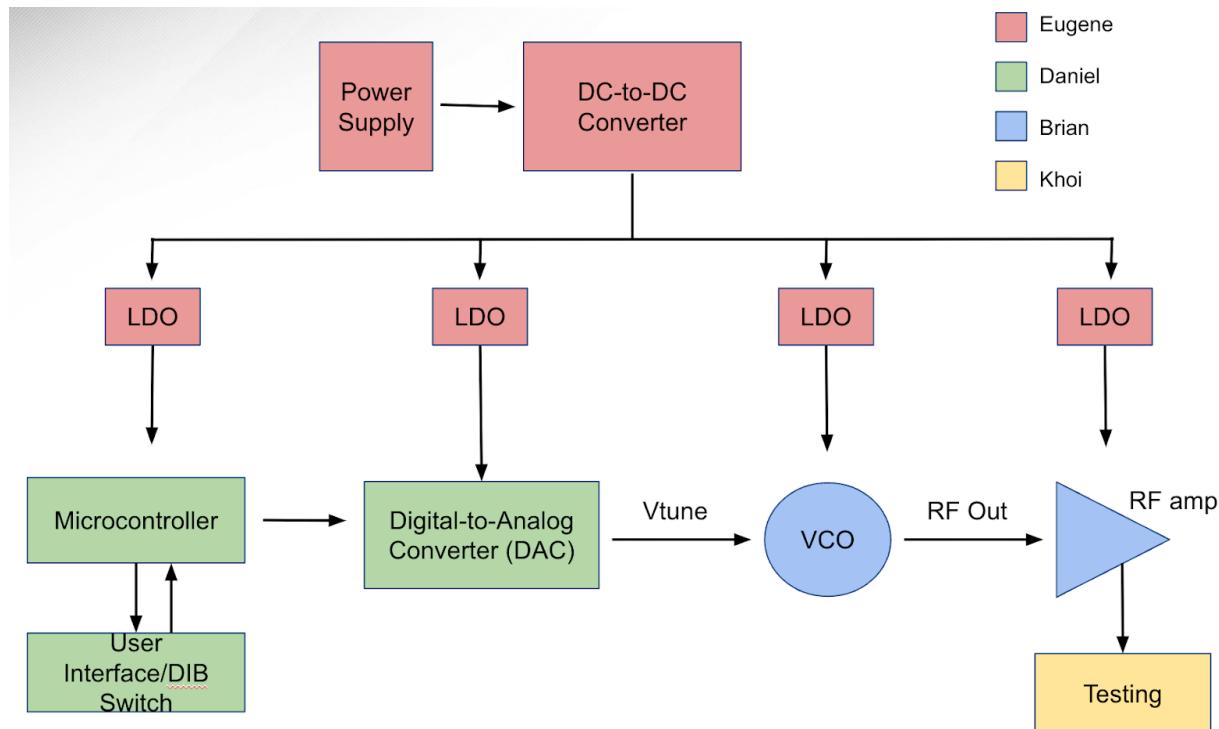
#### **3.3. Mounting Locations**

The interface is based on the hardware interface with the microcontroller functioning as the hardware control of the system. We will not have mounting locations as the end goal of this project is to be used for research and development purposes. This end does not require any mounting or connections because it will be a standalone device.

#### **3.4. Thermal Interface**

Although this generator is low power due to the small size of our project there might be some issues with heating in the VCO and power components. If heating becomes an issue we can use top mounted heat sinks on these components to dissipate the heat in our system. This is an acceptable solution because it does not require additional space on the PCB itself but instead is placed on top keeping it within our desired size.

## 4. Electrical Interface



**Figure 2. Voltage Level Schematic**

### 4.1. Primary Input Power

The RF waveform generator will be powered through the use of two AA batteries. This will be amplified using a DC-DC converter to multiple different rails to provide power to each component of the system. The use of low dropout regulators will be used to provide a stable input and supply voltage to the system. This is important as noise may have a dramatic effect on RF signals. The mitigation of this noise will be paramount to our success.

### 4.2. Signal Interfaces

Using the microcontroller, a sawtooth voltage signal will be made digitally and then converted from digital to analog (DAC). While it isn't possible to directly measure the RF signal without external lab equipment, the tuning voltage could be measured and display the projected frequency of the generator on the oscilloscope and spectrum analyzer.

### 4.3. DIP Switch Interface

A user interface will be placed on the PCB of the RF waveform generator. A DIP switch will be provided to allow the user to manually adjust the state of the system from a direct hardware connection. This DIP switch will also be used to control which user interface to use. The functionality of the switch is described in the table below.

Switches	Binary Inputs	Function
Pin 1: Constant Mode	Pin1 = 1 (Other Pins = 0)	4V Tuning Voltage
Pin 2: Constant Mode	Pin2 = 1 (Other Pins = 0)	7V Tuning Voltage
Pin 3: Constant Mode	Pin3 = 1 (Other Pins = 0)	10V Tuning Voltage
Pin 4: Constant Mode	Pin4 = 1 (Other Pins = 0)	20V Tuning Voltage
Pin 5: Modulation Mode	Pin5 = 1 (Other Pins = 0)	0-20V at 1kHz Tuning Voltage
Pin 6: Modulation Mode	Pin6 = 1 (Other Pins = 0)	0-20V at 5kHz Tuning Voltage
Pin 7: Modulation Mode	Pin7 = 1 (Other Pins = 0)	0-20V at 10kHz Tuning Voltage
Default Mode	Other Pin Configurations	0V Tuning Voltage

**Table 3. DIP Switch Pins Chart**

If the user switches any inputs that are not listed in this table, the state will be set to the default state of a 0V Tuning voltage. If the user selects any two or more pins at the same time, apart from Pin8, the state will be set to the default state.

#### **4.4. Microcontroller Pin Interface**

The microcontroller will be used to control the RF waveform generator once the system is powered on and the user has selected its state. To do this, the chip will connect to peripherals inside and outside the chip to provide the correct functionality of the system. The pin connections of the microcontroller unit are listed in the table below.

Pins	Functionality
1- 2, 9-10	UART Connection
4	Reset Button
6, 22, 26, 43	Vdd: Power
5, 21, 29, 42	Vss: Ground
4, 13, 14	Programming Pins
11, 18, 31, 32, 34	I2C Connection
15	AVDD: Analog Power
16	AVSS: Analog Ground
23	DAC: Output to VCO

27, 28, 33, 35, 38, 39, 40, 41	DIP Switch Inputs
36, 37, 44, 45, 46, 47	LED Outputs

**Table 4. Microcontroller Pins Chart**

# **RF Waveform Generator**

Brian Chau  
Daniel Hickl  
Eugene Asare  
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## **SUBSYSTEM REPORTS**

**SUBSYSTEM REPORTS  
FOR  
RF Waveform Generator**

**PREPARED BY:**

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Author                              Date

**APPROVED BY:**

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Project Leader                      Date

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John Lusher, P.E.                Date

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T/A                                 Date

## Change Record

Rev	Date	Originator	Approvals	Description
-	04/25/24	RF Waveform Generator		Draft Release
1	04/27/24	RF Waveform Generator		Final Report - ECEN 403
2	11/24/24	RF Waveform Generator		Final Report - ECEN 404

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## 1. Introduction

In this project, an RF waveform generator will take sinusoidal input tuning voltage and produce a high-frequency RF waveform. The waveform will oscillate between 1.6 to 3.2 GHz, which is dependent on the magnitude of the tuning voltage. Moreover, the focus of this project is to produce a waveform generator with low SWAP-C (size, weight, power, and cost), minimizing resources and complexity while still meeting output specifications. The system is broken down into four subsystems: Analog Drive, VCO and RF Amplifier, Power, and Testing. Each subsystem was rigorously designed, tested, and validated independently with the notion of subsystem integration moving forward.

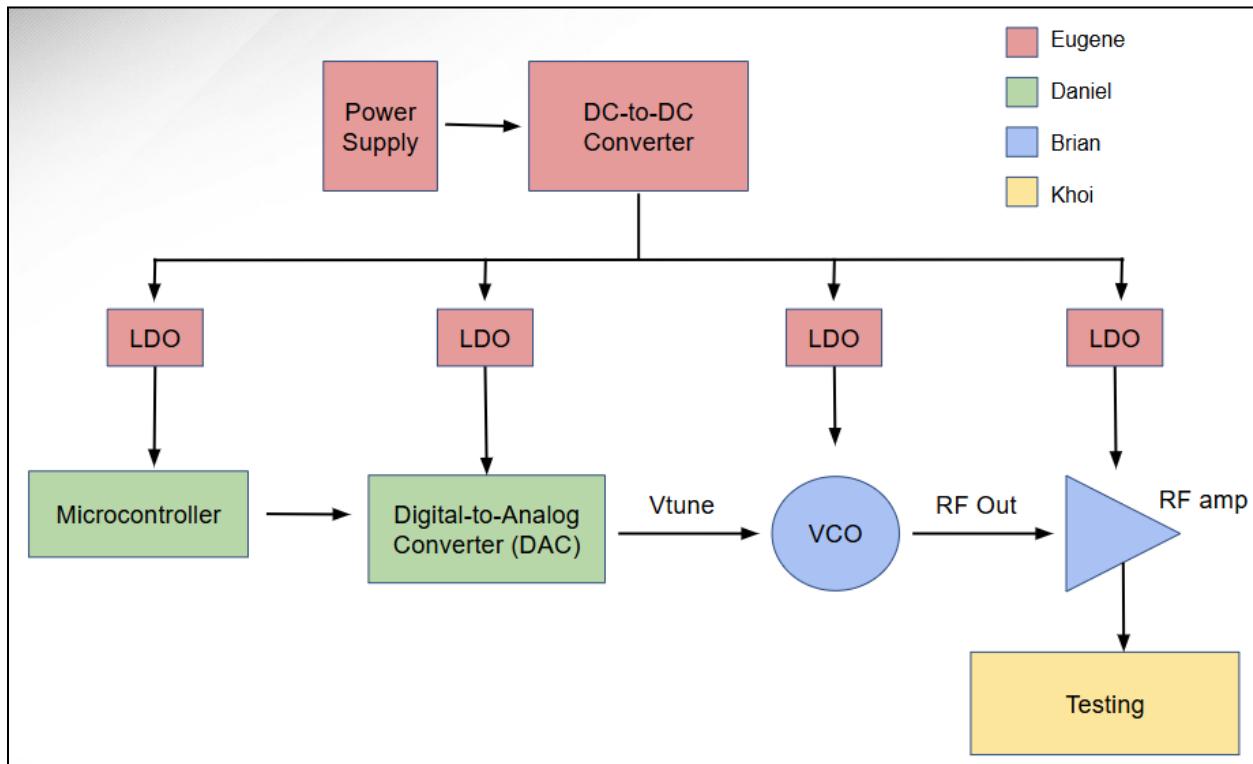


Figure 1. Sub-System Overview

## 2. Power Distribution Subsystem Report

### 2.1. Subsystem Introduction

The power distribution subsystem is the distribution of power to the VCO, RF amplifier, and the microcontroller and making sure that the voltages and currents are at a stable with little noise.

### 2.2. Subsystem Details

#### 2.2.1. System Function

In this subsystem the main power supply that will be used for the entire waveform generator will be 2 AA batteries in series. The system has been separated into three different rails, digital for the microcontroller, VCO for the VCO and RF amplifier, and op amp for the microcontroller op amp. These will provide voltage and current to each specific part. Each rail consists of three steps which are the boost converter, an LDO, and a power monitor. Each rail has a boost converter to step up the battery supply voltage to a targeted value. The LDO that is used for the digital and VCO rails is to bring down the voltage while also lowering the noise that comes with stepping up the voltage. The op amp rail doesn't have an LDO because the op amp is already designed for lowering noise. Lastly a power monitor is on each rail to measure the values. Table 1 shows the targeted values of each rail and the amount of voltage and current that will be used in an operation in greater detail. The figures below show how each rail is divided and the final product of the PCB design.

Table 1. Power Distribution Rail Breakdown

Power System Rail Data							
Digital Rail			VCO Rail			Opamp Rail	
Voltage Ref	Voltage (V)	3.6	Voltage Ref	Voltage (V)	3.6	Voltage Ref	Voltage (V)
Voltage Step	Voltage (V)	5.5	Voltage Step	Voltage (V)	5.5		3.6
Voltage Output	Voltage (V)	3.3	Voltage Output	Voltage (V)	5	Voltage Step	Voltage (V)
							24
Part #	Description	I (mA)	Part #	Description	I (mA)	Part #	Description
PIC32MK	MCU with DAC	200	PE1V14003	VCO	19	LM358DR	Opamp
LTC2945	Power Monitor	2	LTC2945	Power Monitor	2	LTC2945	Power Monitor
			TQL9093	RF Amplifier	160		
	Total (mA)	202		Total (mA)	181	Total (mA)	22

## 2.2.2. Schematics, PCB Layout, and Assembly

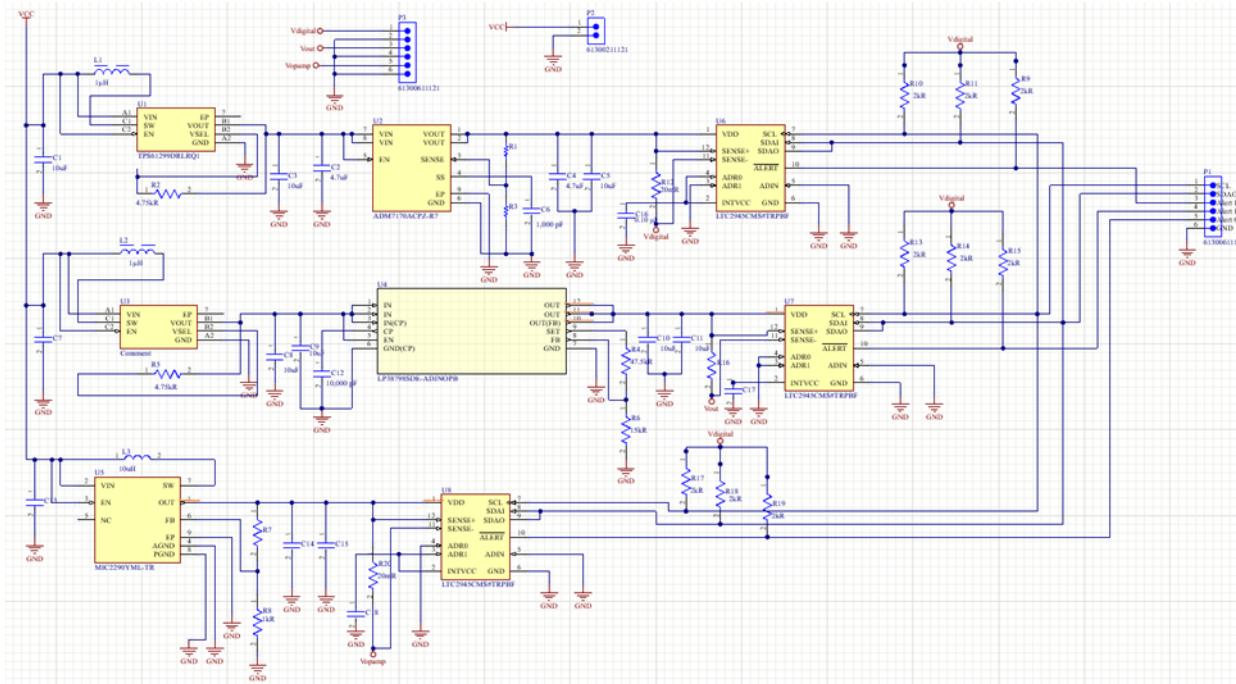


Figure 2. Power Distribution Schematic

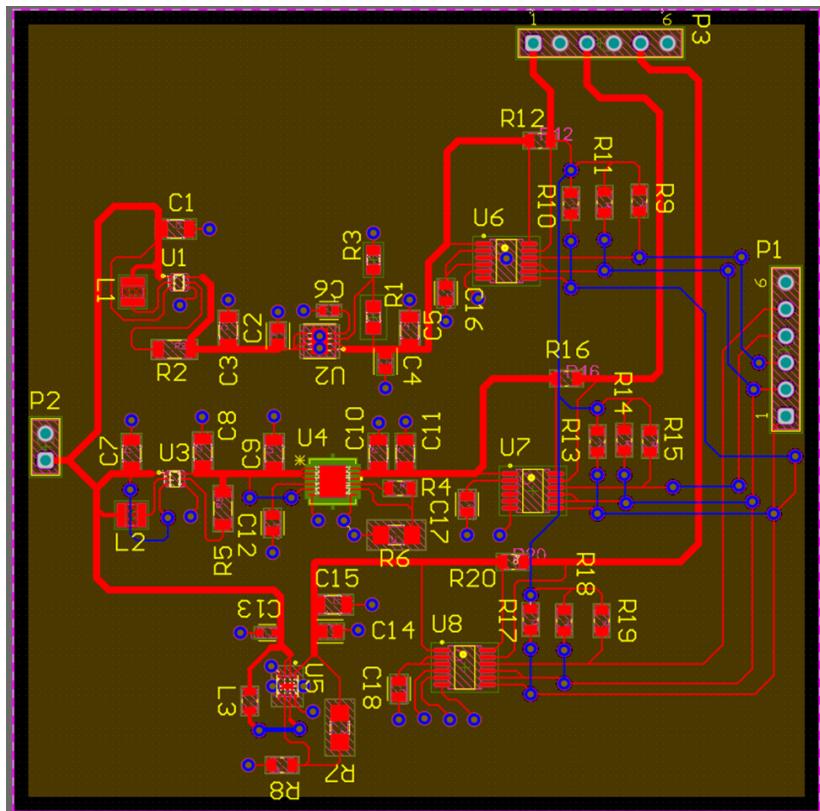


Figure 3. Power Distribution PCB Design Layout

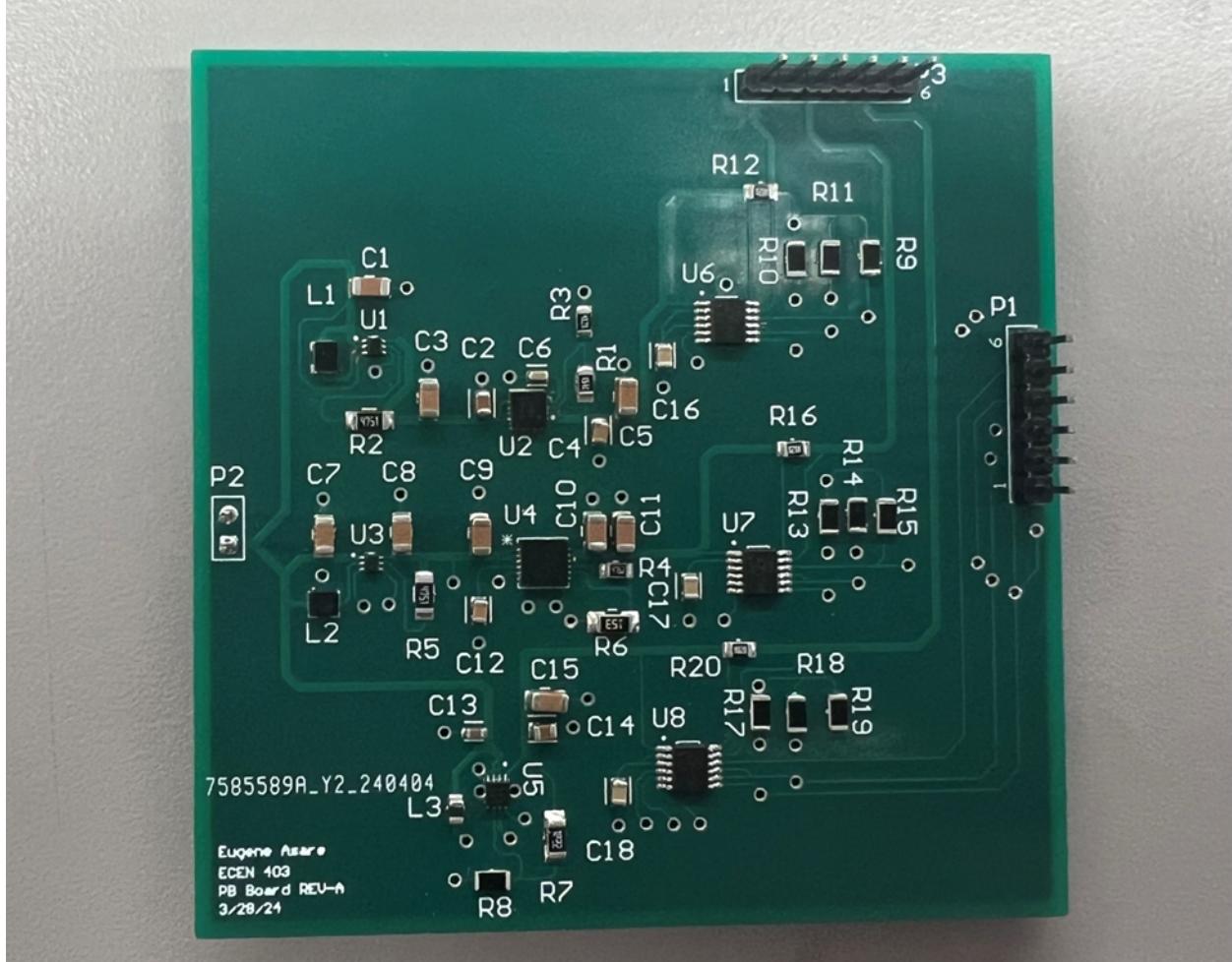


Figure 4. Power Distribution Final PCB

### 2.3. Subsystem Validation

There were two main areas of testing for the power distribution subsystem. The first was to make sure that the correct voltage and current was being supplied at the end of the rail that would later feed into the specific parts during integration. To test the voltages and currents I used a multimeter and when the correct voltage was supplied switched to the battery supply and loaded with the other subsystems to see how much current was being used. The first few tests were very concerning with my rails but there was a huge error that I found and that was the boost converters for the Digital and VCO Rails were pinned incorrectly. Due to the error being caught late in testing the options I had to test the rest of the board were limited. I had to rewire the board in which the boost converters were not connected to the board. The results that are seen with the Digital and VCO rails are ones without the boost converters but just the LDO associated with them so complete validation with the initial board couldn't be validated.

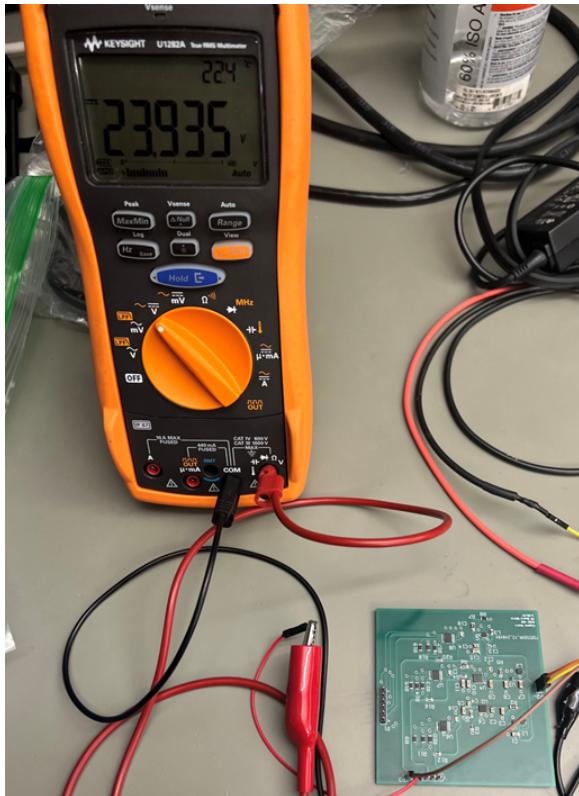


Figure 5. Op Amp Rail No Load Test

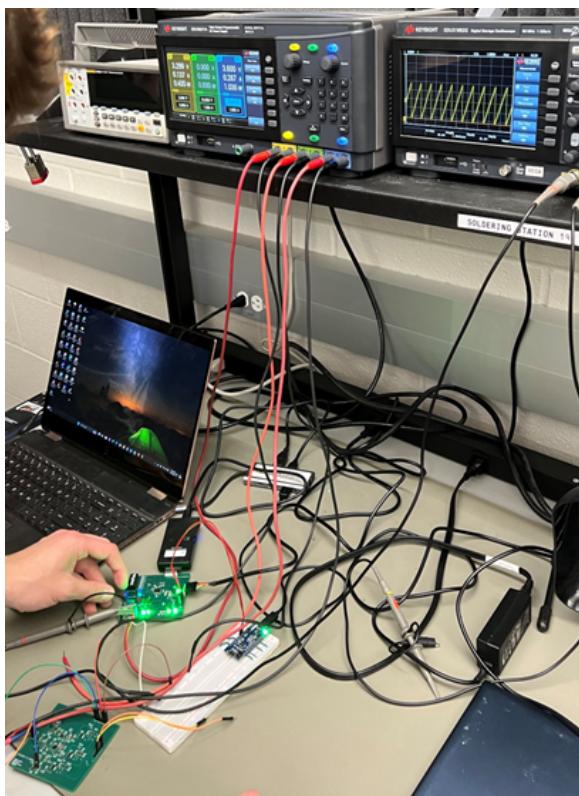


Figure 6. Op Amp Rail with Load Test

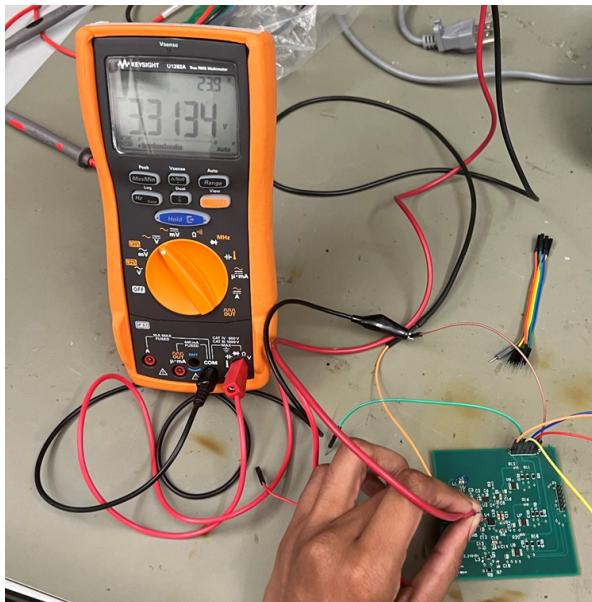


Figure 7. Digital Rail LDO Test

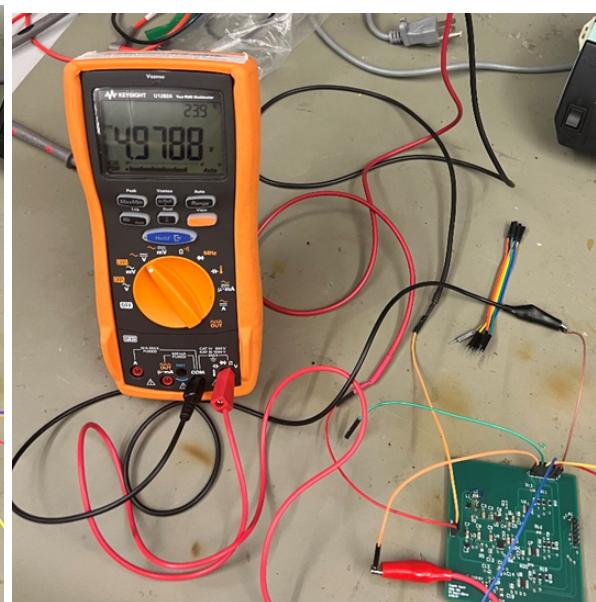


Figure 8. VCO Rail LDO Test

Table 2: Voltage Testing

Test Number	Description	Measured Voltage (V)
1	Digital rail	0
2	VCO Rail	0
3	Op Amp Rail	23.950
4	VCO Rail	0
5	Digital rail	0
6	VCO Rail	0
7	Digital rail	0
8	VCO Rail	0
9	Digital rail LDO	5.435
10	VCO Rail LDO	5.134
11	Digital rail LDO	3.3134
12	VCO Rail LDO	4.9788
13	Op Amp Rail	23.935

The second test was to check if the power monitors were connected correctly within the rail and see if a signal was being pushed through. To validate this, I used an oscilloscope to measure the signals that the power monitor pins were giving out. The limitation of my subsystem is that I can't test the specific addresses of each power monitor due to needing a microcontroller to process that data. The previous error affected the testing of the power monitors due to needing the digital rail voltage to be working properly. Once I corrected the error as best as possible, I was able to receive information for each of the power monitors and their respective pins.

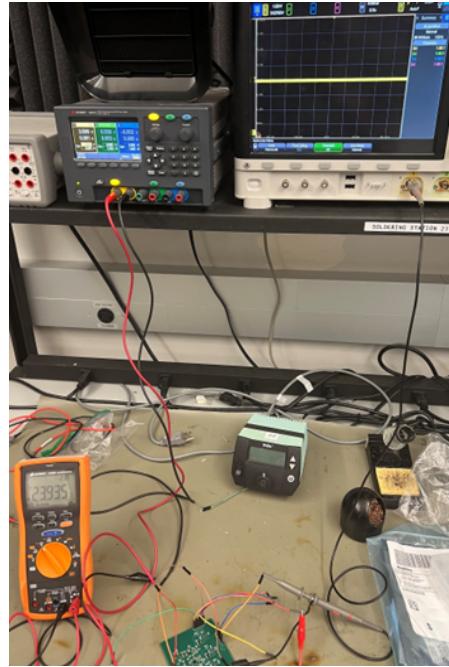


Figure 9. Power Monitor Signal Test

Table 3: Power Monitor Test

Test Number	Description	Signal Measured (Yes/No)
1	Op Amp Power Monitor	No
2	Op Amp Power Monitor	No
3	Op Amp Power Monitor	No
4	Digital Power Monitor	No
5	VCO Power Monitor	No
6	Op Amp Power Monitor	Yes
7	Digital Power Monitor	No
8	VCO Power Monitor	No
9	Op Amp Power Monitor	Yes
10	Digital Power Monitor	Yes
11	VCO Power Monitor	Yes

## 2.4. Subsystem Conclusion

Overall, most of the components selected for distributing the power worked well. It was one major problem that I couldn't see if the boost converters were working due to the pins being wired incorrectly on the PCB board. With this error I can't confirm that it completely works but I was able to verify that the other components that are apart for the rail work correctly and the functionality will prove to be helpful.

*After debugging and testing in 404, this subsystem works properly. All voltages are outputting their required voltages of 3.3, 5, and 24. This means that the power subsystem is complete and ready to integrate*

## 3. Analog Drive Subsystem Report

### 3.1. Subsystem Introduction

The Analog Drive Subsystem controls the Voltage-Controlled Oscillator (VCO) using a microcontroller to produce a voltage waveform. This subsystem is not only pivotal in achieving the main objective of controlling the VCO but also facilitates communication between the board and the Graphical User Interface (GUI). This communication is crucial as it enhances system monitoring, waveform control, and overall accessibility.

*After consultation with our sponsor, there were changes made to this subsystem and integration due to size constraints. Due to the removal of the GUI in 404, there is no communication via UART or I2C. Apart from this, everything has stayed the same*

### 3.2. Subsystem Details

#### 3.2.1. System Function

The Analog Drive Subsystem fulfills several key requirements. Firstly, it provides the analog drive or input voltage to the VCO, which can be adjusted via a hardware DIP switch offering seven distinct waveform states. These states include both modulation and constant frequency modes of the RF waveform. The second requirement is GUI communication through UART, allowing for software-based control of the system. The GUI may control the generator's state and perform error checking. The third requirement involves sensor communication via I2C to relay data necessary for system error checking. This data is transmitted from the MCU to the GUI through a UART connection.

The subsystem's circuitry includes an analog drive PCB equipped with a DIP switch to control the state, multiple LEDs that indicate the system's current state, ports for programming and communication between the sensors and the GUI, and ultimately an output for the DAC signal. The operational flow is depicted in Figure 10, showing inputs from either the DIP switch or the GUI to the microcontroller. The MCU outputs the analog drive waveform from the DAC, which is then amplified by a non-inverting op-amp to meet the VCO's voltage requirements. Concurrently, the MCU polls for voltage and current data from the power subsystem via I2C, which is forwarded to the GUI for analysis. The design was materialized into a PCB as illustrated in Figures 11-13.

*With the new changes of our system, the new requirements of this subsystem are to provide an analog drive voltage to the VCO, modulate this signal with a constant chirp rate,*

*provide the user a way to control the state of the generator, and show the user what state the machine is in.*

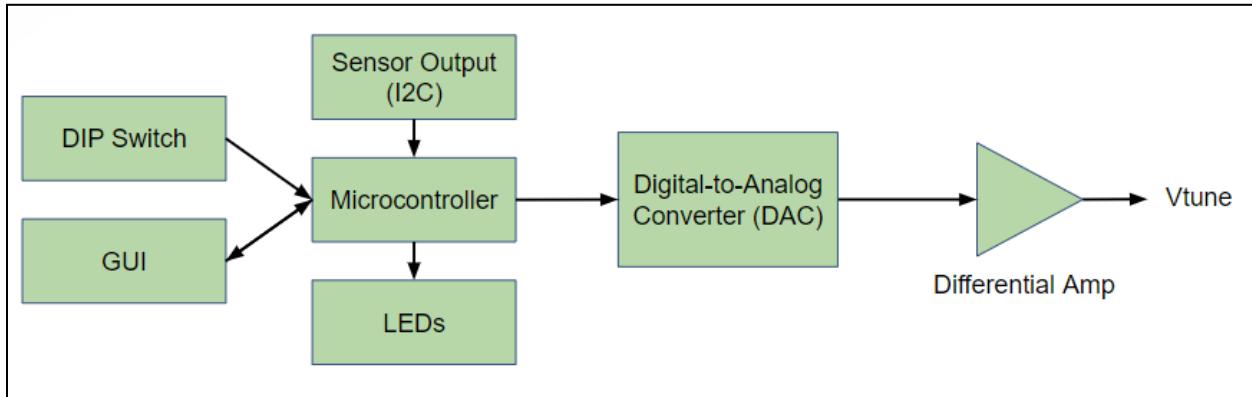


Figure 10. MCU Design

### 3.2.2. Schematics, PCB Layout, and Assembly

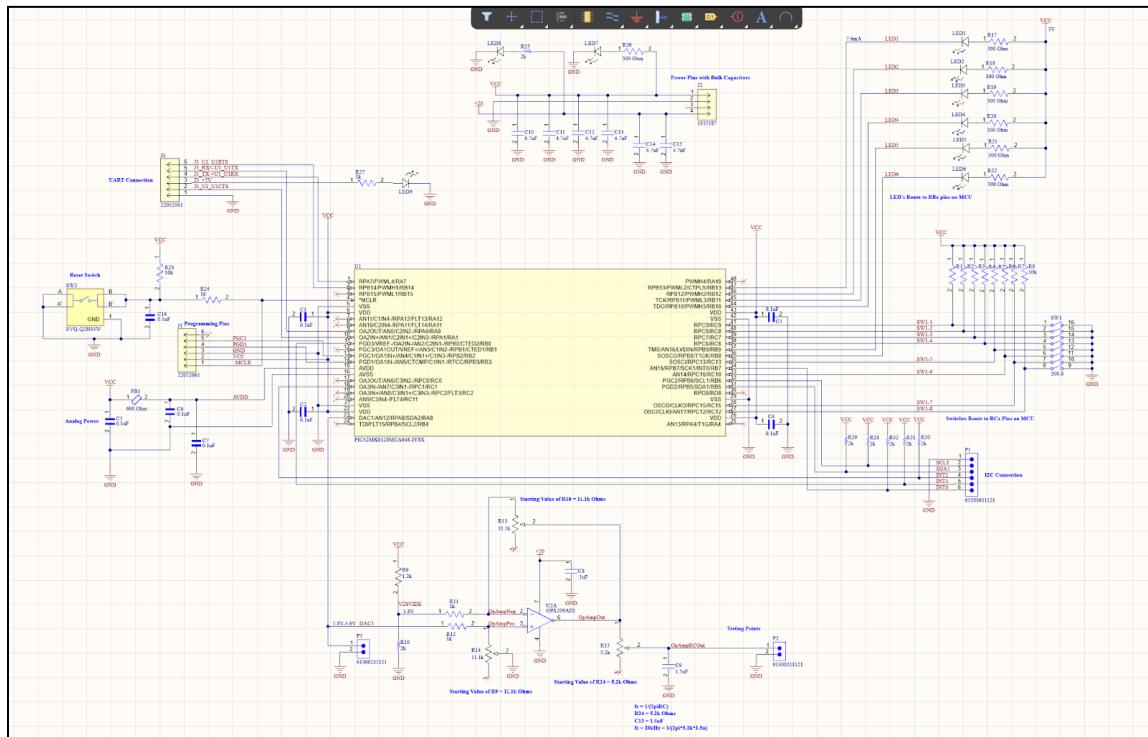


Figure 11. MCU Schematic

## Legend

1. LEDs:
2. I2C
3. UART
4. Programmer Pins
5. Reset Switch
6. MCU
7. Power Pins
8. DAC OpAmp
9. DIP Switch

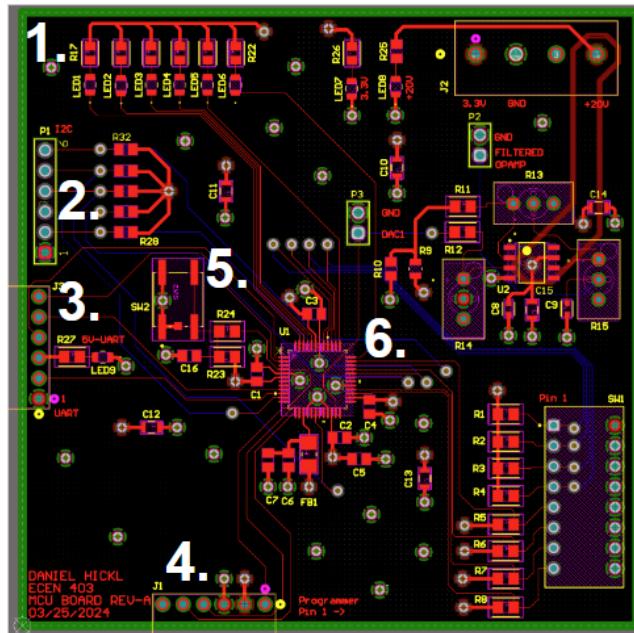


Figure 12. MCU Layout

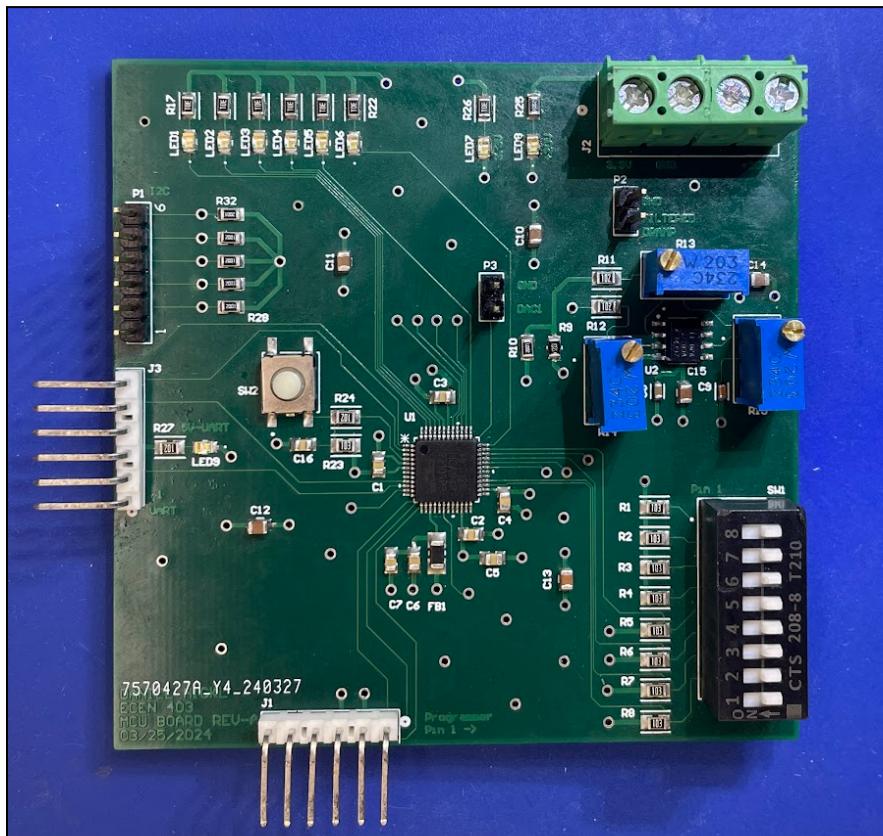


Figure 13. MCU Assembly

### 3.3. Subsystem Validation

#### 3.3.1. Validation Overview

There are two primary areas of testing for the microcontroller/analog drive subsystem: first is to test the MCU code, and second is to test the PCB itself. To test the MCU code, I used the PIC32MK evaluation board, which allowed me to flash code onto the chip and observe its outputs. This enabled the verification of the main functionality of my system, which included the DAC and the states of the generator. Additionally, I used two FTDI devices to assess the I<sub>2</sub>C and UART connections. To test the PCB itself, I utilized the same evaluation board code from earlier tests to flash onto the chip. This provided a consistent baseline for my testing, as any emerging errors could be attributed to the board rather than the code. I tested the seven states of the generator as shown in Tables 4-7 below, along with the UART and I<sub>2</sub>C connections.

#### 3.3.2. Validation Tests

##### 3.3.2.1. Constant Voltage Validation Test

Table 4. Constant Voltage Mode Tests

Constant Voltage Mode					
Test Number	0V (V)	5V (V)	10V (V)	15V (V)	20V (V)
1	0.09	4.98	10.03	15.04	19.89
2	0.09	4.98	10.06	15.02	19.95
3	0.09	5.01	9.94	15.02	19.95
4	0.10	5.00	10.00	15.02	19.96
5	0.09	5.00	10.02	15.01	19.96

##### 3.3.2.2. Constant Voltage Validation Test Analysis

The constant voltage is used to create a constant RF frequency for our system. The tests in table 4 show the validation tests that were conducted to ensure the analog drive subsystem is fully functional for the constant voltage mode. Calibration through the potentiometers of my op amp needed to be done in order to increase the accuracy of these tests. Upon completion, this mode achieves an acceptable accuracy by being under a 0.5% error at the end of calibration.

##### 3.3.2.3. Modulation Validation Test

Table 5. 1kHz Modulation Mode Tests

Modulation Mode - 1kHz		
Test Number	Voltage (Peak to Peak) (V)	Frequency (kHz)
1	20.50	0.92
2	19.90	0.96
3	20.00	1.01
4	20.10	1.01
5	20.00	1.00

Table 6. 5kHz Modulation Mode Tests

Modulation Mode - 5kHz		
Test Number	Voltage (Peak to Peak) (V)	Frequency (kHz)
1	17.90	4.96
2	17.90	4.96
3	17.90	5.06
4	17.90	5.05
5	17.90	5.03

Table 7. 10kHz Modulation Mode Tests

Modulation Mode - 10kHz		
Test Number	Voltage (Peak to Peak) (V)	Frequency (kHz)
1	15.90	9.48
2	15.90	9.76
3	15.90	9.90
4	15.90	10.16
5	15.90	10.05

### 3.3.2.4. Modulation Validation Test Analysis

The modulation mode is what is used to create an RF waveform with varying frequency for our system. The tests in tables 5-7 show the validation tests that were conducted to ensure the analog drive subsystem is fully functional for the modulation mode. Upon completion of these tests, one can see the degradation of the signal as the frequency of modulation increases. The peak to peak voltage of the signal is cut off and does not make it to 20V in the 10kHz and 5kHz tests. This can be explained due to an error in the choosing of my operational amplifier. The slew rate of my current operational amplifier is 6V/us. This is sufficient for the waveform as it increases, but it is insufficient as the waveform decreases. Since the sawtooth signal drops suddenly at the end of its period, the slew rate is much higher than 6V/us. This causes the signal to be clipped at its minimum which can be seen in figures 14-16 below. To fix this problem, I will order a new operational amplifier next semester with a slew rate of 20V/us

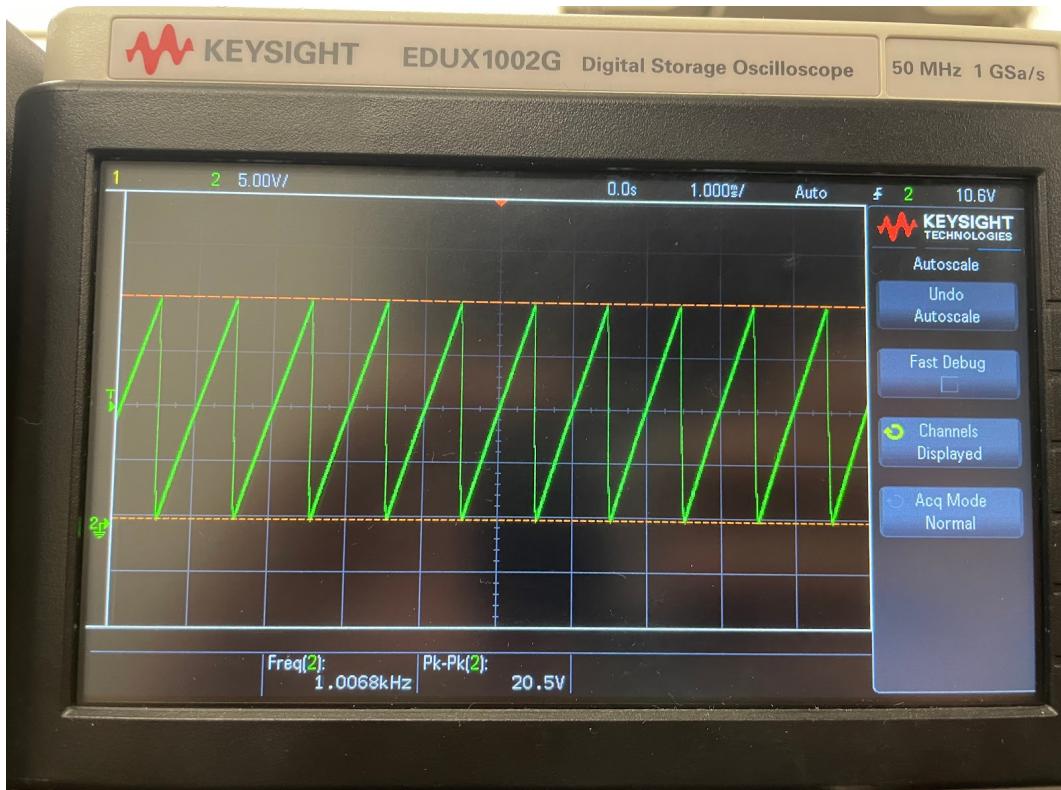


Figure 14. 1kHz Modulation Mode

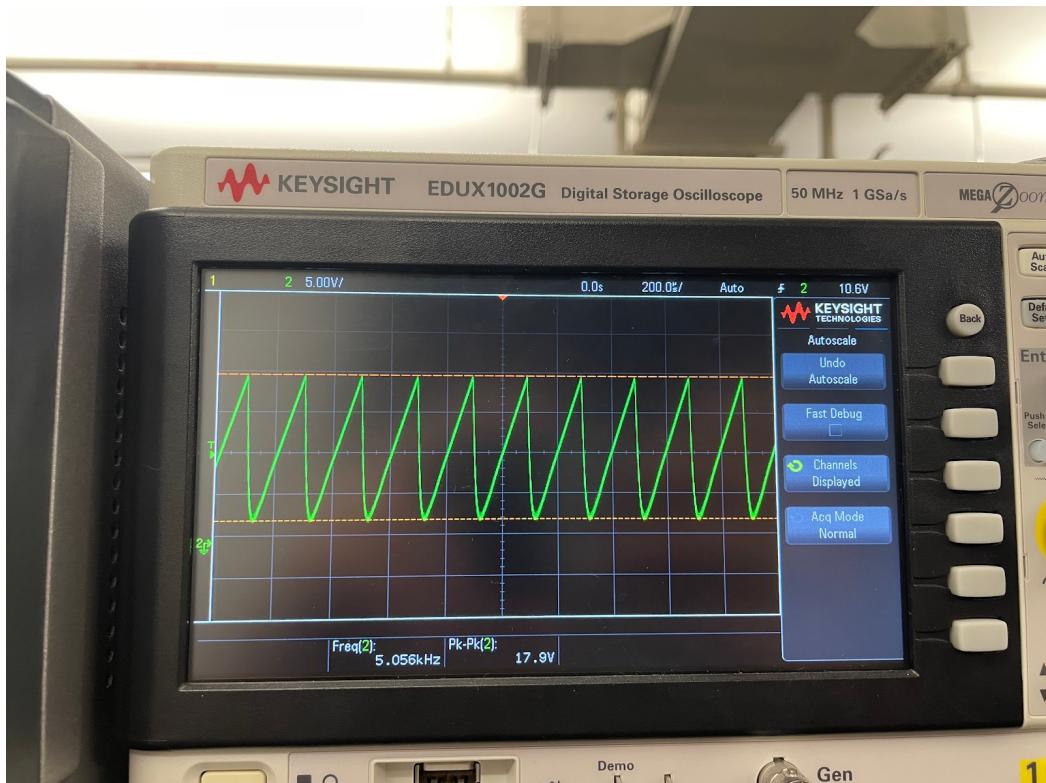


Figure 15. 5kHz Modulation Mode

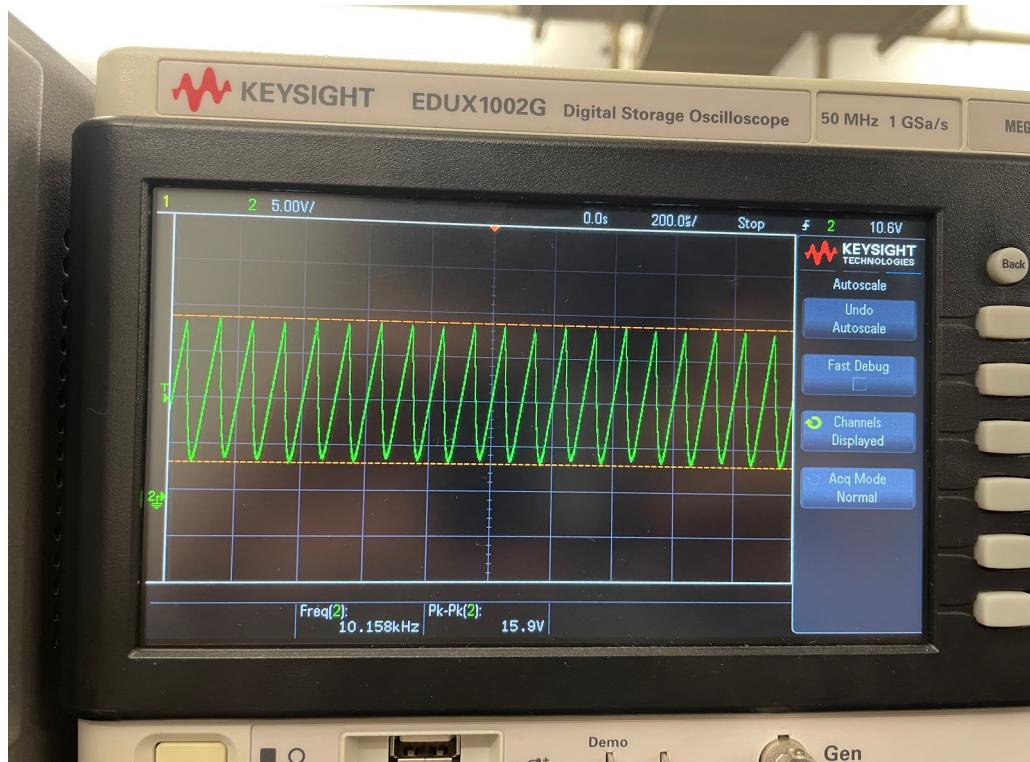


Figure 16. 10kHz Modulation Mode

Upon testing in 404, changes needed to be made to the analog drive of the MCU subsystem. Due to the nonlinearity of the VCO, the output voltage frequency of the generator was not modulating at a constant rate. The solution to this problem was to fit the analog drive curve to match the input graph of the VCO in figure 33. This shows the frequency that matches each input voltage. Since the goal is to produce a sawtooth waveform in the frequency domain, each period must reflect this graph.

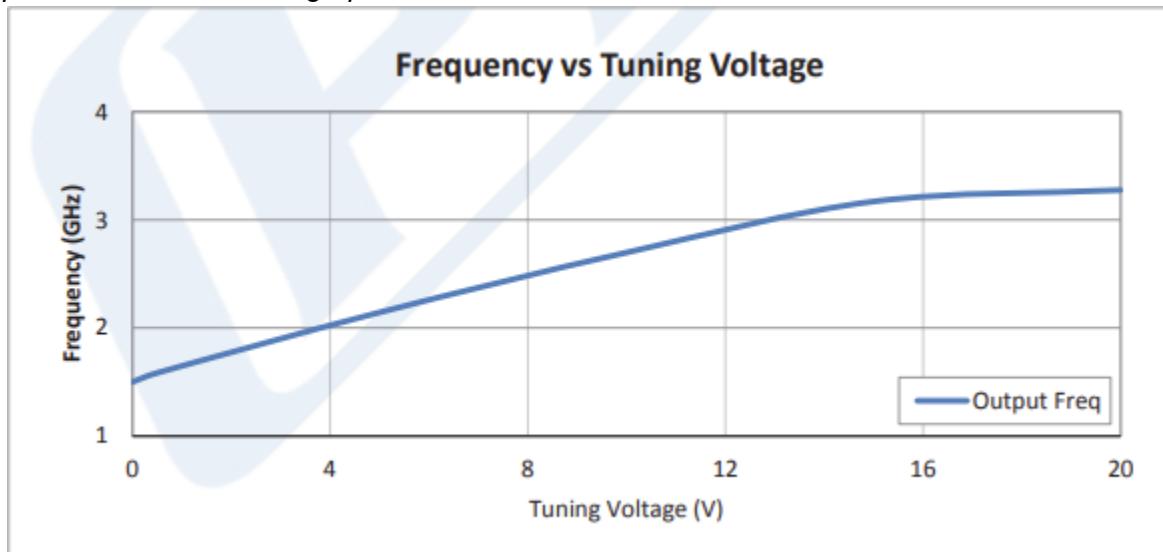


Figure 38: Frequency vs. Tuning Voltage

To create this in the DAC signal, a piecewise defined function was used. Upon inspection of figure 33, there are two main sections of the graph. We approximated these to be linear sections and after doing so, the analog drive signal in figure 34 was produced. After testing, this was found to improve the linearity of the chirp rate.



Figure 39: New Analog Drive Signal

### 3.3.2.5. UART Connection Validation Test

00000000	1713559610.087	1	→	4	
00000001	1713559610.168	1	←	4	
00000002	1713559611.243	1	→	4	
00000003	1713559611.305	1	←	4	
00000004	1713559612.235	1	→	4	
00000005	1713559612.299	1	←	4	
00000006	1713559613.086	1	→	4	
00000007	1713559613.150	1	←	4	

Figure 17. UART Connection

### 3.3.2.6. UART Connection Validation Test Analysis

To test the UART connection, I used a program called SerialTool to send and receive data from my FTDI UART connector. I used this program to send values to my MCU which immediately responded by sending back the data. This proved the functionality of my UART connection.

### 3.3.2.7. I2C Connection Validation Test

00000000	1714250598.606	1	→	4	
00000001	1714250600.512	1	→	4	
00000002	1714250600.671	1	→	4	
00000003	1714250601.968	1	→	4	

Figure 18. I2C Connection

### 3.3.2.8. I2C Connection Validation Test Analysis

To test the I2C connection, I used SerialTool to communicate between my computer and the MCU. My validation plan was to send data to the I2C connection on the MCU when prompted and then receive this data back when prompted. As one may see in figure 18 above, this connection was not functional. The reason for this was because I was not able to properly initialize the I2C testing board. I needed to buy another programmer to initialize this device as the slave. This error shall be fixed next semester during integration.

*Due to the rigorous size reduction of our generator, both the I2C and UART connections were removed from the final project. This decision was made with our sponsor due to the main goal of this project being low SWAP-C. These two communications were not necessary for our generator to function properly. The way of controlling the system is through the DIP Switch*

### **3.4. Subsystem Conclusion**

Upon completion of validation testing, the analog drive subsystem functions well. The PCB works properly and has the ability to flash programs, output data, take inputs, and communicate via UART. The primary requirement, being the DAC output, works as expected barring a small hardware error with the operational amplifier. The UART connection is functional and awaits integration with the GUI. The I2C connection is non-functional, but upon integration, the MCU will directly probe the sensors in the power subsystem, eliminating the need for the connection board which is causing the error. The analog drive subsystem is ready for integration.

*In 404, the analog drive subsystem is completed and works properly. It meets the requirements of our new system.*

## **4. VCO/ RF Amplifier Subsystem Report**

### **4.1. Subsystem Introduction**

The VCO and RF Amplifier subsystem is the heart of the RF Waveform Generator system. It takes a tuning voltage input from the Analog Drive subsystem and transforms it into a high-frequency signal in the RF domain. The primary components are the Voltage-Controlled Oscillator, which makes that transformation to RF, as well as the RF Amplifier, amplifying the RF signal so that it can be read and tested on a Spectrum Analyzer.

### **4.2. Subsystem Details**

#### **4.2.1. System Function**

In this subsystem, a tuning voltage from 0 to 20V is taken as an input for the VCO, which then produces an RF domain with a variable frequency dependent on the tuning voltage. That tuning voltage directly controls the frequency of the RF waveform, so increasing voltage increases the frequency. When the tuning voltage is sinusoidal, the resulting waveform contains a range of frequencies instead of just one since the tuning voltage is being swept across the bandwidth. From the VCO output, the RF amplifier then increases the magnitude of the frequencies for better visibility on the spectrum plot. All circuits surrounding it primarily serve as tuning for the amplifier. Figure # below represents the schematic of the subsystem design.

#### 4.2.2. Schematics and PCB Design Layout

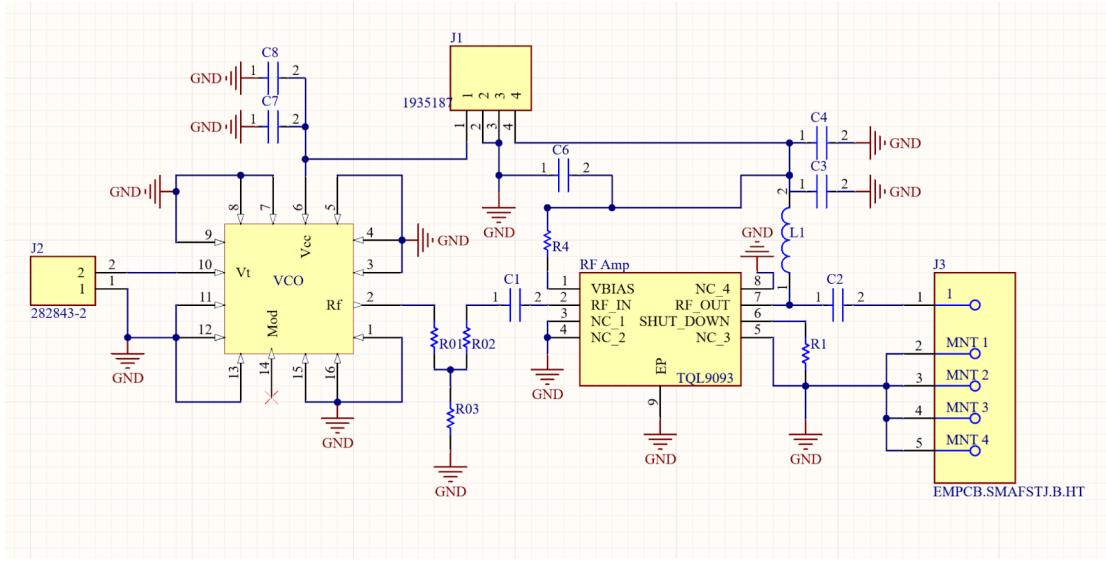


Figure 19. VCO and RF Amp Schematic

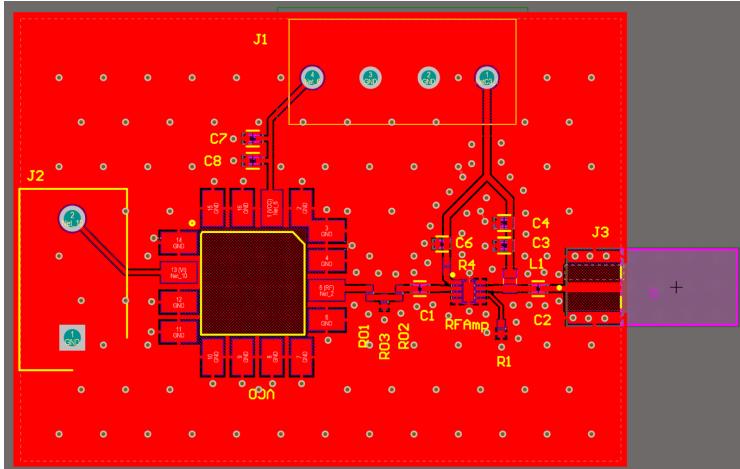


Figure 20. VCO PCB Design Layout

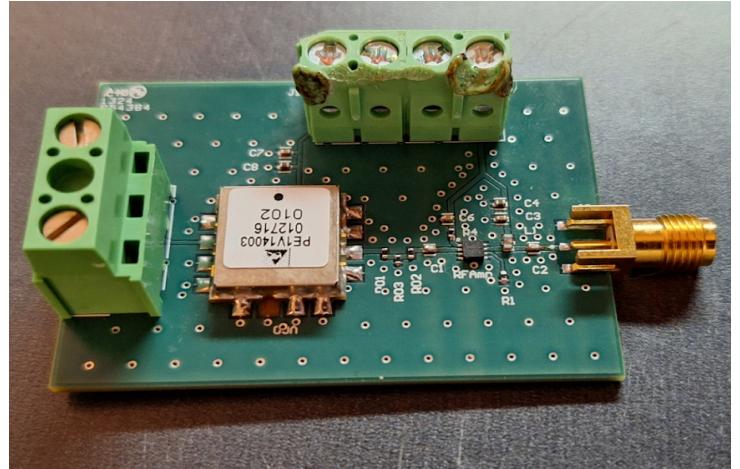


Figure 21. VCO Final PCB

### 4.3. Subsystem Validation

#### 4.3.1. Validation Plan

To test the subsystem, a DC Power Supply is used to provide the necessary supply voltage and current, as well as a Spectrum Analyzer to display the frequency at which the RF waveform is generated. The tests are categorized into two different modes, one for a fixed DC tuning voltage (on) and one for a sinusoidal tuning voltage (modulation). The DC tuning voltage tests are to ensure that the subsystem works before going into modulation mode. The table below represents the different tests used to validate the VCO and RF Amplifier Subsystem.

Table 8. VCO and RF Amp Validation Tests

Mode	Tuning Voltage	Frequency	Description	Status
On	0 V	DC Input	RF waveform response at lowest tuning voltage	Completed
On	10 V	DC Input	RF waveform response at mid-range tuning voltage	Completed
On	13 V	DC Input	RF waveform response at highest tuning voltage	Completed
Modulation	0-13 V	1 kHz	Response to AC tuning voltage at 1kHz	Completed
Modulation	0-13 V	5 kHz	Response to AC tuning voltage at 5kHz	Completed
Modulation	0-13V	10 kHz	Response to AC tuning voltage at 10kHz	Completed

One testing limitation to note is that the Spectrum Analyzer equipment provided at the school can only analyze waveforms up to 3GHz. Because this subsystem was originally meant to go from 1.6 GHz to 3.2 GHz, the range of the tuning voltage had to be narrowed to accommodate for the new bandwidth of 1.6 to 3 GHz. After some trials, 13V is the maximum tuning voltage in which the Spectrum Analyzer can still read (reaching 2.94 GHz in the results below).

### 4.3.2. Test Results

#### 4.3.2.1. DC Tuning Voltage Test Cases

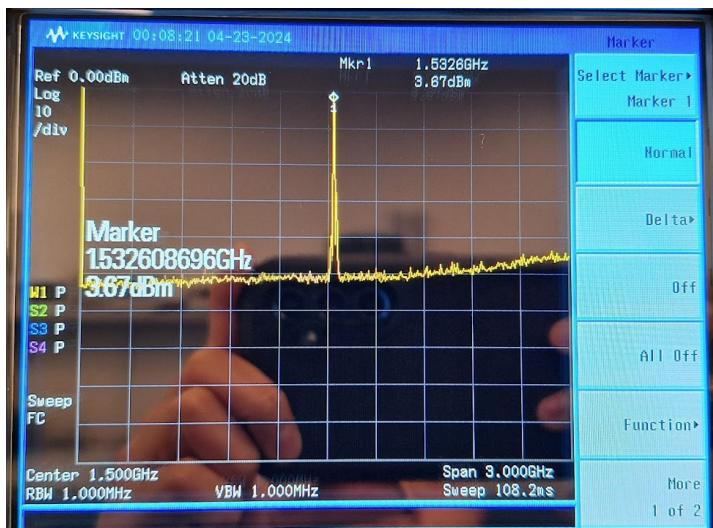


Figure 22. 0V DC Tuning Voltage



Figure 23. 10V DC Tuning Voltage

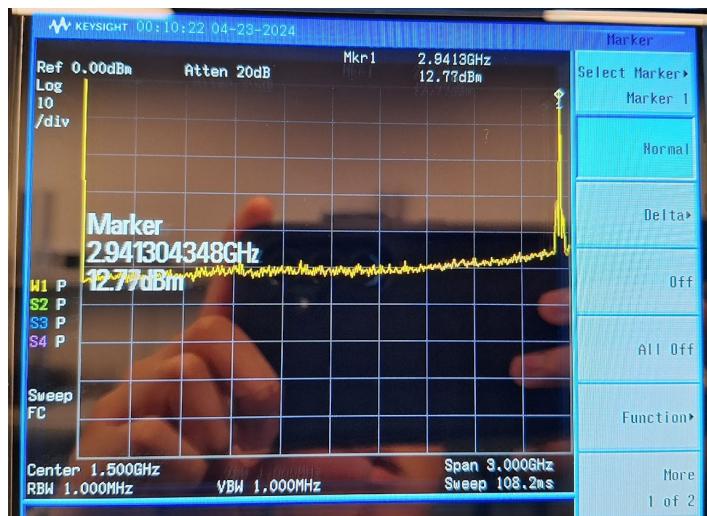


Figure 24. 13V DC Tuning Voltage

#### 4.3.2.2. Modulated Tuning Voltage Test Cases

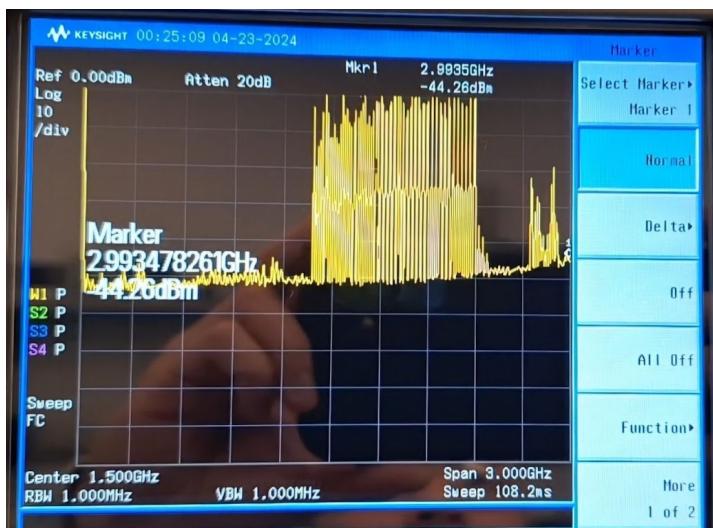


Figure 25. 1kHz AC Tuning Voltage



Figure 26. 5kHz AC Tuning Voltage



Figure 27. 10kHz AC Tuning Voltage

#### 4.3.3. Analysis and Observations

Upon reading the spectrum analyzer plots above, the subsystem successfully works with a DC input voltage. While the 0V chart generates a frequency of 1.53GHz instead of 1.6GHz, the waveform generator is intended to produce RF signals with a wide bandgap and is thus acceptable.

As for the test cases with an AC, sinusoidal tuning voltage, the plot produces what looks like a series of impulse functions across a range of frequencies. This means that when the RF waveform generator is in modulation mode, the waveform should produce a multitude of frequencies which is what is seen on the spectrum plots. As the frequency of the tuning voltage increases, the number of frequencies in the RF waveform also increases making it look more like a step function. In general, these plots are synonymous with the expected results.

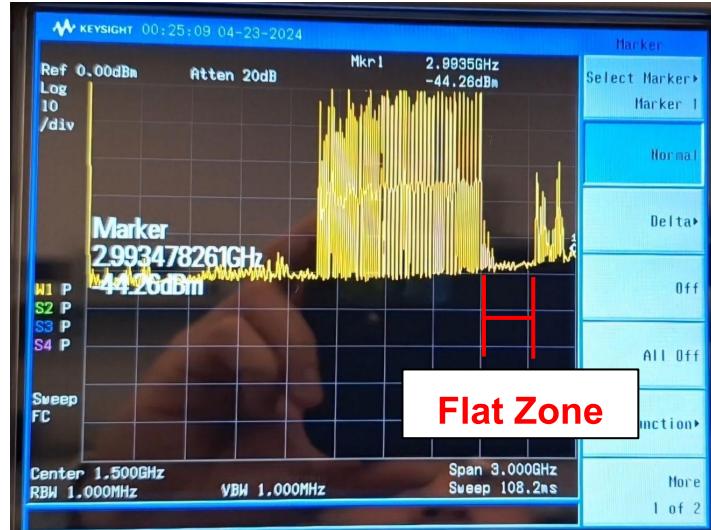


Figure 28. Spectrum Plot Flat Zone

However, one notable issue with the plot is that the range of frequencies doesn't span all the way to 3GHz. Looking at the plot above, the range of frequencies zeros out (flat zone) between 2.27 Ghz and 2.7 Ghz, before resuming back again at the far right of the plots. This is likely due to the DC power supply not providing adequate voltages to the PCB during testing shown below. The voltage supply to the VCO reads 4.239V when it should be 5V, while to the amplifier it is 5.591V when it should be 7V. As a result, the system may not be properly operating at the entire range from 0-13V. This is an issue that will be addressed moving forward prior to system integration, but for the most part, the VCO and Rf Amplifier subsystems successfully works as intended.



Figure 29. DC Power Supply Readings

*Upon testing in 404, these issues were resolved. The max frequency of the generator reached 3.2GHz.*

## 5. Testing Board Subsystem Report

### 5.1. Subsystem Introduction

Due to the scope of RF, testing RF requires expensive equipment so we came up with an affordable testing approach using a mixer. Before we perform our testing methodology using pulse compression technique by the mixer, simulation of the technique in matlab is required to confirm our methodology and also compare the real result with the simulation. Furthermore, the subsystem proposed designing a low-cost mixer along with a low-SWAP RF.

### 5.2. Subsystem Details

#### 5.2.1. System Function

Beside modeling testing methodology, a low-cost mixer will be designed in this subsystem. The mixer performs frequency mixing by combining two input signals: an RF signal and a local oscillator (LO) signal. The output contains both the sum and difference frequencies of these signals, enabling the conversion of the RF signal to a different frequency domain, such as an intermediate frequency (IF) or baseband. Typically, the desired frequency component—usually the IF—is extracted through filtering at the mixer output. This is called an up-down conversion and this will be the main testing method.

#### 5.2.2. Simulation Result

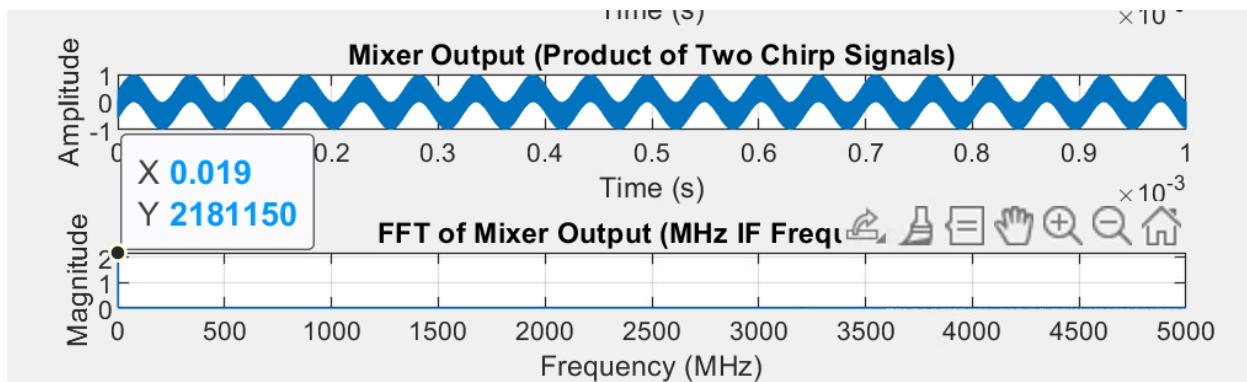


Figure 30. Simulation with 1KHz

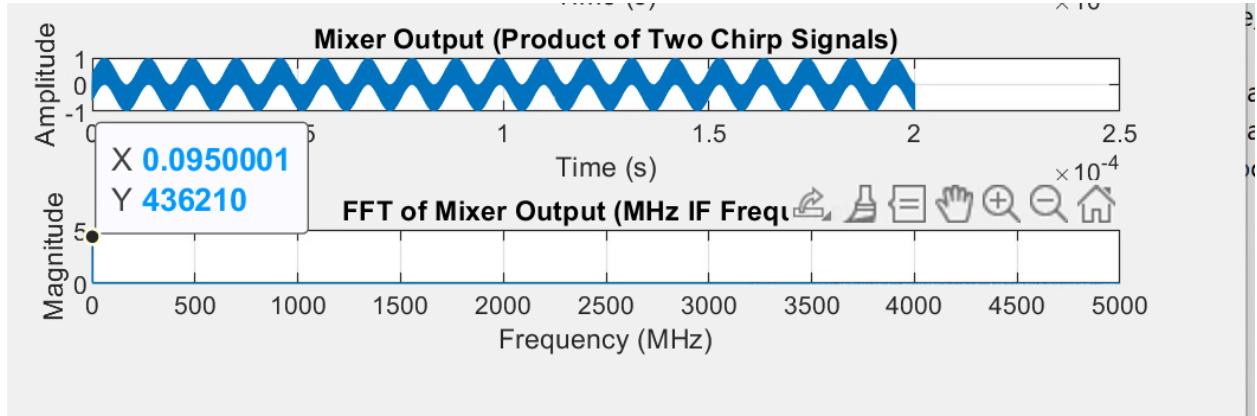


Figure 31. Simulation with 5kHz

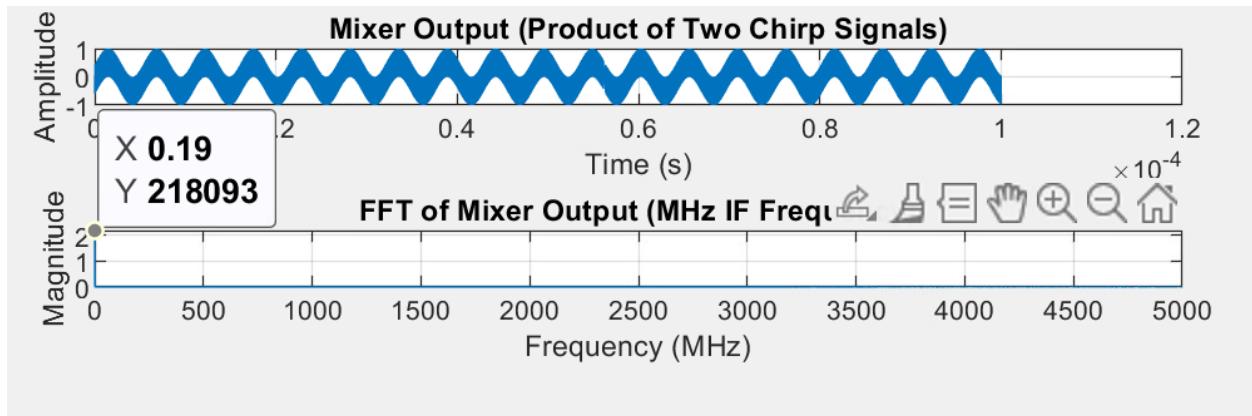


Figure 32. Simulation with 10KHz

PRF	5 kHz
Pulse Width (PW)	200 us
Time Delay (TD)	0.0117 us
Band Width (BW)	1600 MHz
Chirp Rate (BW/PW)	8 MHz/us
IF fq (TD * CR)	93.6 kHz

Frequency	Expected (kHz)	Measured (kHz)	Error
1k	18.72	17.3	7.585470085
5k	93.6	96	2.564102564
10k	187.2	170.9	8.707264957

Table 9. Testing Result for Reference

### 5.2.3. Subsystem Schematic and PCB Layout

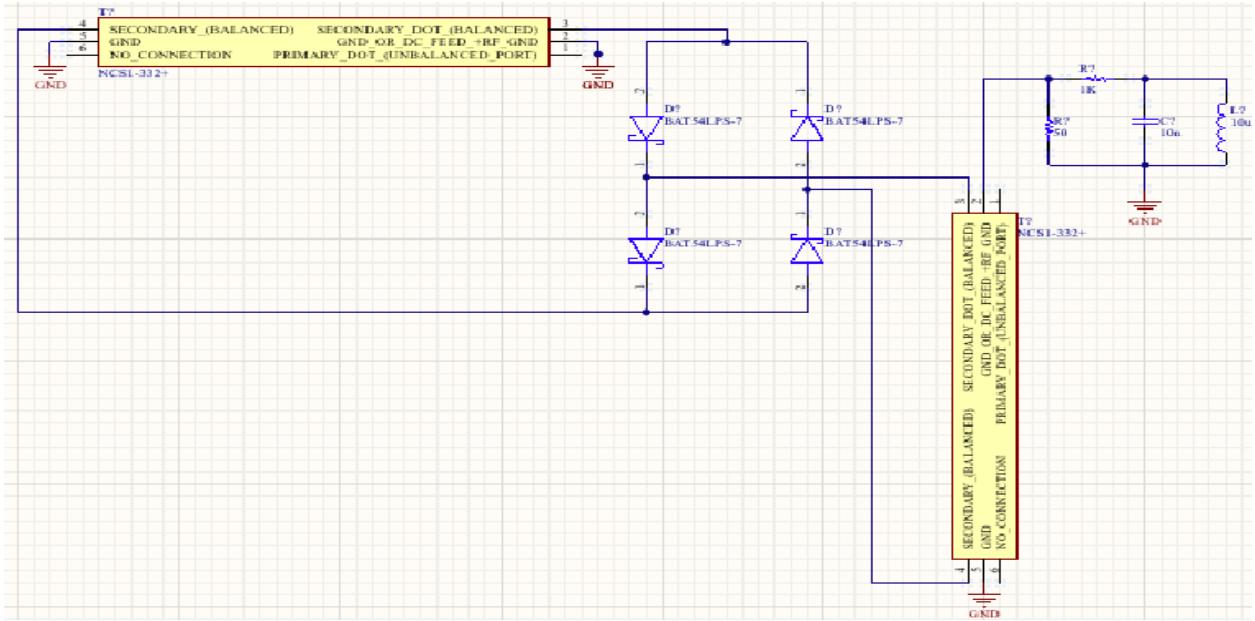


Figure 33. Schematic of mixer

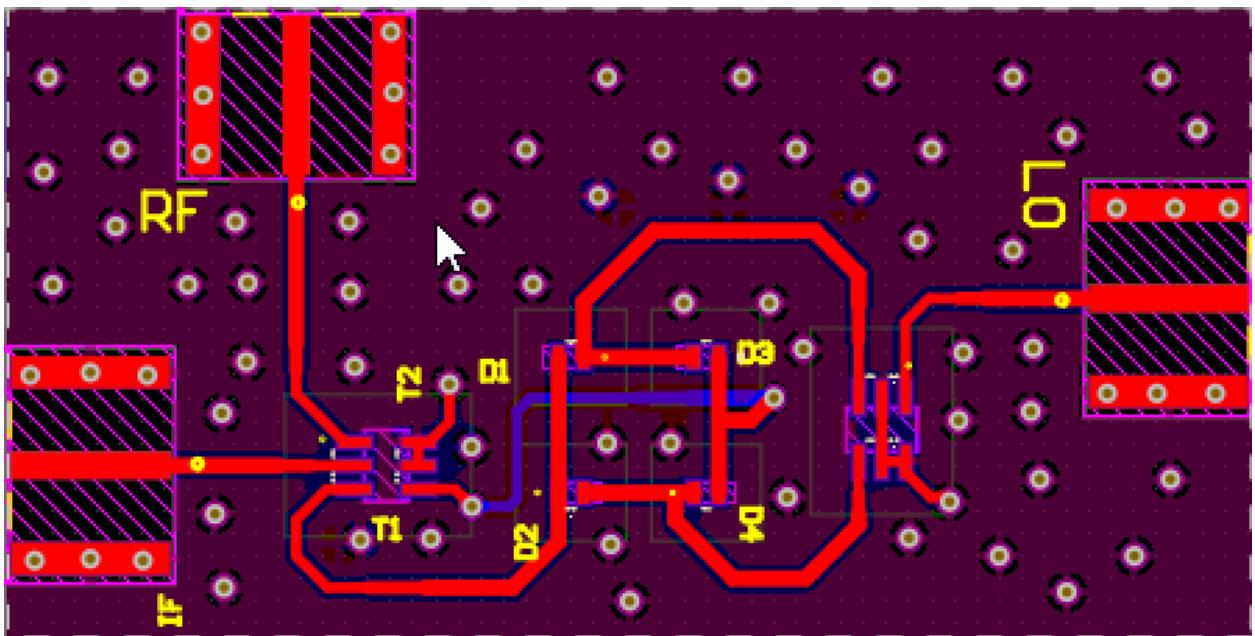


Figure 34. PCB Layout of Mixer

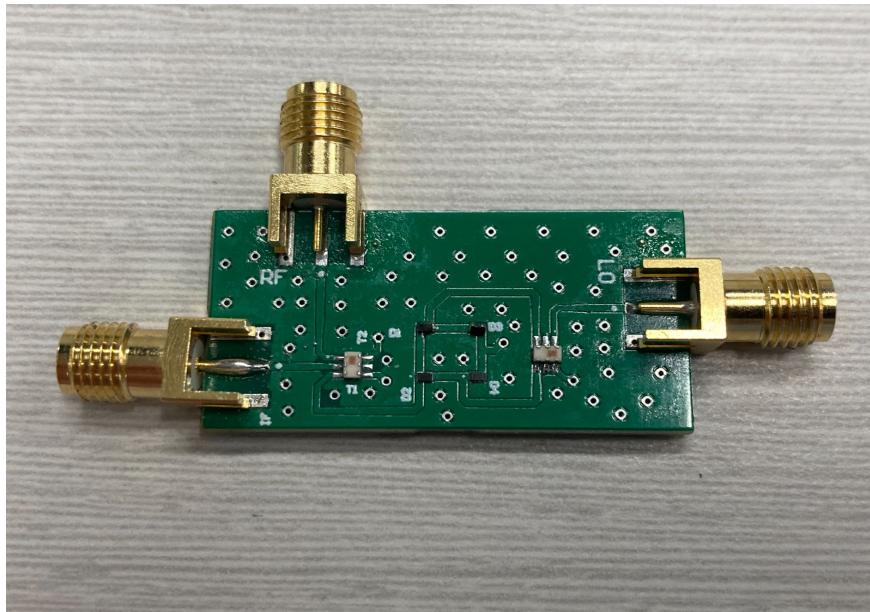


Figure 35. Mixer PCB

### **5.3. Subsystem Validation**

#### **5.3.1. Validation Plan**

To test the subsystem, a Signal Generator is used to provide both the RF input signal and the local oscillator (LO) signal as constant sine waves (up to 30MHz due to limitation of our lab equipment), while a Spectrum Analyzer is used to observe the output frequencies generated by the mixer. This testing mode verifies that the mixer correctly produces output containing both the sum and difference frequencies of the input signals.

Testing MATLAB Code	Matlab code can simulate and visualize pulse compression given oscilloscope output	Generated input signal, do mixer operation then taking FFT and observe output signal	COMPLETED
Testing Circuit Simulation	Compared the Circuit Simulation output with the MATLAB output	Building mixer circuit with specific RF range, using Oscilloscope and Spec Analyzer in simulation to measure the waveform and frequency of output signal.	COMPLETED
Mixer Test	Mixer successfully fuses both reference and time-delayed signal to showcase frequency ramp	Use Oscilloscope and Spec Analyzer in lab to measure waveform and frequency output	COMPLETED

Table 10. Validation Plan for Testing Board Subsystem

### 5.3.2. Testing Mixer Result

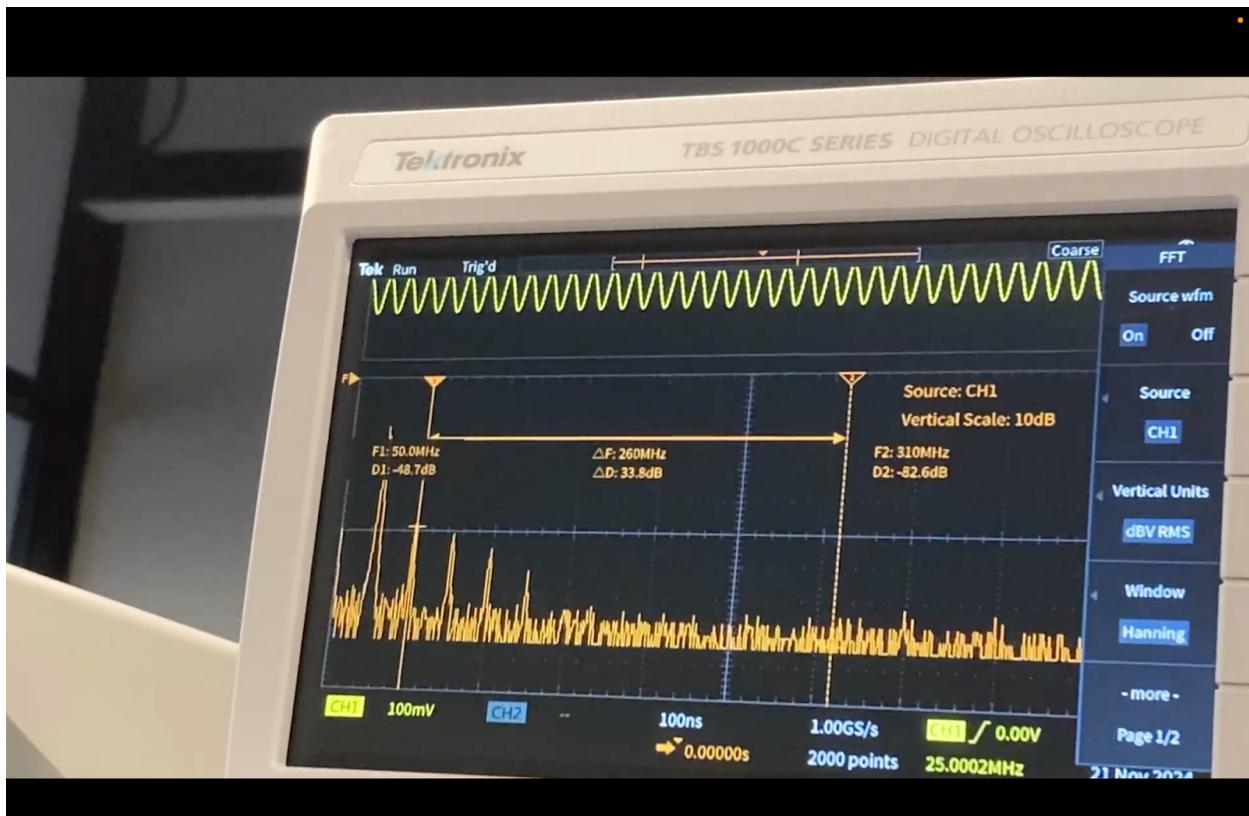


Figure 36. Testing with 25MHz



Figure 37. Testing with 30MHz

The mixer produced some expected IF outputs; for instance, when a 25 MHz LO and a 25 MHz RF signal were applied, a 50 MHz IF signal was observed on the oscilloscope. However, a harmonic frequency of 25 MHz also appeared in the spectrum. One possible explanation for this behavior is the use of low-quality components and the lack of consideration for trace length and spacing, which may have caused RF signals to couple and interfere, resulting in repeated self-mixing. Same for the testing with 30MHz.

## 6. Support Requirements

Due to the nature of this project being R&D there is no technical support service or warranty that is needed.

## Appendix A: Acronyms and Abbreviations

RF	Radio Frequency
GHz	Gigahertz (1,000,000,000 Hz)
SWAP-C	Size Weight and Power - Cost
R&D	Research and Development
VCO	Voltage-Controlled Oscillator
DAC	Digital to Analog Converter
μC	Microcontroller
GUI	Graphical User Interface
LDO	Low Dropout Regulator
PCB	Printed Circuit Board
VDC	Volts Direct Current
DIP	Dual In-Line Package
USB	Universal Service Bus
Op amp	Operational Amplifier
MCU	Microcontroller Unit

## Appendix B: Definition of Terms

DC-DC Boost Converter	A device with a higher output voltage than input voltage. AKA a step-up converter because it “steps up” the voltage.
Digital to Analog Converter	A device that translates digitally stored information from a computer or phone into an analog sound that we can hear.
DIP Switch	Consists of a small block of switches mounted on a dual in-line package. Each switch corresponds to a specific binary digit. Using the switch on the PCB provides flexibility in configuration.
Graphical User Interface	A type of user interface that allows users to interact with a device or software via graphical components such as buttons, menus, windows, or text-based interfaces.
Low Dropout Regulator	A device that takes an input voltage from a power supply and uses that input to output a steady voltage.
Voltage-Controlled Oscillator	An RF oscillator circuit whose frequency can be controlled by a DC input voltage.

# **RF Waveform Generator**

Brian Chau

Daniel Hickl

Eugene Asare

Khoi Le

## **SYSTEM REPORTS**

**SUBSYSTEM REPORTS  
FOR  
RF Waveform Generator**

**PREPARED BY:**

---

Author                                  Date

**APPROVED BY:**

---

Project Leader                        Date

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John Lusher, P.E.                    Date

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T/A                                      Date

## Change Record

Rev	Date	Originator	Approvals	Description
-	11/24/24	RF Waveform Generator		Draft Release

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## 1. Overview

The RF Waveform generator is a low SWAP-C (size, weight, power, and cost) frequency synthesizer that produces a sawtooth RF signal from 1.6 to 3.2 GHz. The system consists of 4 different subsystems: Power, Analog Drive, RF, and Signal Mixing/Testing. These four different subsystems were integrated together and validated to create a working product meeting all project specifications. This will serve as a simple and cost-effective method of mass-producing RFwaveform generators for various communication applications.

## 2. Development Plan and Execution

One of the main goals in this project was to minimize costs and resources, as current systems of RF Waveform Generators are expensive, complex, and resource-heavy in mass production. In this design system, an Analog Drive (using a microcontroller) creates a sinusoidal tuning voltage to the Voltage-Controlled Oscillator which outputs the RF signal. The Power subsystem will take a power source of 2 AA batteries and distribute power to all of the necessary components, which can be measured and displayed on an interface by the GUI/ Monitor Subsystem. Ideally, once the separate subsystems PCB's are created, all four subsystems can be combined into one 2x2 inch PCB that operates fully on its own. Compared to other alternative methods and designs, this design is the simplest and most cost-effective product that still meets all the project requirements.

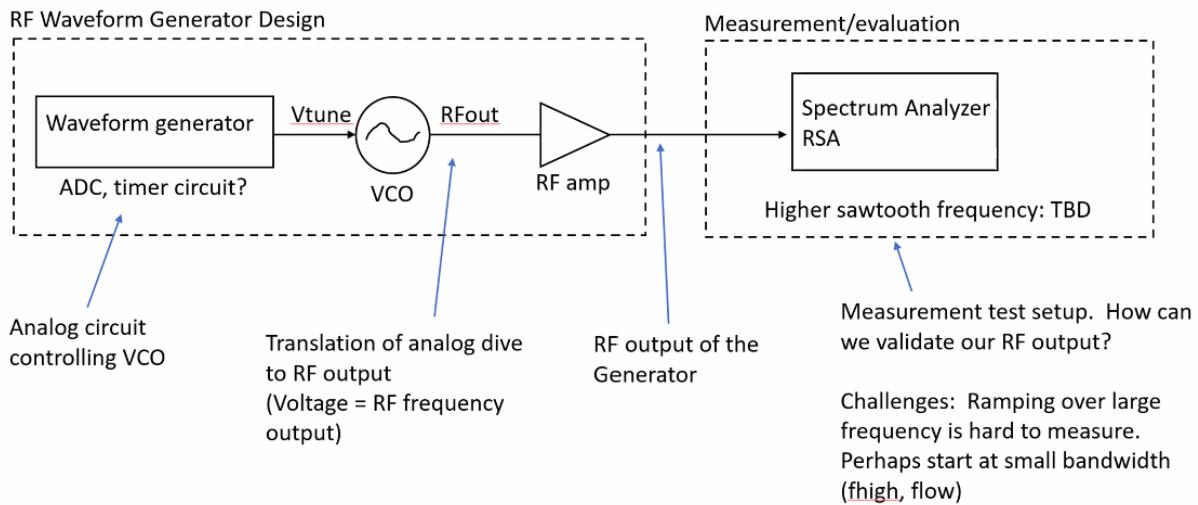
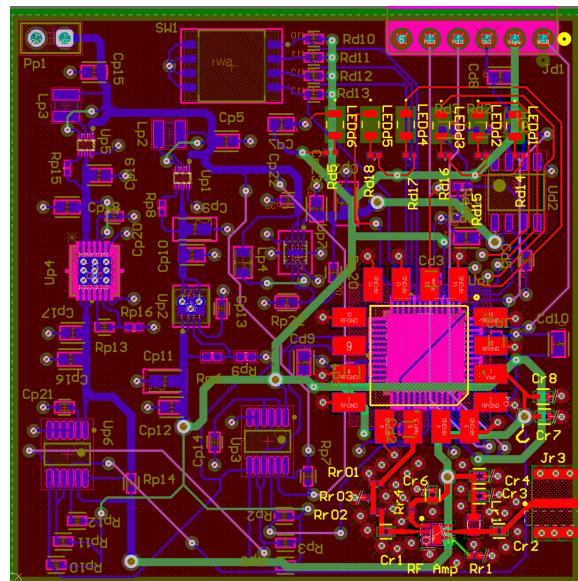


Figure 1. System Design Methodology

## 2.1 Execution

Before any integration can be done, the first step is to first finalize the individual subsystems from the previous semester. With this project being almost entirely composed of hardware, this mainly involved debugging PCB's, validating signal readings on oscilloscopes/ spectrum analyzers, and correcting/ adding updates onto Altium to prevent those issues from occurring again. During this step in the project, a key decision was made to eliminate the GUI/ Monitor Subsystem. After discussing with the professor and project sponsor, it was agreed that this subsystem wasn't needed and caused unnecessary integration difficulties that actually contradicts the scope of the project. Instead, this was replaced by the Signal Mixing/ Testing subsystem, which is focused on creating a Signal Mixer for testing. In short, current testing equipment wasn't equipped with measuring RF signals of this frequency range, hence leading to the creation of this new subsystem to find and implement an alternative testing methodology. Refer to CONOPS for the full subsystem description.

Once the systems were fully assembled and functional, two separate integration methods were implemented. The first integration method was to connect the 4 PCBs together. The Power board provided power to the RF and Analog Drive boards, and the tuning voltage produced by the Analog Drive connected as the input to the RF board. From there, the output of the RF board would be split into two connections, one going into the RF port of the Signal Mixer, another going into the LO port. The Signal mixer would essentially 'mix' the two signals, creating a sine wave that can be measured in the oscilloscope. This testing method utilizes Pulse Compression, which drives down the RF signal to a frequency range that could be measured using the testing equipment in the lab.



*Figure 2. Integration Method 1 PCB Layout*

The second integration method is full hardware integration of the subsystem. In other words, it means combining the Analog Drive, RF, and Power PCBs into one, 2x2 inch PCB. The small size requirement requires a complete redesign on Altium, adding three subsystems together while reconfiguring them in such a way in which all components can fit into the PCB. This PCB would be eight layers and double-sided; top side being the RF layer, the bottom side being the other analog components since RF requires additional rules and constraints in PCB design. The connections made in integration method 1 will be directly connected via PCB traces in this integration method. Again, since the Signal Mixer/ Testing subsystem is only used for validating the system it will be isolated in its own separate PCB.

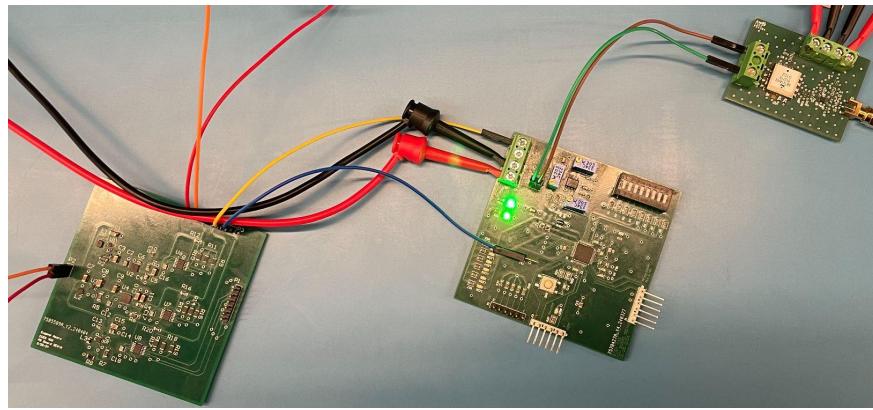


Figure 3. Integration Method 2

## 2.2 Testing Methodology

Due to the insufficiency of the electromagnetic lab equipment, the new testing subsystem was created. Since the spectrum analyzer in this lab does not have a high enough sampling rate, a couple different techniques were used to test our integrated system. The first test was to ensure that the frequency of our generator was producing a signal that was between 1.6GHz and 3.2GHz. This test could be done on the spectrum analyzer. The second test was to ensure that the chirp rate during our modulation states was constant. To do this, one must use a signal splitter along with a signal mixer and measure this output on an oscilloscope. The signal mixer has two inputs: RF and LO. The RF output of the integrated system will be split using a signal splitter. One side will go to the RF input of the mixer, while the other will be connected to a long coaxial cable. This is intended to create a time delayed signal which will go into the LO input of the mixer. The signal mixer would then perform a “downconversion mix”, where it will process the two signals into one output signal called IF port. That IF frequency would be the difference between the signals of the RF and LO inputs. When downconversion is performed, this signal mixing will drive down the IF to a frequency range low enough to be measured with current lab equipment. This was the biggest issue encountered during the validation process, and this method enables us to continue testing without having to outsource or potentially purchase further testing equipment.

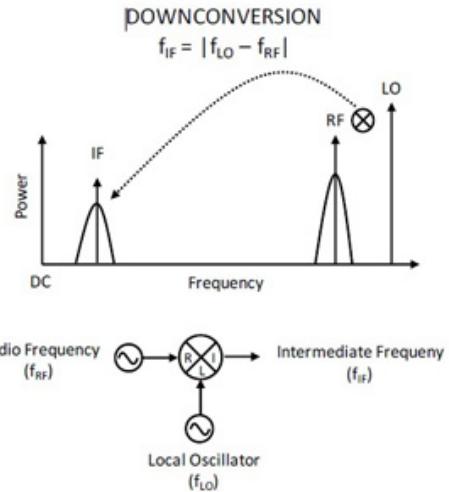


Figure 4. Signal Mixing Diagram

From the IF frequency, an oscilloscope can be used to visualize the signal. Figure 3 below exemplifies the expected output, as it should be a sine wave that is periodic and in wave packets. The wave packets indicate that the modulation from the Vtune is periodic, and the period of those wave packets correspond to the frequency of the tuning voltage.

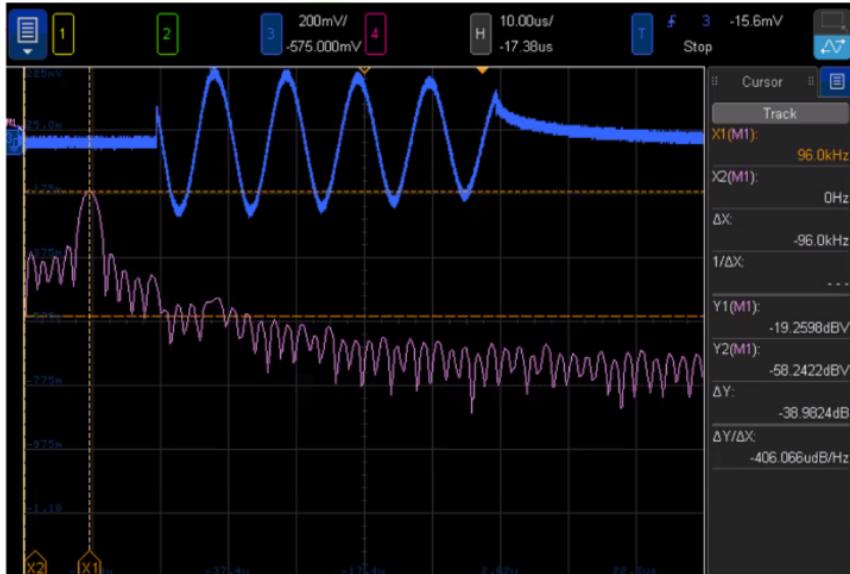
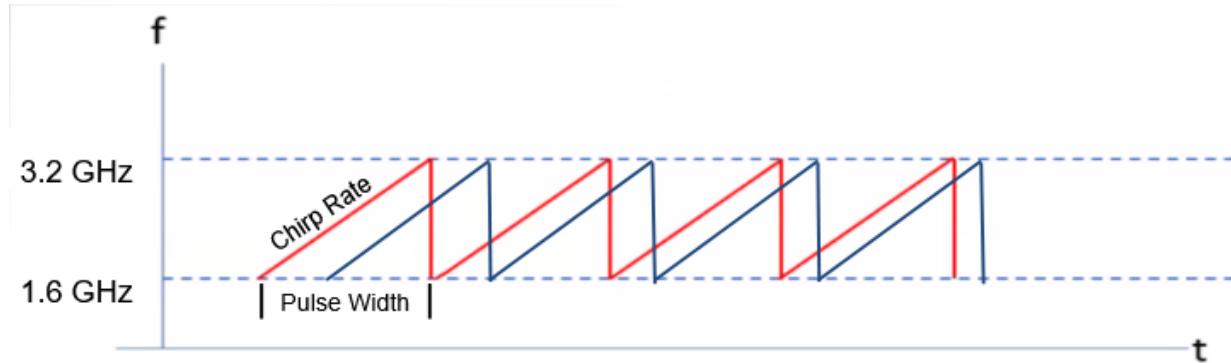


Figure 5. Expected IF Signal

To finally prove that the RF waveform generator produces a sawtooth RF signal, the frequency of the IF signal has to be taken and analyzed. Figure 4 below displays the RF signal (red) as well as its time-delayed signal (blue) going into the signal mixer. If both signals are oscillating at a constant and linear rate, then the frequency of the IF signal should also be constant since it's the difference between the two frequencies. Otherwise, it would be either constantly changing

(nonlinear) or it would be zero (not modulating). Therefore, by showing that the IF frequency is non-zero and constant, the RF signal would be a sawtooth waveform.



*Figure 6. RF Signal and Time Delayed Signal*

Moreover, through some properties of pulse compression, the IF frequency is also proportional to the chirp rate of the tuning voltage. With a known bandwidth and fixed pulse width, the chirp rate (slope of oscillation) can be calculated by dividing the bandwidth by the pulse width. The IF frequency can then be found by multiplying the time delay by the chirp rate, showing that the signal is properly oscillating at the intended bandwidth.

## 2.3 Validation Plan

The validation plan of the RF Waveform Generator can be split into three different categories: Power, DC Tuning Voltage, and Modulation. The first table is the Power readings to the VCO, RF Amplifier, and MCU, showing the target range of voltage/current readings in which the system can operate at.

Power System Constraints			
	MCU Rail	VCO Rail	Op Amp Rail
Volatge (V)	3.3	5	24
Current (mA)	200	180	100
Power (W)	0.66	0.9	2.4
Total Power (W)	5		

*Table 1. Power System Requirements*

The second part of validation is DC Tuning Voltage on the Spectrum Analyzer. To validate that the RF signal spans from 1.6 to 3.2 GHz, its modes of operations shown below will be used to test for the proper RF frequencies of the system. For example, if the DAC is in mode 3, it should produce a DC voltage signal of 7 V and an impulse function should appear on the spectrum analyzer at 2.4 GHz (spectrum analyzer plots magnitude over frequency).

Mode	Mode Type	Input Tuning Voltage (V)	Output Rf Frequency (GHz)
1	DC	0 (OFF)	1.6
2	DC	4	2
3	DC	7	2.4
4	DC	10	2.8
5	DC	20	3.2
6	Modulation	Mod at 1kHz	1.6 - 3.2
7	Modulation	Mod at 5kHz	1.6 - 3.2
8	Modulation	Mod at 10kHz	1.6 - 3.2

*Table 2. Modes of Operation*

One thing to note, when the MCU is in modulation, the spectrum analyzer will not produce an impulse function. Since the resulting voltage signal is oscillating between 1.6 - 3.2 GHz at rate faster than the sampling rate of the spectrum analyzer, the expected result would be a step function from 1.6 to 3.2 GHz, capturing all the frequencies in which the signal oscillates between.

### 3. Testing Results

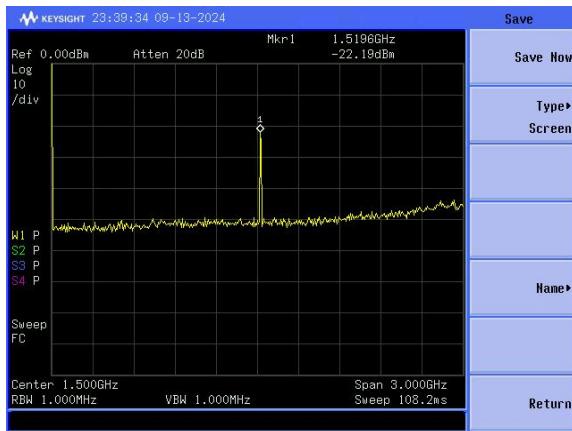
#### 3.1 Power System Readings

Power System Distribution Average Values of 3 Different Modulation States									
	MCU Rail			VCO Rail			Op Amp Rail		
	Minimum	Maximum	Result	Minimum	Maximum	Result	Minimum	Maximum	Result
Voltage (V)	3.197	3.299	3.248	4.845	4.988	4.9165	23.19	23.95	23.57
Current (mA)	165	180	172.5	120	150	135	72	89	80.5
Power (W)	0.528	0.594	0.561	0.5814	0.7482	0.6648	1.67	2.13	1.9
Integrated Power System									
		Minimum	Maximum	Result					
Power (W)		2.7794	3.4722	3.1258					

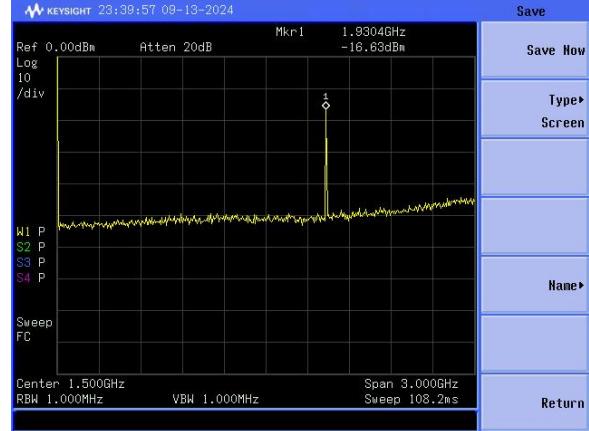
*Table 3. Power System Results*

The table above shows the power readings of the integrated system when operating the three different modulation modes. In total we see that the result of the testing is within the required power system ratings.

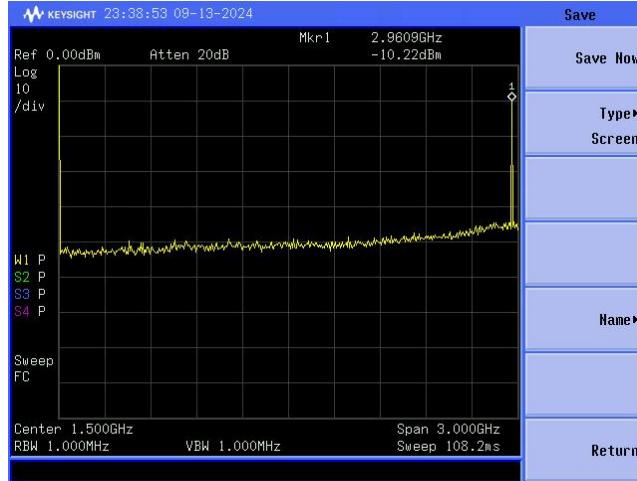
### 3.2 Spectrum Analyzer - DC Vtune



*Figure 7. 0V Tuning Voltage Output*



*Figure 8. 4V Tuning Voltage Output*



*Figure 9. 13V Tuning Voltage Output*

The results of the figures are checking to make sure our frequency range is between 1.6 to 3.2 GHz. With the state off we see that we get an output frequency of about 1.6 GHz and as we continue through the different graphs, we see that our range increases to our desired output frequency of 3.2 GHz. In the figures we see that we have only 3 single DC frequency states of this generator. Note that in the last figure there is no spike showing the frequency above 3 GHz. This is because of the limitation of the spectrum analyzer not being able to read values up to 3 GHz.

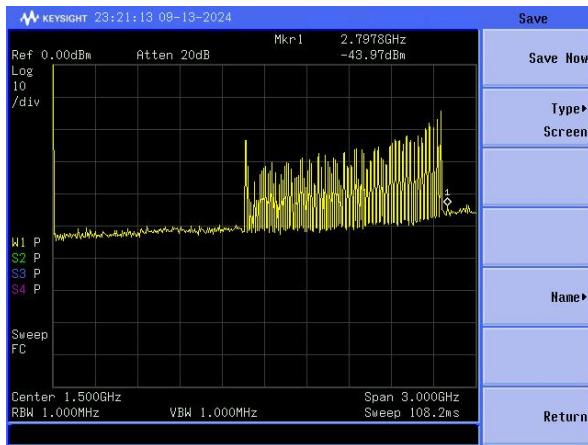


Figure 10. 1k Hz Modulation Mode

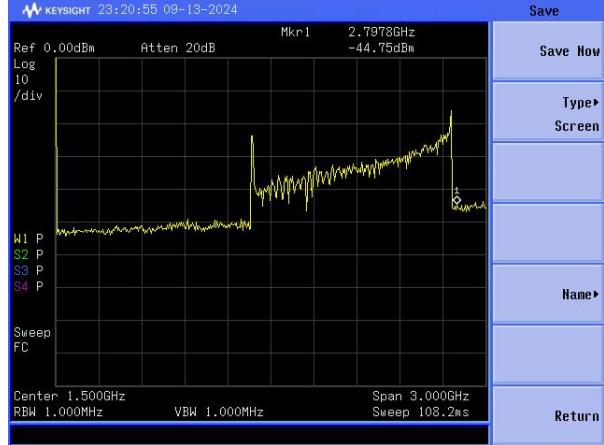


Figure 11. 5k Hz Modulation Mode

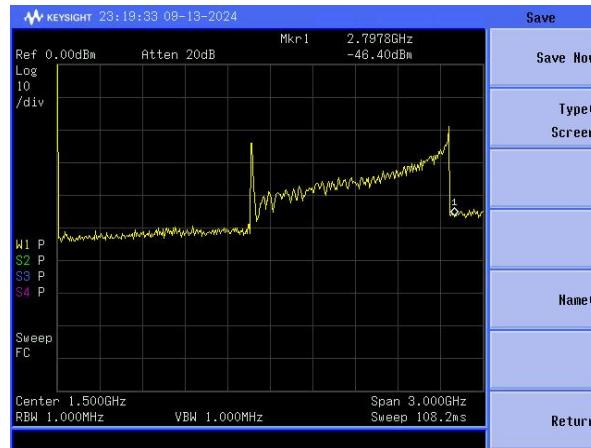


Figure 12. 10k Hz Modulation Mode

The next set of figures show what happens when we change states, and we see a complete range of frequencies. This means that all these frequencies from 1.6 to 3.2 are on and active during this mode. Since this is a modulation state, we are expecting to see this because our system is going to take on many different frequencies between 1.6 to 3.2 at an analog drive frequency at 1k Hz in Figure 8.

Mode	Mode Type	Input Tuning Voltage (V)	Expected Output Rf Frequency (GHz)	Average Measured Output Rf Frequency (GHz)
1	DC	0 (OFF)	1.6	1.56
2	DC	4	2	1.97

3	DC	7	2.4	2.45
4	DC	10	2.8	2.90
5	DC	20	3.2	3.0 (Max)
6	Modulation	Mod at 1kHz	1.6 - 3.2	1.590 - 3.0 (Max)
7	Modulation	Mod at 5kHz	1.6 - 3.2	1.594 - 3.0 (Max)
8	Modulation	Mod at 10kHz	1.6 - 3.2	1.603 - 3.0 (Max)

Table 4. Spectrum Analyzer Validation Results

Note: 3GHz is the highest the spectrum analyzer can measure.

### 3.3 Oscilloscope - Modulation Vtune

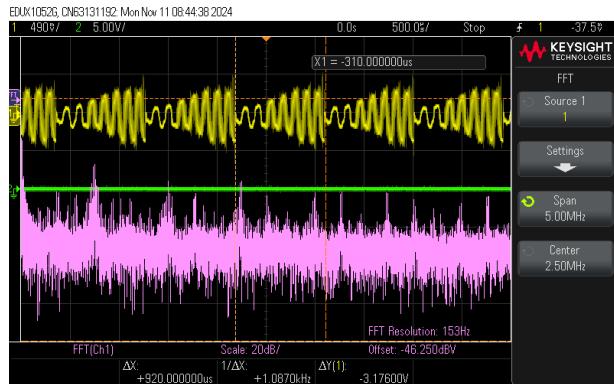


Figure 13. 1k Hz Modulation Mode

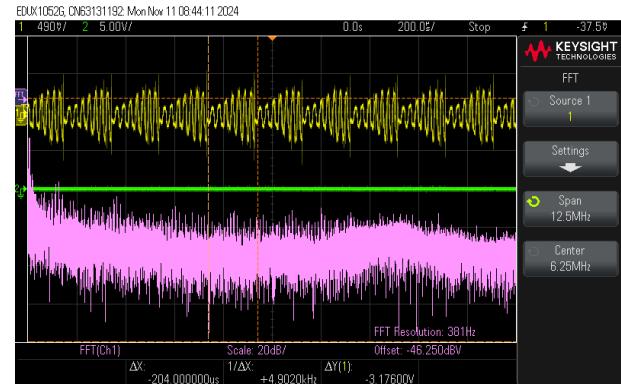


Figure 14. 5k Hz Modulation Mode

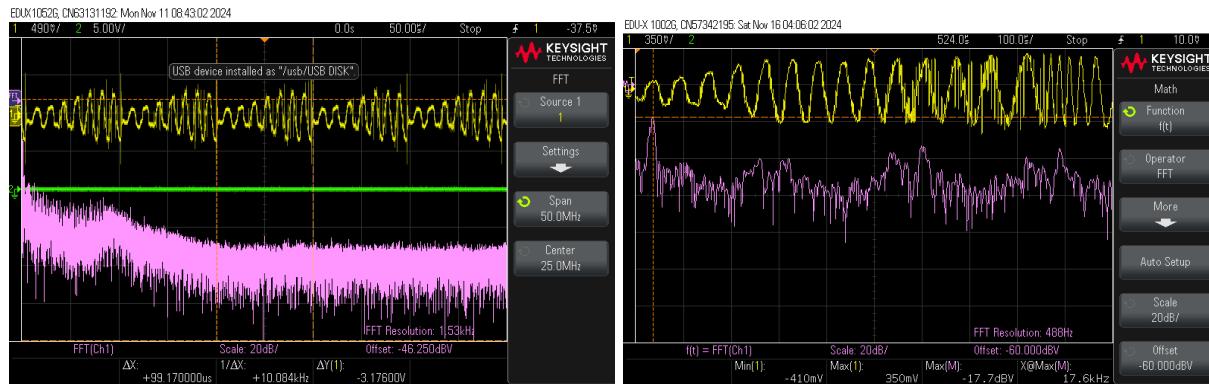


Figure 15. 10k Hz Modulation Mode

Figure 16. 10k Hz (Single Period)

In the above figures we are seeing the output of the VCO that is given through our mixer in order to check the validity of the output signal. Focusing on the 1k Hz modulation we see in the yellow line that the time period of signal matches that of the modulation of 1k Hz. The pink FFT is showing the kHz frequency in modulation.

### 3.4 IF Frequency Calculations

Figure 15 below details the calculations for IF frequencies given the frequency of the tuning Voltage (PRF). Drawing from the table above with these calculations, the RF signals are generally accurate to the expected results, thus proving that the RF signal of the system spans from 1.6-3.2 GHz and is a linear, sawtooth waveform.

PRF	5 kHz
Pulse Width (PW)	200 us
Time Delay (TD)	0.0117 us
Band Width (BW)	1600 MHz
Chirp Rate (BW/PW)	8 MHz/us
IF fq (TD * CR)	93.6 kHz

Frequency	Expected (kHz)	Measured (kHz)	Error
1k	18.72	17.3	7.585470085
5k	93.6	96	2.564102564
10k	187.2	170.9	8.707264957

Table 5. IF Frequency Calculations and Results

## 4. Final Reflection

### 4.1 Key Decisions

Throughout the development of this project, there were two key decisions that were made. The first one was the creation of the new Testing Subsystem. At the end of last semester when the Electromagnetics lab was finally available, we found out that the lab didn't have proper lab equipment that can support the frequency range of the project. At the same time, discussions were made with our project sponsor that Khoi's GUI subsystem was unnecessary and out of the scope of the project. Therefore, it was decided that Khoi's GUI subsystem would be scratched for the new Testing subsystem, one that is essential for project demo and proceeded with that instead.

Additionally, significant integration progress was made on the single, fully integrated PCB board. However, during testing/validation, we found an issue on the PCB that turned out to be a design error on the Altium PCB Layout. For two components on the backside of the assembly board, the footprint somehow didn't get inverted as it switched to the backplane, creating a bug that couldn't be fixed in due time. Due to the timeline of the project and the amount of time it would take to fix it, we decided to proceed with the individual boards instead (integration method 1) to complete the project. Figure 15 and 16 below are the PCB layout of the single integrated board and the progress up until that decision.

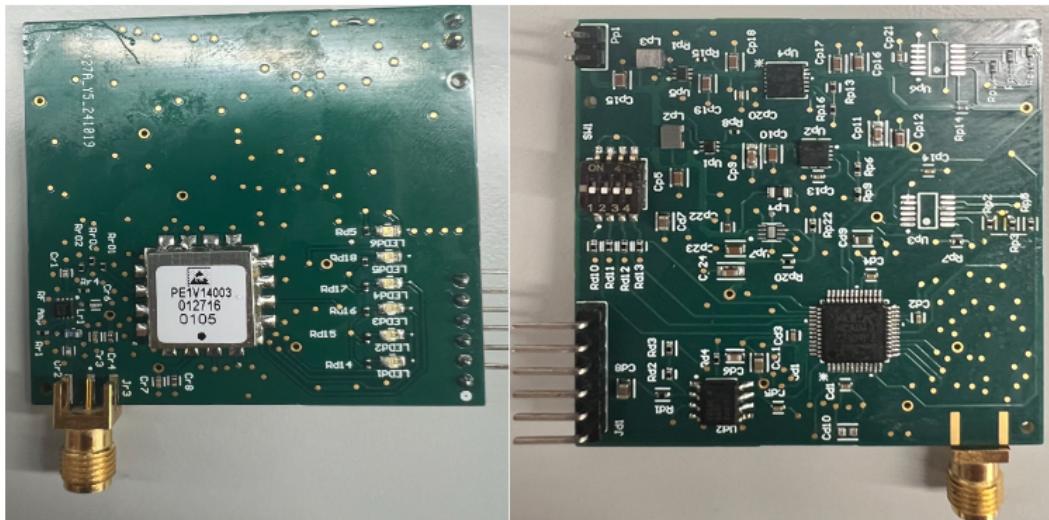


Figure 17. Fully Integrated PCB Assembly

## 4.2 Areas of Improvement

One major improvement that can be made with our goal of low SWAP-C is the size aspect of our boards. Although the single PCB had to be set aside to ensure project completion, it could be reordered with the fixed changes to fit the size criteria. Additionally, to increase accuracy of the IF frequency and model a perfect sawtooth waveform, the tuning voltage can be adjusted to more perfectly fit the VCO specifications. In Figure 18 below, the iRF frequency isn't exactly linear to the input tuning voltage. With more time and testing, fine tuning of this generator could be done to decrease the error in the system. Towards the higher end of the tuning voltage, RF frequency flattens out. In order to ensure a perfectly linear RF signal, a linear regression would have to be done on Figure 18 to approximate the rate of change.

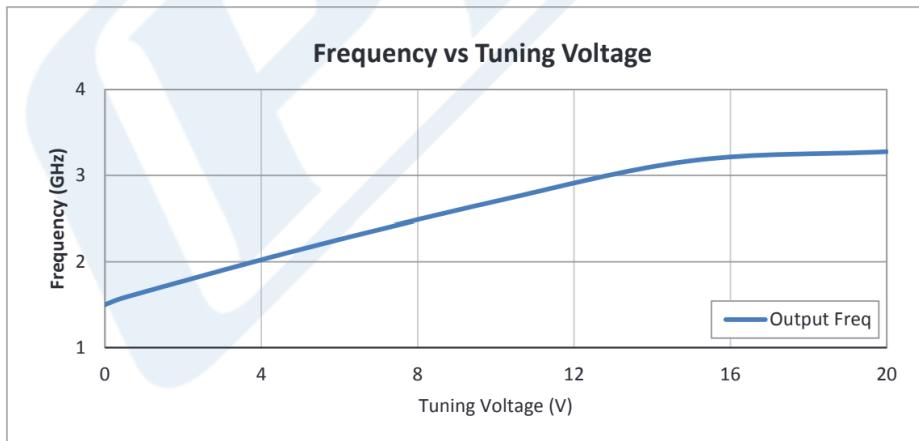


Figure 18. VCO Frequency vs Vtune Plot

From there, a look-up table would be created from that approximation to create a ramp-up tuning Voltage that has a constant rate of change.

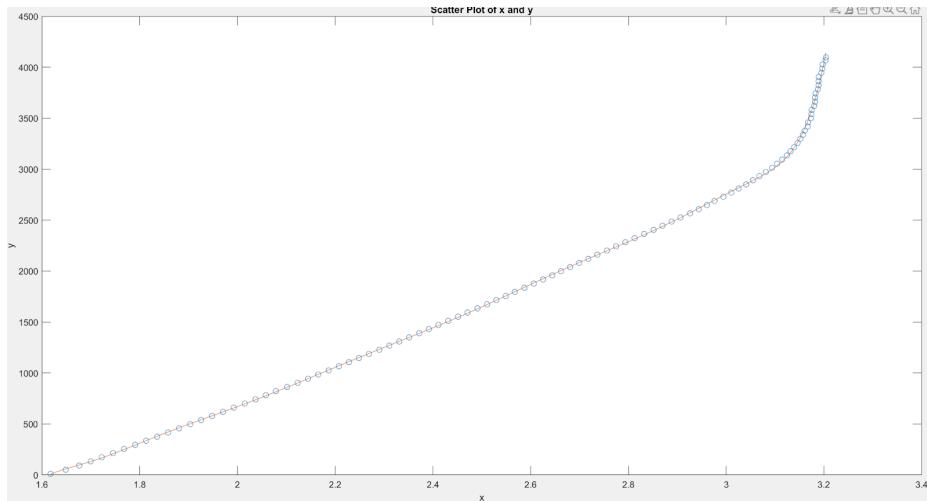


Figure 19. Ideal Analog Drive DAC Output

## 4.3 Conclusion

With the decision of moving forward with the first integrated configuration, many but not all of the project requirements were met. The two key requirements of this project were the generation of a linear sawtooth RF waveform and low SWAP-C. We were successful in creating a linear sawtooth waveform in the required frequency range. Although, we were not fully successful in the low SWAP-C requirement. As seen in figure 16 below, all of these specifications were met except the size requirement. Completion of the second integrated configuration would meet this requirement.

After discussions with our sponsor, Mr. Anthony Ernest, the RF Waveform Generator was deemed a successful project, fulfilling the goal of pushing the boundaries of RF board design and RF waveform generation.

	Goal	Actual
Size	9 square inches	21 square inches
Weight	200 grams	139.9 grams
Power	5 Watts	3.5 Watts
Cost	\$400	\$328
Frequency	1.6-3.2 GHz	1.6-3.2 GHz

Table 6: SWAP-C Goals

## Appendix A: Acronyms and Abbreviations

$\mu$ C	Microcontroller
DAC	Digital to Analog Converter
DIP	Dual In-Line Package
GHz	Gigahertz (1,000,000,000 Hz)
GUI	Graphical User Interface
IF	Intermediate Frequency - Signal Mixer Output
LDO	Low Dropout Regulator
LO	Local Oscillator - Signal Mixer Input
MCU	Microcontroller Unit
Op amp	Operational Amplifier
PCB	Printed Circuit Board
R&D	Research and Development
RF	Radio Frequency
SWAP-C	Size Weight and Power - Cost
USB	Universal Service Bus
VCO	Voltage-Controlled Oscillator
VDC	Volts Direct Current

## Appendix B: Definition of Terms

DC-DC Boost Converter	A device with a higher output voltage than input voltage. AKA a step-up converter because it “steps up” the voltage.
Digital to Analog Converter	A device that translates digitally stored information from a computer or phone into an analog sound that we can hear.
DIP Switch	Consists of a small block of switches mounted on a dual in-line package. Each switch corresponds to a specific binary digit. Using the switch on the PCB provides flexibility in configuration.
Chirp Rate	Rate of change in which the tuning voltage oscillates. This is also the slope of the sawtooth waveform.
Graphical User Interface	A type of user interface that allows users to interact with a device or software via graphical components such as buttons, menus, windows, or text-based interfaces.
IF Frequency	IF signal is the output of the signal mixer, and the frequency of the IF signal is the difference between the RF and LO inputs of the mixer.
Low Dropout Regulator	A device that takes an input voltage from a power supply and uses that input to output a steady voltage.
Voltage-Controlled Oscillator	An RF oscillator circuit whose frequency can be controlled by a DC input voltage.

# **RF Waveform Generator**

Brian Chau

Daniel Hickl

Eugene Asare

Khoi Le

## **EXECUTION PLAN AND VALIDATION PLAN**

# Execution Plan (403)

Actions/Deliverables	15-Jan	22-Jan	29-Jan	5-Feb	12-Feb	19-Feb	26-Feb	4-Mar	11-Mar	18-Mar	25-Mar	1-Apr	8-Apr	15-Apr	22-Apr	27-Apr	
Introduction to Project/Connecting with sponsor																	
Meeting with sponsor																	
Research on RF and Potential subsystems																	
Completion of Initial design																	
Declaration of Subsystems																	
Completion of Initial subsystem design																	
Order parts																	
<b>Midterm Presentation</b>																	
Design Simulations (Interface and DAC)																	
Design Schematic (VCO and Power Subsystems)																	
User Interface GUI Design																	
<b>Status Update</b>																	
MCU Schematic Design																	
PCB Layout (VCO, MCU, and Power Subsystems)																	
Creation of user interface test data																	
Order Boards																	
<b>Final Presentation</b>																	
Microcontroller Evaluation Board Testing & Debugging																	
GUI Improvement (e.g. show value under mouse, axis title)																	
Test and debug user interface																	
VCO PCB Test and Debug																	
Power System PCB Test and Debug																	
MCU PCB Test and Debug																	
<b>Sandia National Labs Update</b>																	
<b>Demos</b>																	
<b>Final Report</b>																	

# Execution Plan (404)

# Validation Plan (403/404)

403 Validation Plan				
Test Name	Success Criteria	Methodology	Status	Responsible
Low RF Output (3.2.1.3)	RF output approximately 1.6GHz given 0.5 Vtune input.	Use Spectrum Analyzer (spectrogram) and Oscilloscope to measure frequency output	COMPLETED	Brian Chau
High RF Output (3.2.1.3)	RF output approximately 3.2 GHz given (max) 20 Vtune input.	Use Spectrum Analyzer (spectrogram) and Oscilloscope to measure frequency output	COMPLETED	Brian Chau
Modulation RF Output (3.2.1.3)	RF output oscillates between 1.6 to 3.2 GHz given periodic Vtune input.	Use Spectrum Analyzer (spectrogram) and Oscilloscope to measure frequency output	COMPLETED	Brian Chau
Power Attenuator (3.2.1.2)	Simple circuit reduces VCO power output to 20dBm +/- 3dBm for RF amplifier.	Simple circuit tested on PCB and measured with voltmeter	COMPLETED	Brian Chau
RF Amplifier (3.2.1.4)	Amplifier produces RF output of 5V.	Use Oscilloscope to measure voltage	COMPLETED	Brian Chau
Power Supply (3.2.3.1.1)	Power supply will provide correct voltage (3.6V) needed for each component (uController, VCO, Amplifier)	Use Oscilloscope to measure voltage	COMPLETED	Eugene Asare
DC-DC Converter (3.2.3.1.2)	The converter will receive a voltage from the 2 AA batteries that will be stepped up to 24 V and 5.5 V for respective rails	Use Oscilloscope to measure voltage	COMPLETED	Eugene Asare
LDO (3.2.3.1.2)	Step down voltage from the DC-DC Converter to 3.3V and 5V	Use Oscilloscope to measure voltage and currents of each LDO	COMPLETED	Eugene Asare
Power Monitors Testing on PCB (3.2.3.1.2)	Each Power Monitor will record the voltage and current inputs with the specific address assigned by the configuration	Use of all Components and PCB	COMPLETED	Eugene Asare
LTSpice LDO Testing (3.2.3.1.2)	Each LDO will output the correct voltage. For the Digital Rail it will output 3.3 V with a 5.5 V input. For the VCO Rail it will output 5 V with a 5.5 V input.	Use LTSpice to simulate the LDO configuration by inputting 5.5 V into each LDO.	COMPLETED	Eugene Asare
LTSpice OpAmp Testing (3.2.3.1.2)	Differential OpAmp shall output correct voltage from 0-20V when input 1.8-3.6V on simulation software	Use LTSpice to simulate OpAmp configuration by inputting a controlled voltage from 1.8 to 3.6 into the OpAmp	COMPLETED	Daniel Hickl
Microcontroller MPLab Testing (3.2.3.2)	Microcontroller C code works as intended with 7 different states: Off, On, Constant Voltage, and On: Modulation. Within the On: Constant Voltage state, there shall be 5 different voltage outputs (5V, 10V, 15V, and 20V). Within the On: Test microcontroller code Using evaluation board. Same success criteria as MPLab Testing. Introduce DIP Switch and LEDs on breadboard to test states.	Use MPLab to test code using interrupts to stop code. These shall be used to determine output voltages and frequencies	COMPLETED	Daniel Hickl
MCU Testing on PCB (3.2.3.2)	Output of opamp shall be 0-20V and shall be able to modulate between 1kHz-10kHz. LED Shall light up when on. GUI shall communicate with MCU. Sensor shall communicate with MCU	Use Evaluation Board to test different states of the Waveform Generator	COMPLETED	Daniel Hickl
Code Debug (3.2.3.2.1)	Code is able to compile, no major bug, GUI display correctly, perform fast, easily to use and read	Use of all Components and PCB	COMPLETED	Daniel Hickl
404 Validation Plan (System Integration)				
Test Name	Success Criteria	Methodology	Status	Responsible
RF Output Mode 1-5 (3.2.1.3)	RF output given DC tuning voltage (0.4,7,10, 20V) outputs respective RF signal frequency (1.6, 2, 2.4, 2.8, 3.2 GHz)	Use Spectrum Analyzer to measure frequency output	COMPLETED	Brian Chau
RF Output Mode 6-8 (3.2.1.3)	RF output oscillates between 1.6 to 3.2 GHz given Vtune frequencies 1k, 5k, and 10kHz	Use Spectrum Analyzer and Oscilloscope to measure frequency output	COMPLETED	Brian Chau
RF Amplifier (3.2.1.4)	Amplifier produces RF output of 5V.	Use Oscilloscope to measure voltage	COMPLETED	Brian Chau
Power Supply (3.2.3.1.1)	Power supply will provide correct voltage current to each device.	Use Oscilloscope to measure voltage	COMPLETED	Eugene Asare
DC-DC Converter (3.2.3.1.2)	The converter will receive a voltage from the 2 AA batteries that will be stepped up to 24 V and 5.5 V for respective rails	Use Oscilloscope to measure voltage	COMPLETED	Eugene Asare
LDO (3.2.3.1.2)	Step down voltage from the DC-DC Converter to 3.3V and 5V	Use Oscilloscope to measure voltage and currents of each LDO	COMPLETED	Eugene Asare
Power Testing on PCB (3.2.3.1.2)	Each Power Monitor will record the voltage and current inputs with the specific address assigned by the configuration	Use of all Components and PCB	COMPLETED	Eugene Asare
MCU Analog Drive Testing	The MCU shall output a constant voltage from the DAC. This voltage shall be amplified anywhere in 0-20V range.	Use the DIP Switch parse through all the constant voltage states of the system.	COMPLETED	Daniel Hickl
MCU Analog Drive Testing	The MCU shall output a varying voltage (1kHz - 10kHz) from the DAC. This voltage shall be amplified anywhere in 0-20V range.	Use the DIP Switch parse through all the modulation states of the system.	COMPLETED	Daniel Hickl
MCU Testing on PCB (3.2.3.2)	Output of opamp shall be 0-20V and shall be able to modulate between 1kHz-10kHz. LED Shall light up when on. GUI shall communicate with MCU. Sensor shall communicate with MCU	Use of all Components and PCB	COMPLETED	Daniel Hickl
Testing MATLAB Code (3.2.3.1)	Matlab code can simulate and visualize pulse compression given oscilloscope output	Generated input signal, do mixer operation then taking FFT and observe output signal	COMPLETED	Khoi Le
Testing Circuit Simulation(3.2.3.2)	Compared the Circuit Simulation output with the MATLAB output	Building mixer circuit with specific RF range, using Oscilloscope and Spec Analyzer in simulation to measure the waveform and frequency of output signal.	COMPLETED	Khoi Le
Mixer Test (3.2.3.3)	Mixer successfully fuses both reference and time-delayed signal to showcase frequency ramp	Use Oscilloscope and Spec Analyzer in lab to measure waveform and frequency output	COMPLETED	Khoi Le