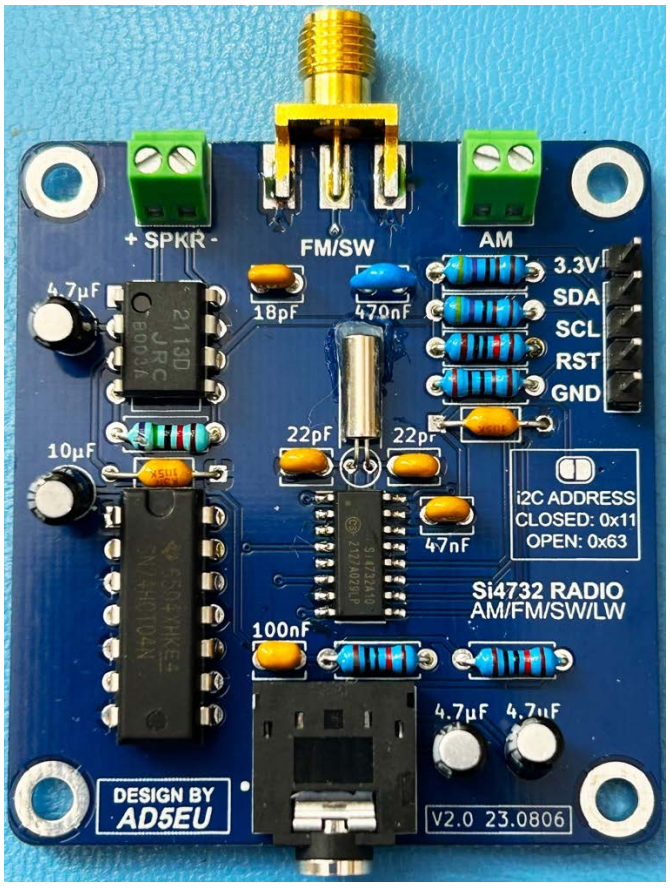
Si4732 Multi-band Radio Through Hole Technology (THT) and Supporting Controller



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Introduction – Radio Module

The popularity of Skyworks (nee Silicon Labs) based radios has expanded a great deal over the last several years based largely on the excellent core Arduino library developed by Ricardo Lima Caratti. The library (PU2CLR Si4735) is available on GitHub at https://github.com/pu2clr/SI4735. Beyond the core library developers have coded many excellent Arduino applications supporting a variety of displays and user interfaces utilizing Ricardo's library.

From a hardware perspective, although there are several schematics for Si473x radios and how-to projects (several developed by myself) these usually rely on surface mount component technology which can be difficult for the casual hobbyist to assemble. Compete radios, such as the ATS25 are available as well.

Given the size of the Facebook group (Si47XX for Radio Experimenters) has grown to nearly 7000 people, there is evidently a great deal of interest in experimentation using the Si473x radio chip. In May 2023 the author was gently challenged to develop hardware for a radio with component technology that is more approachable by a broad spectrum of experimenters.

This project proved to be somewhat more difficult than originally expected, not because of the well understood electronic complexity Si473x radios, but rather due to the difficulty of finding "through hole technology" components appropriate for the economic construction of a full function radio. After two iterations this "bullet proof" design was completed along with an Arduino controller/display board. The core radio module can be built in single unit quantities for ~$20USD excluding the cost of the PCB (available from a variety of suppliers for ~$5.00USD plus shipping detailed in the appendix).

A complete radio with display, Arduino controller and controls can by built for approximately double this cost.

Si4732

The Si4732 is an AM/FM/SW/LW/RDS radio receiver IC that integrates a complete broadcast tuner and receiver function from antenna input to digital audio output. Internally the Si4732 is the same as the Si4735 chip. The only material difference between the two chips is that the Si4735 provides isolated digital audio outputs

DOUT/DFS) whereas the Si4732 multiplexes digital audio onto the same lines used for analog audio. A comparison between the two chips is show in Figure 1.

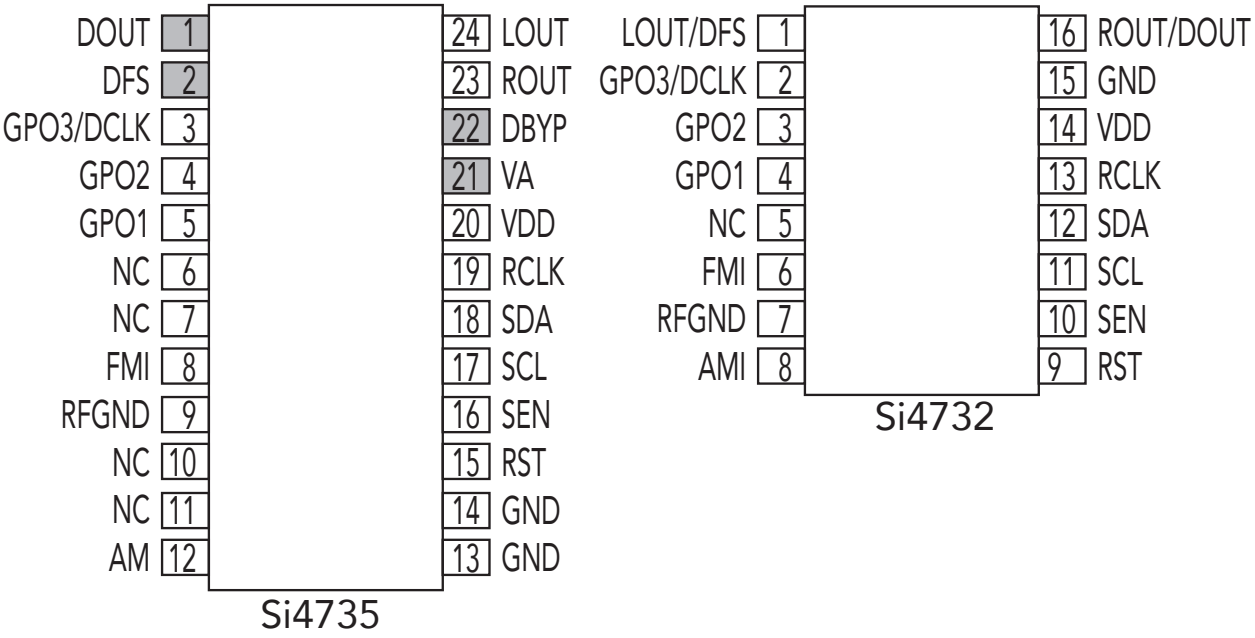


Figure 1 – Comparison between Si4735 and Si4732

For the hobbyist, the important difference is that the Si4732 is packaged in a more hobbyist friendly 16 pin SOIC (Small Outline IC) package with a relatively large 1.27mm (0.05") pin pitch versus the Si4735 which has a more challenging 0.635mm pin pitch (0.025"). The Si4732 can be soldered with a little care, and perhaps some form of magnification whereas the Si4735 needs more specialized tools.

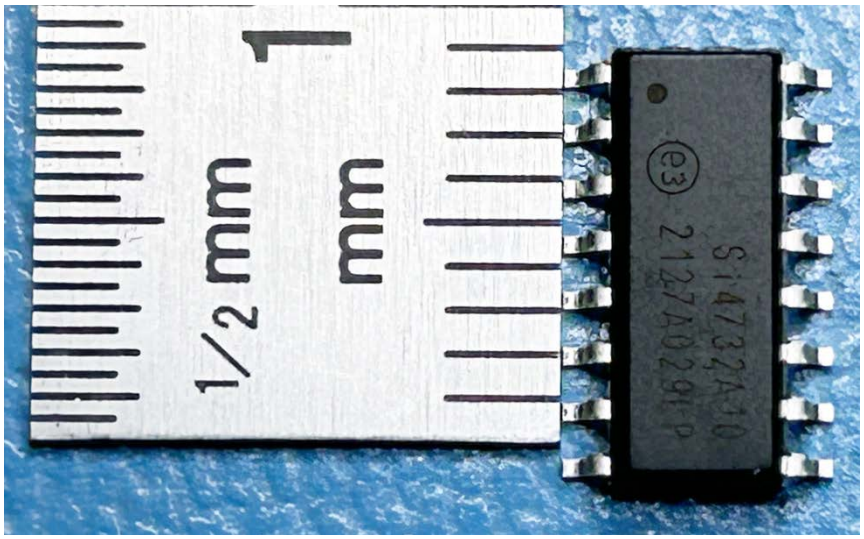
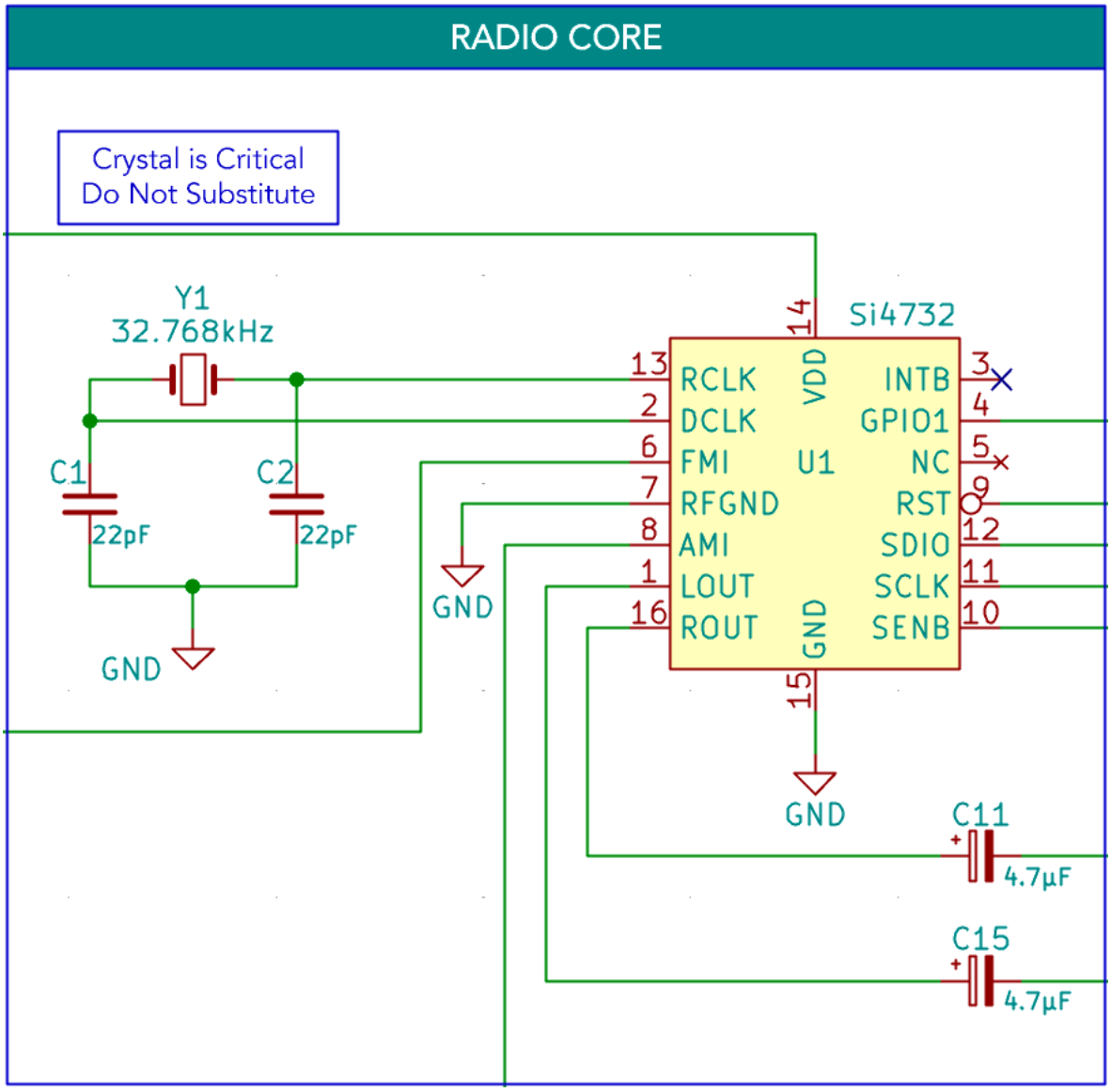


Figure 2 – Si4732 package showing pin pitch. Note the dot in the upper left indicating pin 1

Radio Core

The Si4732 chip only requires a few support components – excluding an audio amplifier just nine (9) capacitors and four resistors.

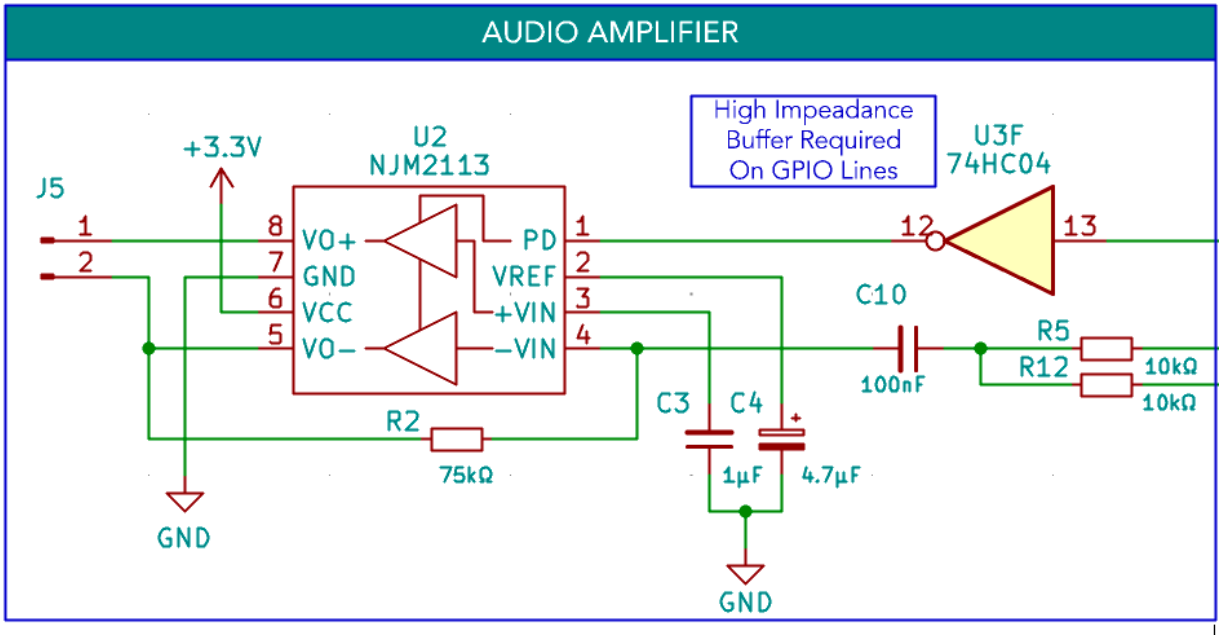


The only critical component (**DO NOT SUBSTITUTE**) is the 32.768kHz crystal required by the Si473x radio. A number of hobbyist of have attempted to build Si473x radios have had issues making the radio work due to the sensitivity of the radio chip to this component. The recommended crystal is the ECS Inc. ECS-.327-12.5-8X available for ~$0.50USD. If this crystal is not available to you, ensure that you pick a substitute crystal with the following characteristics:

Load Capacitance: 12.5pf Equivalent Series Resistance: 35kΩ
Tolerance: ±20ppm (tighter tolerance, e.g. ±10ppm acceptable)

Amplifier

The NJM2113 (Japan Radio Corporation) audio amplifeier compliments the radio . This chip was chosen as it has adequate power for most speakers used in a portable radios (0.4W Class AB), is relatively inexpensive ($1USD), includes internal muting circuitry simplifying the design and is packaged in and easy to assemble 8pin DIP package. The amplifier requires an additional three capacitors, two resistors an a very inexpensive logic chip.



A design feature of this radio is that it uses one of the built in I/O lines of the Si473x chip to control muting saving a pin an I/O pin on the support microcontroller. The I/O lines on the Si473x must not have any electrical loading when the radio boots, or it will hang (not function). A low cost ($0.20USD) logic chip provides the necessary isolation between the mute circuit of the amplifier and the radio chip. Although the 74HCT04 chip used is relatively large (14 pin DIP package) and only 1/6th of the chip is used, it is the simplest least expensive solution the designer could find.

Complete Radio

The complete radio has a total of 27 components:

12	Capacitors	7	Resistors
1	Crystal	3	Chips (Radio/Amplifier/Logic)
5	External Jacks (FM+SW, AM, Speaker, Headphones, Interface)		

The following two pages illustrate the complete schematic and show the bill of materials for the radio.

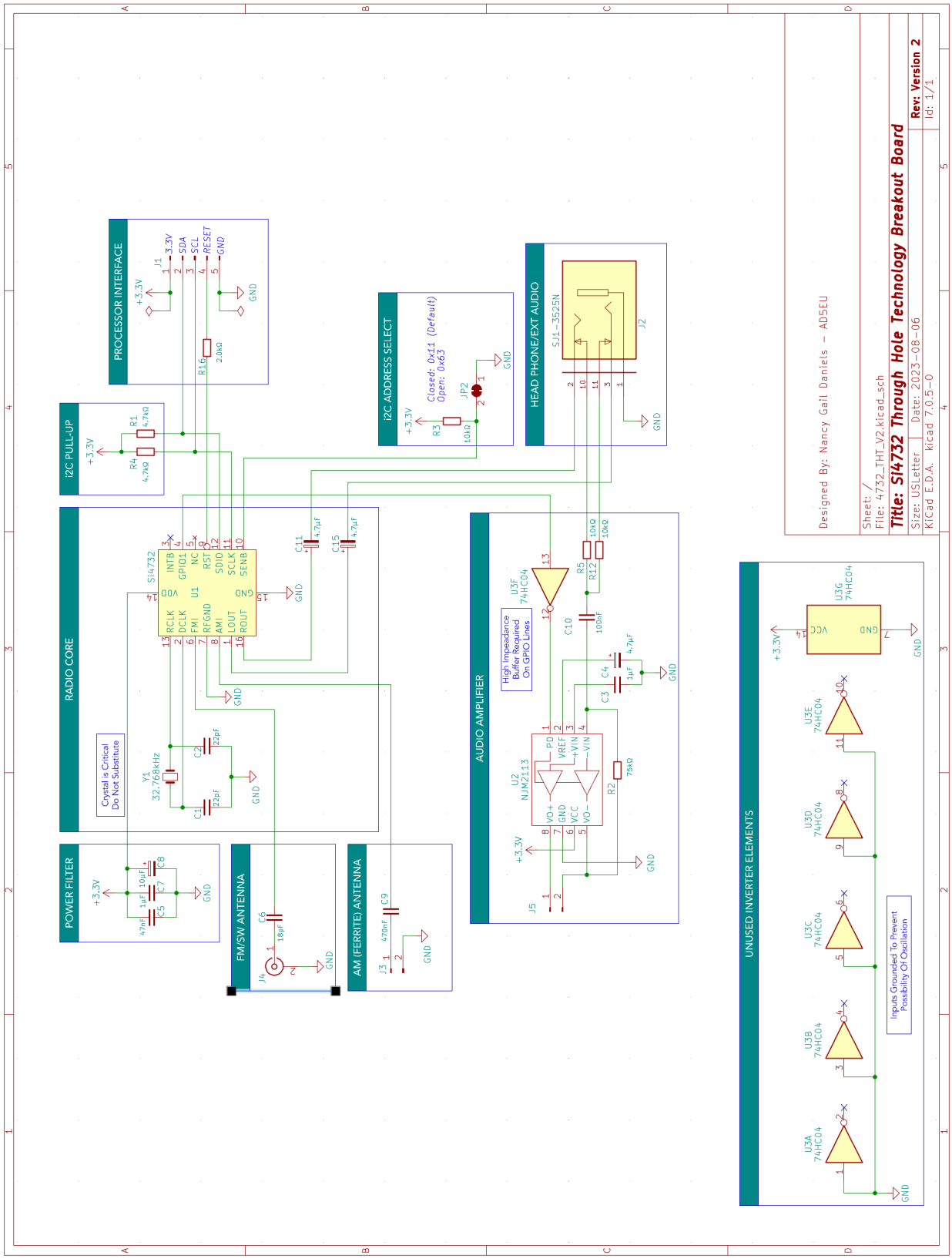


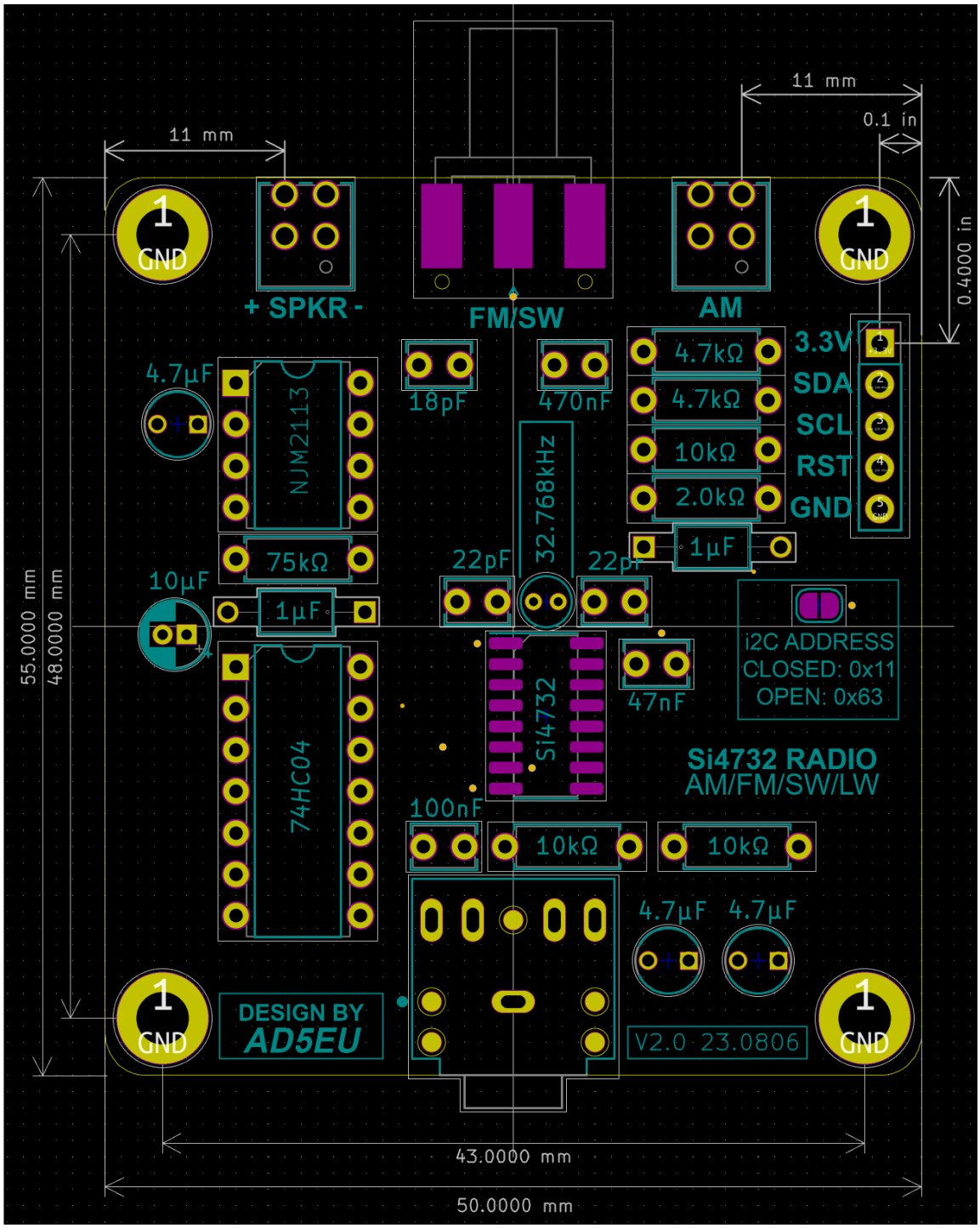
Figure 3 - Radio Module Complete Schematic

Bill of Materials				Si4732 Radio - Through Hole Component Design			Version 2.0 23.0809			
Desig	Qty	Value		Description	Package	Vendor	Vendor PN	Digikey/*Mouser*	Price US$	Extention
C1, C2	2	22pF	±5% 50V C0G/NP0	Capacitor	Radial 4x2.6mm P2.50mm	Vishay	K220J15C0GF5TL2	BC1005CT-ND	$0.27	$0.54
C3, C7	2	1µF	±10% 25V X7R	Capacitor	Axial 4.32xD2.54mm	Kemet	C410C105K3R5TA	399-C410C105K3R5TA-ND	$0.30	$0.60
C5	1	47nF	±10% 50V X7R	Capacitor	Radial 4x2.6mm P2.50mm	Vishay	K473K15X7RF53L2	BC5153-ND	$0.24	$0.24
C6	1	18pF	±5% 50V C0G/NP0	Capacitor	Radial 4x2.6mm P2.50mm	Vishay	K180J15C0GF5TL2	BC1004CT-ND	$0.27	$0.27
C8	1	10µF	±20% 16V Bipolar	Capacitor	Radial_D4.0mm P1.50mm	Panasonic	ECE-A1CKA100	P807-ND	$0.27	$0.27
C9	1	470nF	±10% 50V X7R	Capacitor	Radial 4x2.6mm P2.50mm	TDK	FG18X7R1H474KRT06	445-173276-1-ND	$0.32	$0.32
C10	1	100nF	±10% 50V X7R	Capacitor	Radial 4x2.6mm P2.50mm	Vishay	K104K15X7RF5TL2	BC1084CT-ND	$0.23	$0.23
C4, C11, C15	3	4.7µF	±20% 25V Bipolar	Capacitor	Radial_D4.0mm_P2.50mm	Panasonic	ECE-A1EN4R7U	P1175-ND	$0.24	$0.72
D1	1	T1 LED	16mcd	LED	3mm	Kingbright	WP132XID	754-1211-ND	$0.34	$0.34
J1	1	Conn_01x05_Pin	1x5	Header	2.54mm Vertical	Harwin	M20-9990546	952-2268-ND	$0.26	$0.26
J2	1	2 SW Jack	3.5mm/1/8"	Connector	12x14.3x5mmxP5 RA	CUI	SJ1-3525N	CP1-3525N-ND	$1.11	$1.11
J3, J5	2	Terminal Block	1x2	Connector	2x1 Screw terminal P2.54mm	Phoenix	1725656	277-1273-ND	$1.68	$3.36
J4	1	SMA	Female	RF Conn	SMA EdgeMount Horizontal	Molex	732511153	900-0732511153-ND	$3.99	$3.99
R1, R4	2	4.7kΩ	±1% 0.25W	Resistor	L6.4xD2.4mm	Yageo	MFR-25FBF52-4K7	MFR-25FBF52-4K7-ND	$0.10	$0.20
R2	1	75kΩ	±1% 0.25W	Resistor	L6.4xD2.4mm	Stackpole	RNF14FTD75K0	RNF14FTD75K0CT-ND	$0.10	$0.10
R3, R5, R12	3	10kΩ	±1% 0.25W	Resistor	L6.4xD2.4mm	Yageo	MFR-25FBF52-10K	10.0KXBK-ND	$0.10	$0.30
R16	1	2.0kΩ	±1% 0.25W	Resistor	L6.4xD2.4mm	Yageo	MFR-25FBF52-2K	2.00KXBK-ND	$0.10	$0.10
U1	1	Si4732	AM/FM/SW	Radio	SOIC 16 3.9mm P1.27mm	Skyworks	SI4732-A10-GS	336-5736-ND	$4.70	$4.70
U2	1	NJM2113	400mW	Amplifier	DIP-8_W7.62mm	Nisshinbo	NJM2113D	2129-NJM2113D-ND	$1.06	$1.06
U3	1	74HC32	Hex Inverter	Logic	DIP-14_W7.62mm	TI	SN74HC04N	296-1566-5-ND	$0.49	$0.49
Y1	1	32.768kHz	±20ppm 12.5pF	Crystal	XTAL_ECS-.327-12.5-8X-C	ECS	ECS-.327-12.5-8X	X1123-ND	$0.32	$0.32
									Total	$19.52

Figure 4 - Radio Module Bill of Materials

Radio Module PCB

The radio is built using a 50mm (1.97”) x 55mm (2.16”) double sided PCB with M3 (3mm) mounting holes spaced 43mm(1.69”) and 46mm (1.81”) apart respectively.



Radio Module Assembly

The radio module can be assembled in less than an hour. The following are the suggested steps for assembling the radio.

Step 1 – The Si4732 chip

The Si4732 is the most difficult part of the board assembly and should be installed first.

Although not required, depositing (electronic grade) flux on the Si4732 pads will make soldering the Si4732 easier (shown to the right).

If you do not have a flux dispenser, a flux pen such as the Chip Quick CQ4LF is an alternative.

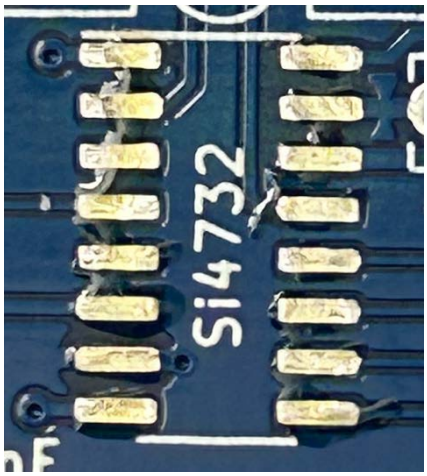


Figure 5 - Fluxed Pads

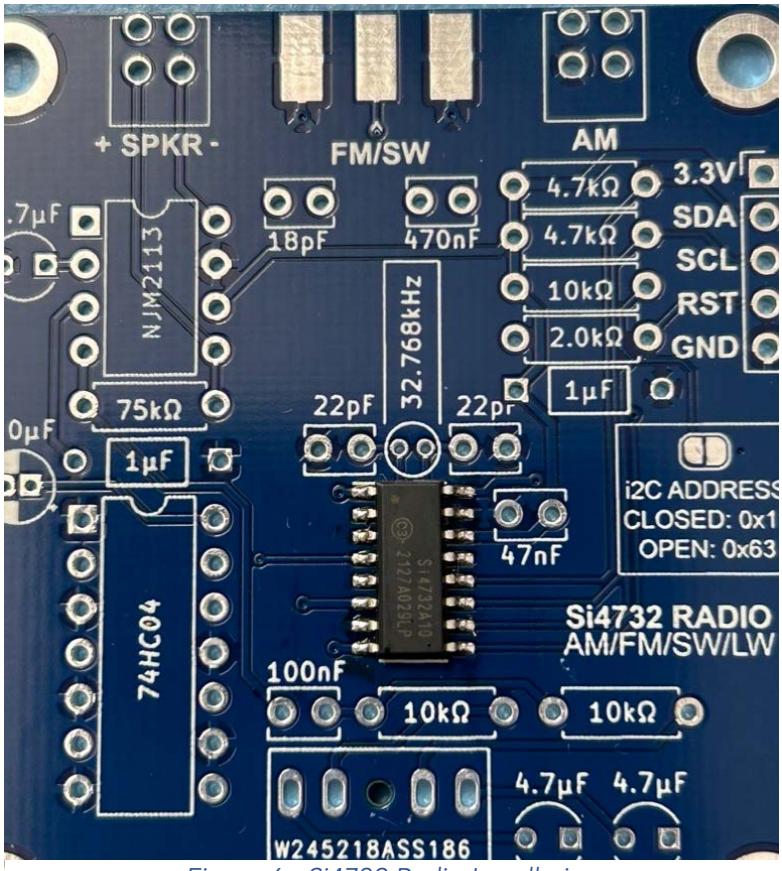


Figure 6 - Si4732 Radio Installation

Note the Si4732 chip is sensitive to static electricity and it is recommended that you "ground yourself" while handling the chip to insure it is not damaged.

Alternatively assembling the board on an anti-static mat can also insure ESD (Electo-Static-Discharge) safety.

Step 2 – Resistors

The next step is to solder on the 7 resistors on the board. In the picture below 1% tolerance resistors are used and as such the color coding may be unfamiliar:

Purple Green Black Red	75.0kΩ	Yellow Purple Black Brown	4.70kΩ
Brown Black Black Red	10.0kΩ	Red Black Black Brown	2.00kΩ

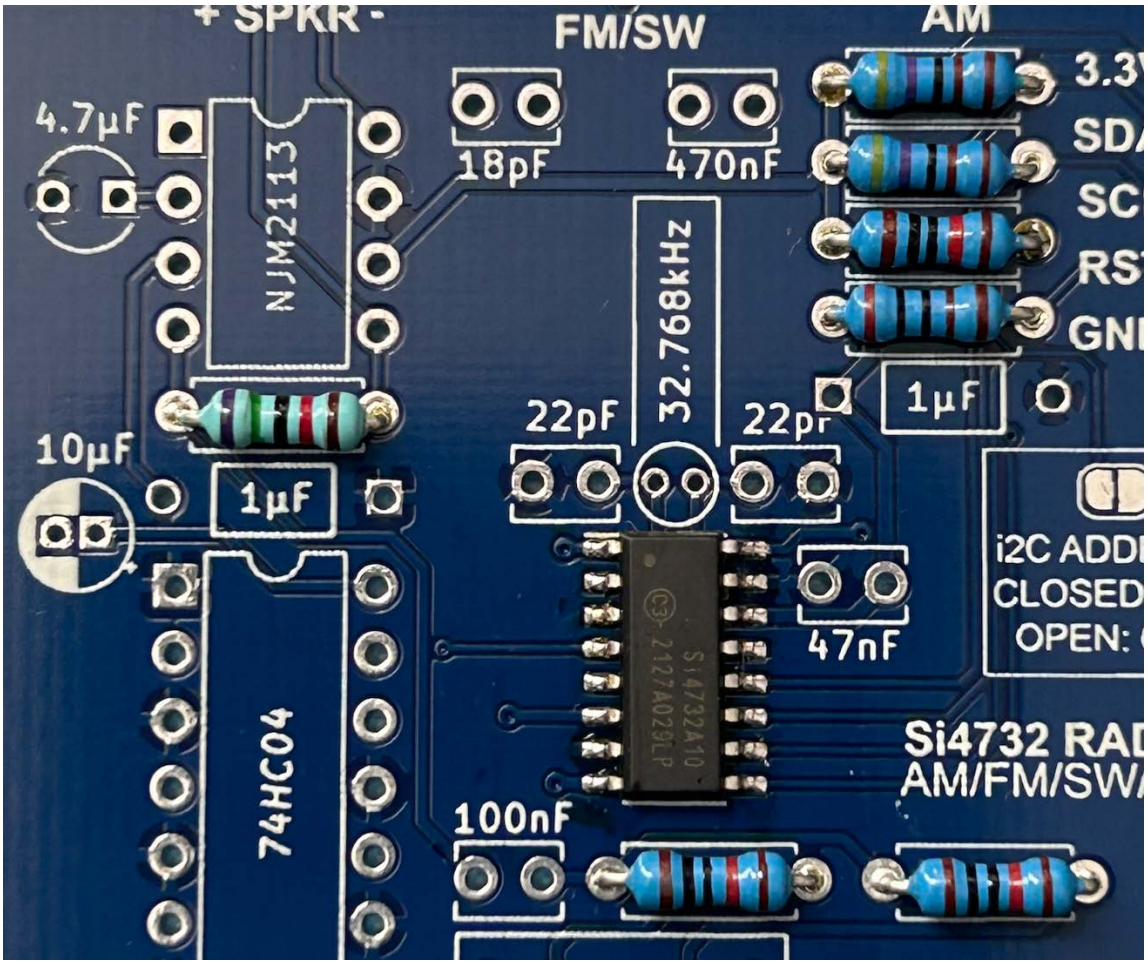


Figure 7 - Resistor Installation

In small quantities 1% resistors can be purchased for the same price as lower tolerance 5% resistors. If you have 5% resistors on hand tolerance is not critical and more commonly available 5% resistors can be used:

Purple Green Orange	75kΩ	Yellow Purple Red	4.7kΩ
Brown Black Orange	10.0kΩ	Red Red Red	2.2kΩ

Step 3 – Small Capacitors

Insert and solder the 5 small capacitors. Note that four of the 5 capacitors look exactly the same but differ in value by several orders of magnitude – be very careful not to mix up the capacitors.

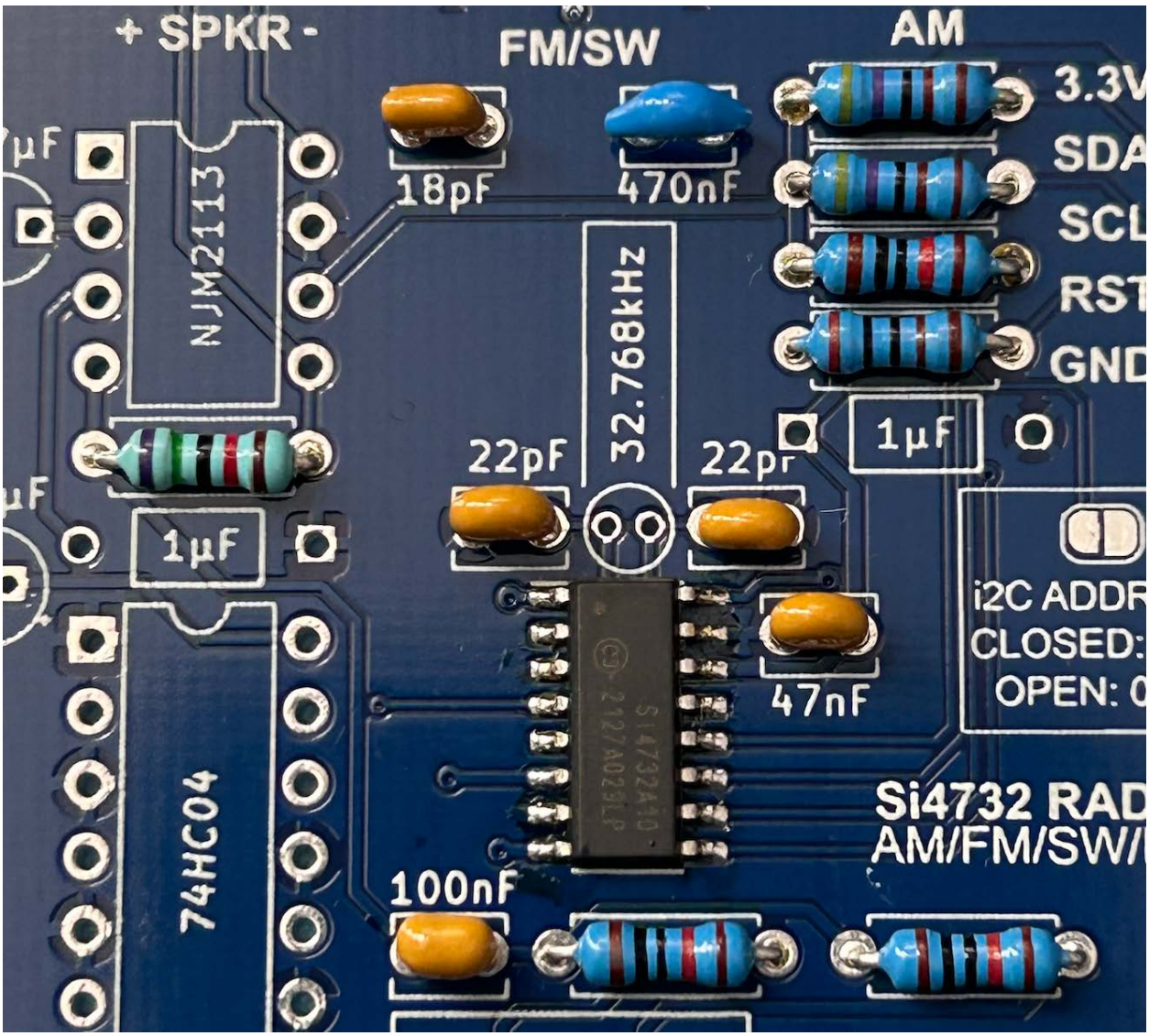


Figure 8 - Small Capacitor Installation

Step 4 – Crystal

Next insert the 32.768kHz crystal. You will notice that the lead spacing on the crystal is quite small and care must be taken when soldering not to accidentally "bridge" solder across the leads. Although not required, a small dab of silicone underneath the crystal will make the radio less susceptible to damage from shock (physically dropping the completed radio).

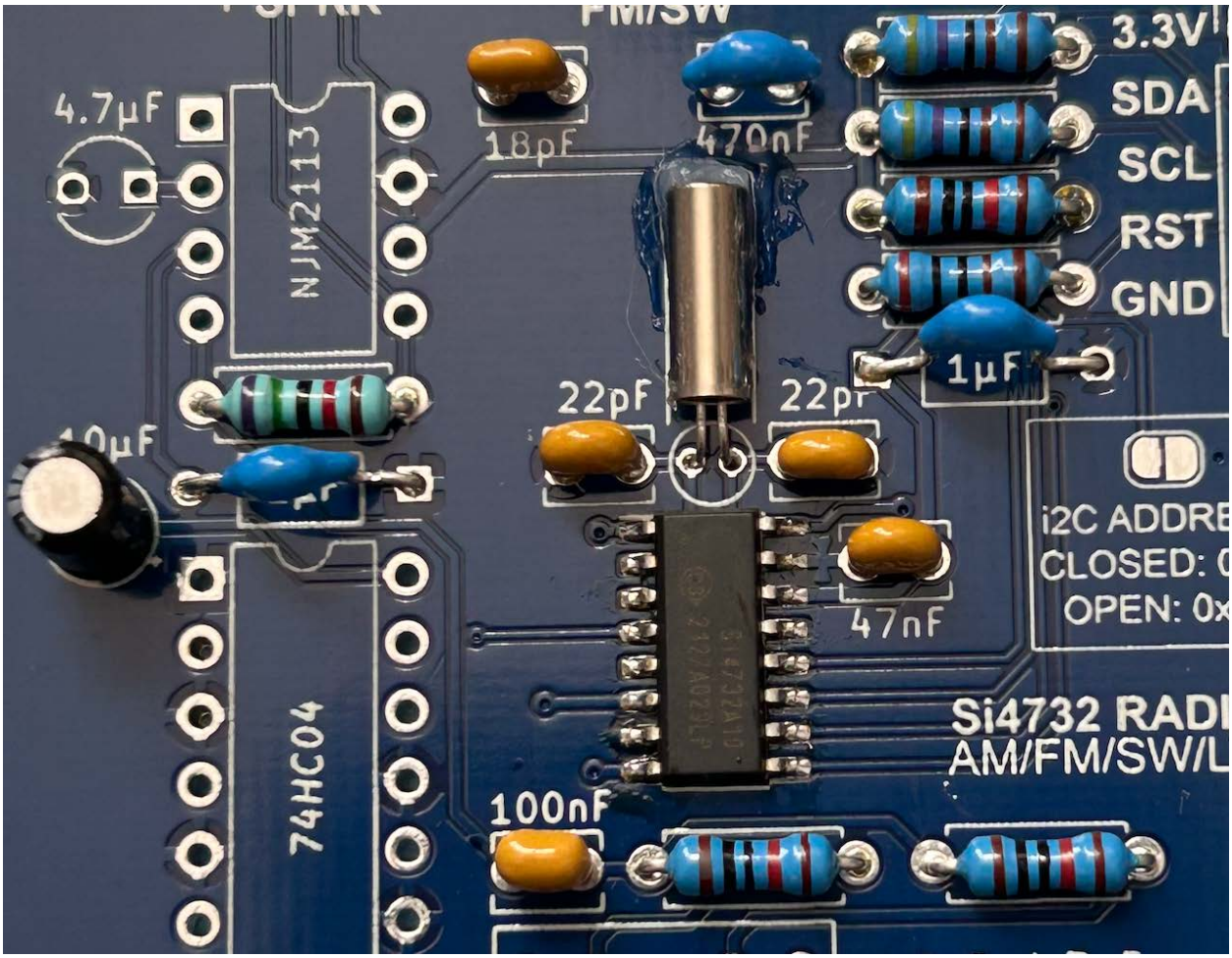


Figure 9 - Installing the Crystal

Step 5 – Large capacitors

Next insert the 6 larger capacitors.

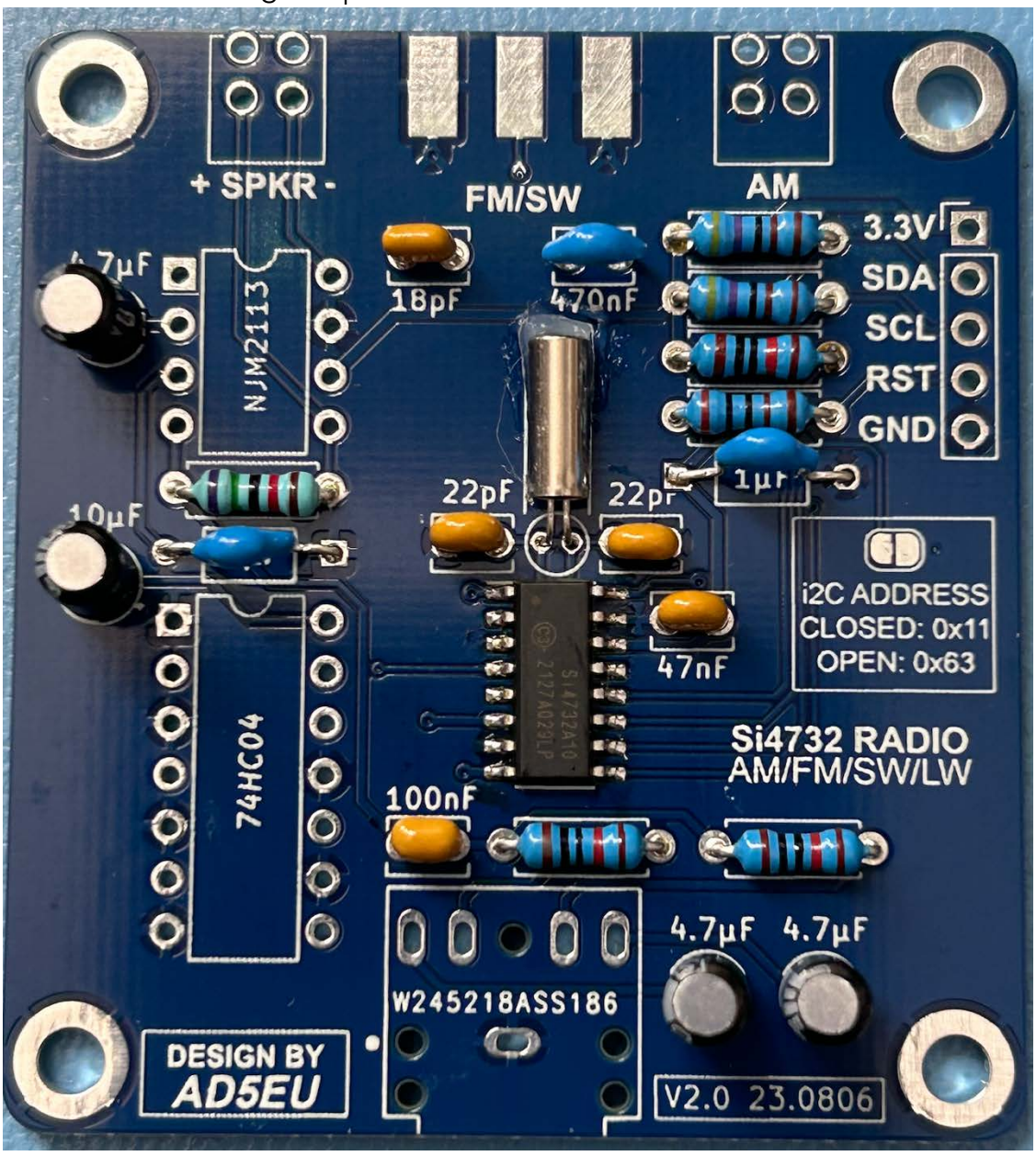


Figure 10 - Installing Large Capacitors

Step 6 – Amplifier and Logic Chip

Next insert the amplifier (NJM2113) and logic chip (74HCT04). When inserting these chips insure that pin 1 (indicated by the insets/indents on the upper part of the chip) is oriented correctly.

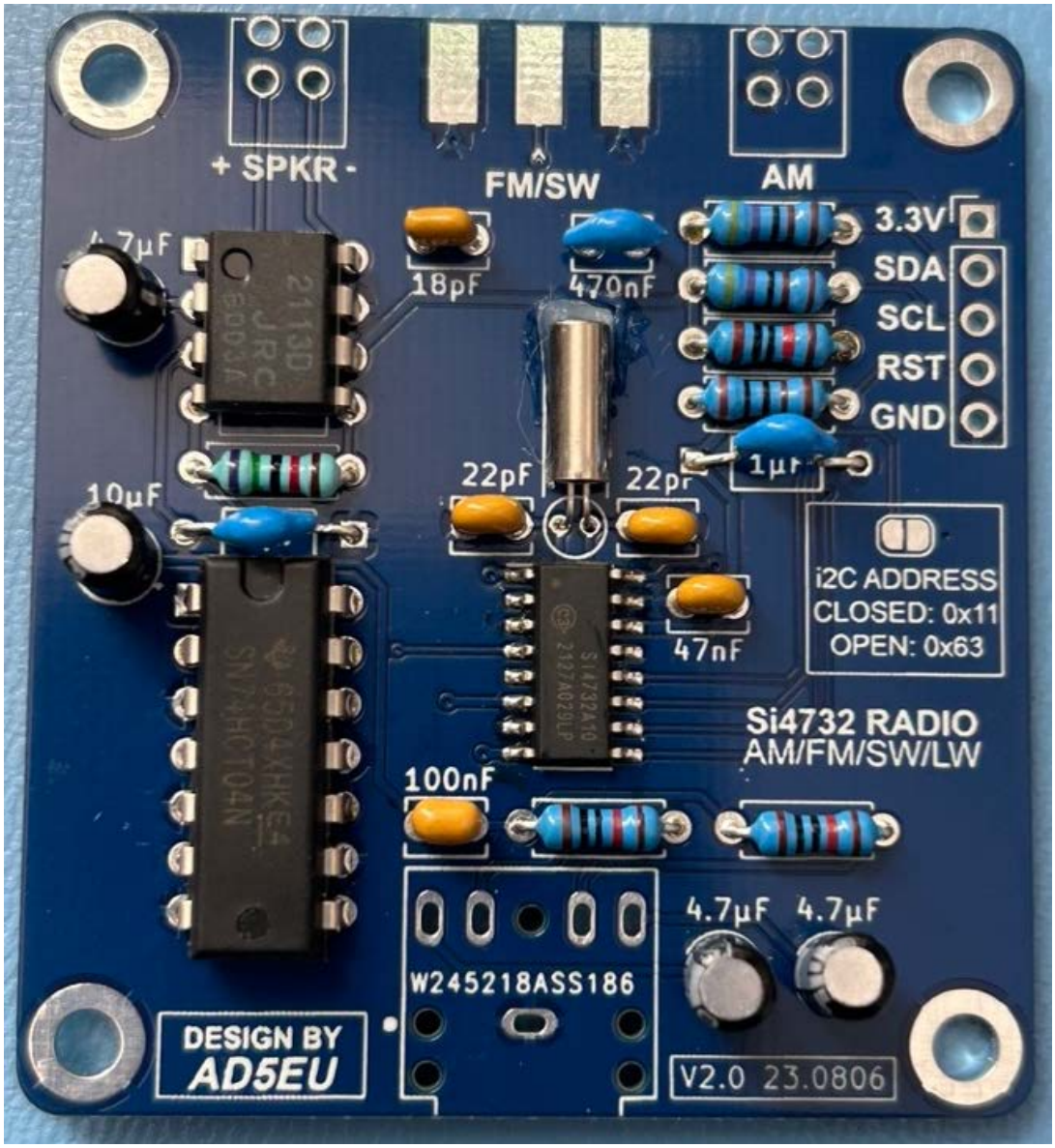


Figure 11- Installation of Amplifier and Logic Chip

Step 7 – Connectors

The last step before the radio is ready to test is to insert the 5 connectors

SMA jack for Shortwave and FM antenna

Two (2) Terminal blocks for the external speaker and AM antenna

3.5mm Audio Jack for Headphones

5 pin) 0.1 header pins for connection to the Arduino

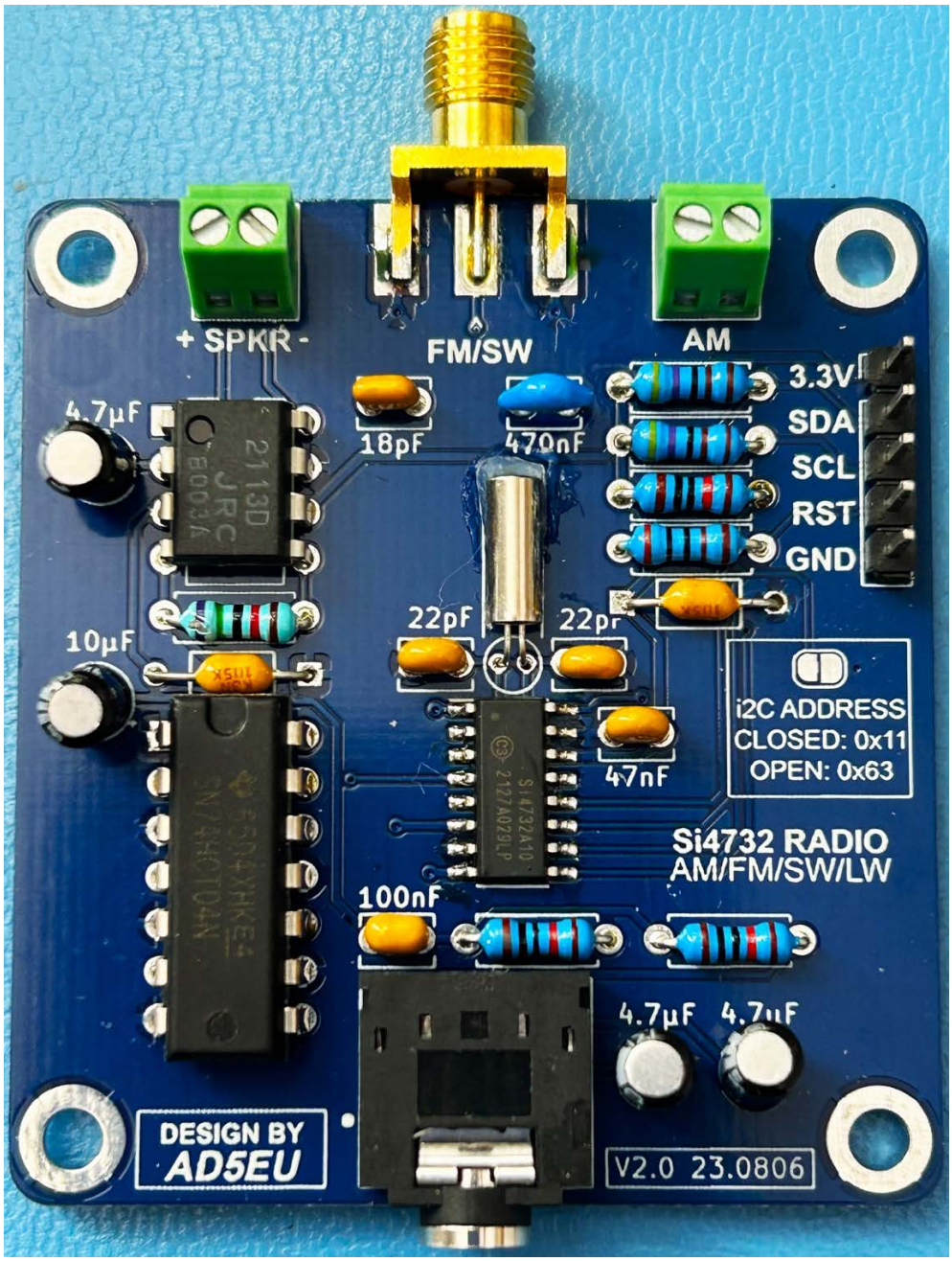


Figure 12 - Installation of Connectors

Testing

To test the radio, the 5 pin connector needs to be connected to your Arduino. The key when pairing the radio with an Arduino is that the Si4732 radio board requires 3.3V and does not have any on board voltage regulator. It is therefore recommended that legacy 5V Arduino boards are NOT used with the board.

One of the least expensive and capable Arduino variants is based on the Raspberry Pi RP2040. Although the following is based on the Adafruit Feather RP2040 any of the RP2040 Arduino variants can be used. Only 5 connections are required.

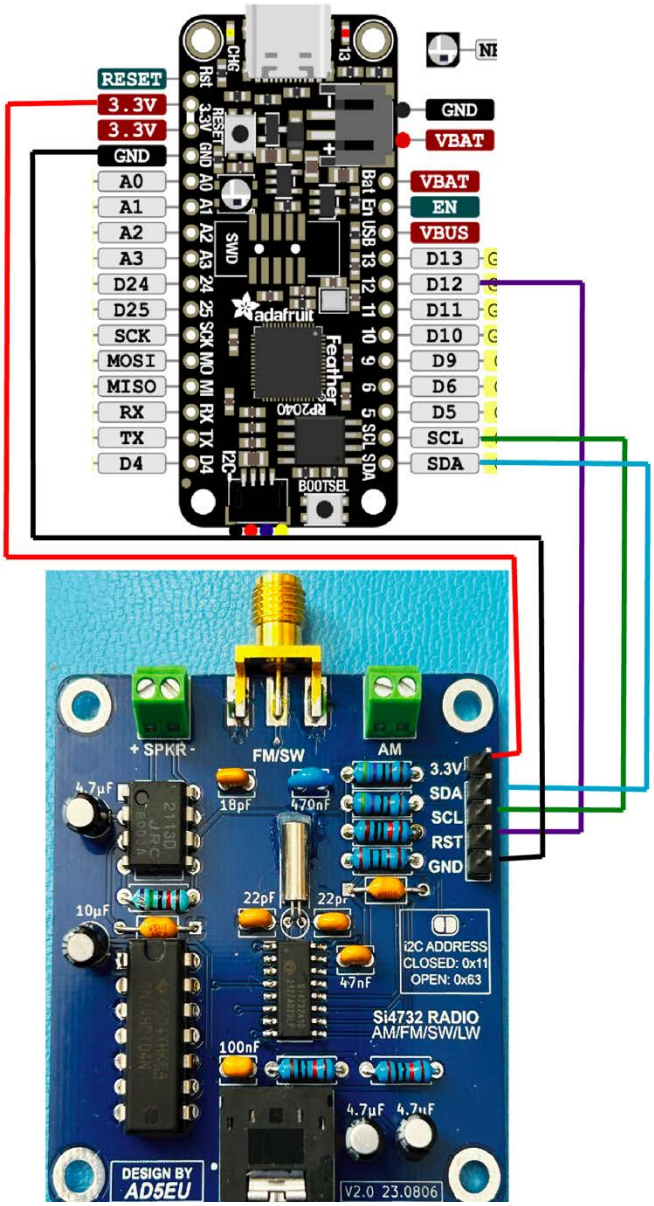
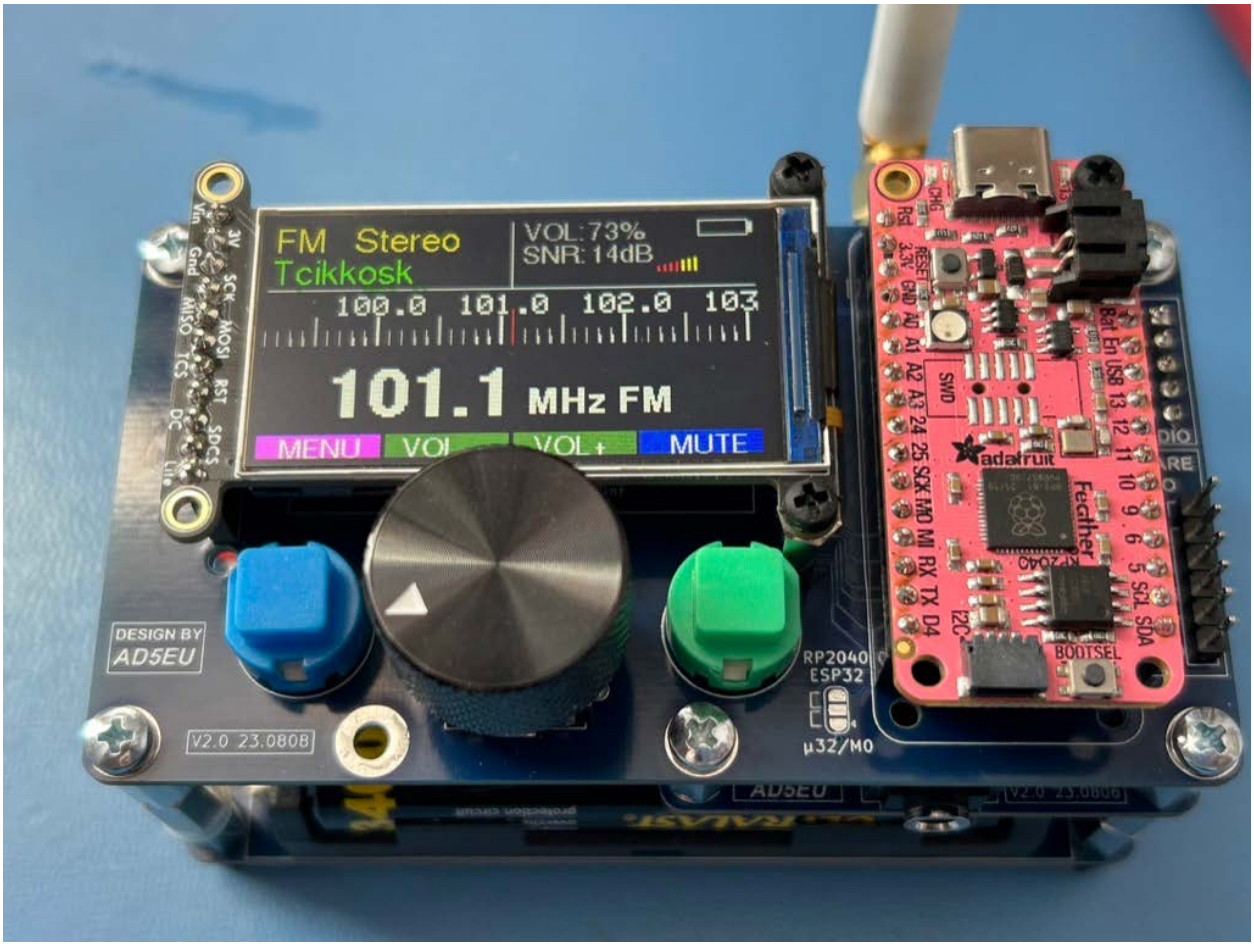


Figure 13- Test Circuit

Part II

Controller and User Interface



Introduction - Controller

To control the radio a simple board was designed which fundamentally serves as a "carrier" for the processor and a basic human interface including a display, rotary encoder and two multifunction switches. From an engineering perspective the controller is a trade-off between cost (~$38.50USD single unit) and a highly capable radio platform. The display is the most expensive component (~$17.50USD single unit), and less expensive displays could have been used at a savings of ~$10USD, but the display chosen provides user experience for the cost.

Processor Core

The Arduino (IDE) core of the controller is a Adafruit Feather module. The core has been designed to support a variety of processor types (with necessary radio code changes) including the ATMega328, ESP32, Cortex M0 (and M4) as well as the Raspberry Pi RP2040. An on board Jumper (JP1) is manages the one pin difference between the various processors.The core controls the display (using the SPI protocol/interface), the radio (using the I2C protocol/interface) and the encoder and switches (simple digital interface)

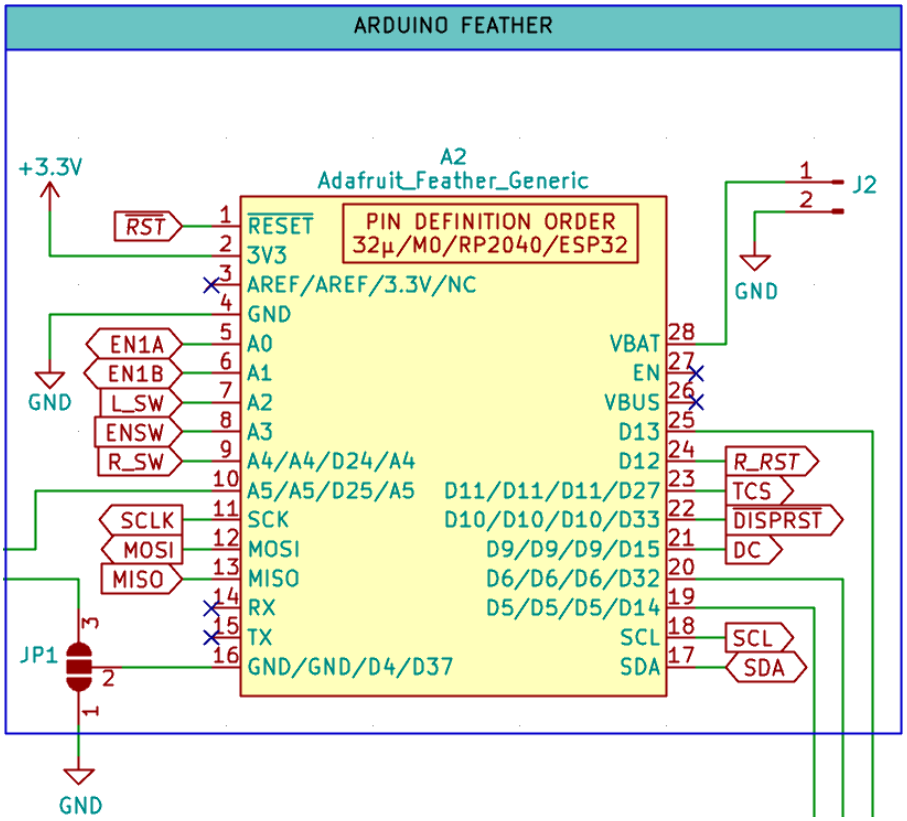


Figure 14- Processor Schematic

Rotary Encoder

A high quality 24 pulse per revolution rotary encoder provides with switch (Bourns Pro-Audio) provides for tuning, volume control and other functions for the radio. Two encoder pulse outputs (to direct direction of rotation) and a switch output are provided to the processor.

Two pull up resistors and a simple filter composed of four resistors and two capacitors are not strictly required, however the encoder manufacturer recommends this for the best encoder reliability.

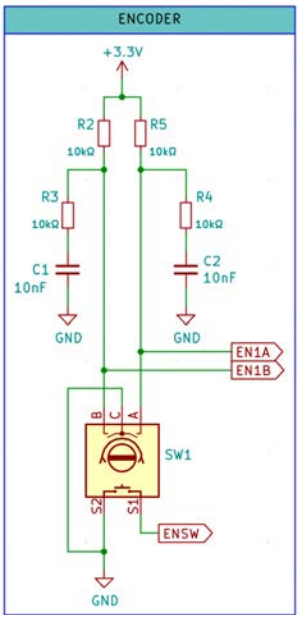


Figure 15 - Encoder Circuit

Multifunction Switches

Two off-momentary on push button switches (left: L-SW and right: R-SW) provide multiple functions for the radio including muting and menu selection.

Two outputs are provided to the processor and are pulled-up internally by the processor with:

pinMode(ButtonName,INPUT_PULLUP); code.

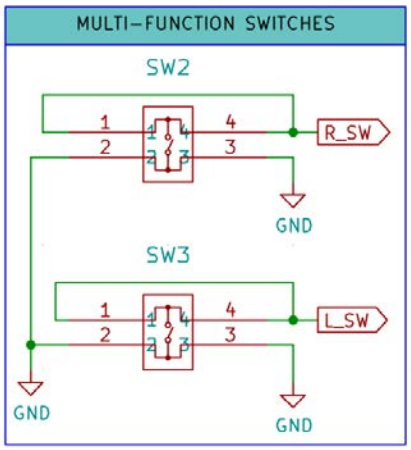


Figure 16 - Multifunction Switch Circuit

PCB

The radio controller is built using a 100mm (3.94”) x 55mm (2.16”) double sided PCB with M3 (3mm) mounting holes spaced 93mm(3.66”) and 48mm (1.89”) apart respectively.

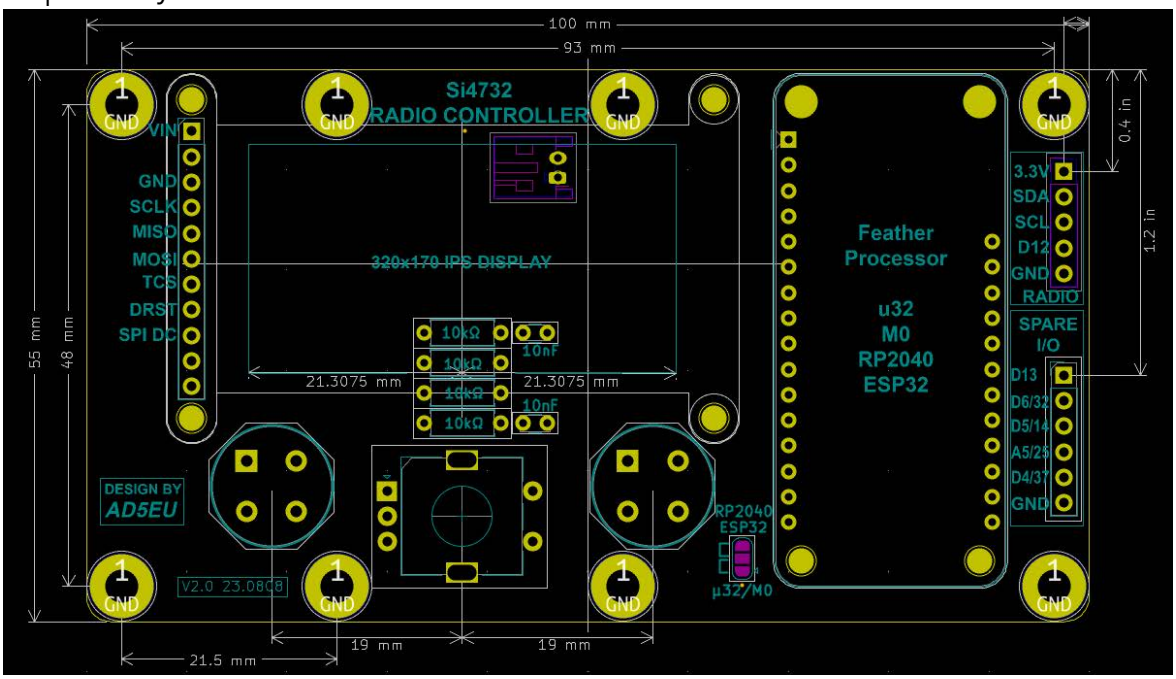


Figure 17 - Controller Board Dimensional Drawing

The board is designed to mate directly to the radio board using four 11mmxM3 threaded spacers. Recommended spacers are:

Würth Elktronik 970110324 Brass Spacer
Essentra Components MTS-11 Nylon Spacer

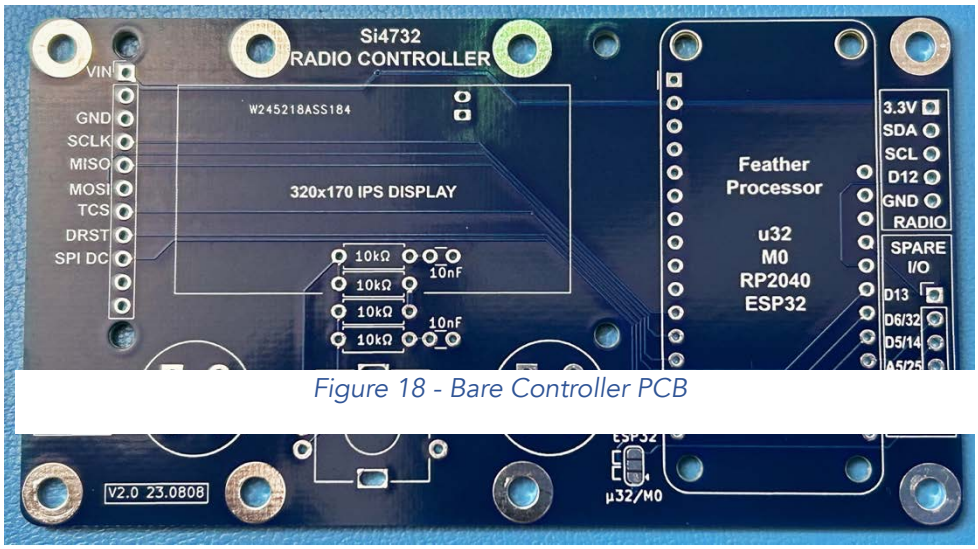


Figure 18 - Bare Controller PCB

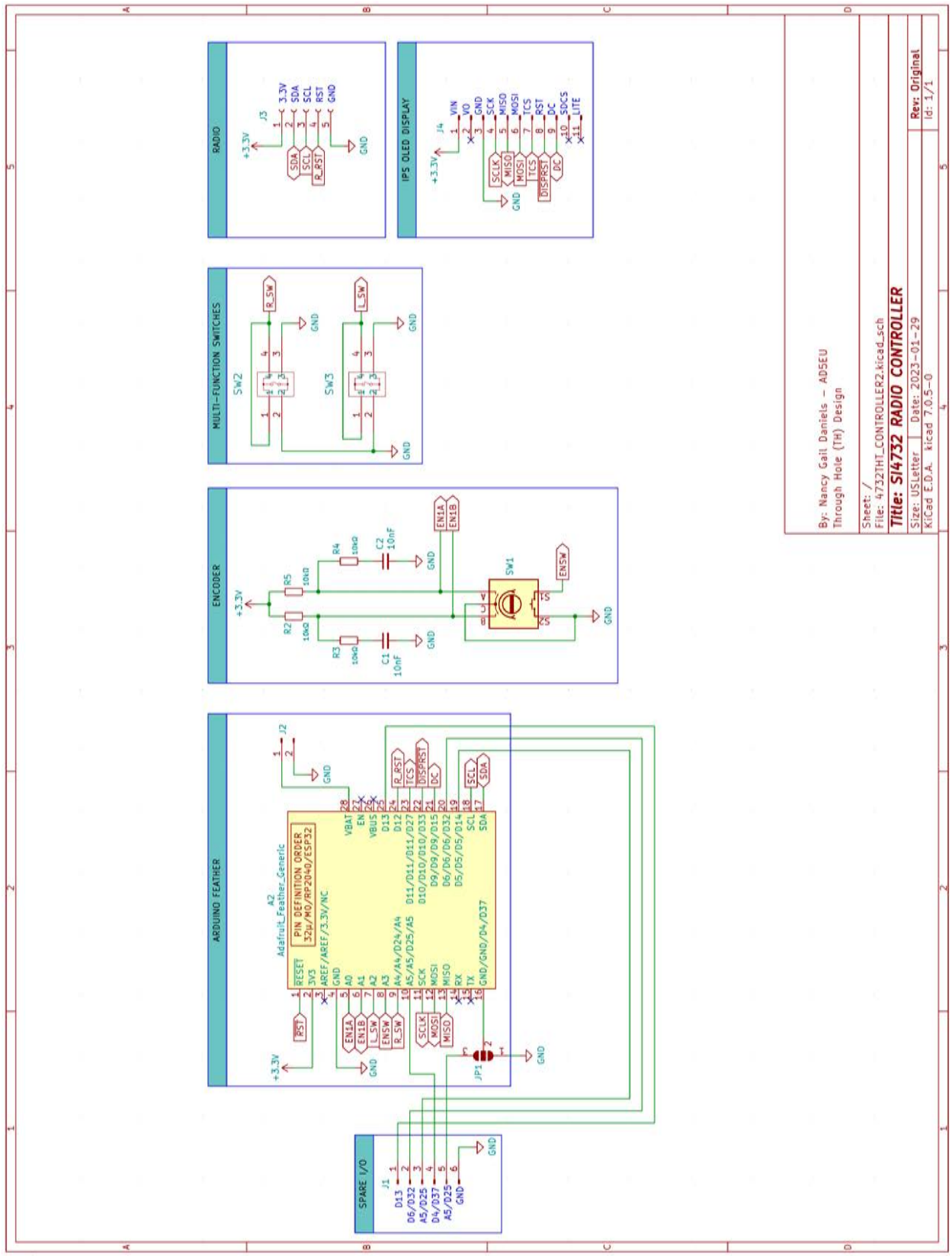


Figure 19 - Radio Controller, Display and Human Interface

Bill of Materials				Si4732 Radio Controller - Through Hole Component Design				Version 2.0 23.0808		
Desig	Qty	Value		Description	Package	Vendor	Vendor PN	Digikey/*Mouser*	Price US$	Extention
C1, C2	2	10nF	±10% 50V X7R	Capacitor	Radial 4x2.54mm P2.54mm	Kemet	C315C103K5R5TA	BC1005C399-4148-ND	$0.22	$0.44
R2-R5	4	10kΩ	±1% 0.25W	Resistor	L6.4xD2.4mm	Yageo	MFR-25FBF52-10K	10.0KXBK-ND	$0.10	$0.40
EN1	1	Rotary Encoder	24 pulses/revolution	Encoder	12.5x13.4mm P2.5mm	Bourns	PEC11R-4215F-S0024	PEC11R-4215F-S0024-ND	$2.12	$2.12
SW1-SW2	2	Push Button Switch (See Note 1)	Momentary/Off 0.1A 32V	SPST Switch	12mmD P5mm	C&K	D6R90 F1 LFS	401-1978-ND	$1.12	$2.24
A1	1	Feather Header Set	See Note 2	µP Connector	1x16 P2.54	Adafruit	2886	1528-1560-ND	$0.95	$0.95
A2	1				1x12 P2.54				$0.00	$0.00
J1	1	Vertical Header	Male Unshrouded	I/O Connector	1x6 P2.54	Harwin	M20-9990646	952-2270-ND	$0.30	$0.30
J2	1	JST Connector	Shrouded	Battery Connector	P2.0mm	JST	S2B-PH-K-S	455-1719-ND	$0.17	$0.17
J3	1	Vertical Header	Female	Radio Connector	1x5 P2.54mm	Sullins	PPTC051LFBN-RC	S6103-ND	$0.48	$0.48
J4	1	Conn_01x11_Male	PinHeader	Display Connector	1x11 P2.54mm	Sullins	PPTC111LFBN-RC	S7009-ND	$0.72	$0.72
Spacer	2	Threaded Spacer	Board to Board	Display Support	11mm M2.5	Harwin	R25-1001102	R25-1001102-ND	$0.62	$1.24
DS1	1	ST7789 IPS Display	1.9" 320x170	Display	57.2x36.6x5.2mm	Adafruit	5394	1528-5394-ND	$17.50	$17.50
M1	1	RP2040 Feather (See Note 3)	ARM Cortex M0+	Processor	Feather	Adafruit	4884	1528-4884	$11.95	$11.95
									Total	$38.51
		Note 1: The D6 Series are available in a variety of button shapes and colors								
		Note 2: Individual Headers Can be purchased but the set is the most economical: Alternate: Sullins PPTC121LFBN-RC + PPTC161LFBN-RC at $1.77								
		Note 3: Various Feather Processors can be used including the ESP32, M0, M4, ATMega328, however the RP2040 is the least expensive								

Figure 20 - Controller Bill Of Materials

Controller Board Assembly

Step 1 – Passive Components

The first step is to solder on the 6 passive components; four (4) resistors and two (2) capacitors on the board. In the picture below 1% tolerance resistors are used and as such the color coding may be unfamiliar: Brown Black Black Red (10.0kΩ).

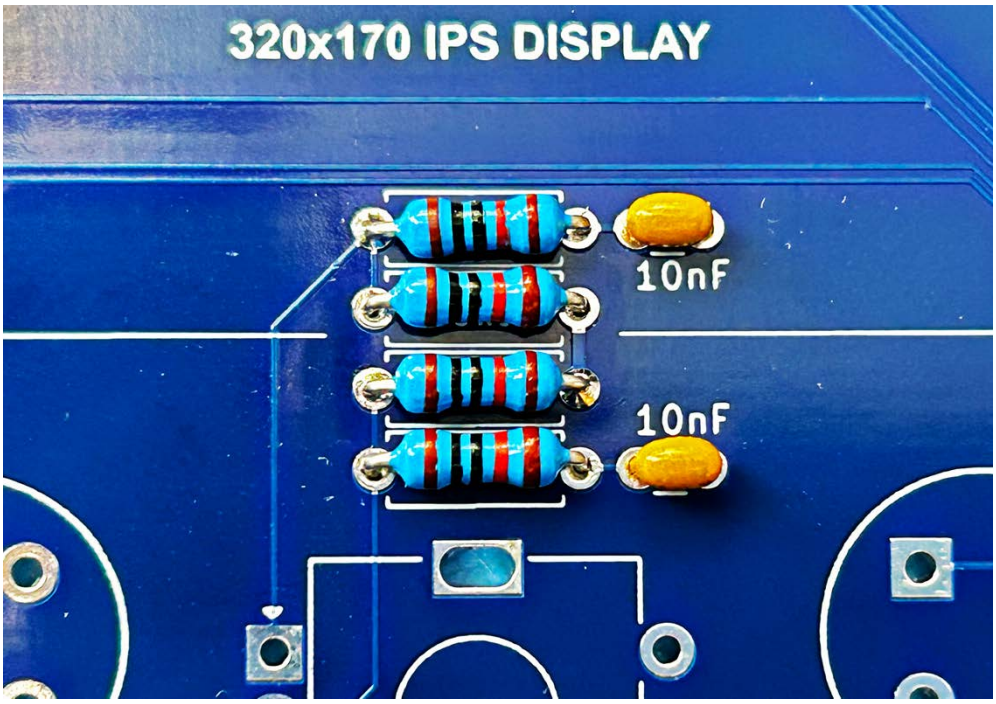


Figure 21 - Controller Passive Components

In small quantities 1% resistors can be purchased for the same price as 5% tolerance resistors. If you have 5% resistors on hand tolerance is not critical and more 5% resistors can be used: Brown Black Orange (10.0kΩ).

The two capacitors have a value 10nF and are marked 103 (10000pf).

Step 2- Display, Processor and I/O Headers

Next install the female headers for the processor, the display and male header for spare processor I/O.

The headers consist of:

- 16 pin 2.54mm (0.1”) pitch female header (Processor)
- 12 pin 2.54mm (0.1”) pitch female header (Processor)
- 11 pin 2.54mm (0.1”) pitch female header (Display)
- 6 pin 2.54mm (0.1”) pitch male header (Spare Processor I/O)

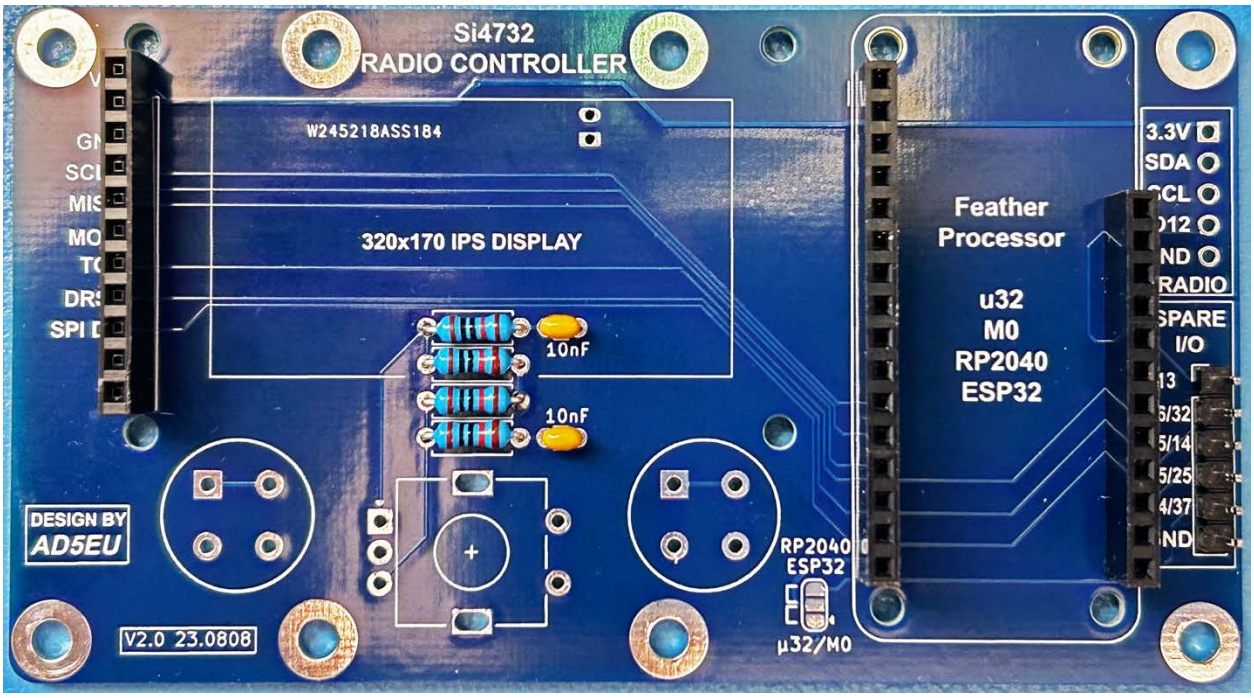


Figure 22 - Installation of Processor Headers

Step 3- Switches and Encoder

Next install the rotary encoder and the two push-button switches.

Note: the switches must be installed with the small notches at the top and bottom.

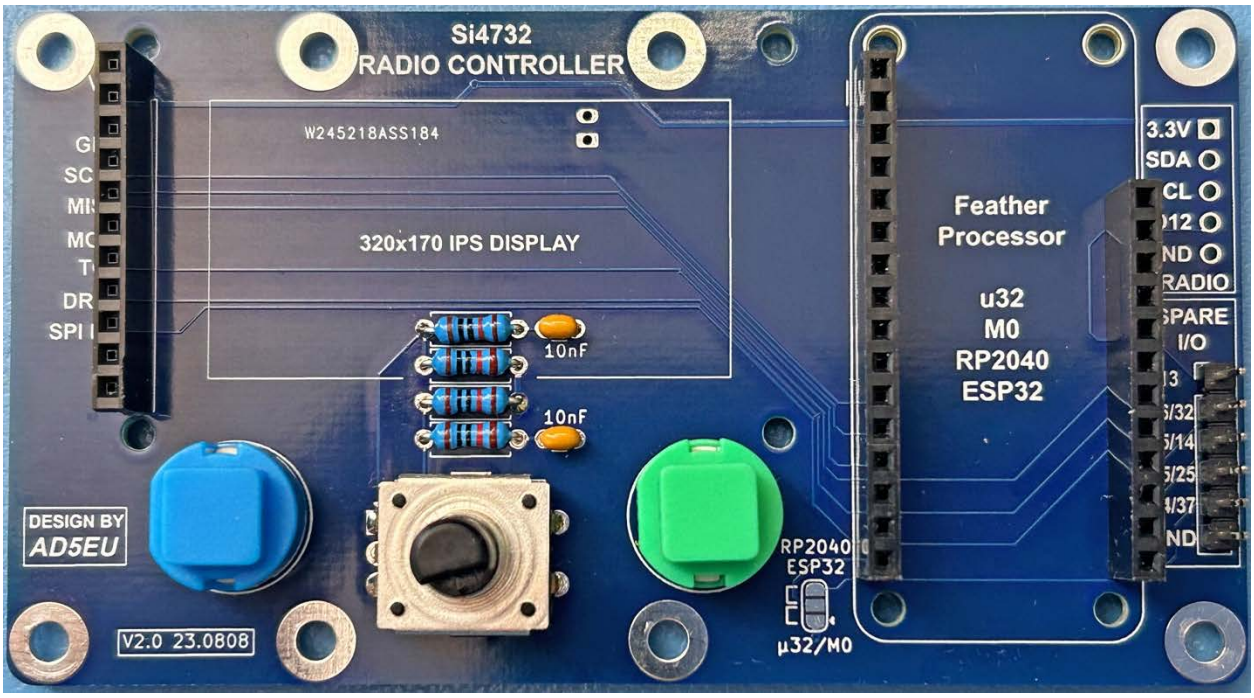


Figure 23 - Installation of Switches and Rotary Encoder

Step 4- Reverse Side – Radio Header and Battery Connector

Next install the two connectors on the reverse side of the PCB.

These consist of:

5 pin 2.54mm (0.1”) pitch female header (Radio)
2 pin 2.54mm (0.1”) pitch JST style male connector (Battery)

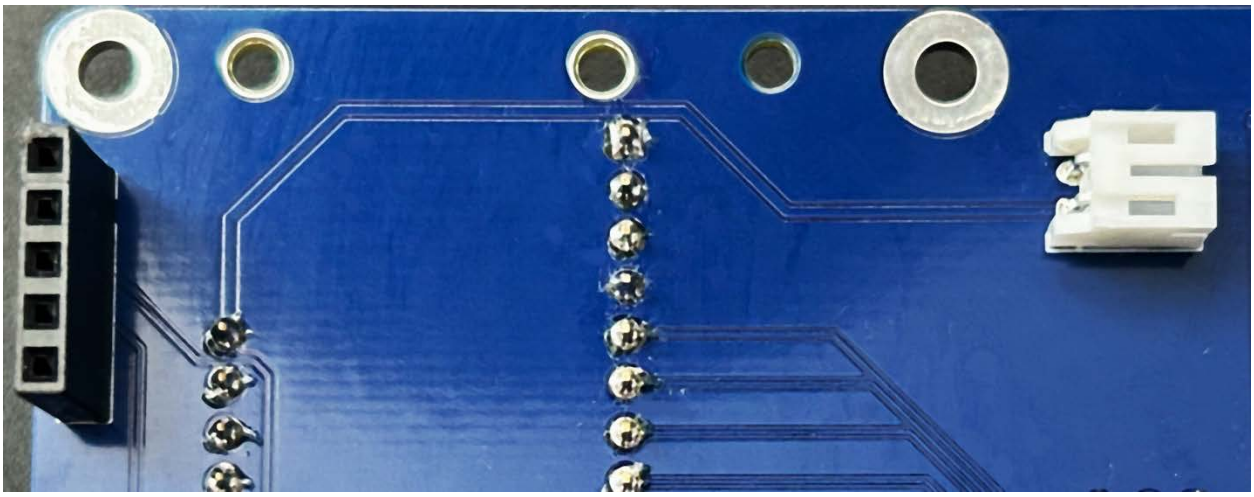


Figure 24 - Controller Reverse Side - Battery Connector and Radio Header

Note that the battery connector is not required as most feather processors feature this style of connector on board. However to provide for a neat routing of the female connector from the battery a second connector on the reverse side is useful.

Step 5- Install Processor and Display

The last step is to install the 1.9”display (Adafruit 5394) and your selected processor. In the figure below a Raspberry Pi RP2040 processor based Feather is shown, but a variety of other processors can be used.

When installing the display two (2) M2.5x11mm threaded spacers should be used to support the right side of the display. The recommended spacer is:

Harwin R25-1001102 Hex Brass M2.5x0.45 Spacer

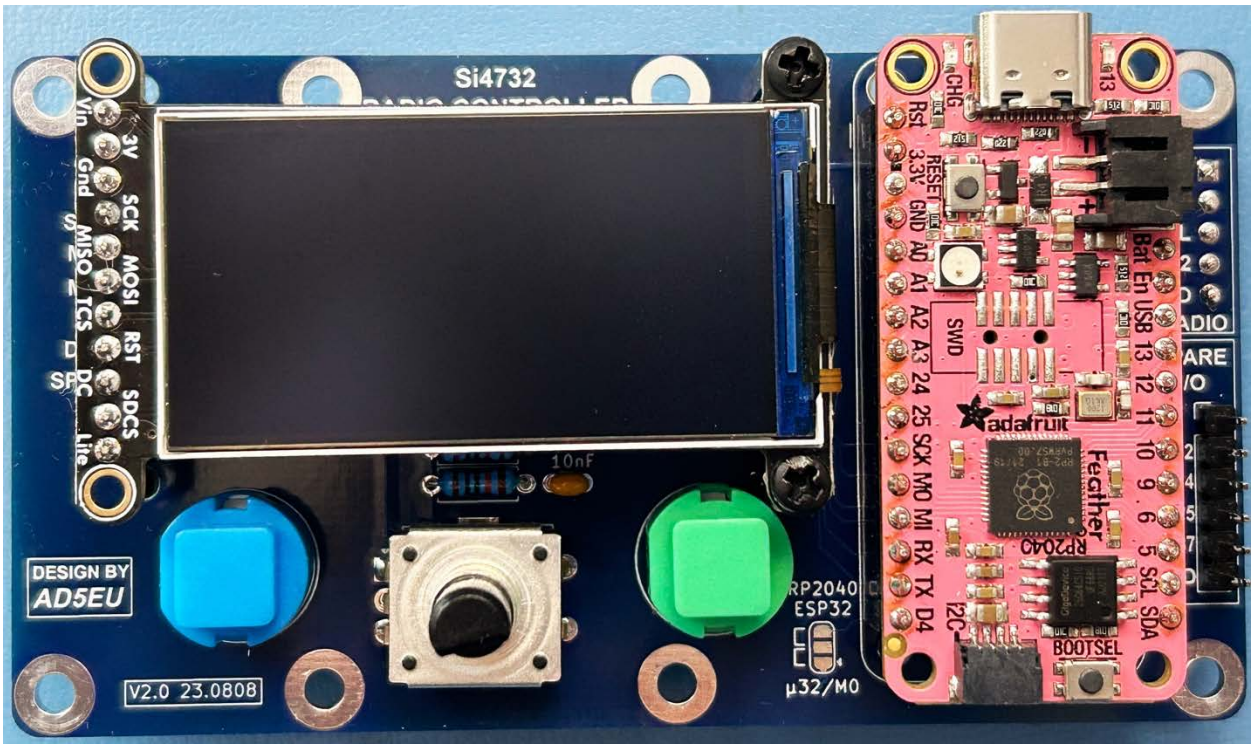


Figure 25 - Competed Controller with Display and Raspberry Pi Feather

Testing

To test the controller, prior to mating with the radio module first load the Adafruit ST7735 and ST7789 library into your Arduino IDE (as of this writing 1.10.3 is the latest version).

Once the library is loaded, in EXAMPLES load the graphcistest_st7789.ino sketch. On line 76 comment out

```
//tft.init(240, 240);           // Init ST7789 240x240
```

And then uncomment line 91

```
tft.init(170, 320);           // Init ST7789 170x320
```

Run the sketch and you should see the display go through a variety of diagnostics.

You can now mate the controller (with 11mm spacers) to the radio board and load the radio sketch.