EEL 4914

Senior Design Project

Team 307

Narrow Band "Oscilloscope" for High Power Tuning of NMR Probes

16 April 2021

Final Report

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Abstract

The National High Magnetic Field Laboratory performs an experiment that involves radio frequency pulses. The tools they use for the experiment are very expensive. For example, the oscilloscopes used for the experiment can cost upwards of $20K. While the oscilloscope is able to observe the experiment, many of its other features go unused. This creates the need for a cheaper, but just as effective solution. Our project uses a Software Defined Radio (SDR) as the oscilloscope's cost-efficient replacement.

Our project develops an oscilloscope based on SDRs because it uses radio frequencies. We program the SDR to observe a range of frequencies. Then, the SDR is used in combination with software to record the incoming radio frequency pulses. That software displays the incoming data to the user as an oscilloscope would. As the data comes in, it must be aligned with the running experiment. To do this, we sync the SDR with the experiment using a trigger. We then add a second SDR set up the same way to observe the second set of pulses. Our SDR solution is then inserted into the experiment exactly where and how the oscilloscope would be hooked up.

Through the completion of this project, we are able to accurately measure, record, and display the radio frequency pulses from the experiment. It can also be programmed to observe different frequency ranges. This allows the SDRs to successfully copy the oscilloscopes. The user can make the correct adjustments to the experiment using our solution. Therefore, the Magnetic Lab can replace the oscilloscopes used for these experiments with our SDR solution. This helps the Lab to save thousands of dollars. It also allows them to use the oscilloscopes for other purposes instead of a simple observation.

Keywords: Software Defined Radio (SDR), Oscilloscope, Trigger.

Disclaimer

Acknowledgement

Thank you, Dr. William Brey, for the opportunity to embark on this project. Without you, this project would not have been ours to complete. Thank you to Keysight Technologies and Paul Holcomb for sponsoring this project and advising us when we needed it. Thank you to Dr. Rajendra Arora, our technical advisor, for guiding us when we were in trouble spots towards alternative solutions. Also thank you to Dr. Samuel Grant for helping us test our prototype. Without you, we would not have been able to obtain the results we did.

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Notation

AD	Analog Devices
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
HoQ	House of Quality
KT	Keysight Technologies
Maglab	Magnetic Lab
MSPS	Mega Samples Per Second
NHMFL	National High Magnetic Field Laboratory
NMR	Nuclear Magnetic Resonance
RF	Radio Frequency
SDR	Software Defined Radio
SW	SOLIDWORKS

Chapter One: EEL4911C

Project Scope

Assemble a prototype which includes a Software Defined Radio (SDR) of choice in addition to specified software running in a host computer to behave like an oscilloscope. The prototype will have a trigger coming from the power source to start the recording of data; these experiments can last days, and therefore require efficient memory or buffer capabilities. The SDR will do so by measuring the Radio Frequency (RF) pulses obtained from experiments where a bi-directional coupler is inserted between an RF power amplifier and a probe to allow the user to monitor Reflected Power (RP).

Customer Needs

SECTION I: Description of Customer Needs Document

The purpose of the following sections is to address all specified needs by the customer (Dr. William Brey, National High Magnetic Field Laboratory) and sponsor (Paul Holcomb, Keysight). The needs were identified during several virtual meetings with the parties mentioned above. The Team carefully assessed all needs and constructed a list of requirements to satisfy said needs. In *Section II,* customer statements are presented and documented from the meetings. Based on those statements, in *Section III,* a complete list of all needs given to by the customer and the sponsor are presented. In *Section IV*, the requirements are stated. Ultimately, in *Section V,* a more in-depth explanation, definitions, and meaning of the needs from *Section III* are presented.

SECTION II: Customer Statements

Question 1: Will the final prototype be addressing multiple users?
Answer: The final prototype doesn't have to address all users.

Question 2: Which kind of information will this device be extracting?
Answer: Users would like to know when the probe fails and how to adjust it (this incorporates the idea that a reversed signal has to be displayed, so that the user may make appropriate decisions during an experiment).

Question 3: What does the displayed signal have to be?
Answer: The displayed signal has to be an envelope.

Question 4: What suggestion was made to decrease the cost of the prototype?
Answer: The use of an SDR was suggested to decrease the cost.

Question 5: What should the output of the SDR display?
Answer: The output of the SDR needs to display the alternation of the Radio Frequency (RF) pulses and the phase.

Question 6: What does the end user want to observe on the display and measure?
Answer: The prototype has to display length of sweep, control frequency, and have enough bandwidth for the spectroposict's experiment (600MHz to 800MHz). In addition, it must aim for one frequency and a clean system that works well.

Question 7: What is the target cost for every channel?
Answer: Target cost per channel needs to be around one thousand dollars.

Question 8: What kind of software is required alongside the SDR hardware?
Answer: The implemented SDR device needs to have appropriate software to be used alongside it such as C++ or MATLAB.

Question 9: What does the prototype need to look like and what is an essential ability it should have?
Answer: The prototype needs to be essentially a "box" (doesn't need a display) but should have the ability to connect to one (such as a computer).

Question 10: How should the prototype operate? Should it read the data continuously?
Answer: The SDR based prototype will run (sample) continuously for a period of time as long as several days. When an external trigger occurs, the recorded data will be saved (the customer can supply a trigger in the form of a Transistor-Transistor Logic (TTL) trigger that goes through Power Amp 100us before the pulse).

Question 11: How long is the pulse width?
Answer: The pulse width is short but can get up to a pulse-train that is 100ms long.

Question 12: How many channels does the prototype need?
Answer: It is a need for the prototype to have at least one channel.

Question 13: What range does the device need to be capable of analyzing?
Answer: The device has to be able to analyze signals with frequencies in a range from 600MHz to 800MHz.

Question 14: What is a sufficient resolution for the SDR's Analog-Digital Converter (ADC) for proper analysis of the signal?
Answer: The resolution must be equal to or more than 8-bits. This would be sufficient, but the scopes used by the customer are 8-bits. Hence, it is a requirement for the need to have a clear image to display on the computer.

Question 15: What is the function of the SDR in the prototype?
Answer: The SDR used in the prototype only needs to receive a signal. Later additional functionality could be to add the capability to compare the input with said received signal (output) from the source.

Question 16: How is it preferable to display the plot of received signal?
Answer: A connected computer needs to display the results from the SDR plotted. Show plot of butterfly (and potentially the ratio of reflected power)

Question 17: Are there any preferences in regard to a particular SDR device?
Answer: The customer would prefer if the implemented SDR device would be HackRF One, so that instructions can be made to use it in the labs.

Question 18: Are there any additional features in mind to potentially be included after completion of the basic prototype?
Answer: As another optional implementation, the customer suggested implementing an alarm when the reflected power ratio is higher than a certain threshold.

SECTION III: Needs of the project

Table I: Needs

No.	Need/Statement	Source
1	Prototype of a single unit (a "box")	Customer
2	Fast receival of reverse signal	Customer
3	Needs to be reparable in case of failure	Customer
4	Needs to show the envelope of the signal at high frequencies	Customer
5	Software code/application needs to be appropriately chosen and configured for SDR connection to PC	Customer
6	Needs to have ability to start and stop readings (externally triggered)	Customer
7	The cost of the prototype needs to be under $1000	Customer
8	Needs to have at least one channel	Customer
9	Needs to be able to run for many days/hours	Customer
10	Oscilloscope needs to work on 600MHz to 800MHz frequencies for 1H channel	Customer
11	No use of NI products	Sponsor

Table 1: Need parameters contained in this table

SECTION IV: Requirements of the project

Table II: Requirements

No.	Need	Requirement/Interpretation
1	1	All devices will be assembled in a single prototype unit, no devices lying around
2	4	SDR will have enough bandwidth to demonstrate the envelope
3	6	Prototype will be connected to an external trigger
4	2	Sampling rate of the SDR will be higher than minimum value for correct scan
5	4	Will capture the entire sample (pulse train)
6	5, 9	Will transmit the digital data of received signal to PC for review, analysis, and storage
7	7	Performs the software and hardware capabilities necessary while staying under budget
8	8	Must receive experiment output for analysis
9	9	Will have external storage of received data
10	4, 10	Prototype will record, analyze and plot 600MHz to 800MHz received signals and reflected power
11	11	Will not incorporate any National Instruments components nor software
12	4	Output digital signal from prototype will have at least 8-bit resolution
13	4	Prototype will have several times the bandwidth of the carrier frequency of the pulse
14	3	Quick access to hardware or code in software to run diagnostics on the system in case of failure

Table 2: Requirement parameters contained in this table

SECTION V: Explanation of Customer Needs

All the customer needs were gathered during direct communication with National High Magnetic Field Laboratory representative Dr. William Brey. There were two meetings in total from the start of the project until September 24, 2020. Dr. Brey provided a proposal of the project in which several technical specifications of the expected product were mentioned. These and additional needs are documented above in *Section II* as interpreted needs. Major needs expressed by the customer were abilities of the prototype to do as follows: accurately receive high frequency signals, display the received signals on the computer and use an SDR as a tool to behave such as the functionality of an oscilloscope. In addition, the cost of the product was asked to be under one thousand dollars. Both portability and repairability were pointed out as a need as well. Further clarifications on the need of portability, led the customer to declare that the final product needs to be a single unit prototype with at least one channel for signal receival. Furthermore, after careful explanation of the environment in which the proposed prototype will be used, the customer brought up the need for the ability to work for a long period of time, potentially even several days. The need to accurately receive high frequency signals was broken down into three specific needs: a fast receival of the incoming signal from the probe, a clear display of the envelope of the signal at high frequencies, and the need to contain a trigger to start or end a recording. To complete the research of total needs for the project, the team contacted sponsor representative Paul Holcomb. On the side of the sponsor there was only one direct need, which was to exclude any use of National Instruments (NI) products. This meant that neither the software nor the hardware made by NI can be implemented or used for the design of the prototype.

It is important to know exactly what the customer is asking for or what the prototype should do prior to beginning any further planning as there may be future additions or subtractions that may occur. Having our customer's needs and requirements tabulated, we can now move onto formulating our functional decomposition.

Functional Decomposition

SECTION I: Brief Introduction

1.1: Explanation of Results

1.1.1: Functional Decomposition Introduction

This document breaks down the functions that the prototype will perform, as driven by the needs and requirements derived from the customer (Dr. William Brey), and the insight from the sponsor (Paul Holcomb). The team was tasked to assess and discuss the functions the prototype must perform. In *Section II*, the function tree explains how the prototype will perform. In *Section III* the decomposition of the prototype is broken down into its appropriate levels. *Section IV* contains each individual module the prototype will contain, as well as its function and purpose within the system. Finally, *Section V* describes how the functions connect, act, integrated, and the overall function resolution.

1.1.2: Data Generation Discussion

For the data generation guidelines, there are several key points that are crucial for outputting the sought signal to the display. The signal will be coming in from a bidirectional coupler that is connected to the Radio Frequency (RF) power source and the pulse source "Figure III". Once the signal is sent out from the pulse source, there are four important aspects that need to have fixed constants for the specified signal; the dynamic range, frequency range, sampling rate, and the trigger. The trigger is activated from the pulse source, which in return, tells the Software Defined Radio (SDR) to map the output signal from the RF power amplifier. The sampling rate relates to how long the pulse actually lasts and the number of samples needed per unit of time, in this case, at least 11MSPs. The dynamic range relates to the resolution on the display, for this project it needs to be at least 8-bits. Finally, the frequency range needs to be able to map the signal for high frequency tuning, between 600 MHz to 800 MHz.

1.1.3: Graphics Introduction

Below are several block diagrams and fundamental properties for the project. The Function Tree "Figure I" is a clean layout of the basic principles that the project has to execute or accomplish. Level 0 "Figure II" deals with the most basic block diagram of the prototype with its inputs and outputs specified. Level 1 "Figure III" is the whole schematic on which the tuning scope will be based off. It shows where the pulsed signal will be coming from, how much power will be directed into the system, where the scope will be connected, and the final output of the display.

1.1.4: Functional Decomposition Discussion

The functional decomposition information was based on the schematic in Dr. Brey's Keysight Oscilloscope proposal. Relevant details were gathered through meetings with our customer, Dr Brey, and Keysight (Sponsor) engineer Paul Holcomb. From those meetings it was clear that an SDR will work in an oscilloscope fashion. This means that the input RF pulses from the pulse generator and the probe must be analyzed as they would have been in an oscilloscope. In addition, the FD was gathered via meetings with Dr. Arora (Advisor), in which concepts of Q factor, trigger implementation and RF pulse display were discussed. The rest of the FD construction was accompanied by the whole team effort in researching the operation of SDRs and their intersystem capabilities and connectivity.

1.1.5: Function Relationships

The upper level function of the prototype is to modulate and analyze RF pulses by continuous sampling of the input RF signals. This function relates to the lower functions of the connected computer monitor to display the input RF power in and power out signals. Also, for the correct display function to be working appropriately, there is a need to introduce a trigger block. The function of this trigger block is to produce a trigger signal to synchronize the SDR timing analysis with the input RF pulse trains. The function of SDR to convert and analyze analog input RF signals depends on the proper operation of the attenuator function to reduce the power of the incoming RF pulse train from the bidirectional coupler.

SECTION II: Function Tree

Figure I: Function Tree

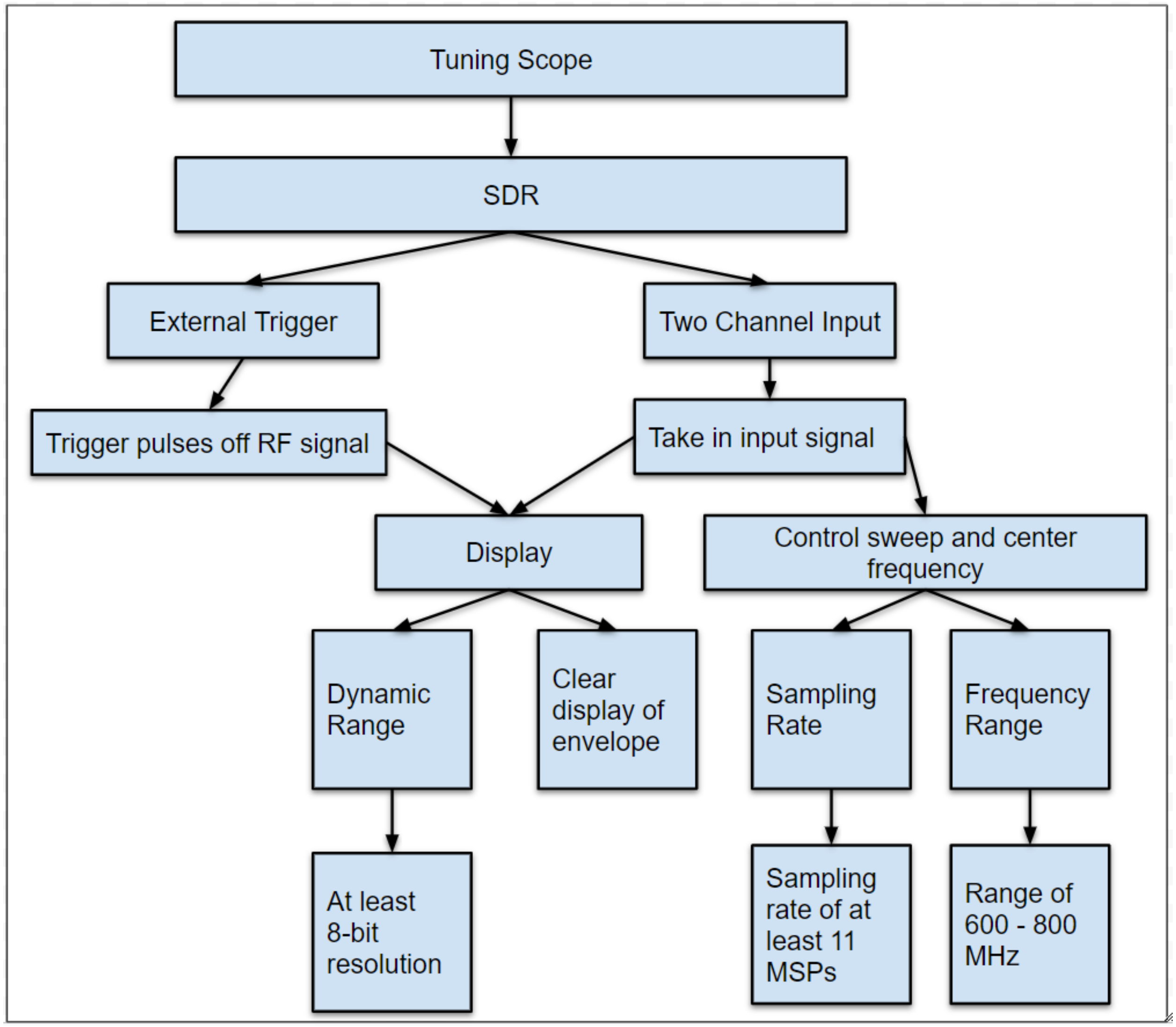


Figure 1: Function Tree parameters contained in this figure

SECTION III: Decomposition Levels

Figure II: Level 0

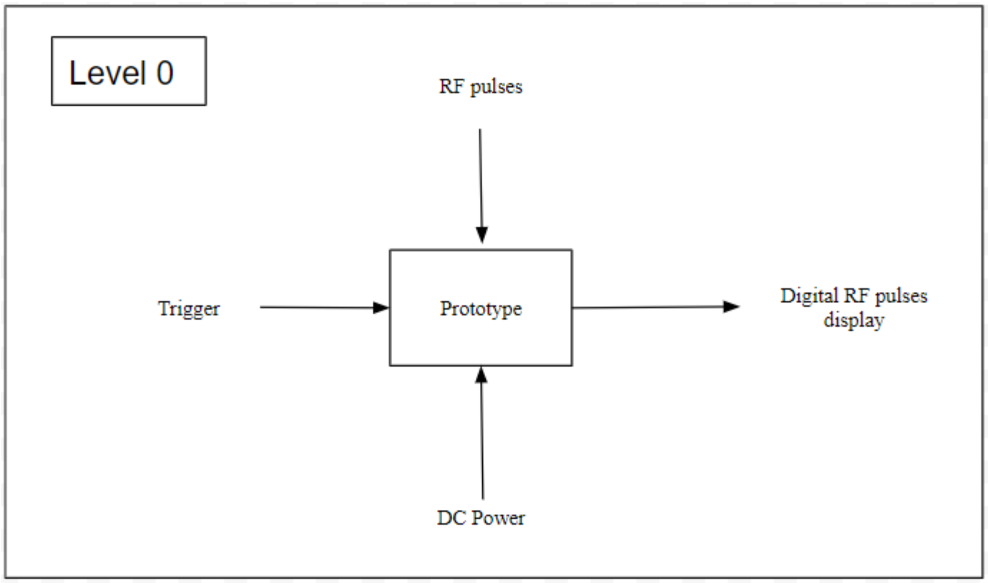


Figure 2: Level 0 Function Block Diagram

Figure III: Level 1

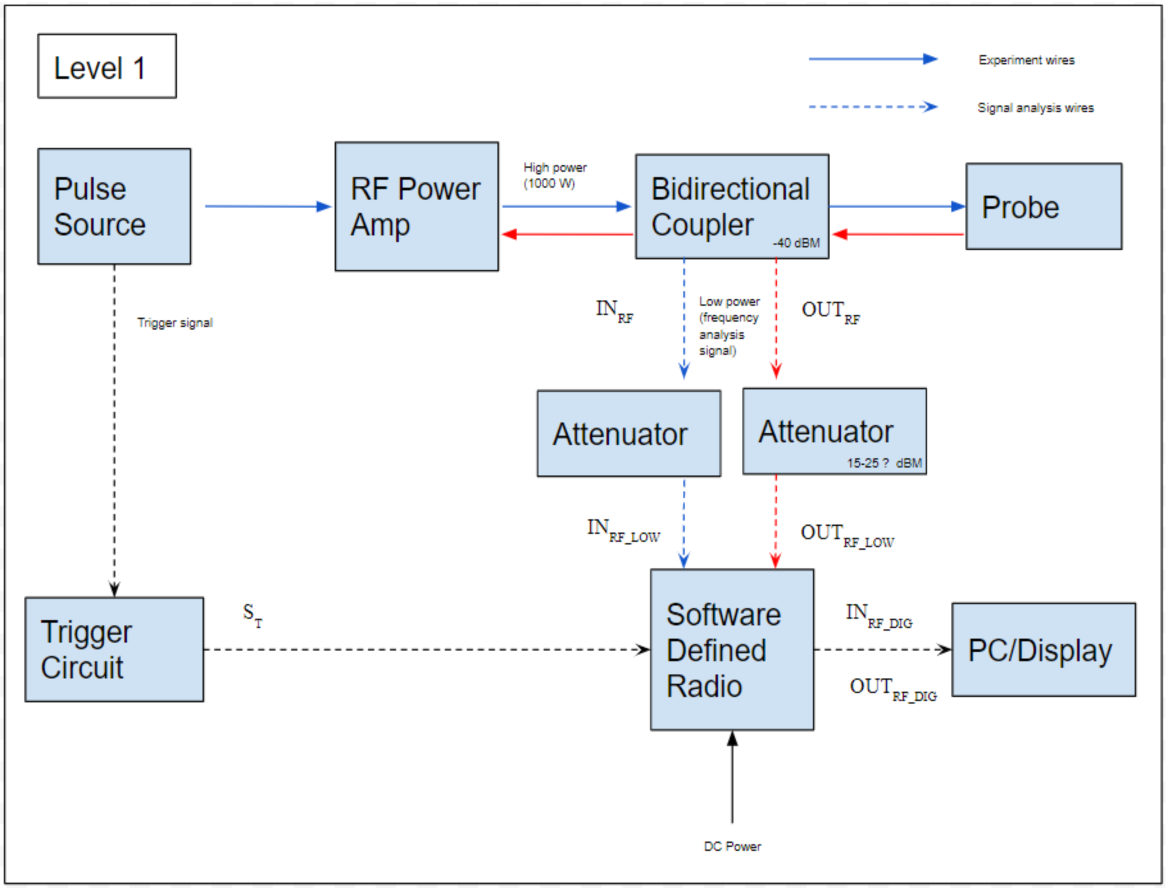


Figure 3: Level 1 Function Block Diagram

SECTION IV: Modules and Description of Functional Behavior

Table I: Level 0

Module	Prototype
Inputs	- RF pulse - Trigger - DC Power: DC input 4.5-5.5 V
Outputs	- Digital RF pulse display
Functionality	Modulates and analyzes RF pulses by continuous sampling. Sends recorded data to display after receival of a trigger signal. Operates on 600 MHz to 800 MHz frequencies

Table 1: Level 0 parameters contained in this table (Prototype)

Table II: Level 1

Module	Trigger Circuit
Inputs	- Power source TTL trigger signal 50 Ohm wire
Outputs	- ST: Trigger signal in a form accepted by SDR
Functionality	Produces the trigger signal to be sent to SDR based on the TTL signal coming from Power Source

Table 2: Level 1 parameters contained in this table (Trigger Circuit)

Table II.I: Level 1

Module	Attenuator_1
Inputs	- INRF: RF signal coming from the Pulse Source input to the probe extracted from Bidirectional Coupler
Outputs	- OUTRF_LOW: RF signal with lower power to be accepted by SDR
Functionality	Reduces the power of the incoming RF signal for further analysis

Table 2.1: Level 1 parameters contained in this table (Attenuator_1)

Table II.II: Level 1

Module	Attenuator_2
Inputs	- OUTRF: RF signal coming from the probe power signal extracted from Bidirectional Coupler
Outputs	- OUTRF_LOW: RF signal with lower power to be accepted by SDR
Functionality	Reduces the power of the incoming RF signal for further analysis

Table 2.2: Level 1 parameters contained in this table (Attenuator_2)

Table II.III: Level 1

Module	Software Defined Radio (SDR) Device
Inputs	- ST: trigger signal to synchronize RF pulse recording with Power Source output - INRF_LOW: - OUTRF_LOW:
Outputs	- INRF_DIG: 8-bit binary representation of INRF_LOW - OUTRF_DIG: 8-bit binary representation of OUTRF_LOW
Functionality	Converts analog input of RF pulse train to binary digital output

Table 2.3: Level 1 parameters contained in this table (Trigger Circuit)

Table II.IV: Level 1

Module	PC/Display
Inputs	- SDIG_RF: recorded digital signal from SDR
Outputs	Plot of oscilloscope analysis onto a monitor using software tools
Functionality	Displays the RF pulses in a format of oscilloscope plot

Table 2.4: Level 1 parameters contained in this table (PC/Display)

SECTION V: Summary

5.1: Connection to Systems

The system under construction involves a prototype with a major function of analyzing analog input signals and outputting analyzed data in a digitized form. This major function is closely dependent on the function of a trigger circuit. The priority of proper operation of the trigger circuit is the highest. In the case, when a proper timing synchronization has been achieved by the trigger circuit and the SDR, the latter is able to perform correct RF pulse train analysis and output it to the computer display. A subsystem of the prototype - trigger system is the SDR USB connection with a computer. The function of a monitor to display the plot of an analyzed signal is dependent on the sampling function of SDR and inner SDR circuitry to output 8-bit resolution data to a computer. Therefore, the last two functions are of higher priority than the display function, which is predefined by a software of our choice. Therefore, an impact of this priority on project objectives is to focus on proper operation of the SDR ADC and the inner circuits to satisfy the operation of the function that outputs a digital signal to the computer. In addition, SDR function to analyze an analog signal is dependent on the attenuator function to decrease the power of the incoming RF pulse train. The attenuator function is then of a higher priority, which directs our project objective to purchasing appropriate attenuator modules for correct modulation of the power of incoming RF pulses.

5.2: Smart Integration

The attenuators work to further decrease the power of the signals output by the bidirectional coupler to prevent the SDR from being damaged. The first is for the incoming power from the source; the second for the incoming power reflecting from the probe. The trigger circuit uses the pulse source to assist the SDR with synchronizing the data desired by the user. Without this trigger, the user may receive undesired data.

5.3: Action and Outcome

The action that our prototype will provide is similar to that of an oscilloscope. The trigger circuit makes use of the pulse source to synchronize the SDR data with the time it is asked for by the user. The attenuators work to output a further reduced incoming power from the bidirectional coupler to prevent the SDR from getting damaged. The PC or display will work to tell the SDR when to retrieve the data, store the data sent from the SDR, and graphically display the desired RF pulse train data to the user.

5.4: Function Resolution

The functions performed by the prototype are entailed in this document. The functions have been assessed and discussed. The prototype's performance has been outlined. The prototype has been decomposed. Each individual module's contents and purpose have been determined. Lastly, the function's relationships and integration for an overall solution have been described. The design for the functional decomposition was established and accomplished by first analyzing the problem at hand and the prototype schematic from a top-level analysis. In addition, this simplified version of analysis allowed for the development of "Figure 2" to be established as a very simplified version of the external inputs and outputs. Further, "zooming in" to this diagram, one can achieve a mid-level analysis to view more layers of complexity. This can be seen in "Figure 3". Overall, the prototype to be designed has to display incoming RF pulses on the computer monitor in oscilloscope fashion. It can be assumed that everything was resolved in the aforementioned sections and therefore this resolution marks the successful completion of the functional decomposition.

Breaking down what our prototype must do into multilevel functions helps to better understand what each module must do and how they work with each other. Having our functional decomposition in place, we now focus our attention on setting the targets our prototype must meet. These targets will be based off the needs and requirements set in our Customer Needs section.

Targets Summary

SECTION I

1: 2-Channel SDR

This target is moderately important because only one channel is necessary. Customers asked for at least one channel, but if two is possible, it is preferable. Without a channel, there is no signal to display. Channel input and output will be directed to the computer for display purposes. This will be tested by experiments using RF pulses and a computer display. Accomplished by using correct SDR and appropriate software.

2: Prototype can operate with no interruptions for a minimal period of two weeks

This target is important as the customer will be operating the experiments for an x_d (14) ,number of days. This target had been gathered after a hand-on virtual demonstration performed by one of the MAGLAB representatives over a Zoom call. It will be tested by leaving prototype ON for a different x_d. This target will be tested using a lower frequency source input and output signal analysis testbench and a camera to record the operation of a prototype and review it later.

3: Prototype plots a signal with a frequency in the range of 600 MHz to 800 MHz

This target is moderately important, because the customer operates on frequencies up to 1500MHz, but the requested prototype only needs to work for the specified range of (600 - 800) MHz. This was derived from the customer's needs. Using an oscilloscope, a circuit with the correct frequency range will be able to display the signal, which in return will give values to compare before use of the prototype. This gives information on how to tune the prototype to better the frequency range needed.

4: Sampling rate of SDR's ADC is at least 90ns or 11MSPS

This target is moderately important, due to the circuit running at half-power bandwidth and the accuracy of the results. Half-power bandwidth is a sampling time of about 90 ns or 11MSPS. This will be tested using an oscilloscope with a specific circuit to determine the nr , number of MSPS, before the circuit is hooked up to the prototype to test for similar results. This will be corrected in the coding syntax.

5: SDR must have an external trigger to receive a signal from the pulsed source to synchronize output digital data from SDR with the beginning of the pulse train

This target is very important, because without a trigger function on the SDR, the pulse will not be sent to the prototype. Trigger, T1, will be implemented into the SDR and the SDR will call on a pulsed source for the output signal. This can be tested by any circuit running while no signal is being mapped to the display, once requested by the user, T1 will be activated and send the signal to the SDR to then be displayed.

6: SDR has at least 8-bit ADC

This target is less important as it will be one of the easier objectives to tackle. 8-bit resolution on a computer screen should be fairly simple, but this is also the least n_b, number of bits, required for the project and therefore the aim is for 16-bit. Will be tested with the signal from SDR and display from the computer screen.

7: Attenuators lower the power of input/reverse signals to 2.5dBm

This target is important, if the attenuators let more than 2.5 dBm in, it can fry the SDR or throw off the desired signal. By examining the SDR's specifications, the proper attenuator needed was derived. This can be accomplished by determining the amount of power coming from the bi-directional coupler and buying the correct attenuator. The power from the circuit and attenuator are needed as well as the SDR's specifications are needed to validate this target.

8: Digital output data from SDR displays the entire envelope of pulse train

This target is very important due to it being the whole purpose of this project. This will be accomplished by applying all targets and functions listed, as well as, the team working together to find solutions to every obstacle or task. This will be accomplished by testing the customer's NMR RF signal on the prototype and oscilloscope, then comparing the results between the two. Will be fixed with troubleshooting all aspects between software and hardware on the project.

9: SDR is compatible with Linux

This target is not very important, it is more of a preference from the customer. Though there is equipment that runs on Windows, most equipment at the National High Magnetic Field Laboratory runs off Linux. Good SDR and Linux compatibility will validate this target. Equipment and computers (running Linux) which the prototype will be tested on will be the tools used.

SECTION II

Table I: Targets Catalog

Metric Number	Need	Metric	Importance	Units	Marginal Value	Ideal Value
1	2-Channel SDR	Hardware	Moderate	N/A	1-2	2
2	Run for days	Duration	Impotant	Days	7-14	14
3	Frequency Range	Bandwidth	Moderate	MHz	600-800	800
4	Sampling Rate	Bandwidth	Moderate	ns or MSPS	11	11
5	External Trigger	Hardware	Very	N/A	1-2	2
6	Resolution	Quality	Least	bits	8	8
7	Attenuators	Resistance	Important	dBm	2.5	2.5
8	Display Envelope	Software	Very	Hz	1	1
9	Linux Compatibility	Software	Least	N/A	N/A	N/A

Table 1: Targets contained in this table

Our targets dictate what our prototype must achieve quantitatively. These allow us to better visualize what our prototype must achieve and needs it does not have to exact with. With the targets that our prototype must meet defined, we now begin to generate concepts for the elements our prototype may use and forms it can take.

Concept Generation

SECTION I: Phases of Concept Generation

1.1: External Search

The external search involved reaching out to the customer, advisor, and Keysight technical advisor to obtain any previous information that helped with the generation of the concepts. For example, a suggested software defined radio (SDR) from the customer was the Hack RF One and to use a software called GNU Radio. This suggestion not only served as concepts on their own, but sparked ideas of research for more SDRs with similar capabilities such as the Adalm Pluto SDR, that also supports the GNU Radio software as well as programming languages like MATLAB and C++.

An approach like "crap shoot" where random concepts are generated via the team's capacity, originality, and creativity was also used to establish the columns of the table. In addition, a force analogy of comparing attributes to systems that are not the same allowed for extra concepts to be generated.

1.2: Internal Search

The internal search involved doing research without the aid of the customer, advisor, or technical advisor's input. Searching forums and the internet for similarly designed projects using the SDRs helped to generate concepts such as using the general-purpose input or output pins on the SDR to trigger its analog to digital converter so that it only starts processing data when the pin is active low or high.

1.2.1: Morphological Chart

The morphological chart was used to generate more ideas via functions or sub-functions of the system. The red selections were obtained via the most feasible and logical path to implementation, but any of the paths can be selected for a concept.

Figure I: Morphological Chart I

MORPHOLOGICAL CHART 1.			
Attenuation	On SDR	On Bi-dicoupler	On Box cable to SDR
Trigger	Digital interpeter circuit	Soldered connection	Input connection
Interface	Keyboard	Switches	Buttons
Software	SDRuno	Simulink	SDRangel
Display	PC monitor	In lab monitor devices	CRT

Figure 1: Morphological Chart I elements contained in this figure

Figure II: Morphological Chart II

MORPHOLOGICAL CHART 2.			
Number of SDR	One (two receiver ports)	Two (one receiver port)	Two (two receiver ports)
SDR	Adalm PLuto	Hack RF One	SDRplay DUO
Power	Battery	DC POWER	USB POWER
Storage	Internal SDR memory	External (PC Hard Drive)	Cloud
Trigger implementation	ADC control (DMA recording)	Tagged Sink Block	Separate circuit PCB design

Figure 2: Morphological Chart I elements contained in this figure

1.2.2: Biomimicry

The concepts generated through the use of biomimicry had to be derived from "outside-the-box" ideas since the prototype is essentially a box itself. Using such an unconventional approach to a stagnant object, the first ideas included reasoning for the shell. Then the actual construction, shape, and design were considered. Lastly, the materials, appearance, and performance were considered. After analyzing all these possibilities, animals or biological entities that carry these characteristics were able to be compared.

The outer shell was compared to such as a turtle, snail, or crab. The material shell itself was conceptualized as compostable or biodegradable material; while maintaining a solid construction like a rock. The shape was compared to the effective use of space like a beehive, and the internal components were thought of as layers like soil in case they are stackable. Added concepts included see through design like a jellyfish, internal thermal control like observed in weather, sealed and inaccessible to the user like a cocoon, and lastly silent components and performance like a predator or a cat.

Figure III: Biomimicry

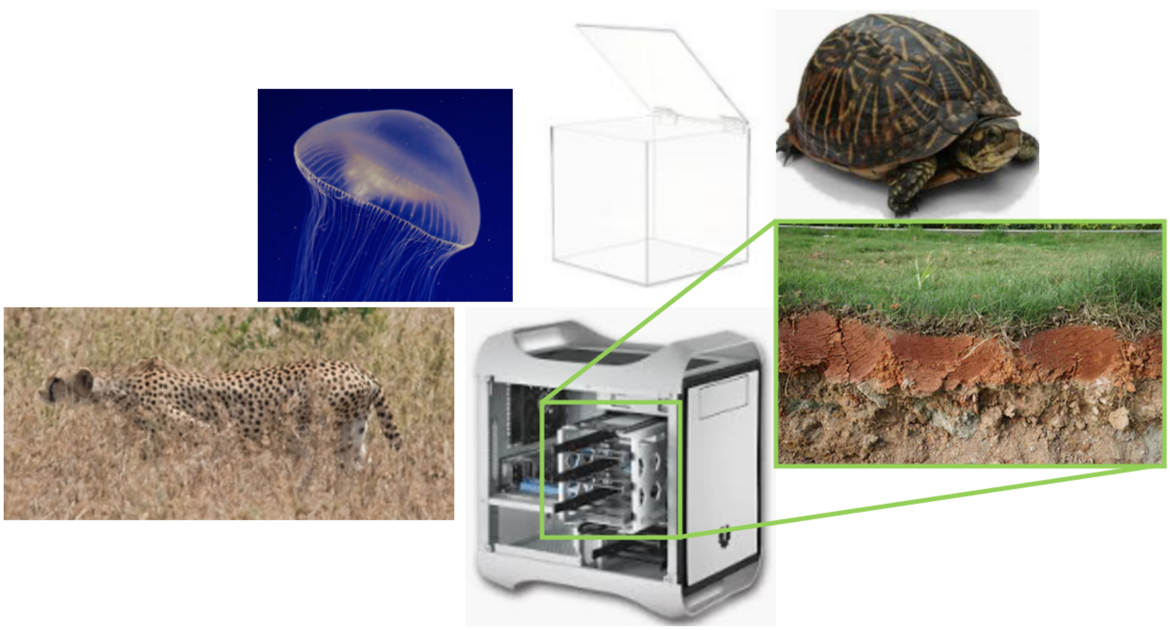


Figure 3: Biomimicry Concepts contained in this figure

1.2.3: Anti-Problem

The anti-problem method was used to come up with a few concepts. Some of these anti-problem concepts helped to generate ideas that work to make the user's experience more difficult than if they used their current equipment. This approach also sparked ideas that were not previously thought of i.e. having any wireless connections would pose an immediate problem whilst working in a magnetic field as the antenna components will be affected.

Figure IV: Anti-Problem I

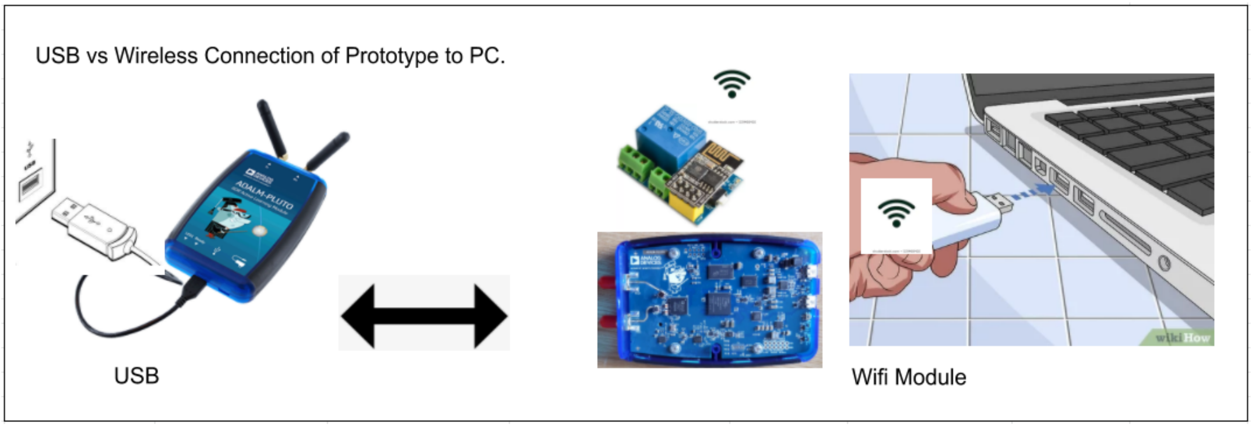


Figure 4: Anti-Problem I contained in this figure

Figure V: Anti-Problem II

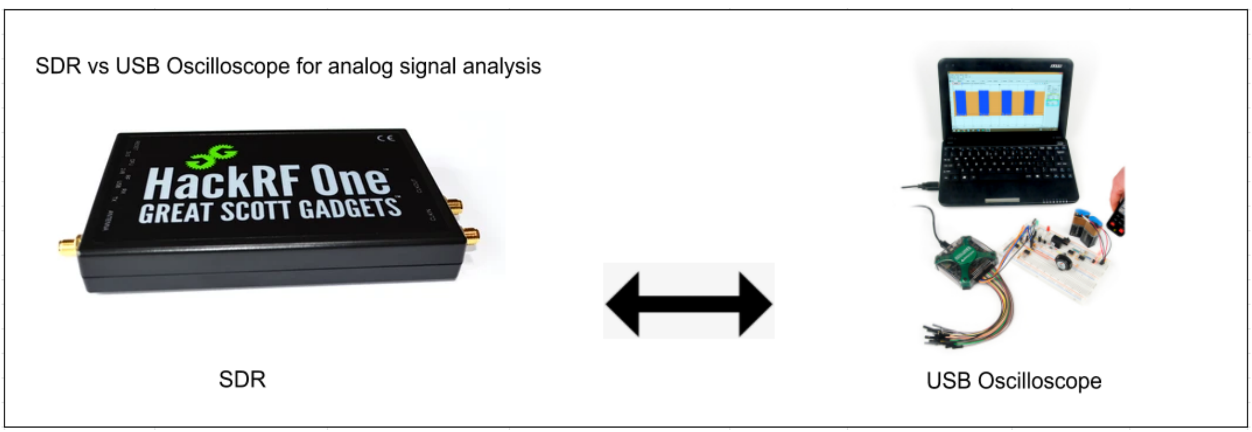


Figure 5: Anti-Problem II contained in this figure

Figure VI: Anti-Problem III

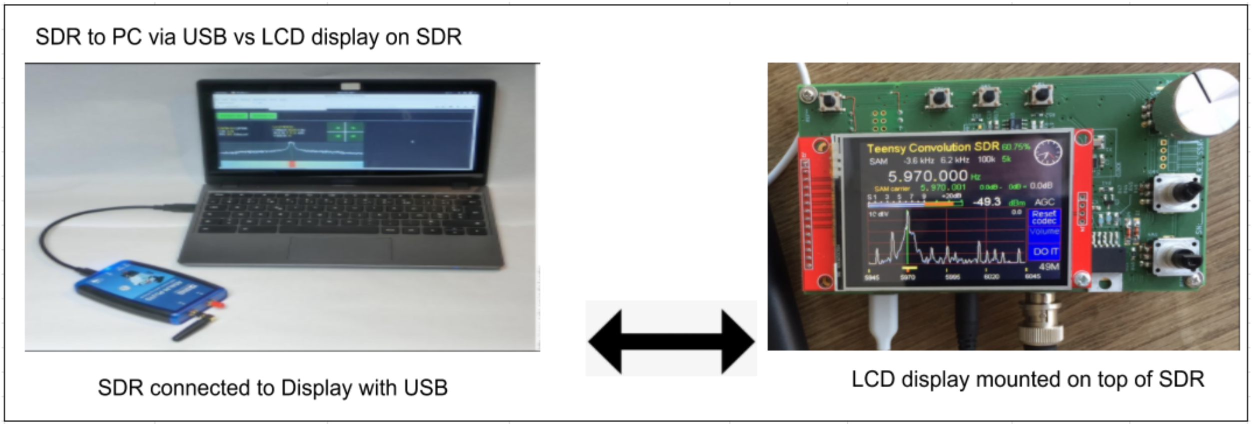


Figure 6: Anti-Problem III contained in this figure

1.3: Systematically Generated Concepts

The systematically generated concepts were created by looking at the different functions that our prototype must perform and breaking down the components and ways they can be performed. For example, for the PC or Display module we would need a PC running an operating system that supports the SDR and its software. Additionally, a display is needed as well as interface for the user to interact with.

SECTION II: Concept Table(s)

Table I: All Concepts I

Number of SDR	SDR	Attenuation	Trigger	Trigger implementation	Connection	Display	Software	Language	Power
One (two receiver ports)	Adalm PLuto	On SDR	Digital interpeter circuit	ADC control (DMA recording)	USB	PC monitor	Ubuntu	libiio	Battery
Two (one receiver port)	Hack RF One	On Bi-dicoupler	Soldered connection	Tagged Sink Block	Ethernet	In lab monitor devices	Windows 10	C	AC Power
Two (two receiver ports)	SDRplay DUO	On Box cable to SDR	Input connection	GPIO digital connection on SDR	Coax	Plasma	Linux	C++	DC Power
	SDRplay RSP2pro			Separate circuit PCB design	RCA	CRT	Viirtual Machine on Linux	C#	USB Power
				Trigger from the PC via USB	VGA		RTL-SDR	Linux Scripts	Outlet
					HDMI		Airspy	Python	surge protector
					DisplayPort		SDRangel	MATLAB	
							SDRSharp		
							GNU Radio		
							SDRuno		
							Simulink		

Table 1: All Concepts Part 1 contained in this table

Table I: All Concepts II

Storage	Interface	Prototype Box Material	Prototype Box Shape	Prototype Box Design	Prototype Box Size	Biomimicry	Anti Problem
Internal SDR memory	Keyboard	Metals	Cylindrical	Compact (space effective)	Shoe box	Outer Shell Protection of Internal Components (like a turtle, snail, crab)	Wireless Connection to PC
External (PC Hard Drive)	Touch	ABS Plastic (3D Printing)	Cubical	Self contained	Small gift box	compostable shell (recyclable material)	USB oscilloscope
Flash Drive	None (run and start)	Cardboard	Heptagonal	Open and accessible	Tight fit box (fit to the sdr's size)	biodegradable shell (organic materials)	On board display
CD	Mouse	Silicone	Hexagon	Closed and accessible (not compact)	Medium box	solid construction that can be thrown around (like a rock)	
Cloud	Knobs	Wood	Hybrid	Attractive Design	Large box	Hexagon shape (like a beehive)	
	Switches	Glass	Non-geometric	Unappealing Design		Layered Design (like soil)	
	Buttons	Resin	Triangular			Clear See-through design (like a jellyfish)	
						Internal thermal control (weather)	
						Sealed/cannot be opened (like a cocoon)	
						Silent Performance/Components (like a predator)	

Table 2: All Concepts Part 2 contained in this table

Table III: Medium Fidelity Concepts

Column1	Column2	Column3	Column4	Column5	Column6	Column7
Number	Concept					
1	Trigger Module	Trigger	Trigger Implementation			
		Digital Interpreter Circuit	ADC control (DMA recording)			
2	PC Module	Software	Language	Display	Connection	Power
		Windows	MATLAB	PC Monitor	HDMI	DC Power
3	SDR Module 1	Number of SDRs	SDR	Attentuation	Connection	Power
		Two (one receiver port)	Hack RF One	On SDR	USB	USB Power
			Adalm Pluto	On Bidirectional Coupler	Ethernet	AC Power
						Battery
4	SDR Module 2	Number of SDRs	SDR	Display	Storage	Anti Problem
		One	Hack RF One	PC monitor	Internal SDR memory	Wireless Connection to PC
			Adalm Pluto	In lab monitor devices	External (PC Hard Drive)	USB oscilloscope
					Cloud	On board display
5	Box Module	Prototype Box Material	Prototype Box Shape	Prototype Box Design	Prototype Box Size	Component Layout
		Plastic	Cubical	Open and accessible	Tight Fit (fit to the sdr's size)	Layered (like soil)

Table 3: Medium Fidelity Concepts contained in this table

Table IV: High Fidelity Concepts

Number	Concept	Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9
1	Prototype 1	Number of SDR	SDR	Attenuation	Trigger	Trigger implementation	Connection to PC	Display	Software	Language
		Two (one receiver port)	Adalm PLuto	On SDR	Digital interpeter circuit	ADC control (DMA recording)	USB 3.0	PC monitor	Windows 10	MATLAB
							VGA		Simulink	Python
2	Prototype 2	Number of SDR	SDR	Attenuation	Trigger	Trigger implementation	Connection to PC	Display	Software	Language
		Two (one receiver port)	SDRplay DUO	On Bi-dicoupler	Soldered connection	Separate circuit PCB design	USB 3.0	Plasma TV Screen	Virtual Machine on Linux	C
							HDMI		SDRuno	
3	Prototype 3	Number of SDR	SDR	Attenuation	Trigger	Trigger implementation	Connection to PC	Display	Software	Language
		One (two receiver ports)	Hack RF One	On Box cable to SDR	Input connection	Tagged Sink Block	Ethernet	CRT	SDRangel	Linux Scripts
							USB		Simulink	

Table 4: High Fidelity Concepts contained in this table

Table V: High Fidelity Concepts (Cont…)

Column10	Column11	Column12	Column13	Column14	Column15	Column16	Column17	Column18
Power	Storage	Interface	Prototype Box Material	Prototype Box Shape	Prototype Box Design	Prototype Box Size (LxWxH)	Biomimicry	Anti Problem
DC Power	External (PC Hard Drive)	Keyboard	Metals	Cubical	Open and accessible (Like a package)	Medium (10x8x4 inches)	Clear See-through design (like a jellyfish)	Wireless Connection to PC
							Silent Performance/ Components (like a cat)	
Power	Storage	Interface	Prototype Box Material	Prototype Box Shape	Prototype Box Design	Prototype Box Size (LxWxH)	Biomimicry	Anti Problem
AC Power	Internal SDR memory	Keyboard	ABS Plastic (3D Printing)	Triangular (two inputs, one output to PC)	Closed and accessible (Like a shoe box)	Small (6x3x3 inches)	Sealed/cannot be opened (like a cocoon)	USB oscilloscope
		Mouse					solid construction that can be thrown around (like a rock)	
Power	Storage	Interface	Prototype Box Material	Prototype Box Shape	Prototype Box Design	Prototype Box Size (LxWxH)	Biomimicry	Anti Problem
USB Power	Flash Drive	Switches	Wood	Hexagon	Compact (space effective)	Tight fit box (fit to the sdr's size)	Hexagon shape (like a beehive)	On board display
		Buttons					Layered Design (like soil)	

Table 5: High Fidelity Concepts (Cont…) contained in this table

Generating concepts is an important part of the design process; no matter how far-fetched they may be. After generating a large amount of concepts our prototype can use and putting together high fidelity concepts that our prototype can become, we want to choose the best possible concept for our prototype. This brings us to the next section: the Concept Selection.

Concept Selection

SECTION I: Concept Selection

1.1: Background

The Concept Selection is a process of analyzing and selecting the best ideas from among the group members. The group members brainstorm several concepts, which are then evaluated based on the probability of a concept moving forward in the design process. Although a practical concept idea would make a good choice, the creativity of the concept should also be taken into consideration when making a decision of an optimal solution. The concept selection will include select types of decision matrices like the Pugh chart, House of Quality, Pairwise Comparison methods, and others.

Note: Some Tables are hard to see in this document, contact information provided at the end of the document if Excel sheets are desired, in addition to final sheet PDFs.

SECTION II: Requirement Analysis

2.1: Background

In the Requirements Analysis phase of the project, the various inputs, outputs, and customer interfaces are defined in greater detail. The functionality of the designed system, or how the system will function is also conceived. Several tools such as the customer tradeoff matrix, which addresses tradeoffs between customer and engineering requirements or between engineering requirements themselves, is an example of the function conceived. This matrix also shows relations between requirements and customer needs.

2.2: Engineering – Customer Tradeoff Matrix

The "Engineering – Customer (Marketing) Tradeoff Matrix" identifies how the requirements of the engineering side impacts the needs of the customer and vice versa. The reasons why some polarity was chosen to be negative is because it may be undesirable to other customers if the product eventually becomes mass produced. For example, the transmission of data of received signal to PC for review is undesirable to a customer already paying a large amount for this product, and eventually should be a self-contained screen within the unit.

Table I: Marketing Matrix

Column1	Engineering Requirements	Assembly in a single prototype unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Will transmit the digital data of received signal to PC for review, analysis, and storage	Performs the software and hardware capabilities necessary while staying under budget	Must receive experiment output for analysis	Will have external storage of received data	Prototype will record, analyze and plot 600MHz to 800MHz received signals and reflected power	Will not incorporate any National Instruments components nor software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure
Customer Need	Polarity	+	+	+	+	+	-	+	+	+	+	-	+	+	+
Prototype of a single unit	+	↑↑		↓				↑	↑						↑
Fast receival of reverse signal	+		↑		↑↑	↑	↑	↑	↑		↑		↑	↑	
Reparability in case of failure	+	↑		↓				↓	↑						↑↑
Show envelope of signal at high frequencies	+		↑↑		↑	↑↑	↑	↑	↑		↑		↑↑	↑↑	
Software code/application needs to be chosen and configured for SDR connection to PC/Display	-						↓↓	↓		↑	↑	↓	↑		↑
Ability to start and stop readings (externally triggered)	+		↑	↑↑		↑		↑	↑	↑	↑				
Cost under $1000	+	↑	↑			↑		↑↑	↑	↑			↑		↑
At least one channel	+	↑	↑		↑	↑		↑	↑↑	↑	↑		↑	↑	
Run for many days/hours	+		↑			↑	↑	↑	↑	↑↑	↑				↑
Range of 600MHz to 800MHz for 1H channel	+		↑		↑	↑	↑	↑	↑		↑↑			↑	
No use of NI products	-						↓	↓				↓↓			

Table 1: Marketing Matrix elements contained in this figure

The "Engineering Tradeoff Matrix" identifies either a positive or a negative correlation by the means of self-comparison or tradeoffs between engineering requirements versus itself.

Table II: Engineering Matrix

Column1	Engineering Requirements	Assembly in a single prototype unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Will transmit the digital data of received signal to PC for review, analysis, and storage	Performs the software and hardware capabilities necessary while staying under budget	Must receive experiment output for analysis	Will have external storage of received data	Prototype will record, analyze and plot 600MHz to 800MHz received signals and reflected power	Will not incorporate any National Instruments components nor software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure
Engineering Requirements	Polarity	+	+	+	+	+	-	+	+	+	+	-	+	+	+
Assembly in a single prototype unit	+														↑
SDR will have enough bandwidth to demonstrate the envelope	+				↑		↑	↑	↑	↑	↑		↑	↑	
Prototype will be connected to an external trigger	+					↑		↑	↑	↑					
Sampling rate of the SDR will be higher than minimum value for correct scan	+						↑	↑	↑		↑			↑	
Will capture the entire sample (pulse train)	+							↑	↑	↑	↑		↑	↑	
Will transmit the digital data of received signal to PC for review, analysis, and storage	-							↑	↑↑	↑	↑		↑	↑	↑
Performs the software and hardware capabilities necessary while staying under budget	+								↑↑	↑↑	↑		↑↑	↑	↑
Must receive experiment output for analysis	+									↑	↑		↑	↑	
Will have external storage of received data	+										↑			↑	
Prototype will record, analyze and plot 600MHz to 800MHz received signals and reflected power	+												↑	↑	
Will not incorporate any National Instruments components nor software	-														
Output digital signal from prototype will have at least 8-bit resolution	+													↑	
Prototype will have several times the bandwidth of the carrier frequency of the pulse	+														
Quick access to hardware or code in software to run diagnostics on the system in case of failure	+														

Table 2: Engineering Matrix elements contained in this figure

SECTION III: House of Quality

3.1: Background

The House of Quality demonstrates the two most important relationships for concept selection: Engineering - Customer Tradeoff Matrix and Engineering Tradeoff Matrix. The former (bottom of the House) shows how Engineering Requirements relate to Customer Requirements. The top of the House shows which of the Engineering requirements have positive or negative or strong positive or negative relationships. The reason for analysis of the bottom is to have a clear vision and understanding of which Engineering Requirements that have been developed have positive or negative relationships. This graphic approach will lead to the choices that have to be made later based on the correlations between the two variables. Similar justification goes to the upper part. The relationship between Engineering Requirements shows which ones are beneficial choices that lead to strengthening the design and positive correlation, and which ones on opposite negatively affect the final performance of the product.

To start the interpretation of the House of Quality (HoQ), all possible relationships must be clearly stated. These interpretations are as follows: positive correlation (up arrow), strong positive correlation (two up arrows), negative correlation (down arrow), and strong negative correlation (two down arrows). To begin analytical discussion and interpretation of the results seen on the fundamental (bottom part) of the HoQ. The following analysis points out most critical parts of this graphical interpretation of the requirements' relationships and will be used in the final concept selection section.

Starting with the customer requirement "prototype of a single unit". This requirement has only one negative relationship with the engineering requirement "prototype will be connected to an external trigger". The reason for this choice is the integration of the trigger within the prototype. The more complex the implementation of the trigger, the harder it will be to keep the prototype as a single unit. Therefore, close attention in the selection of the trigger concept during option selection must be had. In addition to making sure that the trigger implementation will be small enough to not require a separate unit from the main one.

Moving forward from the first customer requirement (CR), the "fast receival of reverse signal" had one strong relationship, namely, with "sampling rate of the SDR will be higher than minimum value for correct scan". Therefore, it is important for final concept selection to choose the SDR with a sampling rate that is at least a double of the minimum required sampling rate. Besides this relationship, there is no place for concern in this when addressing this customer requirement due to the absence of any other negative relationships with the interpreted engineering requirements (ER).

Since the prototype will be used on a daily basis by scientists in the Magnetic Field Laboratory (MAGLAB), there is a direct CR for "repairability in case of failure". Adding to the trigger function implementation concern from the first CR, this CR also has a negative relationship with "prototype will be connected to an external trigger" ER. The reason being is if the trigger is implemented in a complicated, internal manner, the repair in case of failure becomes harder and sometimes not feasible (if the choice of the trigger is not a pin or a FPGA, which can be easily rewired or reprogrammed). Also, this CR relates negatively with the cost ER. The easier it is to repair, the more expensive are the devices used in the prototype. If the choice is made to incorporate devices of lower price, their connection might be not trivial, due to their lack of modularity, therefore the more expensive but easier to repair devices need to be considered for the final concept selection.

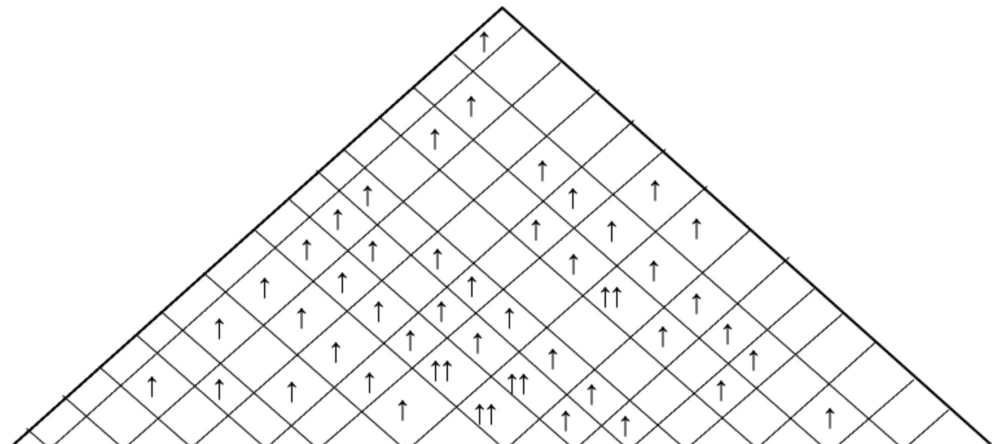
Moving on to the next CR: "show envelope of signal at high frequencies" shows the strong positive relationship with ER: "SDR will have enough bandwidth to demonstrate the envelope". This relationship tells us that the choice of SDR will be strongly impacted on the bandwidth of its receiver, which limits the selection to SDRs with high bandwidth. This derivation is supported by a strong positive relationship between "show envelope of signal at high frequencies" and "will capture the entire sample". At the same time the "show envelope of signal at high frequencies" also (third strong positive relation) relates strongly positively with "output digital data from the prototype will have at least 8-bit resolution". This can be seen as one of the largest constraints, since the lower resolutions of the SDR's analog-to-digital converter will not show the envelope of the signal at high frequencies with a resolution needed for correct tuning of the probe. As the final strong positive relation for "show envelope of signal at high frequencies" is the "prototype will have several times the bandwidth of the carrier frequency of the pulse" engineering requirement. From the observation that the former customer requirement has four strong positive relationships with the engineering requirements and no negative correlations, it can be deducted that in the selection portion for the design this customer requirement will be fully satisfied.

Continuing the analysis of the CRs brings to light the "software code/application needs to be chosen and configured for SDR connection to PC/Display" requirement. This is the one of the two CRs that has the most negative relationships with the ERs. Based on this it can be observed that the programs used to operate on the output digital data from the SDR must be selected in the manner that will carefully avoid the negative impact on the cost and NI software usage.

The following CRs have only positive relationships with the ERs which aids the designers in the concept selection since there are no negative relationships to consider. They are as follows: "ability to start and stop readings", "cost under $1000", "at least one channel", "run for many days/hours", and "range of 600 MHz to 800 MHz for 1H channel". Special attention has to be paid to the reason why the CR "cost under $1000" does not have any negative relationships with any ERs even though in most designs that is not the case. The reason for this anomaly is because SDR devices do not follow linear "the faster - the more expensive" curve. In fact, there are SDRs which cost more and have lower sampling frequencies and lower resolution ADCs. This is due to the fact that those devices with higher cost contain functions that are not particularly necessary for the application (ability to transmit analog signals, include FPGA on the board, etc.). This is why the relationship cannot be described as negative with some of the ERs. However, there are clear positive relations with high bandwidth, software capabilities and external storage since these characteristics are almost always included in any SDR (device concept) and are in the definition of the device's nature. Therefore, it was declared that the cost reduction lower than $1000 actually positively affects some of the engineering requirements that were discussed.

Finally, the second CR that has the most negative relations with ERs is "no use of NI products" requirement. It demonstrates the need to search for concepts that do not include an NI product that has capability to transmit the digital data to the PC and perform all of the software and hardware capabilities while staying under budget. The negative relationships demonstrate that this is the second hardest constraint that must be followed for the satisfaction of customer requirements.

Table III: House of Quality



Customer Requirements	Weight	Assembly in a single prototype unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Will transmit the digital data of received signal to PC for review, analysis, and storage	Performs the software and hardware capabilities necessary while staying under budget	Must receive experiment output for analysis	Will have external storage of received data	Record/Analyze/Plot 600MHz to 800MHz	Will not incorporate any National Instruments components nor software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure		
		+	+	+	+	+	-	+	+	+	+	-	+	+	+		
Prototype of a single unit	+	↑↑		↓				↑	↑						↑	> 1	1
Fast receival of reverse signal	+		↑		↑↑	↑	↑	↑	↑		↑		↑	↑		>= 11	11ns
Repairability in case of failure	+	↑		↓				↓	↑						↑↑	N/A	N/A
Show envelope of signal at high frequencies	+		↑↑		↑	↑↑		↑	↑		↑		↑↑	↑↑		> 600	800 MHz
Software code/application needs to be chosen and configured for SDR connection to PC/Display	-						↓↓	↓		↑	↑	↓	↑		↑	N/A	N/A
Ability to start and stop readings (externally triggered)	+		↑	↑↑		↑		↑	↑	↑	↑					> 1	2
Cost under $1000	+	↑	↑			↑		↑↑	↑	↑			↑		↑	<= 1k	$1k
At least one channel	+	↑	↑		↑	↑		↑	↑↑	↑	↑		↑			> 1	2
Run for many days/hours	+		↑			↑		↑	↑	↑↑	↑			↑	↑	> 7	14d
Range of 600MHz to 800MHz for 1H channel	+		↑		↑	↑		↑	↑		↑↑					> 600	800 MHz
No use of NI products	-						↓	↓				↓↓		↑		N/A	N/A
Marginal Value		> 1	> 1	> 1	>= 11	>= 11	>= 8	N/A	>= 2.5	> 7	> 600	N/A	>= 8	> 600	N/A		
Ideal Value		1	1Hz	2	11ns	11ns	8bits	N/A	2.5dBm	14days	800MHz	N/A	8bits	800MHz	N/A		

Table 3: House of Quality elements contained in this figure

SECTION IV: Pugh Chart

4.1: Background

The Pugh Chart is a concept selection method that sheds light on which concept is the most promising. It is relatively easy to use, and it compares concepts versus criteria. It is a chart with a matrix base where the rows represent criteria and the columns represent concepts or designs in order to weigh out all the options. In the designs, which include close relationships between several requirements, there is a procedure to be done which includes creating multiple Pugh charts, choosing the best option from the first chart and then using that option in the following chart. This is not the case scenario in the Concept Selection. Since most criteria have a wide spread of relationships among each other and would interconnect poorly. The Pugh chart will be created based on the normalized weights from the pairwise comparison.

Table IV: Pugh Chart

		Option 1	Option 2	Option 3
No National Instruments components or software	7	-	-	-
Output digital signal from prototype will have at least 8-bit resolution	6	-	1	-1
Range of 600-800MHz for received and reflected signals	6	-	1	1
Sampling rate of the SDR will be higher than minimum value for correct scan	5	-	-1	-1
Prototype will have several times the bandwidth of the carrier frequency of the pulse	5	-	-1	-
Will capture the entire sample (pulse train)	5	-	-	-
Quick access to hardware or code in software to run diagnostics on the system in case of failure	4	-	-1	-1
SDR will have enough bandwidth to demonstrate the envelope	3	-	-	-
Prototype will be connected to an external trigger	3	-	1	1
Transmit data signal to PC for review, analysis, and storage	3	-	-	-1
Receive experiment output for analysis	2	-	-	-
External Storage of received data	2	-	-1	-1
Performs the software and hardware capabilities necessary while staying under budget	1	-	-	-
Assembled in a single unit	1	-	-	-
Score		-	-1	-11
Continue?		Yes	No	No

Table 4: Pugh Chart elements contained in this figure

4.2: Chart Outcome

In order to analyze the Pugh outcome, there are some necessary things to consider. If normalized sorted weights are displayed and only three significant figures are considered for comparison (due to similarity of shorter values), then the range of 0.006 is chosen to be considered for equivalent importance. Criteria was made that is present in the second column of the Pugh chart shown in “Table IV”. The category weights are distributed as done in the Pairwise Comparison in the next section from 1 (equally important) to 7 (very much more important). Option 1 from Concept Generation was determined to be the reference for the Pugh chart choices of weighted comparison values due to the fact that this option was closest to the ideal implementation of the design. The next two columns of the Pugh chart include Option 2 and Option 3, which were both rated with respect to the reference model. If the choice in the option is better based on the criteria – the positive 1 is assigned. If the choice is worse – the negative 1 is assigned.

The score at the bottom of the chart represents the sum of multiplications between the criteria, and the value assigned by the team to that option’s choice. If the result was positive the “Continue?” statement was awarded a “Yes”. Oppositely, if the result was negative the output was a “No”. Since both Option 2 and Option 3 were awarded a “No” based on the negative scores, the Pugh chart demonstrates that the most optimal choice for the concept selection is Option 1. Option 1 pertained to the Adalm-Pluto SDR, Option 2 pertained to the PlayDUO SDR, and Option 3 pertained to the HackRF One.

SECTION V: Pairwise Comparison

5.1: Background

Pairwise Comparison is a systematic way to compare criteria and requirements to assign weights to the requirements. Each row is compared to each column to determine the importance of one criterion to another. Along the diagonal in the middle is all ones, this is because the criterions are equally matched with themselves. From there, each value's inverse should reflect along this diagonal in relevance to the importance of the comparing criterions.

Once all the above information has been gathered, one can start to see where the importance lies, or which criterions need to have priority in the project. It is easier to see once the geometric mean of each row is calculated. From the geometric mean, the weight of each criterion is then determined. The criterion with the highest value for the weights need to be prioritized more than that of the weights with the lower values.

Table V: Pairwise Comparison

	Performs the software and hardware capabilities necessary while staying under budget	Assembled in a single unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Transmit data signal to PC for review, analysis, and storage	Receive experiment output for analysis	External Storage of received data	Range of 600-800MHz for received and reflected signals	No National Instruments components or software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure		Geometric Mean	Normal Weight
Performs the software and hardware capabilities necessary while staying under budget	1	1	1/2	1/2	1/5	1/5	1/2	1	1/2	1/5	1/7	1/5	1/5	1/3		0.37	0.021
Assembled in a single unit	1	1	1/3	1/3	1/5	1/5	1/2	1/2	1/2	1/2	1/7	1/5	1/5	1/3		0.33	0.019
SDR will have enough bandwidth to demonstrate the envelope	2	3	1	1	1/2	1/2	1	2	2	1/3	1/5	1/3	1/2	1/2		0.78	0.044
Prototype will be connected to an external trigger	2	3	1	1	1/2	1/2	1	1	3	1/3	1/5	1/3	1/2	1/3		0.75	0.042
Sampling rate of the SDR will be higher than minimum value for correct scan	5	5	2	2	1	2	2	3	3	1	1/3	1	2	2		1.83	0.103
Will capture the entire sample (pulse train)	5	5	2	2	1/2	1	3	3	3	1	1/2	1	1	2		1.67	0.094
Transmit data signal to PC for review, analysis, and storage	2	2	1	1	1/2	1/3	1	1	2	1/3	1/5	1/3	1/3	1/2		0.68	0.038
Receive experiment output for analysis	1	2	1/2	1	1/3	1/3	1	1	1	1/5	1/7	1/5	1/3	1/3		0.51	0.028
External Storage of received data	2	2	1/2	1/3	1/3	1/3	1/2	1	1	1/5	1/7	1/5	1/5	1/3		0.45	0.025
Range of 600-800MHz for received and reflected signals	5	5	3	3	1	1	3	5	5	1	1/2	1	1	2		2	0.112
No National Instruments components or software	7	7	5	5	3	2	5	7	7	2	1	2	2	3		3.51	0.197
Output digital signal from prototype will have at least 8-bit resolution	5	5	3	3	1	1	3	5	5	1	1/2	1	1	2		2	0.112
Prototype will have several times the bandwidth of the carrier frequency of the pulse	5	5	2	2	1/2	1	3	3	5	1	1/2	1	1	2		1.74	0.097
Quick access to hardware or code in software to run diagnostics on the system in case of failure	3	3	2	3	1/2	1/2	2	3	3	1/2	1/3	1/2	1/2	1		1.18	0.066
Sum	46	49	23.83	25.17	10.07	10.9	26.5	36.5	41	9.3	4.84	9.3	10.77	16.67			

Table 5: Pairwise Comparison elements contained in this figure

Table V.I: Sorted Weights for Pairwise Comparison

Sorted Weights	
No National Instruments components or software	0.197
Output digital signal from prototype will have at least 8-bit resolution	0.112
Range of 600-800MHz for received and reflected signals	0.112
Sampling rate of the SDR will be higher than minimum value for correct scan	0.103
Prototype will have several times the bandwidth of the carrier frequency of the pulse	0.097
Will capture the entire sample (pulse train)	0.094
Quick access to hardware or code in software to run diagnostics on the system in case of failure	0.066
SDR will have enough bandwidth to demonstrate the envelope	0.044
Prototype will be connected to an external trigger	0.042
Transmit data signal to PC for review, analysis, and storage	0.038
Receive experiment output for analysis	0.028
External Storage of received data	0.025
Performs the software and hardware capabilities necessary while staying under budget	0.021
Assembled in a single unit	0.019

Table 5.1: Sorted Weights elements contained in this figure

Table V.II: Normalized Table for Weights

Normalized Table for Criteria Weight

	Performs the software and hardware capabilities necessary while staying under budget	Assembled in a single unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Transmit data signal to PC for review, analysis, and storage	Receive experiment output for analysis	External Storage of received data	Range of 600-800MHz for received and reflected signals	No National Instruments components or software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure		Criteria Weight (W)	Weight Sum Vector W,	Consistency vector
Performs the software and hardware capabilities necessary while staying under budget	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.01	0.02	0.03	0.02	0.02	0.02		0.02	0.298	14.324
Assembled in a single unit	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.03	0.02	0.02	0.02		0.02	0.269	14.283
SDR will have enough bandwidth to demonstrate the envelope	0.04	0.06	0.04	0.04	0.05	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.05	0.03		0.04	0.627	14.323
Prototype will be connected to an external trigger	0.04	0.06	0.04	0.04	0.05	0.05	0.04	0.03	0.07	0.04	0.04	0.04	0.05	0.02		0.04	0.613	14.312
Sampling rate of the SDR will be higher than minimum value for correct scan	0.11	0.1	0.08	0.08	0.1	0.18	0.08	0.08	0.07	0.11	0.07	0.11	0.19	0.12		0.11	1.52	14.406
Will capture the entire sample (pulse train)	0.11	0.1	0.08	0.08	0.05	0.09	0.11	0.08	0.07	0.11	0.1	0.11	0.09	0.12		0.09	1.347	14.335
Transmit data signal to PC for review, analysis, and storage	0.04	0.04	0.04	0.04	0.05	0.03	0.04	0.03	0.05	0.04	0.04	0.04	0.03	0.03		0.04	0.548	14.352
Receive experiment output for analysis	0.02	0.04	0.02	0.04	0.03	0.03	0.04	0.03	0.02	0.02	0.03	0.02	0.03	0.02		0.03	0.409	14.33
External Storage of received data	0.04	0.04	0.02	0.01	0.03	0.03	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02		0.03	0.37	14.215
Range of 600-800MHz for received and reflected signals	0.11	0.1	0.13	0.12	0.1	0.09	0.11	0.14	0.12	0.11	0.1	0.11	0.09	0.12		0.11	1.595	14.407
No National Instruments components or software	0.15	0.14	0.21	0.2	0.3	0.18	0.19	0.19	0.17	0.22	0.21	0.22	0.19	0.18		0.2	2.822	14.426
Output digital signal from prototype will have at least 8-bit resolution	0.11	0.1	0.13	0.12	0.1	0.09	0.11	0.14	0.12	0.11	0.1	0.11	0.09	0.12		0.11	1.595	14.407
Prototype will have several times the bandwidth of the carrier frequency of the pulse	0.11	0.1	0.08	0.08	0.05	0.09	0.11	0.08	0.12	0.11	0.1	0.11	0.09	0.12		0.1	1.399	14.356
Quick access to hardware or code in software to run diagnostics on the system in case of failure	0.07	0.06	0.08	0.12	0.05	0.05	0.08	0.08	0.07	0.05	0.07	0.05	0.05	0.06		0.07	0.966	14.41

Table 5.2: Sorted Weights elements contained in this figure

Table V.III: Consistency Check

Avg of Consis Vector, λ	Consistency Index	Consistency Ratio (n = 14, RI = 1.57)
14.349	0.027	0.0171

Table 5.3: Consistency Check elements contained in this figure

SECTION VI: Analytical Hierarchy Process

6.1: Background

The Analytical Hierarchy Process is a systematic process of choosing the best design option based on numbers. It works similarly to a Pugh Chart and Pairwise Comparison combined. The final table shown below works similarly to the Pugh Chart by giving each option a "better-or-worse" score and totaling the score based on the attributed weights to the criteria. The Pairwise Comparison element works to give each option its score. Using the pairwise comparison for each criterion, we compare each design option to give a proper, calculated score.

Use the weights from the Pairwise Comparison for the design options. Next, using the Priority Ratings from the comparisons, shown in the Table VI.XV: "AHP Extensions Combined", the ratings for each option is multiplied by the weight of the criteria. For example, the first column of Table VI.XV is multiplied by the weight of "No National Instruments components or software" to get the corresponding score for each option in that criteria. When all columns are filled out, sum up the scores in the columns to score the designs. Once the designs are scored, the scores are compared to determine the best design options for the project. Here, Design Option 1 featuring the Adalm Pluto SDR is the best design choice based on its score.

However, there are other non-calculated reasons as to why Option 1 is the best choice for this project. The Pluto features a plethora of documentation and previous projects that may prove to be useful for this project regarding collecting data, syncing multiple SDRs, and getting it to function as an oscilloscope for radio frequency (RF) signals. In addition, the Pluto supports more software and languages than the SDRplay Duo and HackRF One, making it more versatile and providing more avenues to traverse in the event one turns out to not be feasible. Because of these extra features, option 1 featuring the Adalm Pluto is the best choice for this project.

Table VI: Analytical Hierarchy Process (AHP)

	W	Option 1	Option 2	Option 3
No National Instruments components or software	0.197	0.066	0.066	0.066
Output digital signal from prototype will have at least 8-bit resolution	0.112	0.044	0.075	0.023
Range of 600-800MHz for received and reflected signals	0.112	0.023	0.044	0.075
Sampling rate of the SDR will be higher than minimum value for correct scan	0.103	0.069	0.023	0.038
Prototype will have several times the bandwidth of the carrier frequency of the pulse	0.097	0.043	0.022	0.043
Will capture the entire sample (pulse train)	0.094	0.031	0.031	0.031
Quick access to hardware or code in software to run diagnostics on the system in case of failure	0.066	0.044	0.026	0.013
SDR will have enough bandwidth to demonstrate the envelope	0.044	0.015	0.015	0.015
Prototype will be connected to an external trigger	0.042	0.009	0.019	0.019
Transmit data signal to PC for review, analysis, and storage	0.038	0.017	0.017	0.009
Receive experiment output for analysis	0.028	0.009	0.009	0.009
External Storage of received data	0.025	0.017	0.01	0.005
Performs the software and hardware capabilities necessary while staying under budget	0.021	0.014	0.008	0.004
Assembled in a single unit	0.019	0.012	0.007	0.004
Score		0.413	0.371	0.354

Table 6: Analytical Hierarchy Process elements contained in this figure

Table VI.I: AHP Extension(s) 1

No National Instruments components or software				
Column1	Option 1	Option 2	Option 3	Prioty
Option 1	1	1	1	0.33
Option 2	1	1	1	0.33
Option 3	1	1	1	0.33

Table 6.1: Analytical Hierarchy Process elements contained in this figure

Table VI.II: AHP Extension(s) 2

Output digital signal from prototype will have at least 8-bit resolution				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1/2	2	0.39
Option 2	2	1	3	0.67
Option 3	1/2	1/3	1	0.2

Table 6.2: Analytical Hierarchy Process elements contained in this figure

Table VI.III: AHP Extension(s) 3

Range of 600-800MHz for received and reflected signals				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1/2	1/3	0.2
Option 2	2	1	1/2	0.39
Option 3	3	2	1	0.67

Table 6.3: Analytical Hierarchy Process elements contained in this figure

Table VI.IV: AHP Extension(s) 4

Sampling rate of the SDR will be higher than minimum value for correct scan				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	3	0.67
Option 2	1/2	1	1/2	0.22
Option 3	1/3	2	1	0.37

Table 6.4: Analytical Hierarchy Process elements contained in this figure

Table VI.V: AHP Extension(s) 5

Prototype will have several times the bandwidth of the carrier frequency of the				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	1	0.44
Option 2	1/2	1	1/2	0.22
Option 3	1	2	1	0.44

Table 6.5: Analytical Hierarchy Process elements contained in this figure

Table VI.VI: AHP Extension(s) 6

Will capture the entire sample (pulse train)				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1	1	0.33
Option 2	1	1	1	0.33
Option 3	1	1	1	0.33

Table 6.6: Analytical Hierarchy Process elements contained in this figure

Table VI.VII: AHP Extension(s) 7

Quick access to hardware or code in software to run diagnostics on the system				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	3	0.67
Option 2	1/2	1	2	0.39
Option 3	1/3	1/2	1	0.2

Table 6.7: Analytical Hierarchy Process elements contained in this figure

Table VI.VIII: AHP Extension(s) 8

SDR will have enough bandwidth to demonstrate the envelope				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1	1	0.33
Option 2	1	1	1	0.33
Option 3	1	1	1	0.33

Table 6.8: Analytical Hierarchy Process elements contained in this figure

Table VI.IX: AHP Extension(s) 9

Prototype will be connected to an external trigger				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1/2	1/2	0.22
Option 2	2	1	1	0.44
Option 3	2	1	1	0.44

Table 6.9: Analytical Hierarchy Process elements contained in this figure

Table VI.X: AHP Extension(s) 10

Transmit data signal to PC for review, analysis, and storage				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1	2	0.44
Option 2	1	1	2	0.44
Option 3	1/2	1/2	1	0.22

Table 6.10: Analytical Hierarchy Process elements contained in this figure

Table VI.XI: AHP Extension(s) 11

Receive experiment output for analysis				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1	1	0.33
Option 2	1	1	1	0.33
Option 3	1	1	1	0.33

Table 6.11: Analytical Hierarchy Process elements contained in this figure

Table VI.XII: AHP Extension(s) 12

External Storage of received data				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	3	0.67
Option 2	1/2	1	2	0.39
Option 3	1/3	1/2	1	0.2

Table 6.12: Analytical Hierarchy Process elements contained in this figure

Table VI.XIII: AHP Extension(s) 13

Performs the software and hardware capabilities necessary while staying				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	3	0.67
Option 2	1/2	1	2	0.39
Option 3	1/3	1/2	1	0.2

Table 6.13: Analytical Hierarchy Process elements contained in this figure

Table VI.XIV: AHP Extension(s) 14

Assembled in a single unit				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	3	0.67
Option 2	1/2	1	2	0.39
Option 3	1/3	1/2	1	0.2

Table 6.14: Analytical Hierarchy Process elements contained in this figure

Table VI.XV: AHP Extensions Combined

Column1	P1	P2	P3
1	0.33	0.33	0.33
2	0.39	0.67	0.2
3	0.2	0.39	0.67
4	0.67	0.22	0.37
5	0.44	0.22	0.44
6	0.33	0.33	0.33
7	0.67	0.39	0.2
8	0.33	0.33	0.33
9	0.22	0.44	0.44
10	0.44	0.44	0.22
11	0.33	0.33	0.33
12	0.67	0.39	0.2
13	0.67	0.39	0.2
14	0.67	0.39	0.2

Table 6.15: Analytical Hierarchy Process elements contained in this figure

SECTION VII: Final Concept Selection

7.1: Background

The final concepts were selected via the following figure:

Figure I: Concept Selection Flowchart

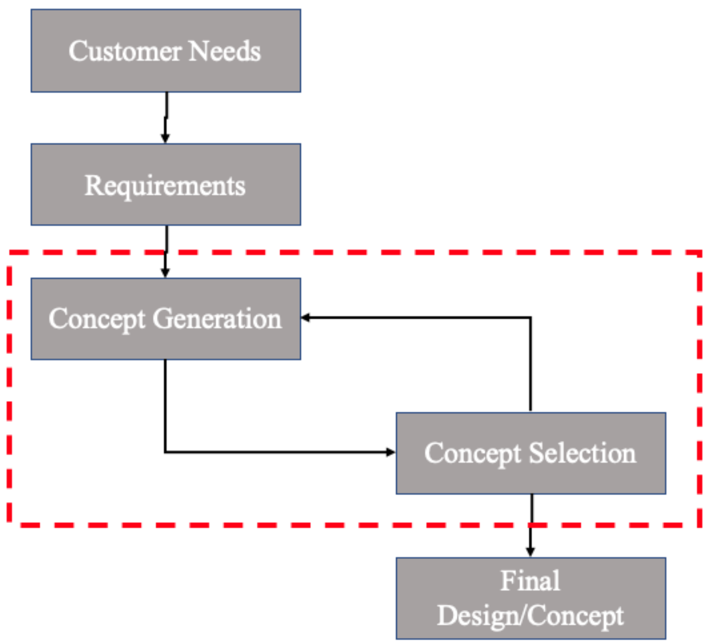


Figure 1: Concept Selection Flowchart elements contained in this figure

This figure provides a flowchart which allows for the team to consider all the possible choices generated at the time of Concept Generation, and then consider one by one before landing on a final selection. This often in return means referencing the tables that were globally obtained in the Concept Selection stage and approving such choice or going back to weigh the outcome of a different Concept from the Generation. Using this flowchart, the components of the final prototype can be well determined, in effect creating a quantitative and satisfactory product.

7.2: Summary

The outcome of the tables (charts) were discussed in their prospective backgrounds or after the table was posted whilst still in that section. That concludes the preparation steps necessary to take in order to evaluate side-by-side correlations within each "molecule" or component in the project. The dissection of concepts and criteria poses a nice benefit, which is to add to the high-fidelity concepts explored in the concept selection phase by evaluating each, as discussed in "Section 7.2" in return making the final concepts a level above high (i.e. extra credit after an assignment already has achieved an A).

The final concept was generated via critical team thinking, weighing out the many outcomes that can be seen in the tables, and following the flowchart discussed previously. Through the Marketing and Engineering Matrices, the HoQ, Pugh Chart, Pairwise Comparison, and lastly the Analytical Hierarchy Process the final concept can be calculated.

From looking at the Concept Generation high fidelity options and the methodologies introduced above the team can then select precise components for the project. From the HoQ, derived from the Marketing and Engineering Matrices (which was extensively discussed in "Section 3") direct positive and negative correlations can be obtained for the final concept selection since it is known what the expected performance will be.

From the HoQ, it was finalized that only one SDR will be necessary, one that contains two channels and defeats the other options as observed in the Pugh chart. This SDR was chosen to be the Adalm-Pluto SDR, the concept selection was also taking into account the sampling rate that is at least double the minimum required sampling rate. The trigger implementation, keeping in mind the things discussed from the HoQ, was carefully thought of to be externally triggered via a separate Printed Circuit Board (PCB) that will be included in the prototype box and likely to be directly soldered onto the SDR itself. In addition to this, the software chosen will be MATLAB in order to have a backup plan as a software trigger in lieu of potential failure. The negative result due to this choice may be a harder repairability function in case of failure, but when weighed out against the satisfaction of achieving the customer's needs it is crucial to make these tough decisions. Other decisions that were made after determining the sacrifice of easy repairability (by looking at correlations and the medium high hierarchy weight) in order to keep that desirable cost low was choosing devices of lower price. To further expand on this idea, a budget of two-thousand dollars was allocated to this project but nearly a little over a fourth of the budget was used to order parts. Additional things satisfied via these selections include "ability to start and stop readings", "cost under $1000", "at least one channel", "run for many days/hours", and "range of 600 MHz to 800 MHz for 1H channel". The extra functionalities of other choices would provide things that are outside the scope of this project (i.e. higher cost, higher channel count or resolution).

In the Pugh Chart section, the outcome was extensively discussed. The choice in the previous paragraph from this outcome was "Option 1" the Adalm-Pluto SDR. As a means to keep the summary short, there are no other things to discuss that the Pugh chart helped choose for the final selection besides enforcing that the team made the correct choice. As an additional thing to mention however, from the concept selection knowing that the Adalm-Pluto will be the SDR of choice, the team can cut down all connections to PC via USB, since that is the one that works with that SDR selection. The selection of the SDR was the most important aspect of the concept selection, as most other concepts concatenate to this tremendous decision. For this exact reason, other decisions can be finalized. Some include: the attenuators needed to abide by the RF thresholds from the Pluto, a connection to power is used through USB connection via about 500mA, choice of internal SDR and if necessary a MATLAB function implementing a circular buffer, and a keyboard interface to work with the computer attached to the SDR. The selection of prototype box shape conceptually will be obtained during the prototyping phase, since this is dependent on the other selections previously mentioned. It is important to note that the assembly in a single unit has the lowest weight (obtained from this next section).

From the Pairwise Comparison, the weights provide the teams choices verifiable. In other words, these weights can be sorted after the chart has been normalized in order to view the grade-scale quantitatively of each engineering requirement. As a result of the pairwise comparison, the decision to satisfy the Sponsor and abide by avoiding National Instrument components was achieved.

Finally, from the Analytical Hierarchy Process (AHP), it can be observed that the Pairwise Comparison step is crucial. The normalization of the Pairwise Comparison table, obtained from the HoQ and Pugh Table observations, and its consistency check derive the weights for the AHP. Within its section itself, the AHP is extensively discussed. It can be observed that the hierarchy obtained positively reinforced all the choices thus far.

Given the entirety of this section, the variables considered, data acquired, criteria generated, and careful selection and analysis; the team stands in a comfortable place to say the official concept selection can come to a conclusion. The aforementioned points brought to attention should not be taken lightly as they “drive the gears” to mobilize this project and allow for the prototyping or design phase to begin. This allows us to move to the largest planning stage: the Spring Project Plan.

Spring Project Plan

SECTION I: Intro

The workflow provided in the next section takes some of the key concepts learned from the Work Breakdown Structure completed earlier in the semester. Since next semester's plan is still abstract due to the small amount of information provided, it voids the task descriptions and instead focuses on a well-designed balance for effective teamwork.

It is important to note that all course deliverables are planned and expected to be delivered one week ahead of the due dates. In addition, there are the following encodings embedded in the table for organization purposes (Workflow table, Gantt, and Microsoft Teams Tasks):

- "Assignment" encoding: **Course Deliverables (D)** are highlighted in **Blue** and the **Team Implementation Tasks (I)** are highlighted in **Red** as main colors. Additionally, **PARALLEL** workflows where multiple sub-teams work at the same time are highlighted in **Green** and **LINEAR** workflows where everyone works together are highlighted in **Yellow** as sub-colors.
- "Due Date" encoding: **Solid Deadlines** (must have finished) are **Bold** and *Soft Deadlines* (open for discussion, sharing, or team choices) are *Italicized*.
- "Flow" encoding: I/D("Assignment" Encoding)_P(Week #)_(Team #) is equivalent to a **PARALLEL** workflow and I/D("Assignment" Encoding)_L(Week #) is equivalent to a **LINEAR** workflow.

SECTION II: Workflow

Table I: Workflow

Assignment	Working Period	Length (Weeks)	Due Date	Due Week #	Flow
Research In-Out Software	01/06-01/10	5 or 7	*Friday January 8*	1	I_P1_1
Dr. Brey's Tools Request	01/06-01/08	3 or 7	Friday January 8	1	I_P1_2
Pluto Testbench Set-Up-1 (1 SDR)	01/11-01/17	1	Friday January 17	2	I_P2_1
Hack RF Testbench Set-Up-1 (1 SDR)	01/11-01/17	1	Friday January 17	2	I_P2_2
Updated Risk Assessment	01/11-01/22	2	Friday January 22	3	D_P1_1
Testbench Set-Up-2 (2 SDRs)	01/18-01/24	1	Friday January 22	3	I_P3_1
Design Review 1	01/18-01/29	2	Friday January 29	4	D_P1_2
Trigger Implementation Research (Software)	01/25-01/29	1	Friday January 29	4	I_P4_1
Trigger Implementation Research (Hardware)	01/25-01/29	1	Friday January 29	4	I_P4_2
Trigger Implementation Research (Combination)	01/25-01/29	1	Friday January 29	4	I_P4_3
Implement Trigger-1 (1 SDR)	02/01-02/14	2	Friday February 12	5 or 6	I_L5 or I_L6
Implement Trigger-2 (2 SDR)	02/16-02/21	6 or 7	Friday February 19	7	I_P7_1
DC Power Supply Research	02/22-02/28	1	Friday February 26	8	I_P7_2
Testing and Validation	02/16-02/26	2	Friday February 26	8	D_P2_1
Assemble Initial Complete Design (ICD)	03/01-03/07	1	Friday March 5	9	I_L9
Design Review 2	02/22-03/05	2	Friday March 5	9	D_P2_2
Circular Testing_1 (ICD)	03/08-03/14	1	Friday March 12	10	I_L10
Circular Testing_2 (ICD)	03/15-03/21	1	Friday March 19	11	I_P11_1
CAD 3D Model Generation	03/15-03/21	1	Friday March 19	11	I_P11_2
Scholarship in Practice	03/08-03/19	2	Friday March 19	11	D_L3_1
Circular Testing_3 (ICD)	03/22-03/28	1	Friday March 26	12	I_P12_1
Final 3D Model to Machine Shop	03/22-03/28	1	Friday March 26	12	I_P12_2
Test ICD with MagLab Equipment	03/22-03/28	1	Friday March 26	12	I_P12_3
Assemble Final Complete Design (FCD)	03/29-04/04	1	Friday April 2	13	I_L13
Operation Manual	03/22-04/02	2	Friday April 2	13	D_P4_1
Test FCD with MagLab Equipment	04/05-04/11	1	Friday April 9	14	I_P14_1
Final Demo Preparation	04/05-04/11	1	Friday April 9	14	I_P14_2
Final Presentation	04/05-04/09	2	Friday April 9	14	D_P4_2
Prototype Demonstration	04/05-04/12	1	Monday April 12	15	D_P4_3
Engineering Design Day	04/05-04/11	1	*TBD*	15	D_L15
Final Report	03/29-04/19	3	Monday April 19	16	D_P4_ALL
Final Exams	04/19-04/23	1	N/A	16	D_L16
Graduation Day	04/19-04/23	1	Friday April 23	16	D_L16

Table 1: Workflow elements contained in this figure

SECTION III: Gantt Chart

The following is for overview purposes of the Spring Project Plan created, using TeamGantt (free online software).

Figure I: Gantt Chart (January)

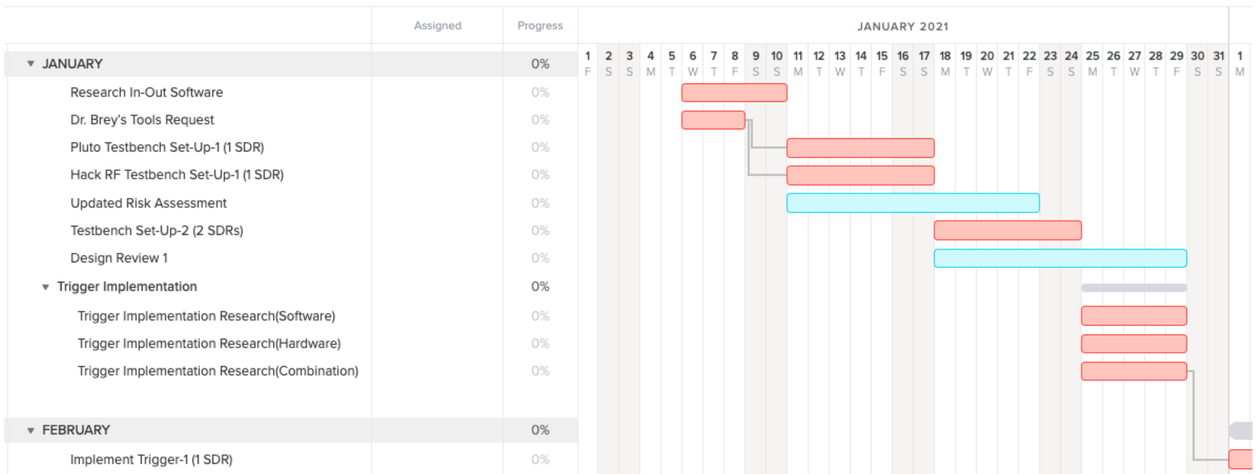


Figure 1: Gantt Chart elements contained in this figure

Figure II: Gantt Chart (February)

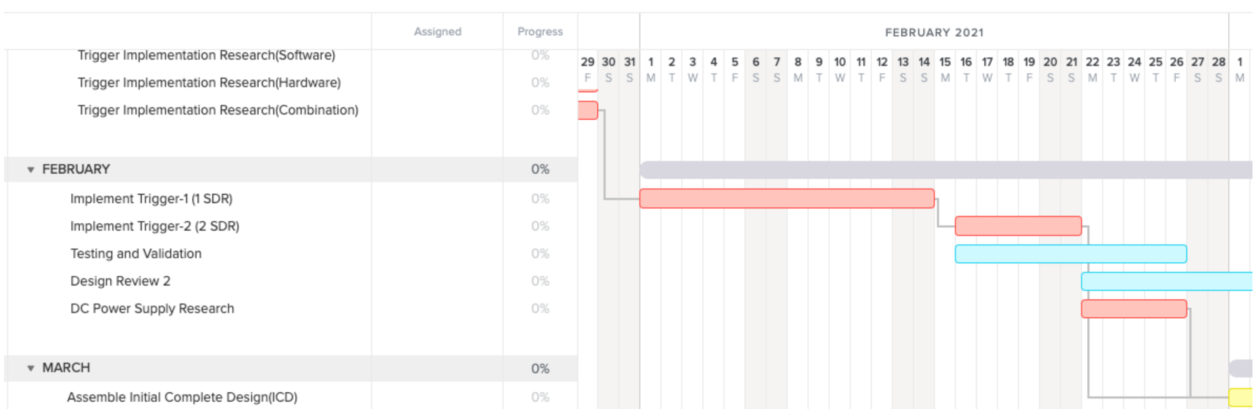


Figure 2: Gantt Chart elements contained in this figure

Figure III: Gantt Chart (March)

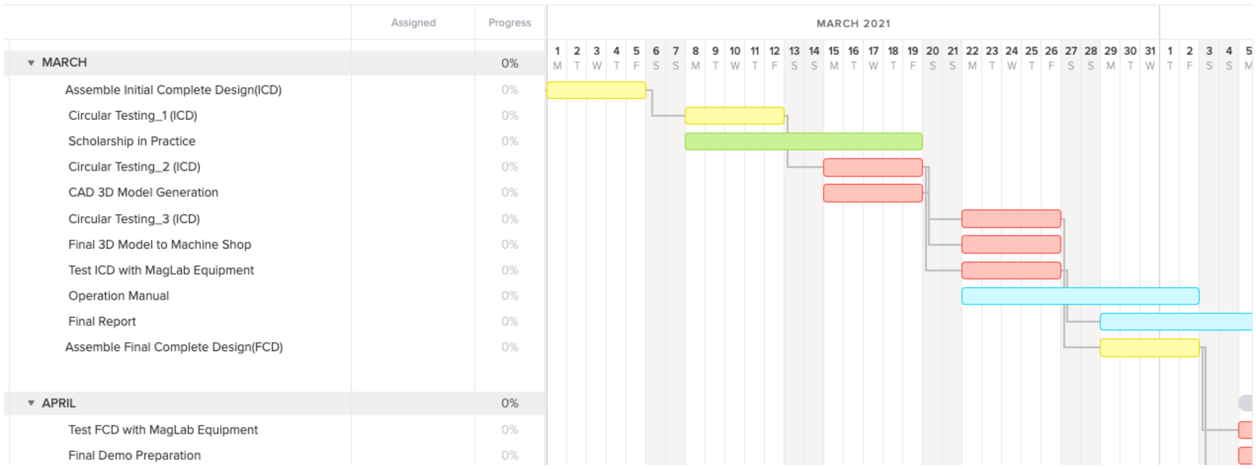


Figure 3: Gantt Chart elements contained in this figure

Figure IV: Gantt Chart (April)

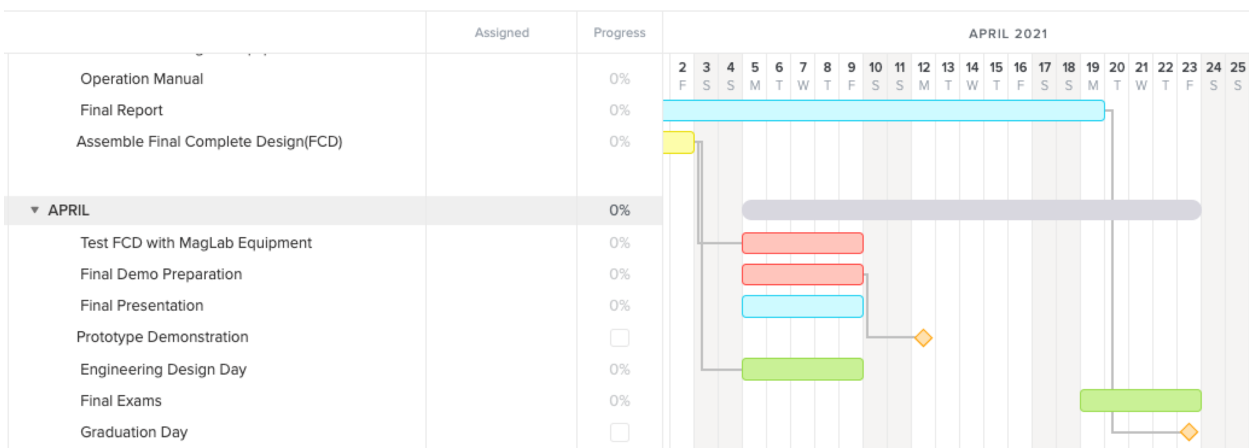


Figure 4: Gantt Chart elements contained in this figure

SECTION IV: Monthly Overview

The following is for overview purposes of the Spring Project Plan created, using MS Teams Planner.

Figure V: Monthly Overview (January)

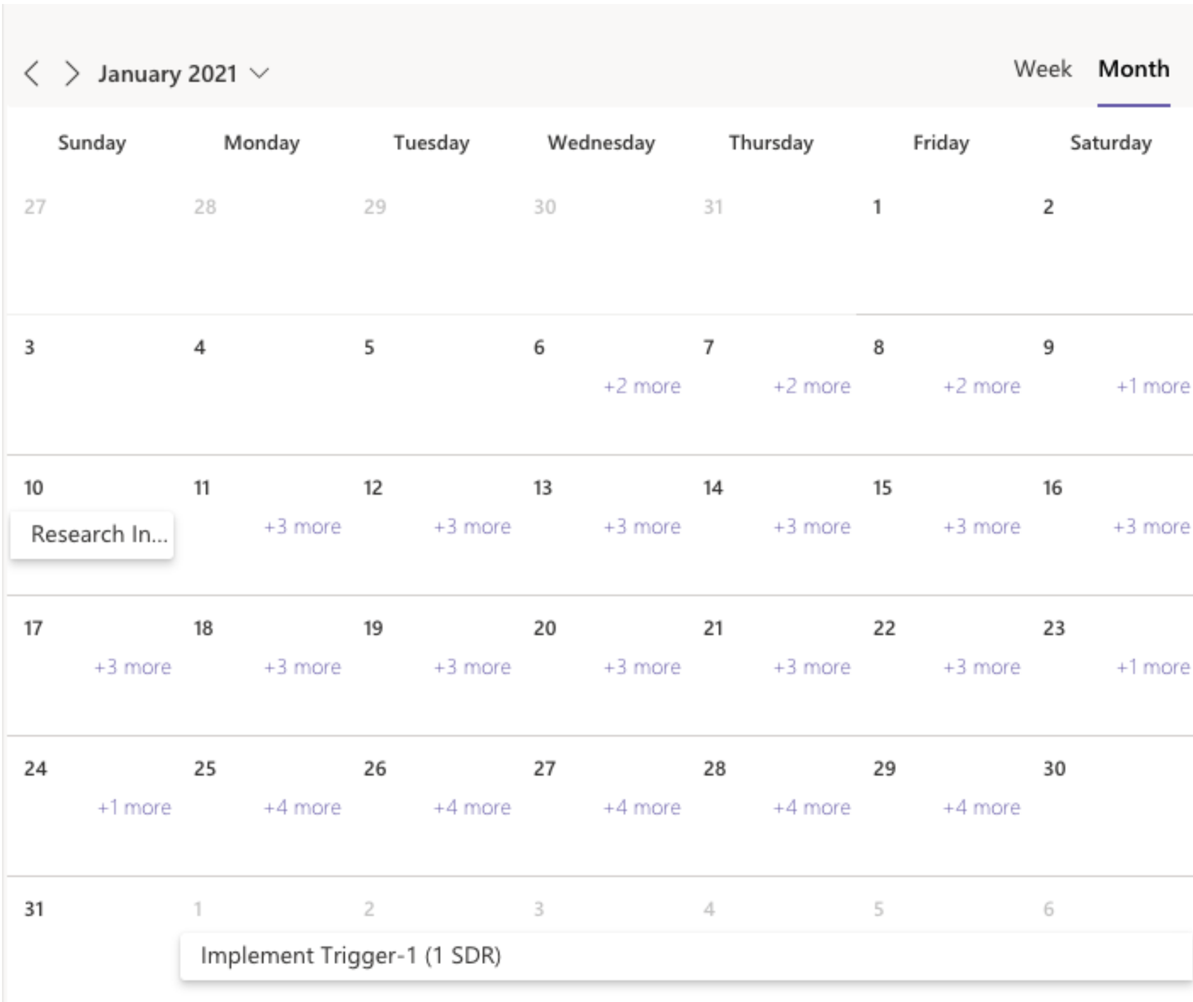


Figure 5: Monthly Overview elements contained in this figure

Figure VI: Monthly Overview (February)

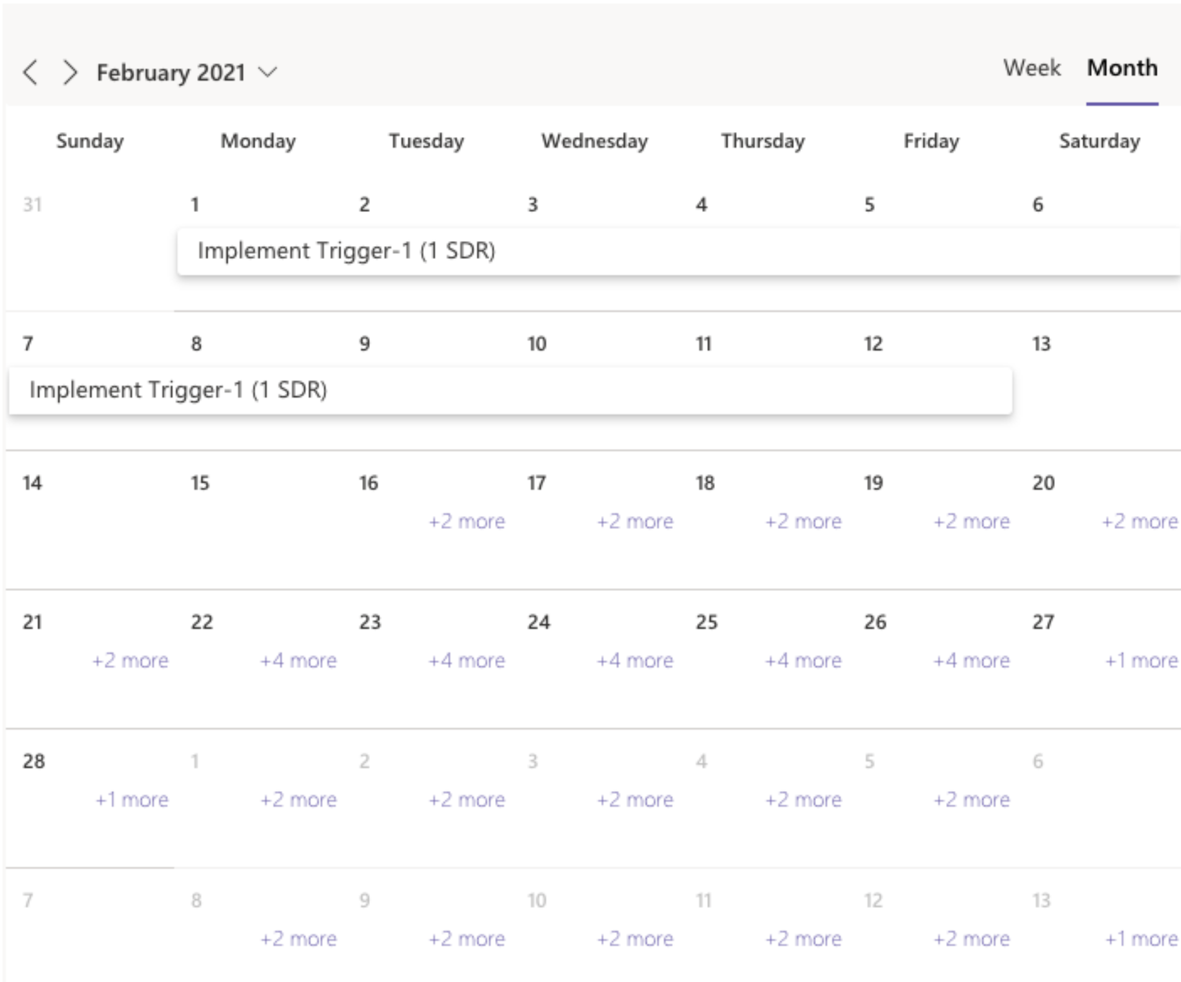


Figure 6: Monthly Overview elements contained in this figure

Figure VII: Monthly Overview (March)

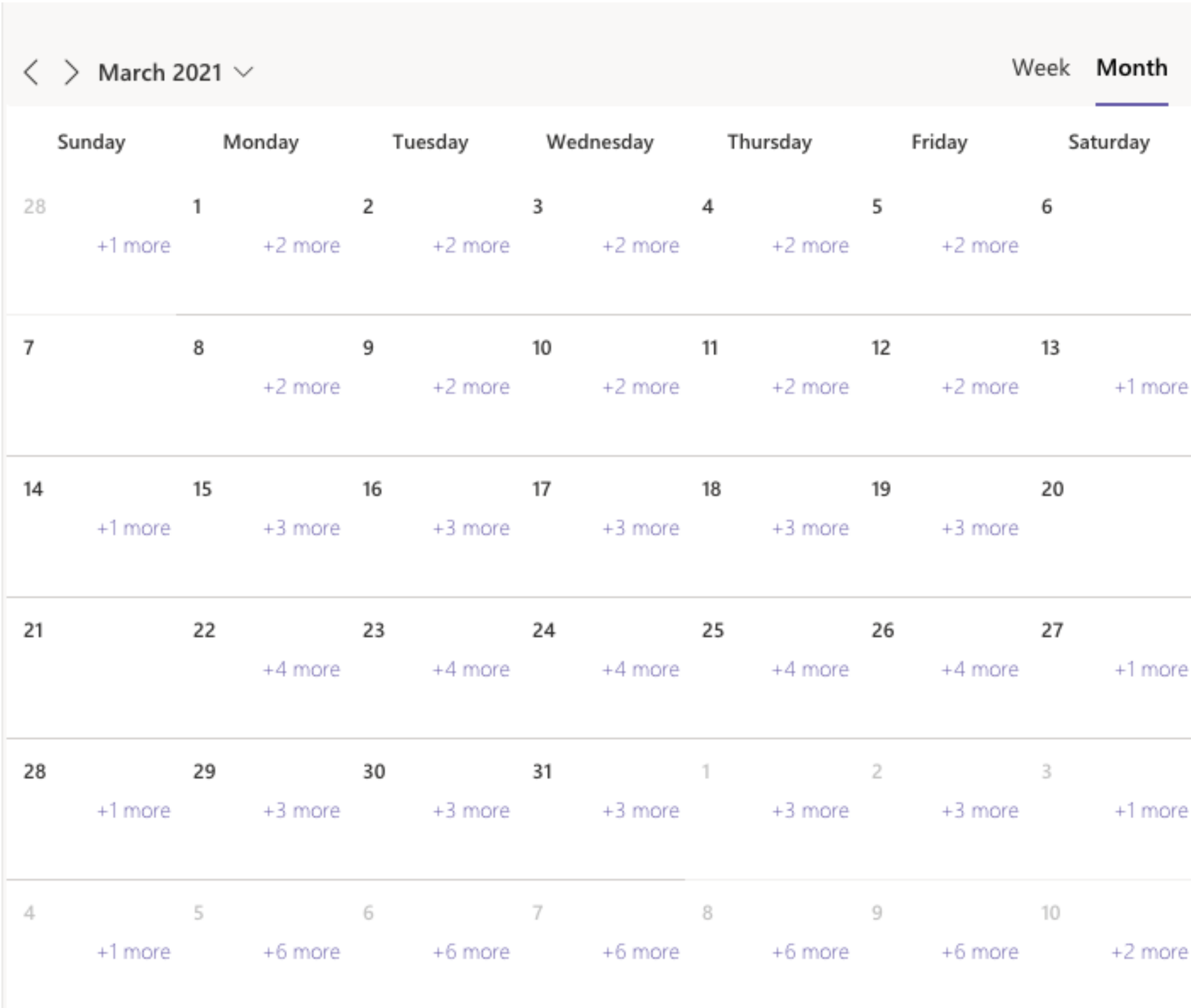


Figure 7: Monthly Overview elements contained in this figure

Figure VIII: Monthly Overview (April)

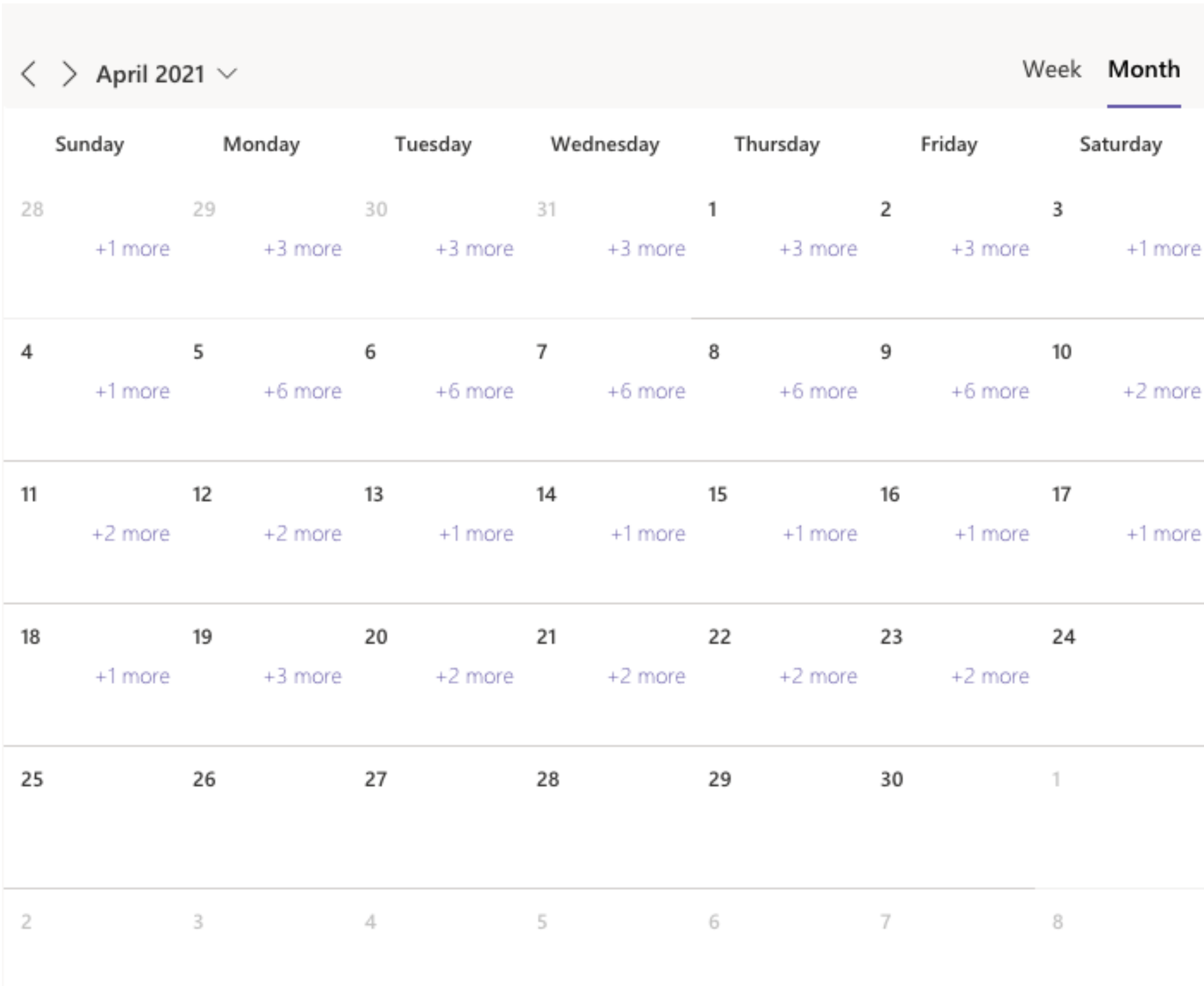


Figure 8: Monthly Overview elements contained in this figure

SECTION V: Weekly Overview

The following is for (weekly) overview purposes of the Spring Project Plan created, using MS Teams Planner.

Figure IX: Weekly Overview (January)

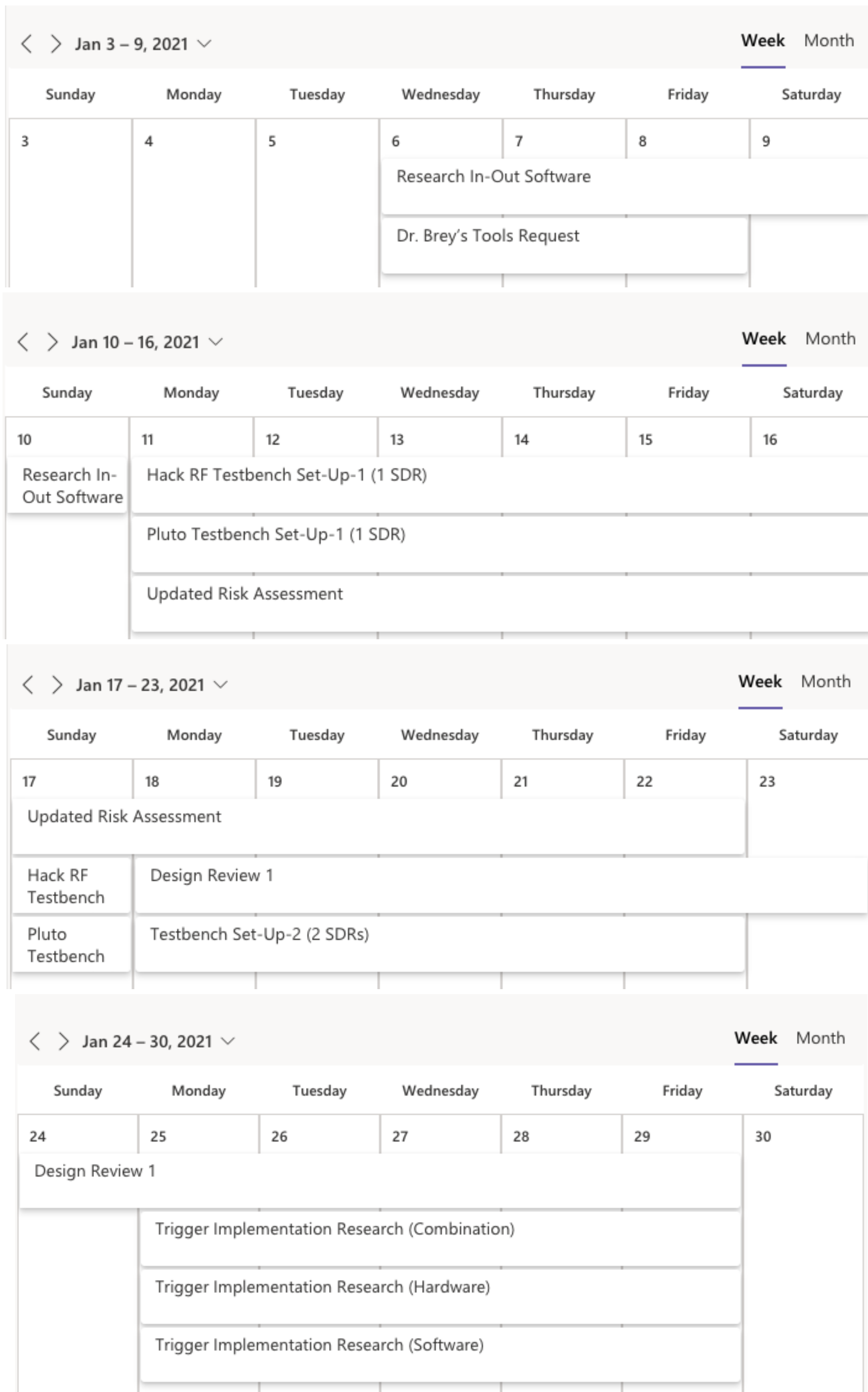


Figure 9: Weekly Overview elements contained in this figure

Figure X: Weekly Overview (February)

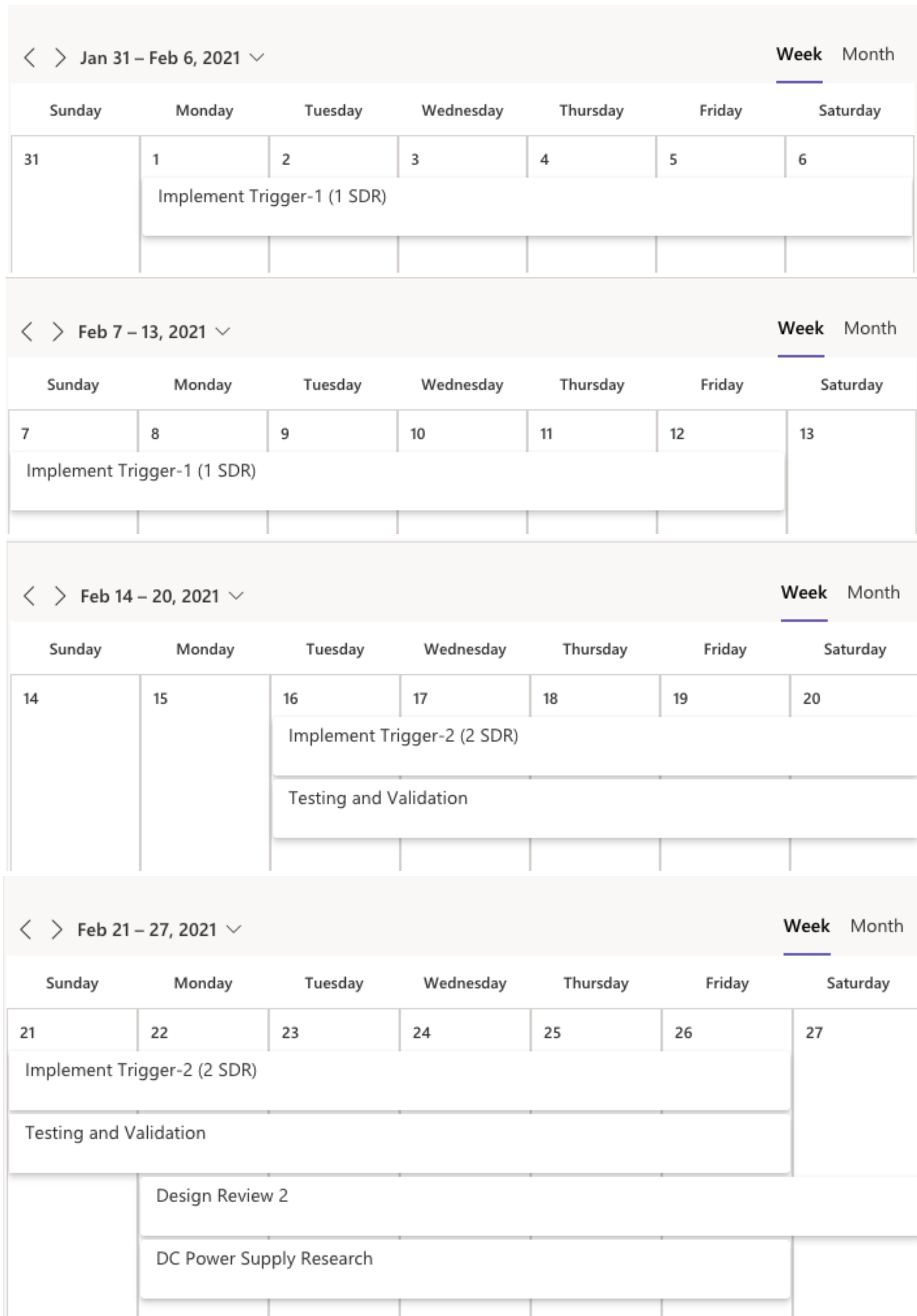


Figure 10: Weekly Overview elements contained in this figure

Figure XI: Weekly Overview (March)

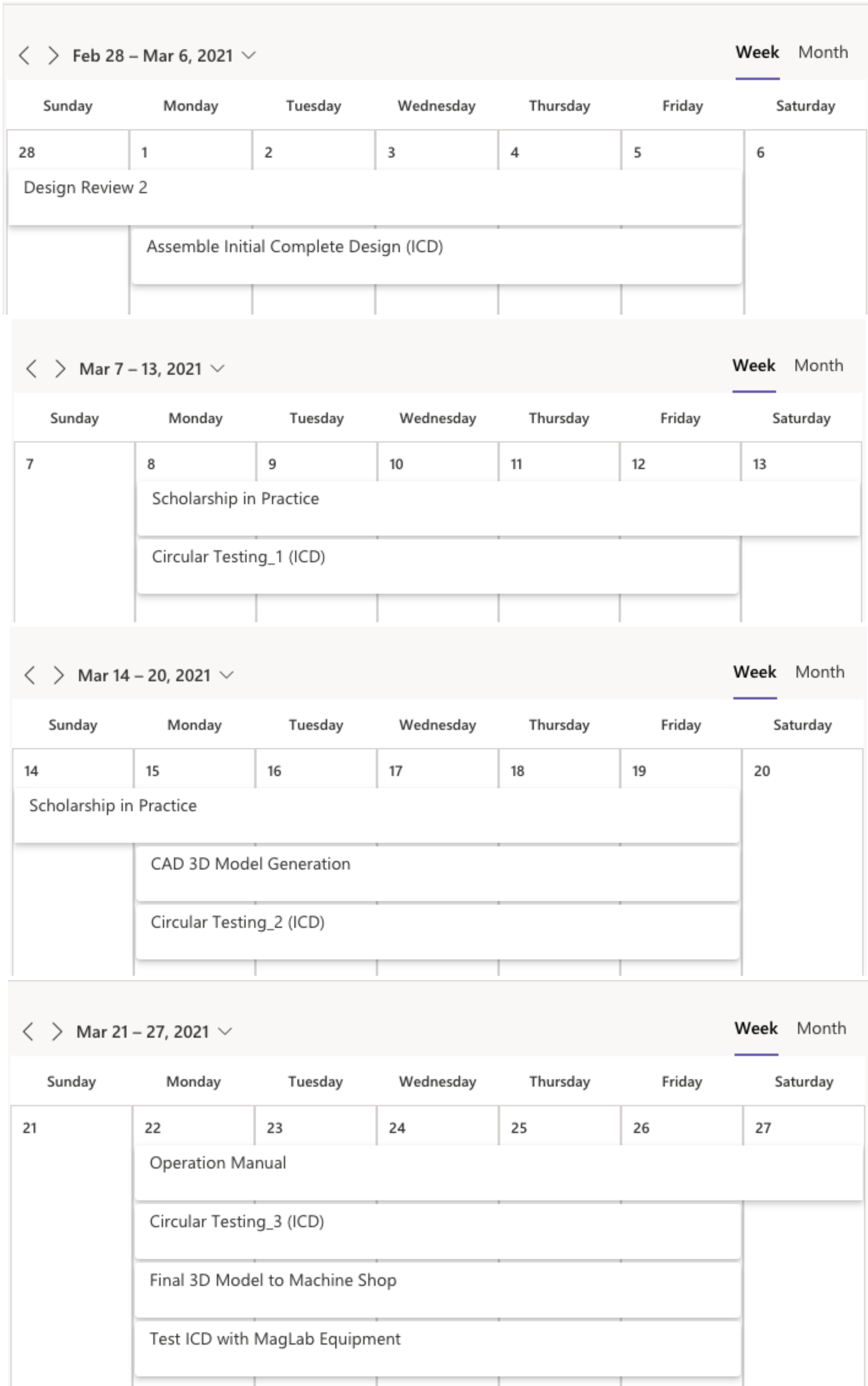


Figure 11: Weekly Overview elements contained in this figure

Figure XII: Weekly Overview (April)

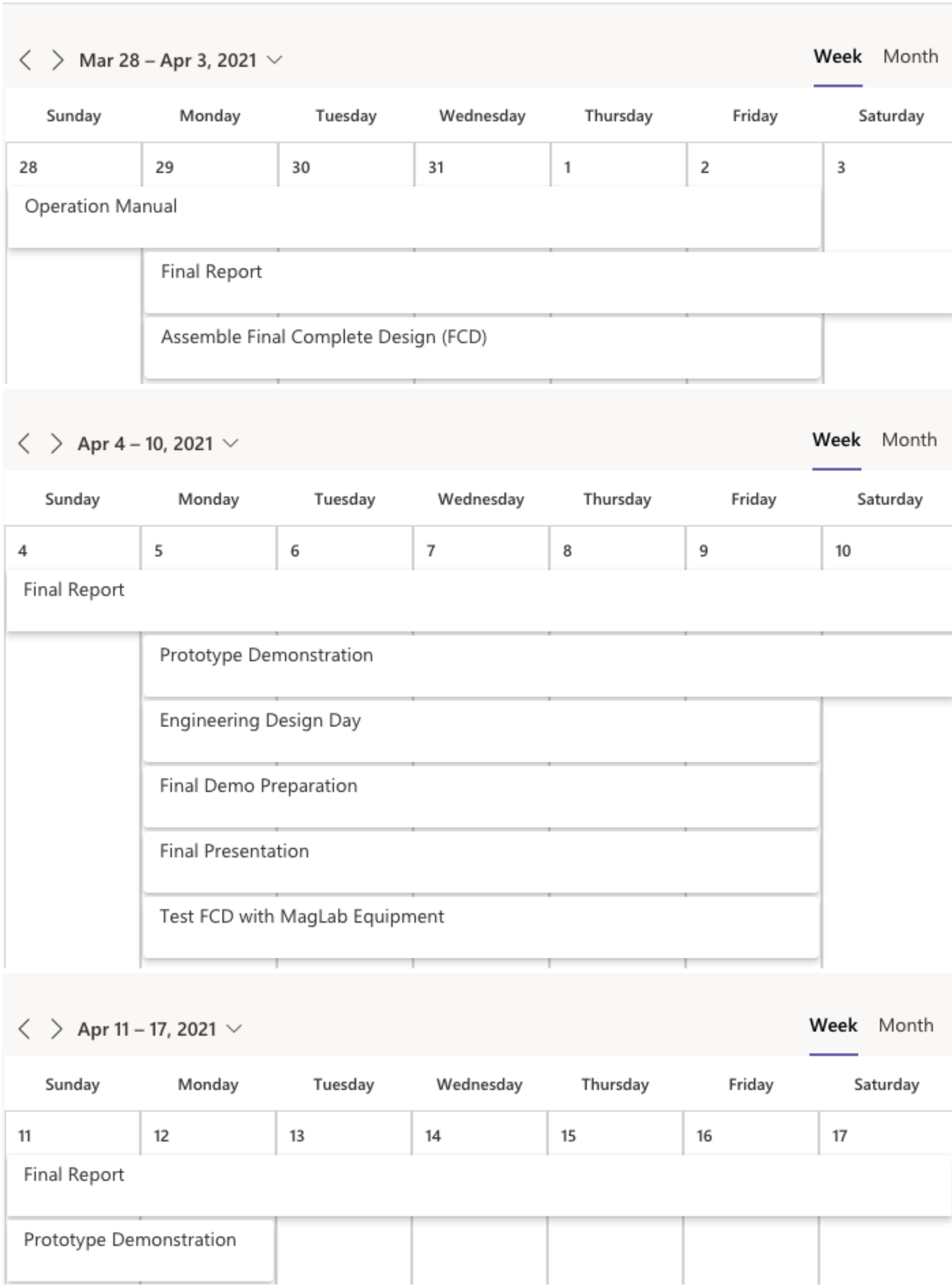


Figure 12: Weekly Overview elements contained in this figure

Figure XIII: Weekly Overview (April Cont…)

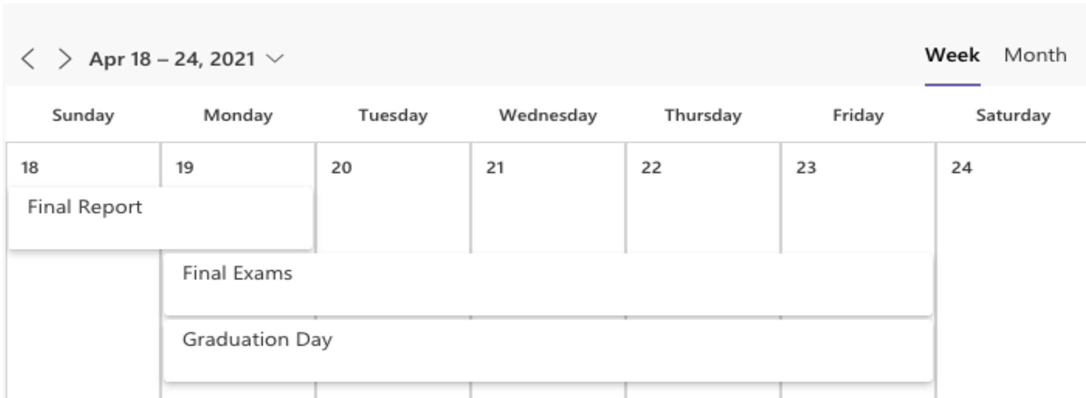


Figure 13: Weekly Overview elements contained in this figure

Having a plan gives a better chance of finishing everything we need to on time while making sure to complete all of the requirements we need to meet. With the completion of our Spring Project Plan, we can begin working on purchasing, building, and testing our prototype.

Chapter Two: EEL4915C

Restated Project Definition and Scope

Assemble a prototype which includes a Software Defined Radio (SDR) of choice in addition to specified software running in a host computer to behave like an oscilloscope. The prototype will have a trigger coming from the power source to start the recording of data; these experiments can last days, and therefore require efficient memory or buffer capabilities. The SDR will do so by measuring the Radio Frequency (RF) pulses obtained from experiments where a bi-directional coupler is inserted between an RF power amplifier and a probe to allow the user to monitor Reflected Power (RP).

Operation Manual

SECTION I: Product Description

Table I: List of Parts

Part	Specification	Quantity
Prototype	Box / Base	1
Prototype	Lid	1
Prototype	Lid EL Wire	1
SDR	Adalm Pluto	2
Arduino	Due	1
Screw(s)	#4 7/8"	4
Screw(s)	#4 1/2"	13
Screwdriver	Phillips	1
Cable	Micro USB to USB	2
Cable	SMA to SMA	2
Variable Attenuator	JFW 50DR-055 0-30dB	1
PC	Windows OS	1

Table 1: List of Parts contained in this table

Table II: List of Additional Parts

Part	Specification	Quantity
RF Pulse Generator	Bruker	1
Adapter	BNC to SMA	2
Splitter	1 SMA : 2 SMA	1
Cable	BNC Jumper	1
Cable	SMA	2
Cable	Micro USB to USB	3
Circuit	Arduino IC for EL Wire	1
Power Source	IC for EL Wire (3.3-12V)	1
Power Source	Outlet / Surge Protector	1
PC	Monior / Linux OS	1

Table 2: List of Additional Parts contained in this table

1.1: Instructions

The following Instructions are for the purpose of providing information to keep in mind when reading the document:

a) This document was created with the intention to aid the user with handling this Prototype but by no means does it cover in extensive detail every possible scenario or situation that could happen.
b) In case of failure, troubleshooting will be required by the user and not the team.
c) Each instance and OS where the Prototype may be used might have a different Set-up which will essentially require to use the document as a general mapping of how to get it working.
d) The document is written with the sense that the user should be knowledgeable enough in the field to follow the details in this document to make the product work.

1.2: Set-up (Software)

Initial set-up for software includes these few simple tasks to get started:

a) Upgrade the SDR Firmware using this link (https://github.com/analogdevicesinc/plutosdr-fw/releases/download/v0.32/plutosdr-fw-v0.32.zip).
b) Download the SDR latest drivers from this link (https://github.com/analogdevicesinc/plutosdr-m2k-drivers-win/releases/download/v0.7/PlutoSDR-M2k-USB-Drivers.exe).
c) Upgrade Adalm Pluto SDR Firmware using this link (https://github.com/analogdevicesinc/libiio/releases/download/v0.21/libiio-0.21.g565bf68-Windows-setup.exe).
    I. If Due is desired to be used also, download the Arduino software from here (https://www.arduino.cc/en/software) or use an editor of choice for programming in C (i.e., Visual Studio Code).
    II. Another great software that goes well with Arduino is called Processing and it can be found here (https://processing.org/download/).

At this point all the initial software drivers and firmware is installed.

a) Next, download the newest IIO-Oscilloscope software using this link (https://github.com/analogdevicesinc/iio-oscilloscope/releases) make sure to download the executable, not the source code zip folders.

Software is now set up, and the user is ready to proceed to the hardware set-up section.

1.3: Set-up (Hardware)

To construct the Prototype in the final configuration chosen by the team, the following steps must be followed:

a) Lay down the Prototype Box / Base in a non-slippery surface, gather the Philips screwdriver, screws, SDRs, Arduino Due, and Prototype Lid.
b) Unscrew the SDRs from the back and keep their lids in a safe place (it is helpful to number them to keep track of which part pertains to which SDR), also remove the Due from the clear plastic base that comes with it.
    I. The Due's base was modified slightly to fit into the box, if it is a brand new Due the tab sticking out used to connect it to breadboards or other Dues must be trimmed using sandpaper or a sharp knife.
c) Screw in two of the #4 7/8" screws per SDR and five #4 1/2" screws for the due (four to secure it to the Prototype Box / Base and one to secure the Due to its own base).
    I. Any further configurations such as banana cables to / from the SDRs or Due (i.e., supplying power to the EL Wire with the Due) should now be connected.
d) Gather the Prototype Lid and secure it with the remaining eight #4 1/2" screws in a cross-hatch pattern (as if mounting a motherboard to a PC).

I. Reference Appendix "Figure A" if needed to visualize assembly.

1.4: Wiring

The Prototype has the following ports available for wiring:

a) SDR External Ports
   I. T_x SMA
   II. R_x SMA
   III. Micro USB (I/O)
   IV. Micro USB (Power)
b) SDR Internal Ports
   I. GPIO
   II. DAC1 – DAC2
   III. GPO0 – DAC3
   IV. ADC
   V. VDD
   VI. GND
   VII. Please reference other ports here (https://wiki.analog.com/university/tools/pluto/hackers) or the main documentation here (https://wiki.analog.com/university/tools/pluto).
c) Due External Ports
   I. Micro USB (Programmer Port)
   II. Micro USB (Native Port)
   III. Power (7V – 12V 2.1mm DC Plug)
d) Due Internal Ports
   I. Please reference the Arduino Due pin-out diagram found here (https://forum.arduino.cc/index.php?topic=132130.0).
   II. More information and technical specs can also be found here (https://www.arduino.cc/en/pmwiki.php?n=Main/arduinoBoardDue).

To aid the user with this wiring, "Figure 1" depicts the proper connections.

a) Connect two SMA jumpers, carrying two RF analog signals, to the rightmost SMA ports of each SDR (the Rx port).
b) Connect two USB 2.0 cables to the middle port (USB data port) of each SDR.

Figure I: Prototype I/O

Figure 1: Prototype I/O (two input SMA cables on the top, and two output USB 2.0 cables on the bottom).

The final wiring configuration for the Prototype can also be referenced in the Appendix in "Figure B".

1.5: Integration

The final step of the prototype set-up process is to integrate the downloaded software (IIO-Oscilloscope) and earlier assembled hardware (prototype).

a) Make sure all USB ports of your device are empty.
b) Open two instances of IIO-Oscilloscope on the same screen.
   I. double click the shortcut  twice to open two instances of the software.
c) Connect the two USB cables coming from the prototype to the computer.
d) Search for *Command Window* in the Windows search bar and open it.
e) **Very important step!** Type this command: *iio_info -s* in the command window.
   I. this will output USB port IDs of the two SDRs that were just connected.

Figure II: Command Window Example

```
C:\Users\emilg>iio_info -s
Library version: 0.21 (git tag: 565bf68)
Compiled with backends: xml ip usb serial
Unable to create Local IIO context : Function not implemented
Available contexts:
        0: 0456:b673 (Analog Devices Inc. PlutoSDR (ADALM-PLUTO)), serial=1044730a1997000f10000500126f7c559d [usb:1.5.5]
        1: 0456:b673 (Analog Devices Inc. PlutoSDR (ADALM-PLUTO)), serial=1044730a19970001f4ff2e00811e7b82cd [usb:1.4.5]
```

Figure 2: Screenshot of the Command Window output, showing two usb ids on the most right in [usb:x.x.x] format.

f) Next, in the *osc.exe* windows that were opened in "Step b)", choose *USB Device,* and select the *Device* option to be *Manual*. In the newly appeared empty line type usb port ID exactly in the [usb:x.x.x] format shown in "Figure II" and press *Enter* on the keyboard.
g) Repeat "Step f)" for the second SDR.
h) Now, the two SDRs should be shown on the *osc.exe* bottom right, so the next step would be to simply click *Connect*.
i) Repeat "Step h)" for the second SDR.
j) At this point, two Plotting Windows will appear. It is the user's job to move manually each plot to two different sides of a screen to get access to both *ADI IIO Oscilloscope settings* windows that have now appeared behind the *Plotting* windows.
k) Drag each of the *settings* windows to split the screen. Navigate to the *AD936X* tab in settings.
l) Under *Controls* in *AD9361/AD9364 Receive Chain* the user should change four parameters related to specific RF signal test: *RF Bandwidth, Sampling Rate, RX LO Frequency (this is tune in frequency), and Hardware Gain(dB).*
    I. Note: User is advised to switch *Hardware Gain* to *Manual*.

Project demonstration example involved 500 [MHz] pulse trains, with 2 [ms] width and 200 [ms] delay between each pulse. For proper operation on this signal, we recommend RF Bandwidth of 10 [MHz], Sampling Rate of 11 [MSPS], RX LO Frequency of 500 [MHz], and Hardware Gain switched to *Manual* at 5 [dB]. Figure "Figure 3" demonstrates the above-mentioned settings.

Figure III: Core Software Settings

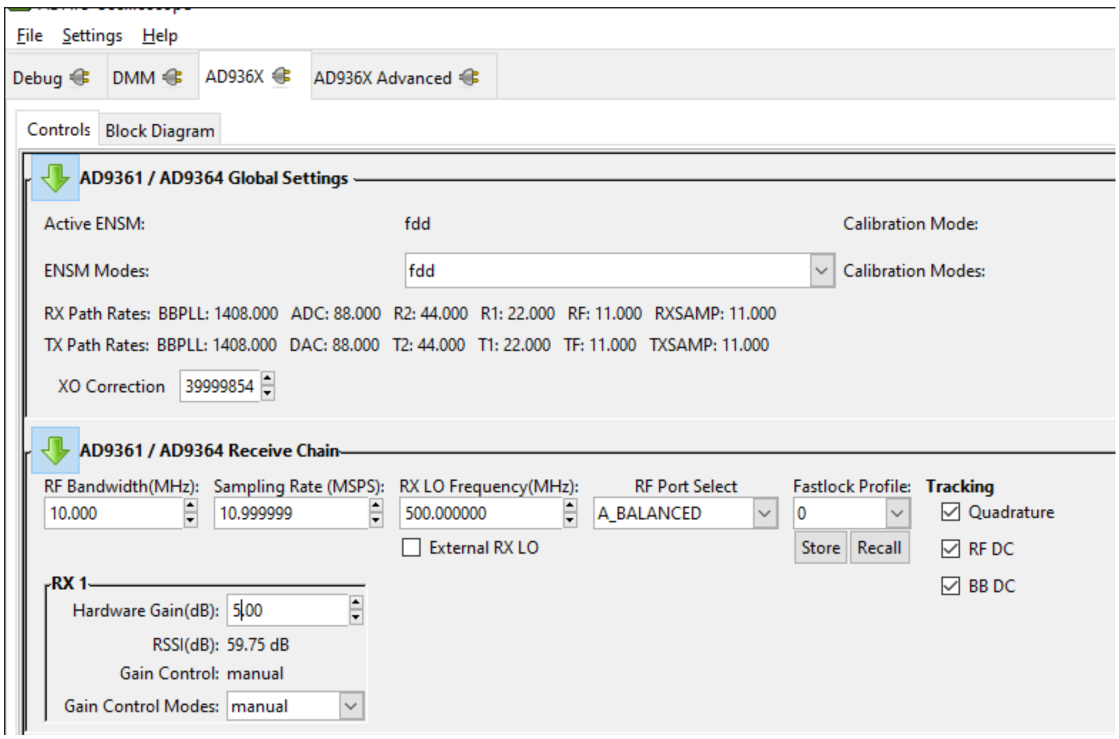


Figure 3: Core software set-up configuration window for analysis and plotting of RF signals.

m) Repeat "Step l)" for second the SDR.

n) Do not close the settings windows. Simply move the two Plotting panels in front and split the screen.

o) On the Plotting panel, the user can find the *Time Scale* setting. Specify any comfortable value in [µs]. We recommend 10000 [µs] for the test signal described above. Repeat this step for the second SDR.

p) Next, on the top left corner of the *Plotting* window press *Enable All.* This enables both *voltage0* and *voltage1* signals (which correspond to I and Q components of a received RF signal respectively). Repeat this step for the second SDR.

q) Right click on the main channel *cf-ad9361-lpc* and select *Trigger Settings*. Choose the voltage signal based on which software defined trigger will be enabled (we recommend using *Channel for trigger: voltage0* and *Trigger Level* of 100 for 500 MHz signal. Set the trigger to act on falling edge. Repeat this step for the second SDR.

r) Lastly, make sure both signals are enabled and press the triangular *Start* button on the top left of the Plotting Window. Repeat this for the second SDR.

The Entire set-up of hardware-software integration is now complete, and the two signals should appear on the two Plotting Windows of IIO-Oscilloscope software as depicted on "Figure 4".

I. Note: The red and green boxes, arrows, and values are placed posteriori for demonstration purposes.

Figure IV: Properly Set-Up Plotting Windows

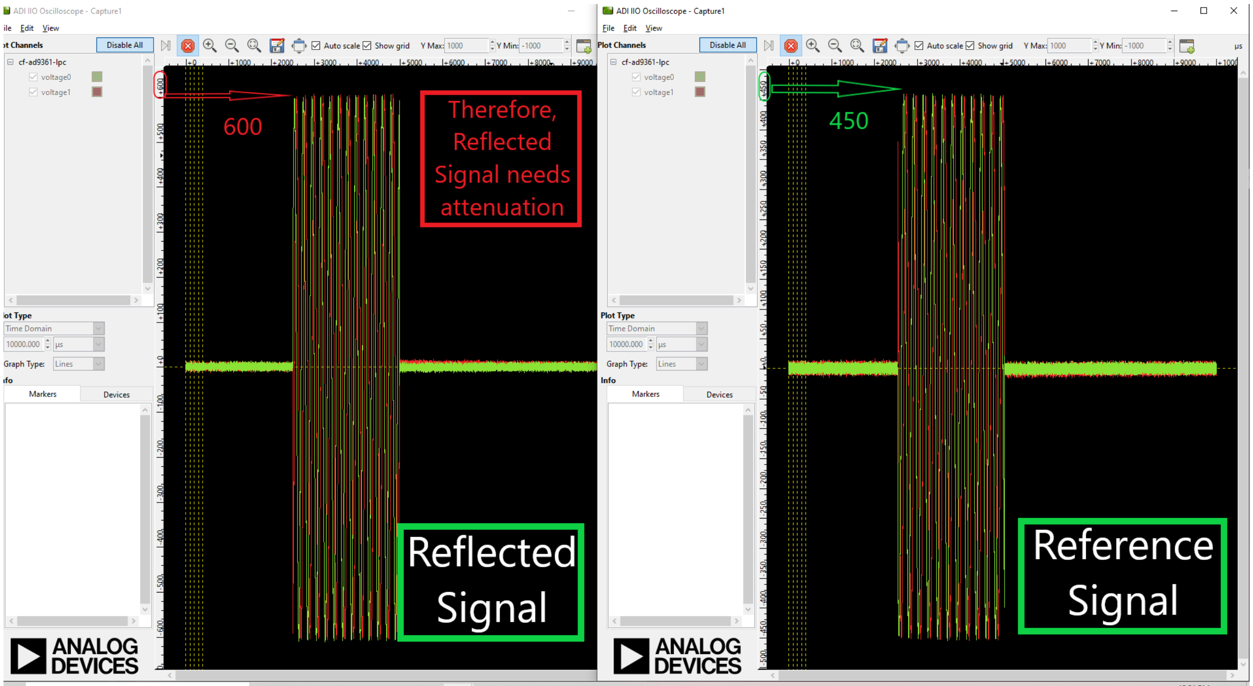


Figure 4: Properly set-up IIO-Oscilloscope Plotting Windows for RF signal tunning.

1.6: Important Documents

These documents can be found in either the compressed "T307_Oscilloscope.zip" file or in the team website here (https://web1.eng.famu.fsu.edu/ece/senior_design/2021/team307/).

Table III: Files

File	Description
Abstract	Project abstract and introduction
Bill of Materials	Materials bought for the project
Testing and Validation	Testing and analysis done for the project
Final Presentation	Final project presentation
Final Report	All relevant submitted documents

Table 3: Files contained in this table

A video demonstration of the Prototype can be found here (https://www.youtube.com/watch?v=xZnUgrdPSTs&t=79s).

SECTION II: Repair Info

2.1: Troubleshooting Tips (Software)

IIO Oscilloscope documentation can be found here (https://wiki.analog.com/resources/tools-software/linux-software/iio_oscilloscope).

a) Make sure to review “Section 1.2” if the software is causing issues.

2.2: Troubleshooting Tips (Hardware)

Adalm Pluto SDR documentation can be found here (https://wiki.analog.com/university/tools/pluto).

a) Make sure to review “Section 1.3” and “Section 1.4” if the hardware is causing issues.

Arduino Due documentation can be found here (https://www.arduino.cc/en/Guide/ArduinoDue).

a) Make sure to review “Section 1.2” and “Section 1.4” if the hardware is causing issues.

SECTION III: Safety Information

In general, it is relatively difficult for the product to cause injury. However, please follow the following rules for product use:

a) Avoid shorting pins or connections.
b) When connecting to I/O pins in the Adalm Pluto or Arduino Due, avoid applying external voltages or signals not specified in this Document.
c) When connecting to I/O pins in the Adalm Pluto or Arduino Due, make sure to ground the circuit schematic first if using an external breadboard or in the case of disconnecting the schematic for servicing before connecting the voltage again.
d) When disconnecting I/O pins from the Adalm Pluto or Arduino Due avoid disconnecting ground first (i.e., disconnect voltage first).
e) Use the “One Hand Rule” when dealing with circuitry, which implies using only one hand to modify the circuits while leaving the other hand in a pocket near your waist to avoid risk.
f) If in the National High Magnetic Field Laboratory (NHMFL), keep product away from magnet and follow their safety requirements.
g) Use common sense to maintain safety requirements, we are not liable in the case of an accident.

SECTION IV: Appendix

Figure A: Assembled Prototype

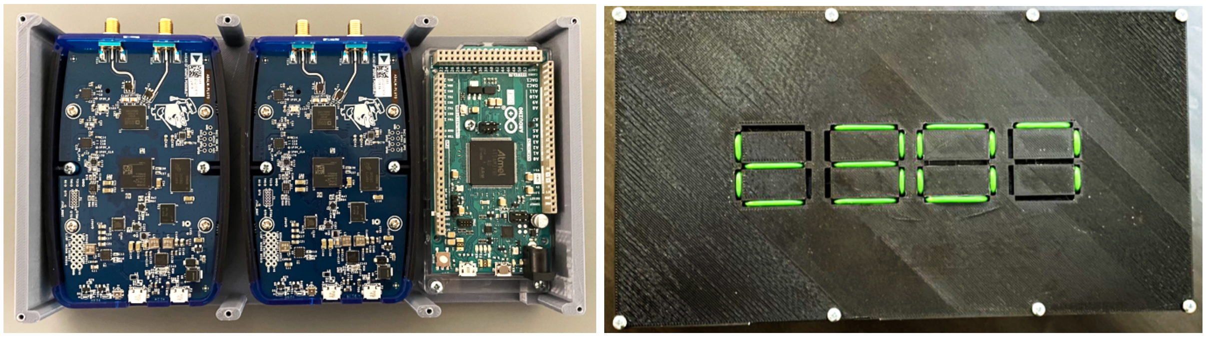


Figure A: Assembled Prototype contained in this figure

Figure B: Detailed Schematic

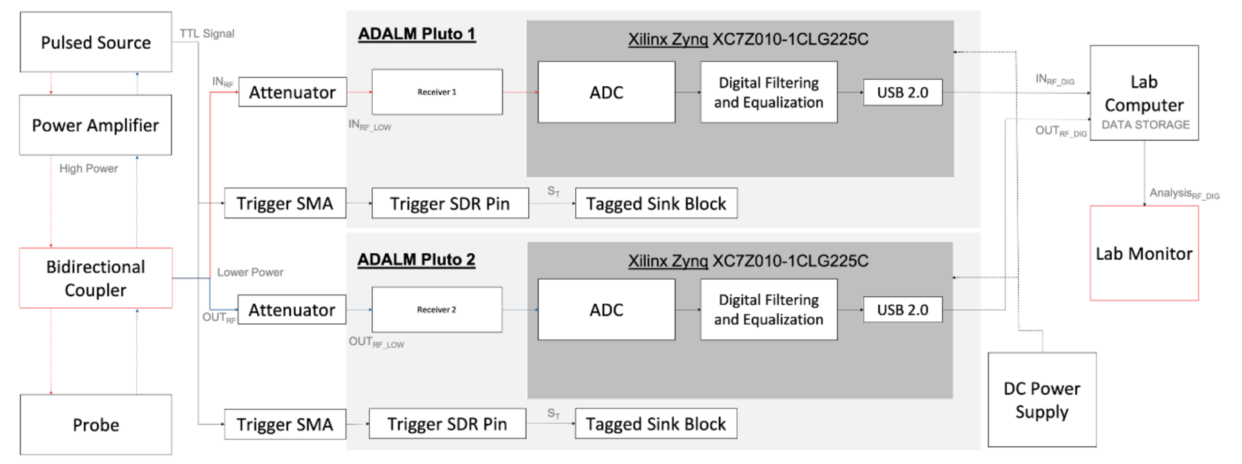


Figure B: Detailed Schematic contained in this figure

Results

Our project was a success and we were able to achieve the important requirements we strived to meet. Our prototype was assembled in a single unit box and easily be repaired by following the troubleshooting and repair instructions in our Operation Manual. The result after designing the prototype box can be seen below in Figure I.

Figure I: Finished Prototype Box

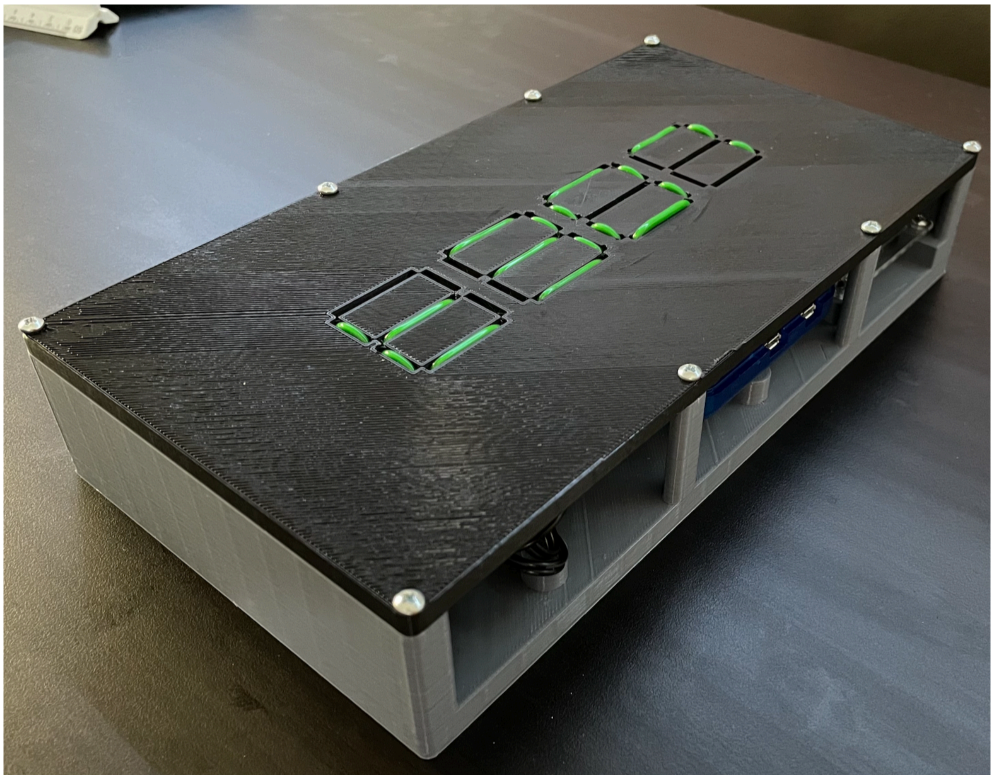


Figure I: The finished prototype box is shown in the figure

The software our prototype utilizes becomes simple to use with our Operation Manual and allows the user to easily tune on the desired frequency, sampling rate, and trigger settings when needed. Our prototype is able to successfully display two RF signal pulses. This can be seen in Figure II below.

Figure II: Two RF Signal Pulses

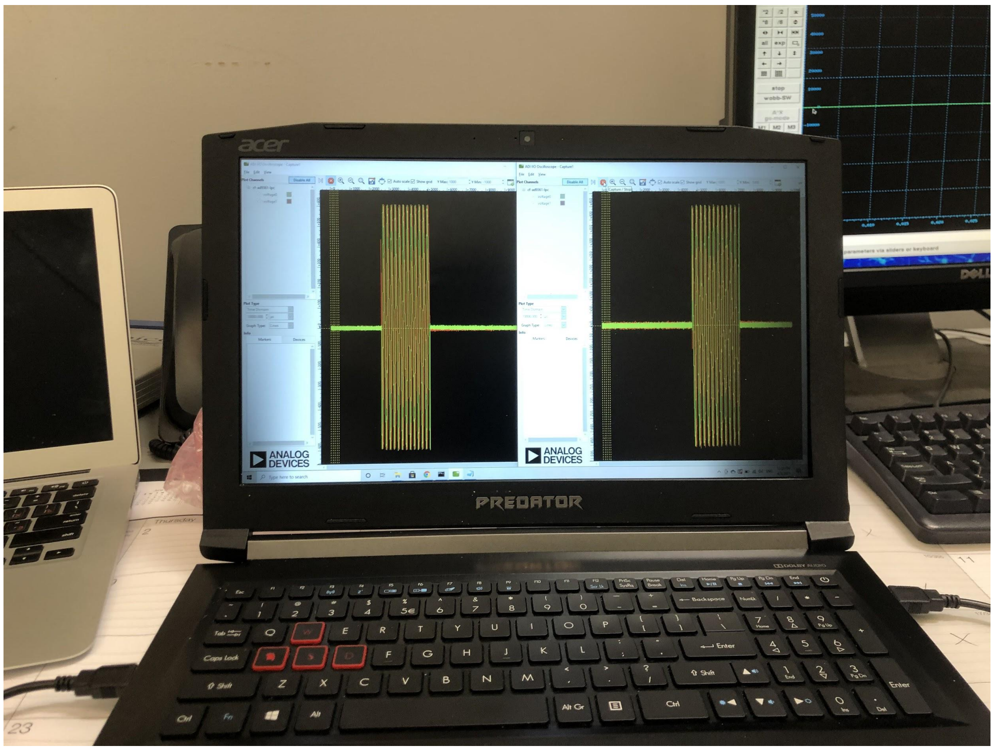


Figure II: Two RF signals are displayed on a screen utilizing the prototype

With the ability to view the RF signals, the user can compare the signals and tune them appropriately. In the following images, we can see the “reflected” signal on the left side of the Figure III is not matching the “reference” signal on the right side of the figure. Therefore, it must be manually tuned to match the reference signal. To mimic the tuning process, we use a variable attenuator to “tune” the signal to the reference.

Figure III: Reflected and Reference Signals Untuned 1

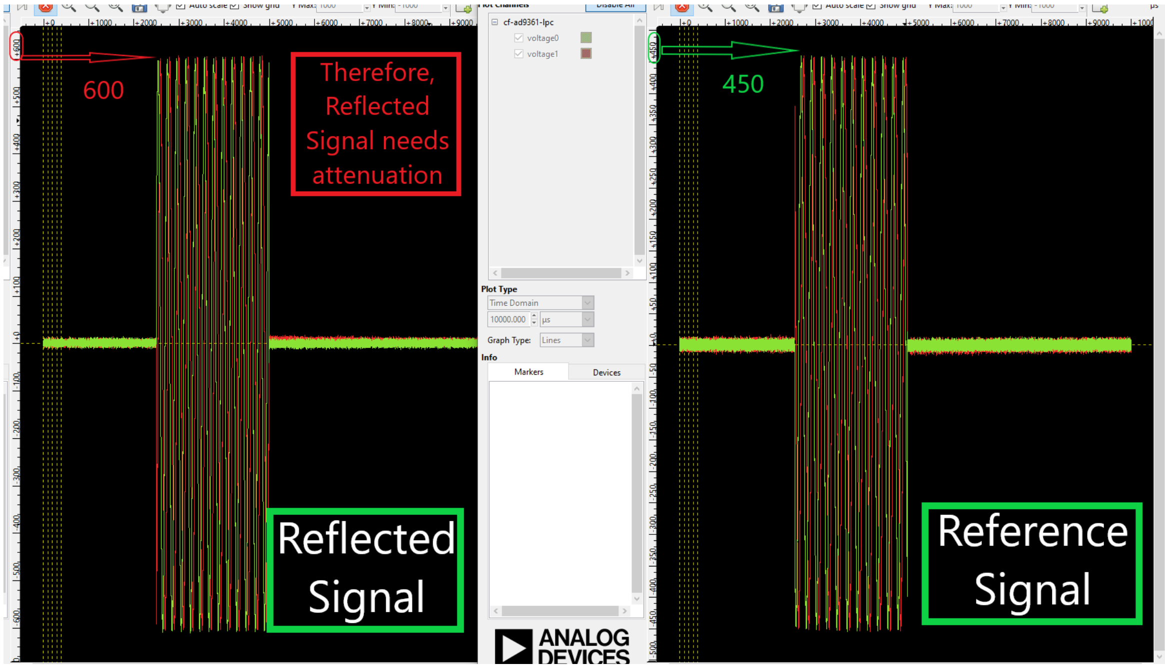


Figure III: Two unmatched RF signals are shown in the figure

Here in Figure IV, we can see that the signal is still not matching the reference signal. Therefore, we continue to "tune" the signal using the attenuator.

Figure IV: Reflected and Reference Signals Untuned 2

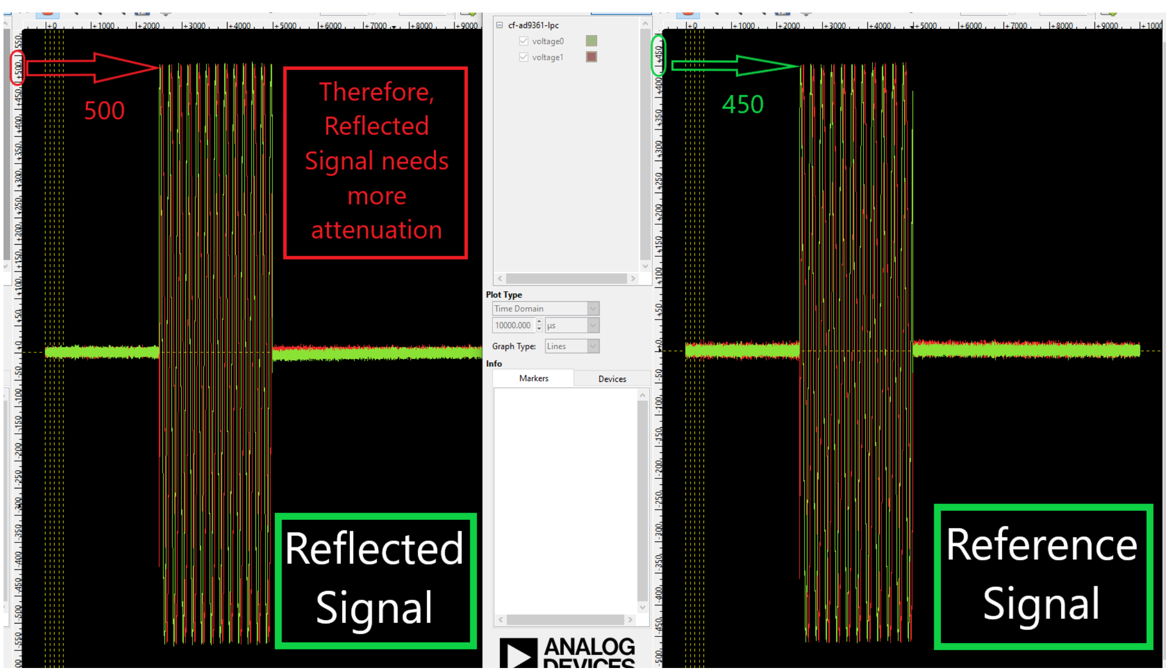


Figure IV: Two unmatched RF signals are shown in the figure

Finally, we have tuned the reflected signal to match the reference signal and have simulated what our customer will be using our prototype to do.

Figure V: Reflected and Reference Signals Tuned

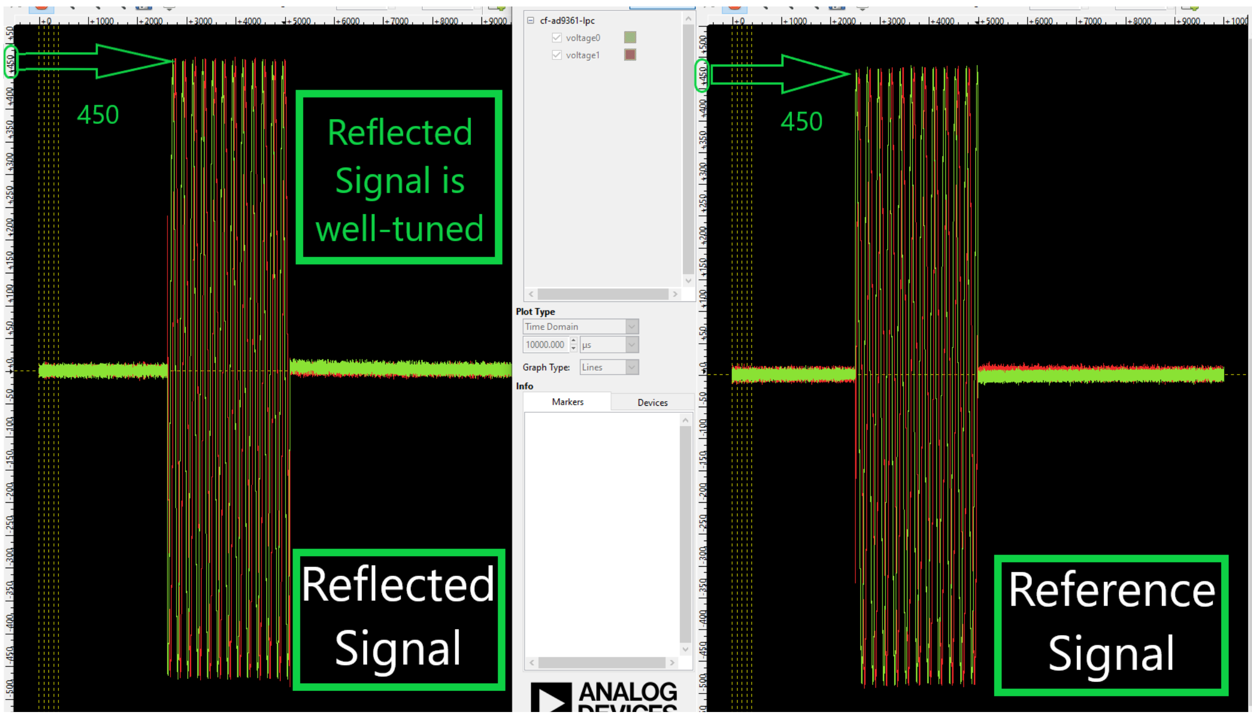


Figure V: Two matched RF signals are shown in the figure

This quick functional demonstration of tuning the probe concludes the results section of this report. If interested, in addition to presented figures, one can find Final Prototype Demonstration video on our team website accessible via FAMU-FSU College of Engineering website.

Discussion

To start off our discussion section, it is vital for the reader to understand that throughout engineering design, consideration, and complete evaluation of several approaches, as well as hard work of the entire team, our project was successfully completed. Requested by the proposal prototype was built, tested, and delivered. It is working with full functionality, performs all the required tasks and satisfies all the needs described in earlier sections.

Diving deeper into discussion of results, the most time-consuming part of our project was testing and validation of alternative designs. Extremely thorough engineering analysis presented in concept generation and concept selection sections, has led the team to formulate these alternative designs. Now finished prototype in no shape or form corresponds to the initial design choices that were acquired. However, it is exactly due to trials, failures, successes, and re-design of alternative approaches, we were able to design our final prototype. The first approach that was taken during initial design stages was to use Adalm Pluto SDR with MATLAB software. Constructing an early-stage prototype, assembling it and integrating it with MATLAB defined the completeness of this approach. However, we have encountered several dead ends in this design. The first one was the MATLAB's dependency on offline data acquisition and analysis. When performing plotting in real time, MATLAB stopped running (computer processing power bottleneck) and further integration of the second SDR module into an already weakly working prototype-software integration was dubbed as not plausible. The second approach was to directly extract encoded by the SDR's ADC digital codes (corresponding to received voltages of an input RF signal) and plot them using a microcontroller connected to a computer and running open-source plotting software called Waveform AD2. This approach was built and tested, however there was one crucial error in this design that signified a necessity for another approach. This problem was the fact that AD2 microcontroller worked great with low frequency signals, plotting ADC values corresponding to input RF signal voltages in time domain. However, with high (RF) frequency signals, this microcontroller was not able to function as expected. The frequency of the incoming signal was much higher than the operating frequency of the microcontroller (i.e., RF signals were 500MHz-800MHz, the microcontroller operating frequency was 250-750 kHz). The third approach was to use Adalm Pluto SDR with direct connection to a computer as in the first approach, however this time with a different software. After long, but very productive telephone conversations with Analog Devices field application engineering team as well as discussions on ADI forum with engineers that have made this SDR, we were able to get source codes for a software called IIO-Oscilloscope. It was written by the same people, who have manufactured the SDR and suited for purposes like ours. Additionally, the most important feature of this newfound at that time software was time domain plots that were working errorless with RF signals. The rest of this approach was testing to find correct settings and apply those settings in the program for software defined triggers. After the software was updated and compiled, we were able to visualize RF signals in time domain on two separate plots! This was not an option in any other approach that the team has completed previously, leading to choice of exactly this design.

Continuing the discussion of our project is the final prototype. Before diving in into description of the final prototype, it is vital to mention the following risks and hazards associated with it. This excerpt is taken from our operation manual and serves as extra precaution for the user.

In general, it is relatively difficult for the product to cause injury. However, please follow the following rules for product use:

a) Avoid shorting pins or connections.

b) When connecting to I/O pins in the Adalm Pluto or Arduino Due, avoid applying external voltages or signals not specified in this Document.

c) When connecting to I/O pins in the Adalm Pluto or Arduino Due, make sure to ground the circuit schematic first if using an external breadboard or in the case of disconnecting the schematic for servicing before connecting the voltage again.

d) When disconnecting I/O pins from the Adalm Pluto or Arduino Due avoid disconnecting ground first (i.e., disconnect voltage first).

e) Use the “One Hand Rule” when dealing with circuitry, which implies using only one hand to modify the circuits while leaving the other hand in a pocket near your waist to avoid risk.

f) If in the National High Magnetic Field Laboratory (NHMFL), keep products away from magnet and follow their safety requirements.

g) Use common sense to maintain safety requirements, we are not liable in the case of an accident.

After reviewing these risks and hazards, it is time to discuss the final prototype and satisfaction of the provided needs for our project. The prototype was assembled in a single unit box (refer to Section IV of Operation Manual Figure A). The SDR chosen, Adalm Pluto, contained ADC with sampling rates up to 60 MSPS, satisfying the need to have fast receival of reverse (reflected) signal. Quick repairability of our prototype is satisfied by using only eight screws for holding the top panel, which gives quick access to the internals in case of failure or malfunctioning. Using IIO-Oscilloscope software with our prototype, when correctly set up (refer to operation manual Section 1.5) the plot demonstrates the entire envelope of an incoming reference and reflected RF signals. Also, this software satisfies the fifth need of proper configuration for SDR and its connection to PC. The user can modify tune in frequency, sampling rate, bandwidth, and hardware gain directly from the software. Incorporation of above-mentioned software (with its software defined trigger functionality) satisfied the need to have an ability to start and stop readings. The overall cost of our prototype is $340.30 which is almost 1/3 of the target price of $1000! This satisfies budget constraints of the project. Since, we were able to incorporate two Adalm Pluto SDRs to work simultaneously on the same computer, the need to have at least one input channel was satisfied. We purposely did not include any batteries or accumulators inside our prototype to satisfy the need for it to work continuously for many hours/days. Taking the power from the computer via the same USB cable used for extraction of the data, our prototype satisfies continuous operation need. Prototype performs the same functionalities as a high end oscilloscope for plotting signals that range from 325MHz to 3.8GHz in time domain. This satisfies the need for our device to work on 600 MHz to 800 MHz frequency range. Finally, the only three components that were used in final design were manufactured by Analog Devices and Arduino. This satisfies the need to exclude any National Instruments Components.

The successful satisfaction of all proposed needs for our project, signifies completeness of our design and overall rating of the prototype.

Conclusions

To conclude the work that the team had accomplished throughout the last two semesters, let us first mention the vital help that we have gotten from our advisers and reviewers. After several meetings with each of our advisors, the team quickly recognized the importance of consideration of given suggestions and advices from those more knowledgeable in the field. Also, it was seen that direct communication with a manufacturer of an electronic device is the key to successful operation and utilization of that device.

Described in discussion section different approaches have given insightful feedback for the final design. Even though containing errors, dead ends, troubleshooting failures, the time spent exploring those approaches have not been in vain. The lessons, tips, engineering configurations, calculation mismatches, and side discoveries, all led to realization of the end goal of our project. Starting from a very detailed plan in the Fall 2020 semesters and keeping our organization levels high for Spring 2021 semester, also aided the team to complete all of given deadlines, including department deadlines and proposed by the team deadlines.

Additionally, the final prototype is fully operational, and can be used right away for its intended purpose, namely, plotting of reflected and reference RF signals. Written by the team operation manual provides all of the details regarding set-up and operation of the prototype from scratch, as well as troubleshooting advices for hardware and software in case of malfunctioning. The prototype underwent numerous testing of its modules isolated from the system, integration of those modules and the end user acceptance test. After passing each of the specifically designed tests that aimed to verify targets for our design, the prototype was awarded a final version title and passed on to our customer.

Future Work

There is no future work for the proposed project, since the final prototype successfully satisfied all the needs described by our customer in the beginning. Though the automation of the probe tuning process through the microcontroller is something that may be implemented in the future, it is outside the scope of this project. However, in the last weeks of this semester, the team added an Arduino Due microcontroller into the prototype that expands the operation of the project in case the user wants to automate the process of tuning in the future. This can be done by directly taking ADCs' output signals from the pin (see SDR schematic) and feeding the two signals into Arduino Due GPIO ports. Then writing a facile code in C that compares the average magnitudes of the pulse trains and sends a motor driver controller signal to rotate a tuning knob.

References

a) “A Narrow Band “Oscilloscope” for High Power Tuning of NMR Probes”, Project Proposal, W. Brey, 2020.

b) “NMR Operation at NYSBC”, NYSBC Solid State NMR Short Course, http://comdnmr.nysbc.org/comd-nmr-educ/comd-nmr-lecture-notes/lecture-notes/solidstateNMRcourse.pdf

c) “Design, Care and Feeding of NMR Probes” tutorial presented by Kurt Zilm at the 2011 ENC, http://www.enc-conference.org/Portals/0/Probes_2011_Part_I.pps

d) G. Amouzandeh, V. Ramaswamy, N. Freytag, A. S. Edison, L. A. Hornak and W. W. Brey, "Time and Frequency Domain Response of HTS Resonators for Use as NMR Transmit Coils," in IEEE Transactions on Applied Superconductivity, vol. 29, no. 5, pp. 1-5, Aug. 2019, Art no. 1102705, doi: 10.1109/TASC.2019.2902522.

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g) Sunnylearning, director. PCM - Analog to Digital Conversion. YouTube, YouTube, 16 Nov. 2018, www.youtube.com/watch?v=HlGJ6xxbz8s&t=356s.

StevesLectures, director. Pulse Code Modulation (ITS323, L11, Y15). YouTube, YouTube, 20 Sept. 2015, www.youtube.com/watch?v=9hkHO-klwME.

Appendix

Code of Conduct

Team 307

A Narrow Band "Oscilloscope" for High Power Tuning of NMR Probes

Names:
Burt, Jonathan
De Leon, Gabriel
Lobachev, Emil
Rich, Asher
York, Kyle

Date:
15 January 2021

Mission Statement

Our team seeks to develop the necessary deliverables to perfection through a positive work environment that ensures professionalism, integrity, respect, trust, and teamwork. Every member will contribute a full effort to the creation and realization of such an environment and to produce the best motive in all team members, outside resources involved, and the project at hand.

Roles

Each team member is delegated a specific role based on their experience and skill sets and is responsible for all here-within:

Team Leader

– Asher Rich

Manages the team as a whole; develops a plan and timeline for the project, delegates tasks among group members and himself according to skill sets; finalizes all documents and provides input on other positions where deemed necessary. The "Team Leader" is responsible for promoting synergy and increased teamwork for the benefit of the team and project. If a problem arises, the "Team Leader" will act in the best interest of the project. He keeps the communication active and flowing between the team members. The team leader approves meetings scheduled by the "Dedicated Group Representative" (DGR). Finally, he gives or facilitates presentations by individual team members and is responsible for overall project plans and progress.

Financial Advisor / Circuit and Hardware Assembly Lead

– Gabriel De Leon

Manages the budget and maintains a record of all credits and debits to the project account. Any product or expenditure requests must be presented to the advisor, who is then responsible for reviewing and the analysis of equivalent or alternate solutions. They then relay the information to the team and if the request is granted, order the selection. A record of these analyses and budget adjustments must be kept. Assemble components following a detailed schematic. Test product with the "ECE Lead" to ensure conformance to the requirements.

Programming Lead / Document Lead

– Jonathan Burt

Manages the software end; develops and maintains a repository with record of all the changes to the group software files.

In addition, he is responsible for keeping a record of all correspondence between the group and 'minutes' for the meetings. Documents all necessary information from all meetings.

Research Lead

– Kyle York

Takes charge of the mechanical design aspects of the project. Keeps line of communication with the "Lead ECE" in addition to the "Circuit and Hardware Assembly Lead". Is responsible for knowing details of the design and presenting the options for each aspect to the team for the decision process. Keeps all design documentation for record.

Lead ECE / Dedicated Group Representative (DGR)

– Emil Lobachev

He is responsible for the EE, IE, or CE design portion in support of the project. He maintains a line of communication with the "Research Lead" and helps the "Team Leader" maintain the communication active between the team and POCs. He keeps the communication active and flowing between the external Points of Contact (POCs) like the sponsor, advisor, and reviewer. He records and posts all meetings and applicable documentation for record in the shared Google Drive.

He takes the lead in organizing, planning, and setting up meetings with support from "Team Leader". As a ECE Lead, he is in charge of proper choice of the components and proper design from the research of the "Research Lead" and the "Circuit and Hardware Assembly Lead". Helps to perform circuit tests and validates the results against the targets.

All Team Members:

- Work on certain tasks of the project
- Buy into the project goals and success
- Deliver on commitments
- Adopt team spirit and motivation
- Listen and contribute constructively (feedback)
- Are effective in trying to get message across
- Are open minded to others ideas
- Respect other's roles
- Are ambassadors to the outside world in own tasks

Communication

The main form of communication will be over Zoom, Discord, GroupMe, and Microsoft Teams. If that form fails, a secondary form of communication will be by Phone for issues that are time sensitive. Email will be a third form of communication for issues not being time sensitive. For passing information like files and presentations, the shared Google Drive will be used by the team. Each group member must have a working email and google account for the purpose of communication and file transfers. Members must check these forms of communication at least once a day. Meeting dates and pertinent information regarding sponsors will be sent in the GroupMe and posted in the shared Google Sheets within the shared Drive. If a meeting must be canceled, the group must be notified by any means listed above 24 hours in advance. Any team member that cannot attend a meeting must give a notice 24 hours in advance. This notice must also include reason for absence unless personal. Repeated absences will not be tolerated and are in violation of this agreement.

Team Dynamics

Students will work as a team while allowing one another to feel free of making suggestions and constructive criticisms without the fear of being ridiculed and/or embarrassed. If any member on the team finds a task to be too difficult it is expected of them to speak out and ask for help from other teammates. If any member of the team feels disrespected or not taken seriously, they must bring this issue to the attention of the team to be resolved immediately. We shall NOT let emotions dictate our actions. Everything done is for the benefit of the project and together everyone achieves more.

Ethics

Team members are required to be familiar with the NSPE Engineering Code of ethics as they are responsible for their obligations to the public, the client, the employer, and the profession. There will be stringent following of the NSPE Engineering Code of Ethics.

Dress Code

Team meetings will be held in casual attire. Sponsor meetings and group presentations will be business casual to formal as decided by the team per the event.

Weekly and Bi-weekly Tasks

Team members will participate in all meetings with the sponsor, advisor and instructor. During said times ideas, project progress, budget, conflicts, timelines, and due dates will be discussed. In addition, tasks will be delegated to team members during these meetings. Repeated absences will not be tolerated.

Decision Making

It is conducted by consensus and majority of the team members. Should ethical/moral reasons be cited for dissenting reason, then the ethics/morals shall be evaluated as a group and the majority will decide on the plan of action. Individuals with conflicts of interest should not participate in decision-making processes but do not need to announce said conflict. It is up to each individual to act ethically and for the interests of the group and the goals of the project. Achieving the goal of the project will be the top priority for each group member. Below are the steps to be followed for each decision-making process:

- Problem Definition – Define the problem and understand it. Discuss among the
- group.
- Tentative Solutions – Brainstorms possible solutions. Discuss among the group most plausible.
- Data/History Gathering and Analyses – Gather necessary data required for implementing Tentative Solution. Re-evaluate Tentative Solution for plausibility and effectiveness.
- Design – Design the Tentative Solution product and construct it. Re-evaluate for plausibility and effectiveness.
- Test and Simulation/Observation – Test design for Tentative Solution and gather data. Re-evaluate for plausibility and effectiveness.
- Final Evaluation – Evaluate the testing phase and determine its level of success. Decide if design can be improved and if time/budget allows for it.

Conflict Resolution

In the event of conflict amongst team members the following steps shall be respectfully employed:

- Communication of points of interest from both parties. This may include demonstration of active listening by both parties through paraphrasing and/or other tools acknowledging clear understanding.
- Administration of a vote, if needed, favoring majority rule.
- Team Leader intervention.
- Instructor intervention.

Statement of Understanding

By signing this document, the members of Team 307 agree to all of the above and will abide by the code of conduct set forth by the group.

Name	Signature	Date
Jonathan Burt		01/15/2021
Gabriel De Leon		01/15/2021
Emil Lobachev		01/15/2021
Asher Rich		01/15/2021
Kyle York		01/15/2021

Functional Decomp Charts

Figure I: Function Tree

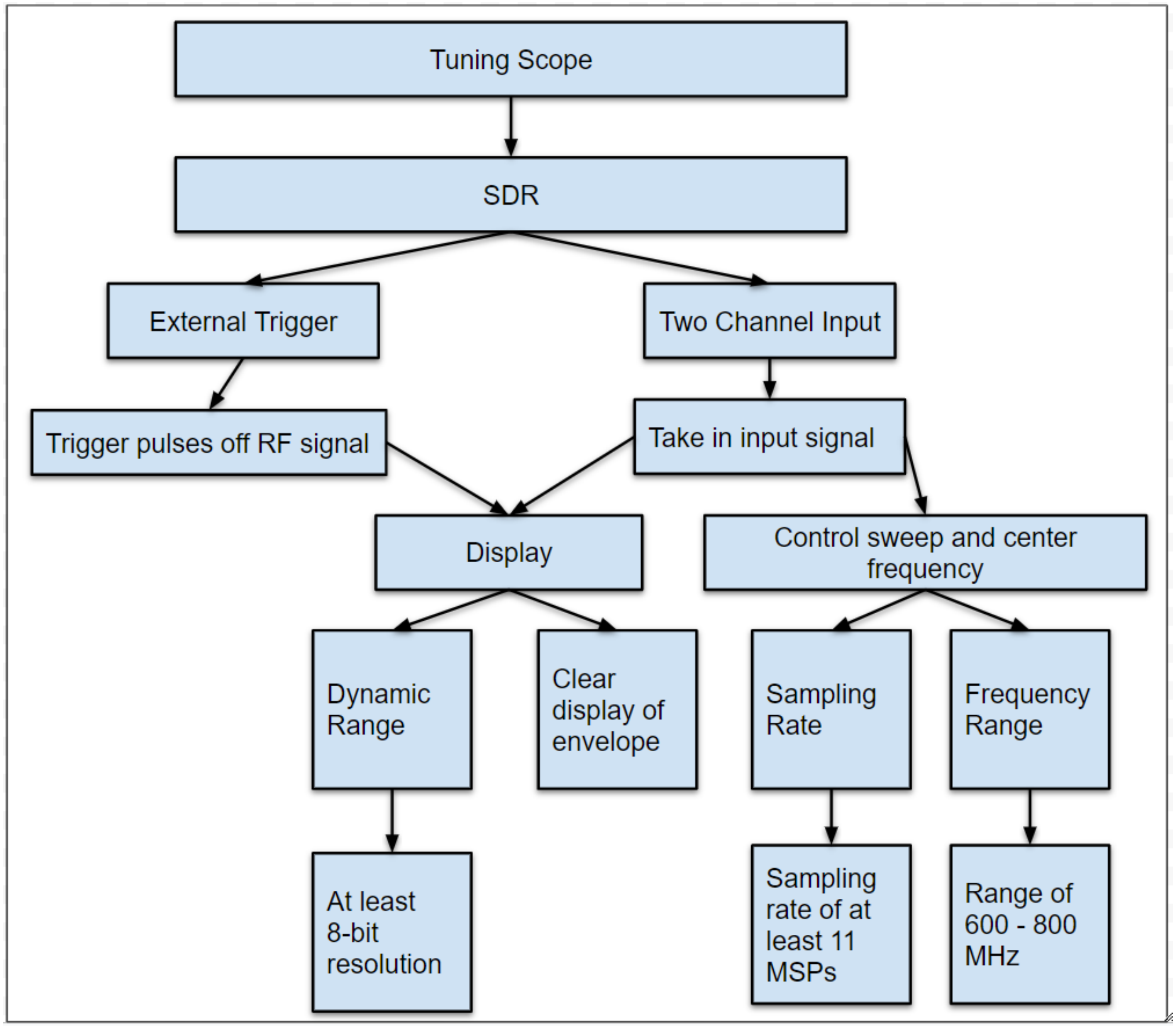

Figure 1: Function Tree parameters contained in this figure

Target Catalog

Table I: Targets Catalog

Metric Number	Need	Metric	Importance	Units	Marginal Value	Ideal Value
1	2-Channel SDR	Hardware	Moderate	N/A	1-2	2
2	Run for days	Duration	Impotant	Days	7-14	14
3	Frequency Range	Bandwidth	Moderate	MHz	600-800	800
4	Sampling Rate	Bandwidth	Moderate	ns or MSPS	11	11
5	External Trigger	Hardware	Very	N/A	1-2	2
6	Resolution	Quality	Least	bits	8	8
7	Attenuators	Resistance	Important	dBm	2.5	2.5
8	Display Envelope	Software	Very	Hz	1	1
9	Linux Compatibility	Software	Least	N/A	N/A	N/A

Table 1: Targets contained in this table

Engineering Drawings

Figure I: Signal Flow Schematic

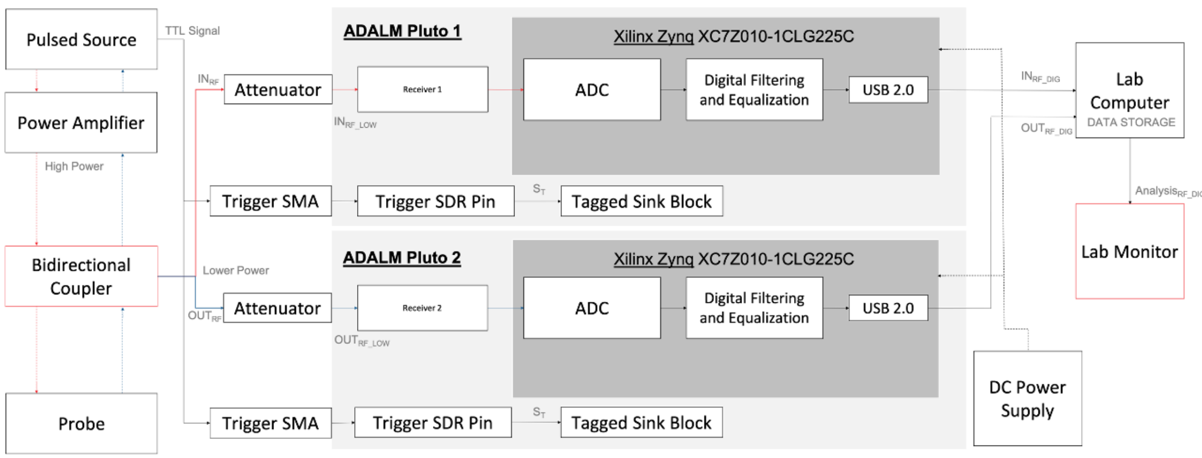

Figure I: Schematic of the signal flow for the initial design

Figure II: Prototype Body SOLIDWORKS Model

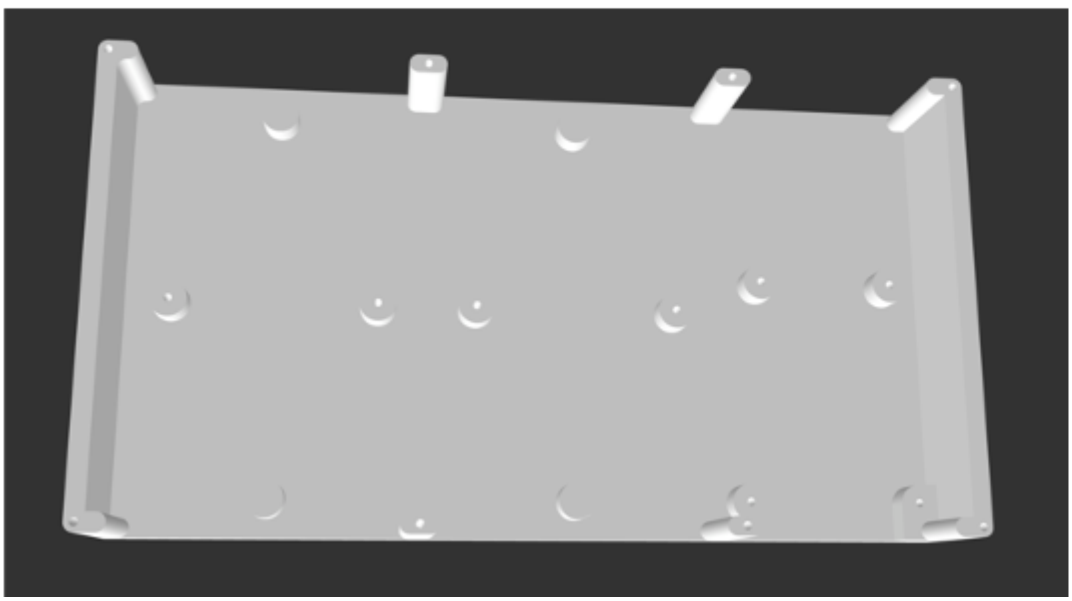

Figure II: A SOLIDWORKS model of the prototype body is shown in the figure

Figure III: Prototype Lid SOLIDWORKS Model

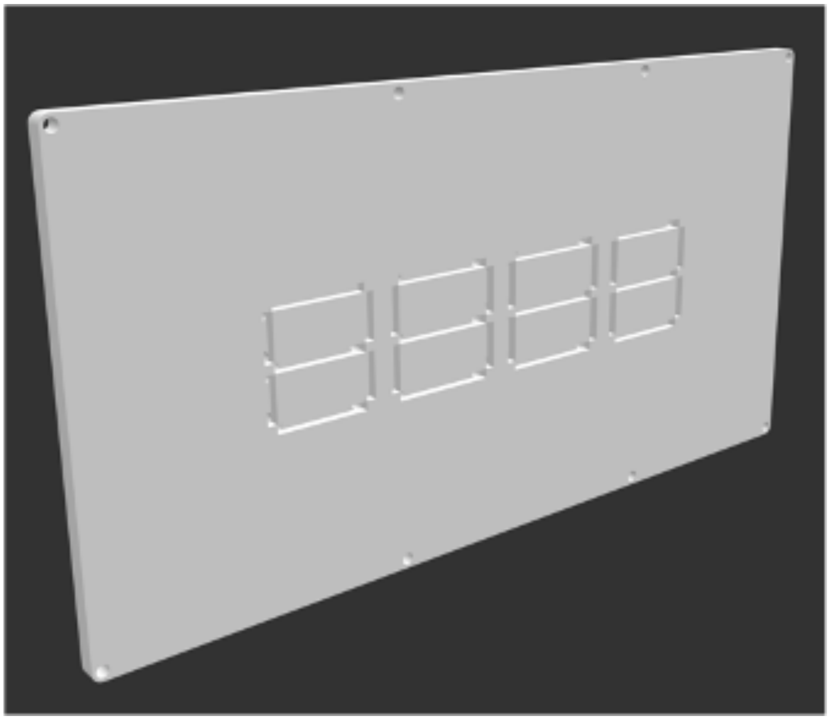

Figure III: A SOLIDWORKS model of the prototype lid is shown in the figure

Calculations

This project was heavily software based and did not require any calculations to reach the desired conclusions. However, to understand the meaning of RF pulse analysis inside of the SDR FPGA module, several mathematical models have been merely analyzed by the team for purposes of general understanding. An example of such a model can be the extraction of voltage magnitudes of the incoming RF pulse trains from their I and Q components. Since the final prototype works on Windows OS machine, we did not proceed further with this analysis, after careful consideration and questioning of our customer about this matter. However, in case another user will need those magnitude values provided in volts, a Linux OS machine can be used with the same procedure described in the operation manual. On Linux OS, IIO-Oscilloscope has an in-built *math* function which can be set to calculate the following equation.

$$Voltage_{Peak} = \sqrt{I^2 - Q^2}$$

In that case, the user will be able to visualize magnitudes in volts vs time. Our prototype plots ADC codes vs time, which are proportional to those magnitudes in voltage described earlier. Therefore, proper tuning is still achieved, simply based on different values.

To add to the previous statement, the project was heavily research based, where the most complicated and challenging tasks revolved around the software side. After several source code changes in various programs, testing and validation, each module was granted to proceed to the next stage. The lack of mathematical calculations that were necessary to complete the project was heavily balanced by the amount of research and engineering design work and procedures that were required.

Risk Assessment

Figure I: Project Hazard Assessment Worksheet 1

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Project Hazard Assessment Worksheet

PI/instructor: Oscar Chuy	Phone #: (850) 410-6468	Dept.:EE/CpE	Start Date: 8/24/20	Revision number: 1
Project: Team 307 - Keysight Oscilloscope			Location(s): FAMU-FSU COllege of ENgineering	
Team member(s):Asher Rich, Kyle York, Jonathan Burt, Emil Lobachev, Gabriel De Leon			Phone #: (954) 850-2897	Email: ar16b@my.fsu.edu

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
Transporting components to and from the lab.	Electrical engineering lab	Entire Team	Damaging components that don't have extra protection of have been dropped	Accomplished by correct transportation methods i.e. transportation by cart or extra padding in box.	Gloves	Can be thrown away unless damaged components is leaking fluid, then contact instructor immediately	HAZARD: CONSEQ:2 Residual: Low Medium	Safety controls are planned by both the worker and supervisor. Second worker should be knowledgeable of the hazard.
Checking Environment	Electrical engineering lab	Entire Team	Trip and slip hazards such as cables or water left on the floor	Check the entire lab before starting the experiment to ensure no trip hazards are around. Put everything away when done with it.	N/A	N/A	HAZARD: CONSEQ:1 Residual: Low	Safety controls are planned by both the worker and supervisor.
Assembly of Hardware and Operations	Electrical engineering lab	Kyle York Gabriel De Leon	Burning from equipment or shock	Turn all equipment off when not in use, start from low voltage to ensure all components work correctly and do not bust.	Goggles, Alligator clamps	All solder should be cleaned up with a wet sponge and not left around the workstation.	HAZARD: CONSEQ:2 Residual: Low Medium	Safety controls are planned by both the worker and supervisor. Second worker should be knowledgeable of the hazard.

Principal investigator(s) PHA certification: I certify that I have reviewed and approved the PHA worksheet and will ensure the control measures are available and implemented in the laboratory.

Figure I: Project Hazards are described in this figure

Figure II: Worksheet 1 Signatures

Figure II: Signatures for Worksheet 1 are shown in this figure

Figure III: Project Hazard Assessment Worksheet 2

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Project Hazard Assessment - Project Narrative

Name of Project:		**Date of submission:**
Team member	**Phone number**	**e-mail**
Kyle York	**(850) 728-8953**	**kny18b@my.fsu.edu**
Asher Rich	**(954) 850-2897** 1/17/2020	**ar16b@my.fsu.edu**
Emil Lobachev	**(954) 765-9818**	**el17d@my.fsu.edu**
Jonathon Burt	**(954) 882-8151**	**jonathan1.burt@famu.edu**
Gabriel De Leon	**(407) 989-8711**	**gwd16b@my.fsu.edu**
Faculty mentor	**Phone number**	**e-mail**
Oscar Chuy	**(850) 410-6468**	**chuy@eng.famu.fsu.edu**
Jerris Hooker	**(850) 410-6463**	**hooker@eng.famu.fsu.edu**

Rewrite the project steps to include all safety measures taken for each step or combination of steps. Be specific (don't just state "be careful").

Soldering: Wear glasses in case of metal popping, use clamps to hold wires to avoid skin contact with solder or soldering iron, return iron to stand when not in use, make sure the iron is off when not around or finished soldering.[1]
Power Source: Start with low current input until voltage stabilizes to avoid frying or popping components, wear safety goggles in case of component popping and shrapnel flying.[2]
Wires: Inspect wiring used and identify where faults may be to avoid shock, replace any faulty wire.[3]
Environment: Be aware of any objects in the surrounding area to avoid compromising experiment, no water should be in the lab, wires should be hung up to avoid tripping hazards, no jewelry or clothing hanging over work environment so nothing catches flames or produces shock. Don't leave any electronics plugged in.[4]
Transporting: When transporting any equipment or components, extra caution needs to be apparent so nothing is broken, no leaks from components such as batteries, and no chance of explosions. Can be accomplished by correct transportation methods i.e. transportation by cart or extra padding in box.[5]

Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

In the case of solder burn, quickly apply anti burn cream or run cold water over the burned area. If any foreign substance gets in eyes, contact 9-1-1 immediately, do not attempt to remove the substance.
If the electrical component is fried or popped, immediately dispose of the component once it has cooled and clean up any mess it has made.
If shocked from the wire, quickly inspect the area to confirm no injury, if unsure, consult a faculty member or lab partner. Any damage to lab equipment must be reported to faculty members.
In case of a sensitive component in transportation being affected in any way, immediately notify faculty to dispose of it correctly while not letting others near the area.
For all accidents or injuries, the lab user must report to an instructor to complete an accident report.

List emergency response contact information:

- Call 911 for injuries, fires or other emergency situations
- Call your department representative to report a facility concern

Name	Phone number	Faculty or other COE emergency contact	Phone number
Claudia Jimeno	**(561) 267-6557**	**Shannon Lollie (Campus Services)**	**(850) 410-6293**
Thayne Greer	**(832) 257-6248**	**Elizabeth McGhee (HR)**	**(850) 410-6421**
Evan Woodard	**(561) 601-6760**		

Figure III: Project Hazards are described in this figure

Figure IV: Worksheet 2 Signatures

Figure IV: Signatures for Worksheet 2 and references are shown in this figure

– END OF DOCUMENT –