FUNCTIONAL SPECIFICATION

SOFTWARE DEFINED RADIO

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Revision History			
Version	**Date**	**Description**	**Author**
0.1	9/30/18	Most Sections Identified, Authors Named	James Bell
0.2	10/14/18	Sections compiled and reviewed for Inaccuracies.	James Bell
0.3	10/15/18	References added, and writing checked	James Bell
1.0	10/17/18	Approvals given and document signed	James Bell
1.1	10/17/18	Removed “Build kit” due to miscommunication and redefined as “educational tool”	James Bell

Table of Contents

1 Introduction

In this Project the end goal is an operational software defined radio for educational purposes. It will be a half-duplex device operating in the North American High Frequency Range as allocated by the North American International Telecommunications Union.

1.1 *Summary (James Bell)*

The sponsor for this project is Dr. Stapleton in the Ingram School of Engineering whom wants this project to help radio enthusiasts of all ages learn about digital signal processing, radio construction and radio communications.

This will be a prototype modified from pre-existing specifications to be designed for optimized price and functionality as the intent is to make the device affordable and of good quality for those whom are just learning about radio.

1.2 *Sponsor Requirements (James Bell)*

The following is a list of Sponsor requirements and Stretch goals for the project as approved by the Sponsor in the Statement of Work. As well as the specifics for each of the items on the list shown as "Performance Targets".

- It will be able to turn on and off.
- It will be capable of receiving desired frequencies on the North American high frequency range.
- It will take the received transmissions and convert them to an audio signal.
- It will have real time audio.
- It will be capable of transmitting on the north American high frequency range.
- It will be capable of taking in audio and converting it for transmission.
- It will transmit the converted audio.
- A clear and simple to access way to alter the frequency transmitting and receiving on in the high frequency range.
- It will show the frequency currently tuned in to in a visual way.
- It will be able to run on standard US power.
- Its estimated unit cost should be less than $300.
- The prototype device should resemble the specifications posted as closely as possible.
- The signal received will be understandable and clear.
- The device will have a volume control for the speaker.
- The device will have the option to select license class.
- The device will have an enclosure for safety.

- The device shall allow the user to select a licence class to inhibit possible illegal transmissions.
- Optional: Higher power amplifier.
- Optional: Have the ability to run on an alternate power source.
- Optional: Be able to run with a Teensy or a Raspberry Pi.
- Optional: Should have a headphone jack.

Product Performance:

Features	Performance Targets
Turn on and off	Turns on and off
Receiving and transmitting on a desired frequency	We will tune to a desired frequency on the North American high frequency range with this device
Take a radio signal and convert it to an audio signal	Using the Teensy microcontroller, the device will take in Single Sideband Radio signals and convert them to audio signals
Output and input audio in real time	Latency of less than 100 milliseconds
Transmitting receiving on North American HF 80m and 20m bands	80m: 3.500MHz – 4.000MHz 20m: 14.000MHz – 14.350MHz
Take audio from the user to transmit	It will be able to take in audio from a microphone and convert that signal in the Teensy to a Single Sideband radio signal
Transmit and receive audio with limited latency	It will do the audio to Single Side band conversion in less than 100 milliseconds
Clear and simple way to alter frequency	Have a dial to select the frequency wanted
Make the desired frequency visible to the user	Have a display showing the current frequency
Run on standard US power	The device can be powered by 120V and 60Hz AC power from any US power outlet
Its estimated unit cost should be less than $300	The unit will cost less than $300 to produce
The signal received will be understandable and clear	The signal-to-noise ratio of the final device should be 25dB or more
The device will have volume control	The device will have a dial knob to control gain
The device will have an enclosure for safety reasons	The User will only be able to access the control components such as the volume control, mode control, signal selection, and the on and off switch
The device shall allow the user to select a licence class to inhibit possible illegal transmissions.	
Optional: Have the ability to run on an alternate power source	Run on a 12V battery for at least 4 hours of constant transmission
Optional: Be able to run with a Teensy or a Raspberry Pi	Be able to run with a Teensy or a Raspberry Pi
Optional: Should have a headphone jack	Will have a 3.5mm standard headphone jack for audio reception

1.3 Existing System (James Bell)

The design and source code we will be using for our starting point is from Charlie Morris's Software Defined Radio Project as posted on his Blog and YouTube video series.

Charlie Morris's design uses digital signal processing in software to process both the receiving signal and the desired transmit signal. It is built unsafely as many components are exposed to the air which could be very dangerous, and it must fall within the North American High Frequency Range. As his design is for a different region it does not do this well and as it will be a device for learning should not be able to access frequency ranges outside of the legal North American High Frequency Range to start with. For this design to be turned in to an educational tool which can be recreated by others in North America safely, cheaply and with clarity so that they may understand exactly what they are doing while creating the device it needs to be modified and clearly documented.

1.4 Terminology (Zachary Schneiderman)

Term	Description
SDR	Software Defined Radio
SSB	Single Side-Band
IF	Intermediate Frequency
HF	High Frequency
RF	Radio Frequency
AF	Audio Frequency
AM	Amplitude Modulation
FM	Frequency Modulation
IQ	In-Phase and Quadrature
LO	Local Oscillator
BPF	Band Pass Filter
LPF	Low Pass Filter
ITU	International Telecommunications Union

2 Functional Description

2.1 User Attributes and Use Cases (Zachary Schneiderman)

The primary audience of this product are students who are looking to increase their knowledge in the field of engineering and amateur radio. This audience can further be classified into sub groups. The first group is composed of those who are do not hold a radio operator’s license. This group will only be able to receive and listen to frequencies (as defined by the radio), but not will not be allowed to transmit. The next group is composed of those who do hold some sort of radio operators license, and they will be able to receive on any frequency, but only transmit on frequencies allows by the North American ITU frequency bands. These restrictions will be controlled by a rotary switch, in which the user will turn the dial to the setting that appropriately corresponds to their licensing level. These levels will be: Unlicensed, Technical, General, and Extra. These licence levels, Technical, General, and Extra, are clarified by the Federal Communications Commission but are easier found on the Amateur Radio Relay League, or the ARRL website.

2.1.1 Configuring the Radio for Receiving

Step 1: The user must ensure that the radio is plugged into a proper power source

Step 2: The user switches the device on, and verifies that the power LED is illuminated, and that the frequency LCD screen is illuminated

Step 3: The user will select the appropriate licensing level using the multi pole turn knob

Step 4: The user will adjust the volume knob so that the receiving signal is audible

Step 5: The user will switch between which band (80m or 20m) they wish to tune on

Step 6: The user will use the rotary encoder to tune to the desired frequency within their select band

2.1.2 Configuring the Radio for Transmitting

Step 1: The user must ensure that the radio is plugged into a proper power source

Step 2: The user switches the device on, and verifies that the power LED is illuminated, and that the frequency LCD screen is illuminated

Step 3: The user will select the appropriate licensing level using the multi pole turn knob

Step 4: The user will adjust the volume knob so that the receiving signal is audible

Step 5: The user will switch between which band (80m or 20m) they wish to tune on

Step 6: The user will use the rotary encoder to tune to the desired frequency within their select band

Step 7: The user will press the Push to Talk button to begin their live transmission

2.1.3 Powering Down the Radio

Step 1: The user should turn the licensing level dial to 'Unlicensed'

Step 2: The user should turn the volume knob all the way down

Step 3: The user should switch the power switch to off and verify that the power LED is no longer illuminated

2.2 Administration Functions (Samuel Hussey)

The intent of the build is to provide a learning tool and resource in the form of an educational tool that can be replicated. Therefore, all users will have equal access to both the hardware and software portions of the final product but can select restrictions for themselves based on the license level they hold.

The system will be administered by whomever the current user is. This means that all functions of the radio can be considered administrative as all schematics, dataflow charts, and code will be accessible to any user.

There are no security functions built in with the intent of restricting access to any portion of the machine. The software can only be edited if the Teensy is connected to the Arduino IDE with the proper installer for the Teensy loaded in to the Arduino IDE and an edited program is uploaded manually, so no accidental modifications to the software can be made.

2.3 Error Handling (Samuel Hussey)

Inputs:

Should the user attempt to tune to a frequency outside of the 3.500MHz-4.000MHz or 14.000MHz-14.350MH range, the system will loop back to the opposite end of the spectrum. Frequencies outside of these ranges will be blocked within the Teensy software as well as 20m and 80m bandpass filters.

If the user does not possess the proper level of licensure required to transmit on certain frequencies within the HF spectrum, it is their responsibility to stay within the legal ranges as this knowledge is covered within the licensing exam for amateur radio. However, the user may select a license level from the devices pre-sets to inhibit any possibly illegal accidental transmissions.

Power:

The SDR transceiver will be powered by a 12V source, as this is one of the most common voltages of portable power systems. If the supply voltage is less than 12V, low power output and poor RF stability may occur. If supply is less than 10V-11V, the radio will not function, while a voltage supply exceeding 13V-14V will put components in danger of burning out.

The Teensy is rated to handle between 3.6V-6V, less than 3.6V will fail to power the device while more than 6V may cause irreparable damage. The other components in the build that require their own voltage supply are the LCD (4.8V-5.2V), NE612’s (4.5V-8V), SI5351 (3V-5V), and SN74HC74 (2V-6V). Like the Teensy, a supply lower than the components’ threshold voltage will fail the power them, while a supply that exceeds their threshold may damage them.

Should a portable source be used, the current design gives no indication of low power or a dead battery. The user will be responsible for ensuring that the proper voltage is being supplied.

Teensy Microcontroller:

The software implemented on the Teensy’s microprocessor to handle the DSP will be easily accessible and changeable. Modifying the code may cause errors or total failure of the radio. If one desires to modify the software, a copy of the original working program should be made first to ensure that it can be reset.

2.4 Safety and Security (James Bell)

As a radio this device has many opportunity’s to be used improperly but as it is an educational tool and all components and code will be accessible by the user for learning purposes it will be impossible to stop misuse after the device has been assembled and is operational. However, steps will be taken to ensure it is not overtly easy to miss use or be injured by the device.

For Safety all components excluding those necessary for operation such as the power switch, tuning nob, volume control, and other such control components, will be encapsulated in a case. This case will keep the components safe from accidental contact with the user or other outside objects. The case will also allow the option for “mapping” the components locations in the future to limit the distances of cables and secure the components in place. Hopefully this will limit the chances of failure due to internal damage. This case will allow access to the micro-controller as it is necessary if the user wishes to view or modify the code contained on the device for learning purposes.

The device will have an indicator of power such as an LED designed to show the user that the components are receiving power. The case will also have a warning label stating that if the device is powered, the LED is illuminated, and not to touch the components within the case.

As this is a learning tool the device does not need security and its safety features are limited to only the most essential for safe operation.

2.5 Help and User Documentation (Zachary Schneiderman)

The user is expected to be proficient enough to operate an amateur radio and understand the rules and regulations before transmitting with any sort of radio equipment. If the user is not proficient in the basics of amateur radio, they should practice operating the product with somebody who is and licenced in the region of operation. There will be an instruction manual included with the product, however, it will not list rules and regulations, nor will it list proper radio etiquette when transmitting. This instruction manual will explain basic operation of the device and basic technical details of the device so that users will be able to get the best learning experience and proper use of the product can be followed. You may not contact any of the authors of this project for help with the use of the product.

2.6 Interfaces

2.6.1 User (Zachary Schneiderman)

The user will have access to two rotary switches, one for switching between 80m and 20m bands, and one for selecting their licensing level. The user will also have access to one rotary encoder which will control which frequency the device is being tuned to, as well as one knobbed potentiometer to control the volume, and finally one two pole switch to switch the product on and off.

The user will have two forms of display as well, one LCD screen to show the current tuned frequency, and one LED as a power indicator.

2.6.2 Software (James Bell)

The microcontroller used in this project is the Teensy USB Development Board. This device is programmed via the USB port with the Teensy Loader Application add on to the Arduino Software environment.

For the User to load new software to the device first they must install the Arduino coding environment and then the Teensy Loader Application.
The documentation for both the Arduino coding environment and the Teensy Loader Application are both available online on the Arduino Website and the PJRC website where the Teensy is sold. A step by step guide for the Teensy coding environment set up is available under the “tutorial” webpage about the Teensy.

Some Stretch goals that would be nice to achieve. The device may be operable with a Raspberry PI or a Teensy, be able to run on a 12volt battery for 4 hours of constant transmission, and have a 3.5, standard headphone jack for audio reception.

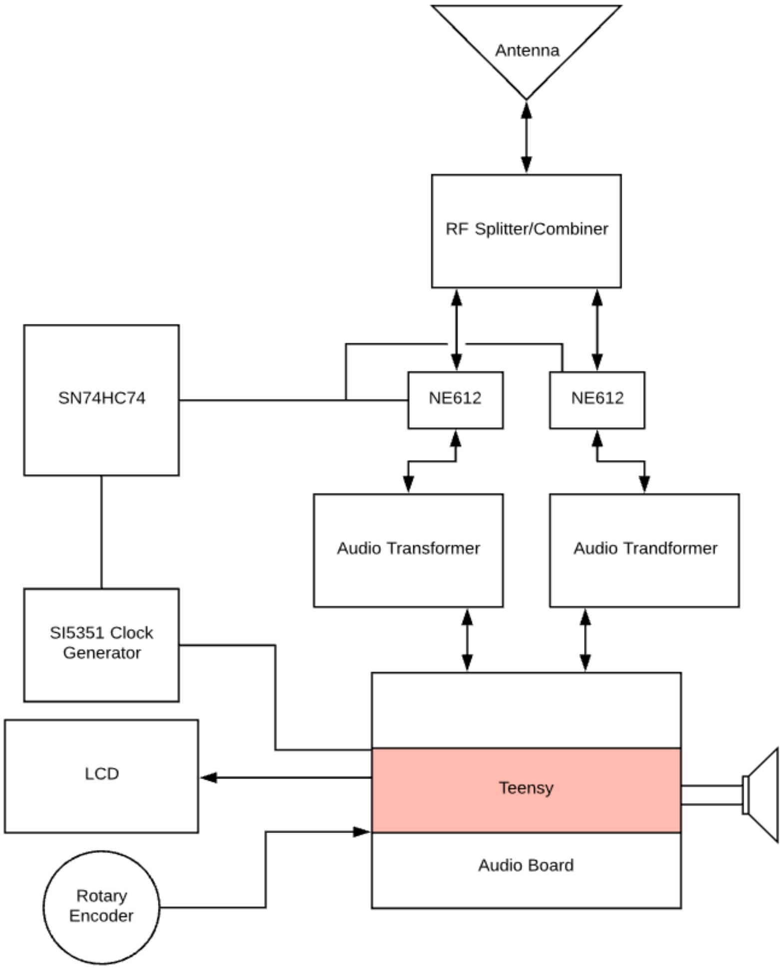
2.6.3 Hardware (Samuel Hussey)

All hardware elements of the build can be connected on a breadboard initially with the implementation of a PCB being a stretch goal. Either a 12V battery or other 12V source will feed into the RF amplifier to supply the power. Voltage regulators will then be used to step the voltage down to 5V and 7V to power the other components.

The Teensy will work in conjunction with the audio shield to interface with the rotary encoder, the LCD, the SI5351 clock generator, the audio transformers, the microphone, and the speaker.

The antenna will feed the received signal into the NE612 mixers which will then interface with the SN74HC74 and SI5351.

The various components interfacing with each other can be seen in the diagram below.



2.6.4 Mechanical (Samuel Hussey)

Mechanical interfaces include an on/off switch to control the power supply, a rotary encoder for the tuning the frequency and changing the display on the LCD, and a set of two mechanical relays to switch between the 80-meter and 20-meter bandpass filters.

2.7 Boundary Conditions and Constraints (Zachary Schneiderman)

Boundary	**Constraint**
The device should operate around the US specification of 120V AC 60Hz	The input power must be minimum 100V AC 50Hz, and cannot exceed 240V AC 60Hz
Boundary	**Constraint**
The RF Amplifiers Gain will be 15-20 at 3.5MHz and 12-15 at 14.5MHz	The RF Amplifiers Gain cannot exceed 60 over the 3.5-14.5MHz band
Boundary	**Constraint**
The NE612 will receive 5V from a linear voltage regulator	The NE612 can receive 4.5V to 8V for Vdd

Boundary	Constraint
The 74LS7474 will receive 5V from a linear voltage regulator	The 74LS7474 can receive 4.5-5.5V for Vcc
Boundary	**Constraint**
The Teensy will receive 5V from a linear voltage regulator	The Teensy can receive 2.7-5.5V for Vcc
Boundary	**Constraint**
The radio will only operate on frequencies from 3.5-4.0MHz and 14.00-14.35MHz	The radio can tune to any frequency on the HF band, 3Mhz to 30Mhz
Boundary	**Constraint**
The Teensy will amplify the microphone signals from 0-20dB	The Teensy can amplify the microphone signals by 0-63dB
Boundary	**Constraint**
The lineout gain of the Teensy will be 13-20dB	The lineout gain of the Teensy can be 13-31dB
Boundary	**Constraint**
The typical transmit power will be between 18-25mW	The maximum transmit power cannot exceed 31mW
Boundary	**Constraint**
The radio will transmit signals from the microphone to the antenna in under 100ms	The radio cannot exceed a 500ms delay as it would make radio conversation difficult
Boundary	**Constraint**
The NE612 will receive RF frequencies of 3.5-14.5MHz	The NE612 can receive 0-500MHz
Boundary	**Constraint**
The LM741 will receive a supply voltage of 12V	The LM741 can receive a supply voltage of +-22V

2.8 Performance (James Bell)

Hardware Performance Parameters					
Parameter	**Test Conditions**	**Min**	**Max**	**Units**	**How to test**
The device should operate around the US specification of the device should operate around the US specification of 120V AC 60Hz	The primary power source for the device must be able to connect to and operate the device with a US power outlet	The input power must be minimum 100V AC 50Hz and the output must be 12V DC	The input power cannot exceed 240V AC 60Hz and the output must be 12V DC	Volts	A set of input and output probes will be used to measure the input voltage and the output voltage through the spectrum listed in the Min/Max requirements.
The RF Amplifiers Gain will be 15-20 at 3.5MHz and 12-15 at 14.5MHz	The RF Amplifier will have a gain of between 15 and 20 at 3.5MHz	The gain will be 15	The gain will be 20		The devices input and output will be mapped with a multi-meter so that we can measure the gain from input to output
The RF Amplifiers Gain will be 12-15 at 14.5MHz	The RF Amplifier will have a gain of between 12 and 15 at 14.5MHz	The gain will be 12	The gain will be 15		The devices input and output will be mapped with a multi-meter so that we can measure the gain from input to output
The NE612 will receive 5V from a linear voltage regulator	The NE612 will receive 5V from the source it is being supplied by	The NE612 can receive at least 4.5V for Vcc	The NE612 can receive up to 8V for Vcc	Volts	The devices input and output will be mapped with a multi-meter so that we can measure the voltage from input to output

The NE612 will receive RF frequencies of 3.5-14.5MHz	The NE612 will receive RF frequencies of 3.5-14.5MHz for testing	The NE612 can receive 0MHz	The NE612 can receive up to 500MHz	Mega-Hertz	
The LM741 will receive a supply voltage of 12V		The device can receive -22V	The LM741 can receive a supply voltage of +22V	Volts	
The 74LS7474 will receive 5V from a linear voltage regulator	The 74LS7474 will receive the min and max voltages from the source it is being supplied by	The 74LS7474 can receive 4.5 for Vcc	The 74LS7474 can receive up to 5.5V for Vcc	Volts	The devices input and output will be checked at the low- and high-end levels to see if the output is still the expected 5v
The Teensy will receive 5V from a linear voltage regulator	The Teensy will receive the min and max voltages from the source it is being supplied by	The Teensy can receive 2.7V for Vcc	The Teensy can receive 5.5V for Vcc	Volts	The devices input and output will be checked at the low- and high-end levels to see if the device still performs the functions is has been assigned, DSP, Audio board control, LCD control, microphone input, speaker output.
The radio can tune to any frequency on the HF band, 3Mhz to 30Mhz	The radio can tune to any frequency on the HF band, 3Mhz to 30Mhz	The radio should be able to tune to frequencies as low as 3MHz	The radio should be able to tune to frequencies as high as 30MHz	Mega-Hertz	Test code will be created covering the spectrum where the input and output is known, the actual and expected will

					be compared and the device altered as needed until there is not a discrepancy.
The radio will only operate on frequencies from 3.5-4.0MHz and 14.00-14.35MHz	The radio can tune to any frequency in the range 3.5-4.0MHz and 14.00-14.35MHz, and transmit and receive single sideband signals	3.5MHz for the 80-meter and 14.00MHz for the 20-meter bands	4.0MHz for the 80-meter and 14.35MHz for the 20-meter	MHz	For transmit we will have a receiver that is calibrated and can receive our signal to verify they are what they are.
The lineout gain of the Teensy will be 13-20dB	The lineout gain of the Teensy will be 13-20dB	The lineout gain of the Teensy will be at lease 13dB	The lineout gain of the Teensy will be at most 20dB	dB	A digital-Multi-meter will be attached to the input and output with probes and the gain measured from there to see If it matches.
The typical transmit power will be between 18-25mW	We will be measuring the transmit power of the device.	The minimum transmit power cannot fall below 18mW	The maximum transmit power cannot exceed 31mW	milli-watts	A digital-Multi-meter will be attached to the input and output with probes and the power will be measured from there to see If it is within the range.
The radio will transmit signals from the microphone to the antenna in	Measuring time difference between the input and output	The minimum is 0ms.	The radio will transmit signals from the microphone to the antenna in	milli-seconds	We will monitor the input from the microphone and the output of the radio and compare

under 100ms			under 100ms		the time stamps to gauge the total time from audio input to radio output and make modifications as needed to stay under the 100ms total transmission time.

Software Performance Parameters					
Parameter	**Test Conditions**	**Min**	**Max**	**Units**	**How to test**
The software used in DSP cannot exceed 1 megabyte	The software must be smaller than 1Mb total		The software cannot exceed 1Mb	Megabytes	The size of the file will be checked before downloading to the Teensy to make sure it will fit on the Teensy.

2.9 Software Platforms (James Bell)

The following list is the list of software's that will be supported by this device.

- The Arduino environment (1.8.7) with the Teensy Loader Application (1.44) addon.
- As a stretch goal this device will support the Raspbian operating system for the Raspberry PI microcontroller.

2.10 Service, Support, & Maintenance (James Bell)

The device will not have software updates pushed out. A repository of code will be available online by version of the educational tool. For instance, version 1 will have its corresponding code available on a repository for everyone to access. This is to allow those who modified or deleted the initial code to restart with something that is sure to work if the hardware has not been modified or assembled incorrectly.

The case will allow for easy access to the components and microcontroller, so cleaning and part replacement or access will be easy.

2.11 Expandability or Customization (James Bell)

The device will be an educational tool, meaning it can be easily modified, expanded, or customized in any way the user sees fit but is not designed with that in mind. Only the initial schematics and code for the microcontroller will be provided.

3 Project Alignment Matrix (Samuel Hussey)

Outside Advisors (if any) and affiliations:

TABLE 1: Knowledge Alignment Matrix

Course No.	**Core knowledge**	**Specific knowledge incorporated by team**
EE 3350 (Electronics I)	Design and analysis of active devices and equivalent circuits	Amplifier and RF splitter design.
EE 3370 (Signals and Systems)	Frequency domain representation of signals and frequency response, transfer functions	Bandpass/low pass filtering and the resulting frequency response.
EE 3420 (Microprocessors)	Principles of operation and applications of microprocessors	Interfacing the Teensy microcontroller with various peripherals such as the LCD, timer, and speaker.
EE 4352 (Introduction to VLSI Design)	Analysis and design of CMOS integrated circuits	No IC design will be implemented in this project.
EE 4370 (Communications Systems)	Transmission of signals through linear systems, analog and digital modulation, and noise	

TABLE 2: Constraint Alignment Matrix (and applicable standards)

ABET Criterion 3 (c): “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.”

Constraint Type	**Specific Project Constraint**
Economic	Keep educational tool total cost low to keep it market viable.
Environmental	Will not be unnecessarily wasteful
Health and safety	Enclose live components and wires, volume control
Social/Ethical	Will conform to social and ethical standards as documented by ARRL
Applicable Standards	FCC regulations pertaining to amateur radio

4 References

[1] ON Semiconductor 2N3904 NPN Bipolar-Junction Transistor Datasheet.
https://www.onsemi.com/pub/Collateral/2N3903-D.PDF

[2] Phillips Semiconductor NE612 Double-Balanced Mixer and Oscillator Datasheet.
http://ee.sharif.edu/~comcirlab/NE612.pdf

[3] Texas Instruments LM741 Operational Amplifier Datasheet.
http://www.ti.com/lit/ds/symlink/lm741.pdf

[4] Silicon Labs SI5351 I2C-Programmable Any-Frequency CMOS Clock Generator + VCXO Datasheet. https://www.qrp-labs.com/images/synth/si5351a.pdf

[5] Texas Instruments SN7474 Dual D-Type Positive Edge Triggered Flip-Flops Datasheet. http://www.ti.com/lit/ds/sdls119/sdls119.pdf

[6] Charlie Morris's Hardware Schematics and Code Used with Arduino
http://zl2ctm.blogspot.com/2018/03/homebrew-ssb-sdr-rig.html

[7] International Telecommunications Website
https://www.itu.int/en/Pages/default.aspx

[8] United States Federal Communications Commission Website
https://www.fcc.gov/

[9] Amateur Radio Relay League's Defined Band Plan Website
http://www.arrl.org/band-plan

5 Approvals

The signatures of the people below indicate an understanding in the purpose and content of this document by those signing it. By signing this document, you indicate that you approve of the proposed project outlined in this Functional Specification and that the next steps may be taken to proceed with the project.

Approver Name	Title	Signature	Date
	Project Manager		
	D2 Project Manager		
	Faculty Sponsor		
	Sponsor		
	Instructor		