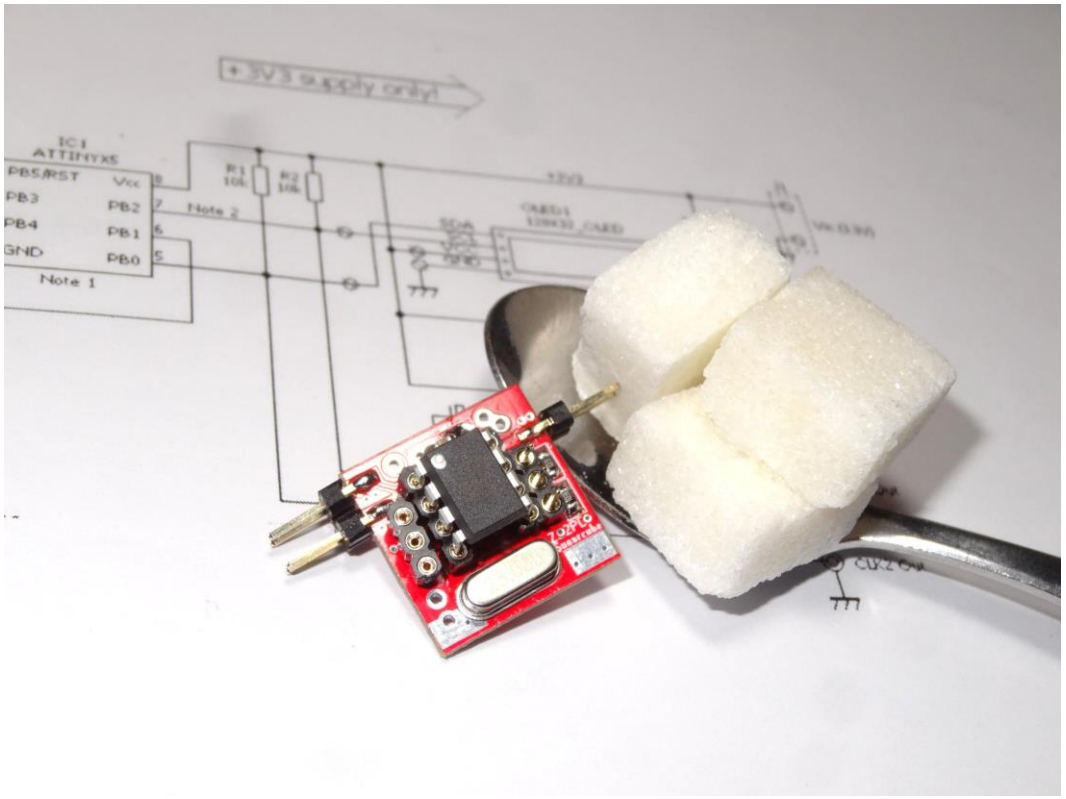
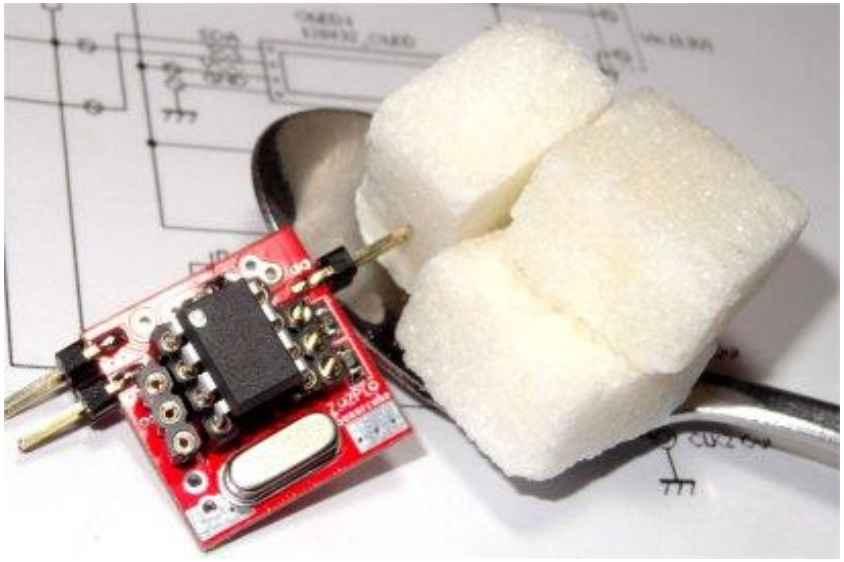
Building the SugarCube VFO

An introduction to the features of this versatile three-output oscillator and a guide to successfully building one for yourself or as a Club project!



Introduction



Features of the SugarCube VFO include:

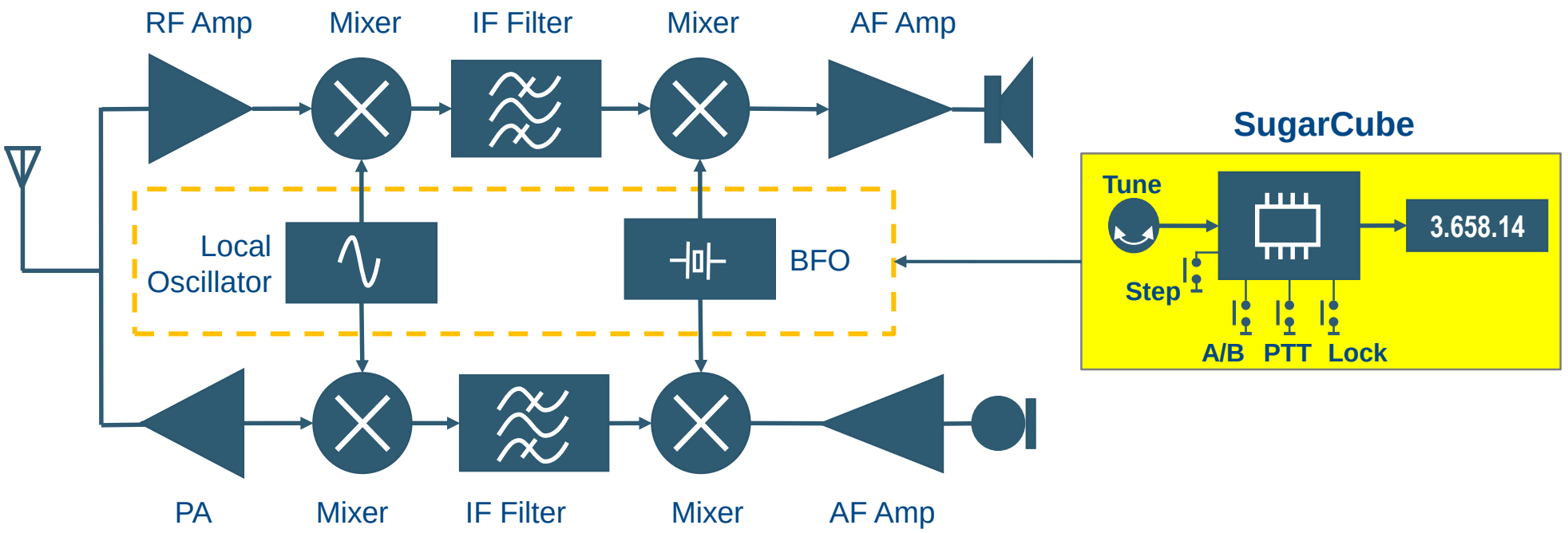
- Range: 5kHz to 290MHz
- Tuning: 5Hz, 100Hz, 1, 10 and 100kHz, and 1MHz steps using a rotary encoder
- Dual VFOs: VFO A and VFO B selectable
- Three oscillator outputs: i.e. Tx VFO, Rx VFO, CIO/BFO
- Quadrature outputs supported (3.5 – 109MHz)
- Crystal-locked PLL stability (~20ppm) *
- PTT input supports Tx/Rx frequency/IF offsets
- Tuning Lock pushbutton for portable operation

- Bright clear compact OLED frequency display with icons for tuning step, PTT, and lock
- Integrated bar meter display on OLED for signal strength/RF power (0 - 3.3VDC input)
- Programmable: Parameters are user-programmable with the SC+ VFO MS Excel™ spreadsheet
- Inexpensive

* Optional: It is possible to add a low cost ‘TCXO’ circuit for FT8 etc

Applications… ("Yeah, but how do I actually use it?")

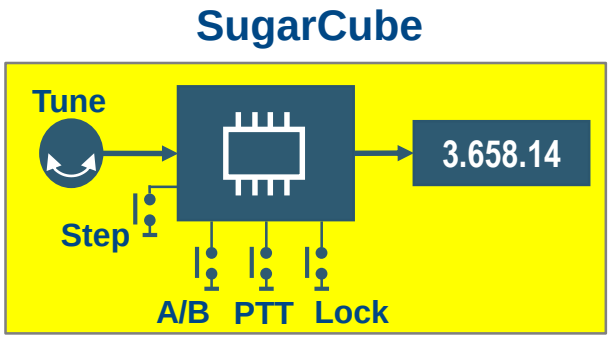
The SugarCube VFO is a cheap, easy to build digital VFO which can be easily integrated into most transceivers e.g. BitX, KD1JV, Antek, Ararinha, ZL2BMI DSB, etc



Block Diagram of a Typical Transceiver

Applications (continued)

As well as transceiver applications, the SugarCube VFO can be also used as a basic RF signal generator – It can even generate AM modulation!



	Examples*	
	SSB transceiver with 9MHz IF	Signal generator
Output 0	A: 3.5 to 3.9 MHz B: 7.0 to 7.5 MHz	A: 1 to 10 MHz B: 11 to 20 MHz
Output 1	A: 12.5 to 12.9 MHz B: 16.0 to 16.5 MHz	A: 21 to 30 MHz B: 31 to 40 MHz
Output 2	A: 8.997MHz B: 9.003MHz	A: 455kHz B: 10.7MHz

*** Output 0 and 1 are VFO outputs that start at a programmable frequency**
Output 2 is a fixed frequency used to replace a fixed BFO or CIO crystal

Applications (continued)

The EEPROM inside the ATtiny85 controlling the SC+ can be programmed with a variety of user-specific values to personalise the VFO for each user's application

Key SugarCube VFO Parameters:	
Crystal frequency	25000000
VFO A Start Frequency	14100000
VFO B Start Frequency	3650000
IF Offset	11997300
BFO/CIO for VFO A	11997300
BFO/CIO for VFO B	12000700
Mixing method:	
VFO A Rx Mode	1
VFO B Rx Mode	3
VFO A Tx Mode	2
VFO B Tx Mode	0

The PLL reference frequency allows precise calibration of each SC+

This allows you to set the IF frequency (Zero for direct conversion)

Provides for USB and LSB BFO settings

Key SugarCube Mixer Modes		
0	VFO out = Frequency	No offset
1	VFO out =Frequency + IF Offset	High-side injection
2	VFO out =Frequency - IF Offset	Low-side injection
3	VFO out = IF Offset - Frequency	Inverse injection

Versions and Variations

The original SC design gave rise to the SC+ with enhanced user programming and the SC+XX channelised versions with Excel-based EEPROM file creation/edit spreadsheets

Original

Basic version:

- Parameters were stored in program code
- No longer supported

SC+

SC-Plus:

- User programmable
- Parameters stored in ATtiny EEPROM
- High/Low/Inverted offset VFO modes
- Dual A/B CIO/BFOs
- Auto-EEP files*

SC+4
SC+16
SC+99

Channel-based:

- For older commercial transceivers e.g. Codan
- Yaesu/Kenwood/Heath etc crystal replacement
- Most SC-Plus features
- Auto-EEP files*

Other Si5351a VFOs are available on www.ZL2PD.com

- 8-band VFO with RIT and other features for more elaborate transceivers
- 9-band/memory modular VFO with dual keypad and encoder tuning
- MKARS-80 VFO for use with the UK 80m BitX SSB QRP transceiver
- 3-output Li-Ion powered tiny RF signal generator
- Condor SC+ VFO

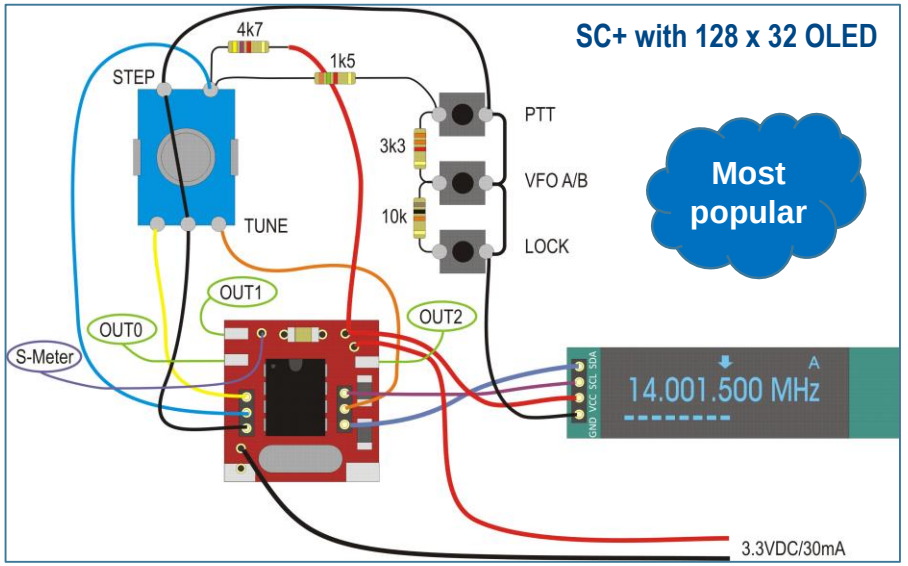
* The ATtiny's EEP-format file saves the SC+XX user configuration parameters. It is generated by a MS Excel™ spreadsheet with a single mouse-click

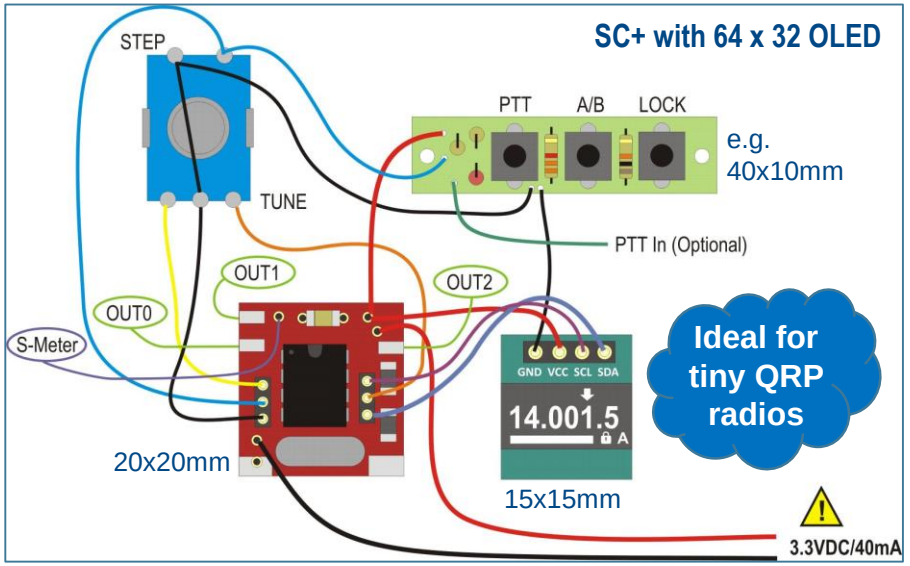
Installing the SC+ in a radio is quite easy – It's small!

- Different versions of SC+ firmware provide oscillators covering a wide range of uses
- They all use the same basic circuit and PCB with minor external circuit variations
- The SC+ requires 3.3V (40mA max) (**NOT 5V!!!**)
- RSSI is 0-3V3 input (i.e. 0V = S0 and 3V = S9++)
- PTT input expects a signal going to ground when the Tx PTT is active

Installation

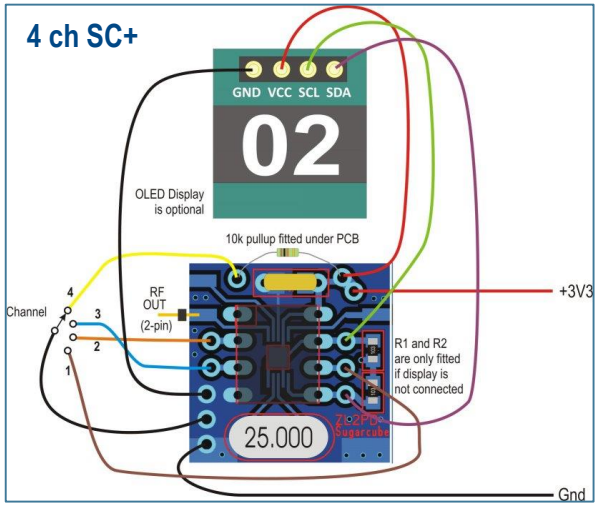
- Design uses external pushbuttons and rotary encoder to provide easy front panel installations
- Add a 3V3 regulator if required

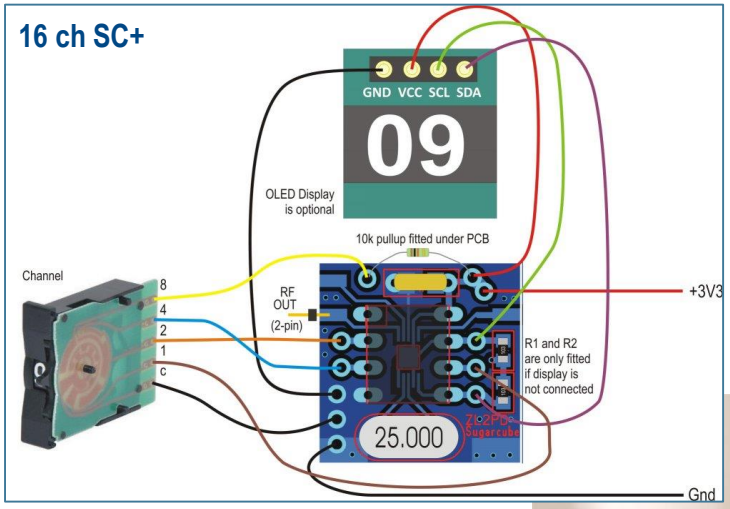




Other versions are available for fixed tuned applications

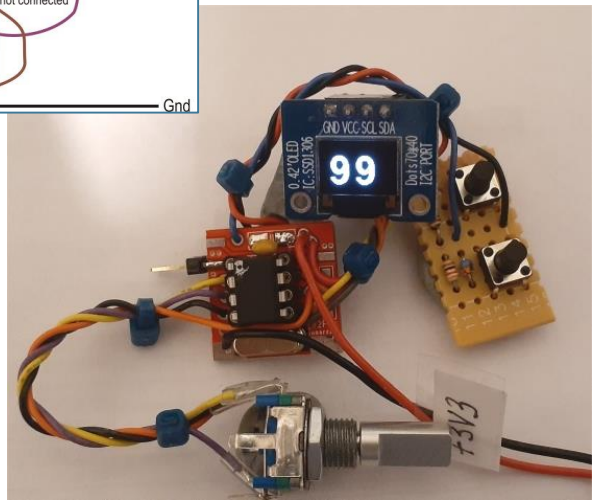
4 and 16 channel versions were created for transceivers such as the Codan 6801 or to replace expensive HFO crystals in Yaesu FT-101, Kenwood TS-520, Heathkit SB-101 etc





These versions usually replace crystals

- 99 channel version has programmable START and LAST channels
- Easier implementation of SC+XX with a specific number of channels
- These three versions may all use the 64x32 OLED display
- Other OLEDs can be used – or NO OLED display at all!

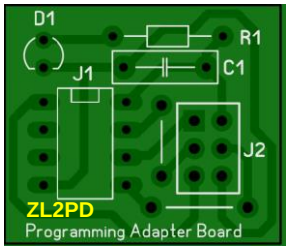


99 ch SC+

Programming "Ecosystem"

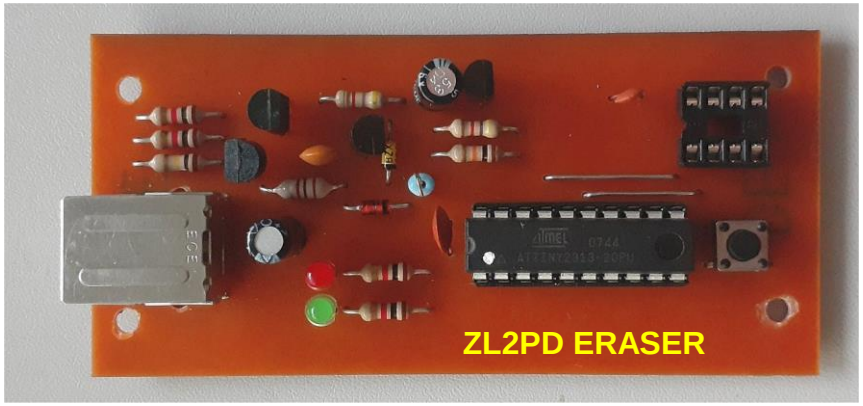
A cheap **USBasp** programmer is used to program the ATtiny85 and an optional low cost USB "eraser" board can erase/reset the chip if users want to change settings later

- A USBasp programmer can be purchased online
- Buy one with the ribbon cable and adapter
- Usually less than $US5 delivered (in 2020)



A "daughterboard" simplifies programming of the ATtiny85

Plugs into USBasp

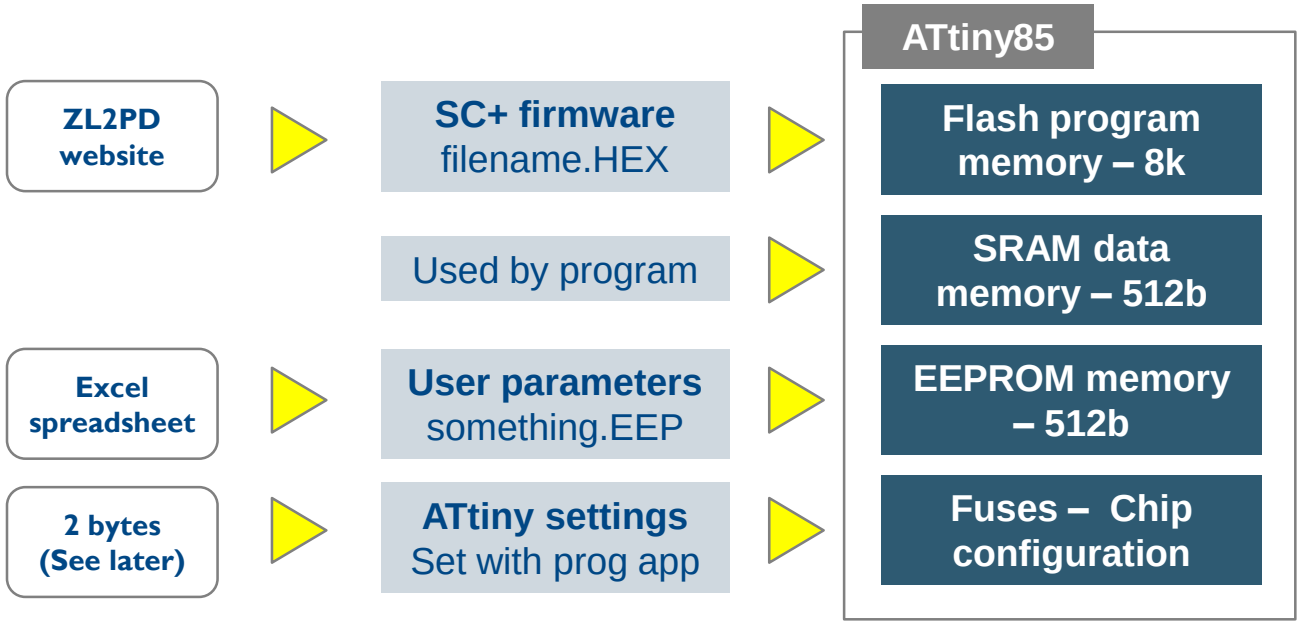


This (OPTIONAL) **Eraser** resets programmable fuses and memory of programmed ATtiny chips and is powered from a 5V USB wall-wart or USB port

Programming

The 8-pin ATtiny85 8k flash memory coontains the SugarCube+ software, the user parameters go into the EEPROM, and the "fuses" set up the chip's internal hardware

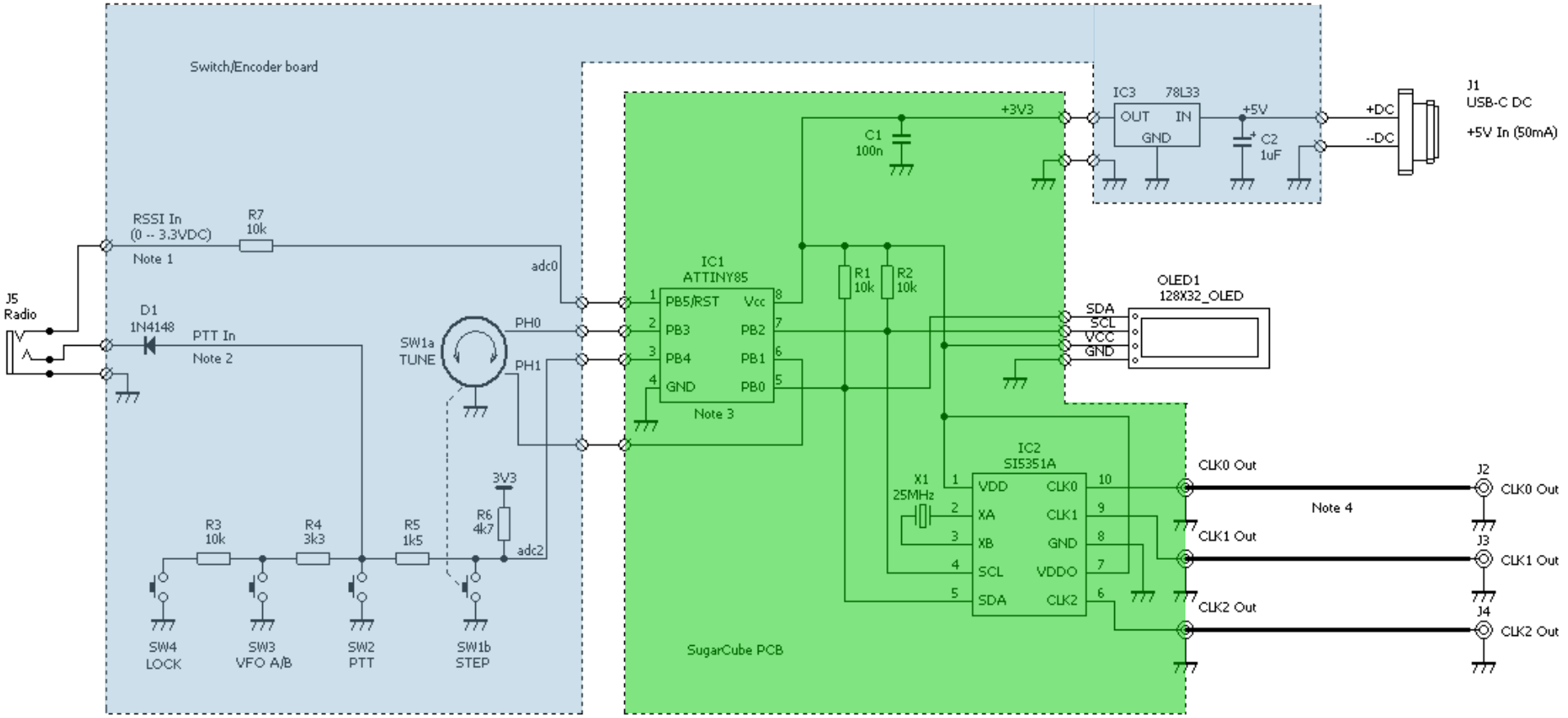
- Download & install a suitable programming application into your PC
  e.g. Extreme, Khazama etc



SC+ with 128x32 OLED – A Club Project Construction Guide

The following pages contain the instructions for building a 'stand-alone' version of the SC+ VFO in a plastic box as a club project.

SugarCube VFO – Club Project Schematic

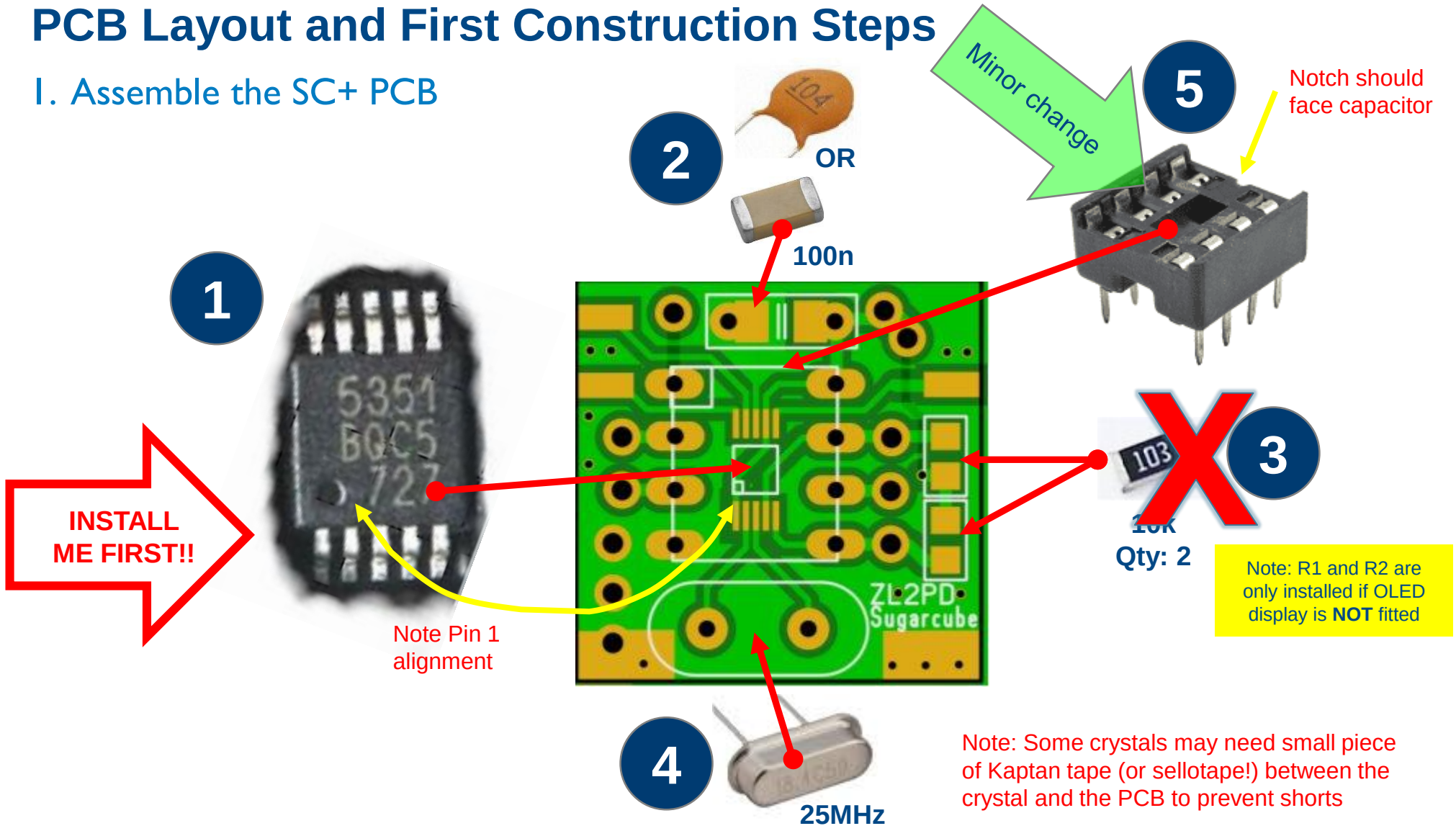


Note: R1 and R2 are only installed if OLED display is **NOT** fitted

ATtiny85 SI5351A Sugarcube VFO Club Project

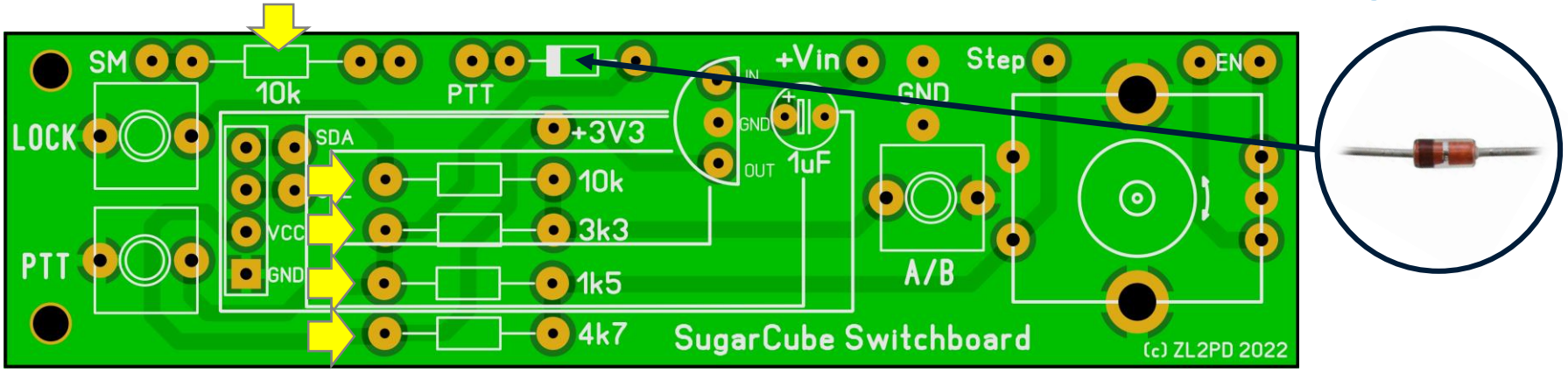
PCB Layout and First Construction Steps

1. Assemble the SC+ PCB



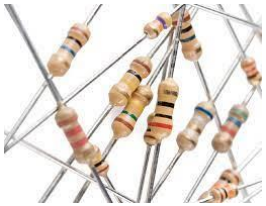
Construction (cont'd)

2. Build the "Switchboard" PCB – This holds the encoder, switches and 3.3V regulator



6 **Bend the leads, then install and solder the five resistors onto the PCB:**

- **10k resistor (Brown – Black – Orange) (Two of these to be fitted!** ( )
- **3k3 resistor (Orange – Orange – Red)** ( )
- **1k5 resistor (Brown – Green – Red)** ( )
- **4k7 resistor (Yellow – Violet – Red)** ( )



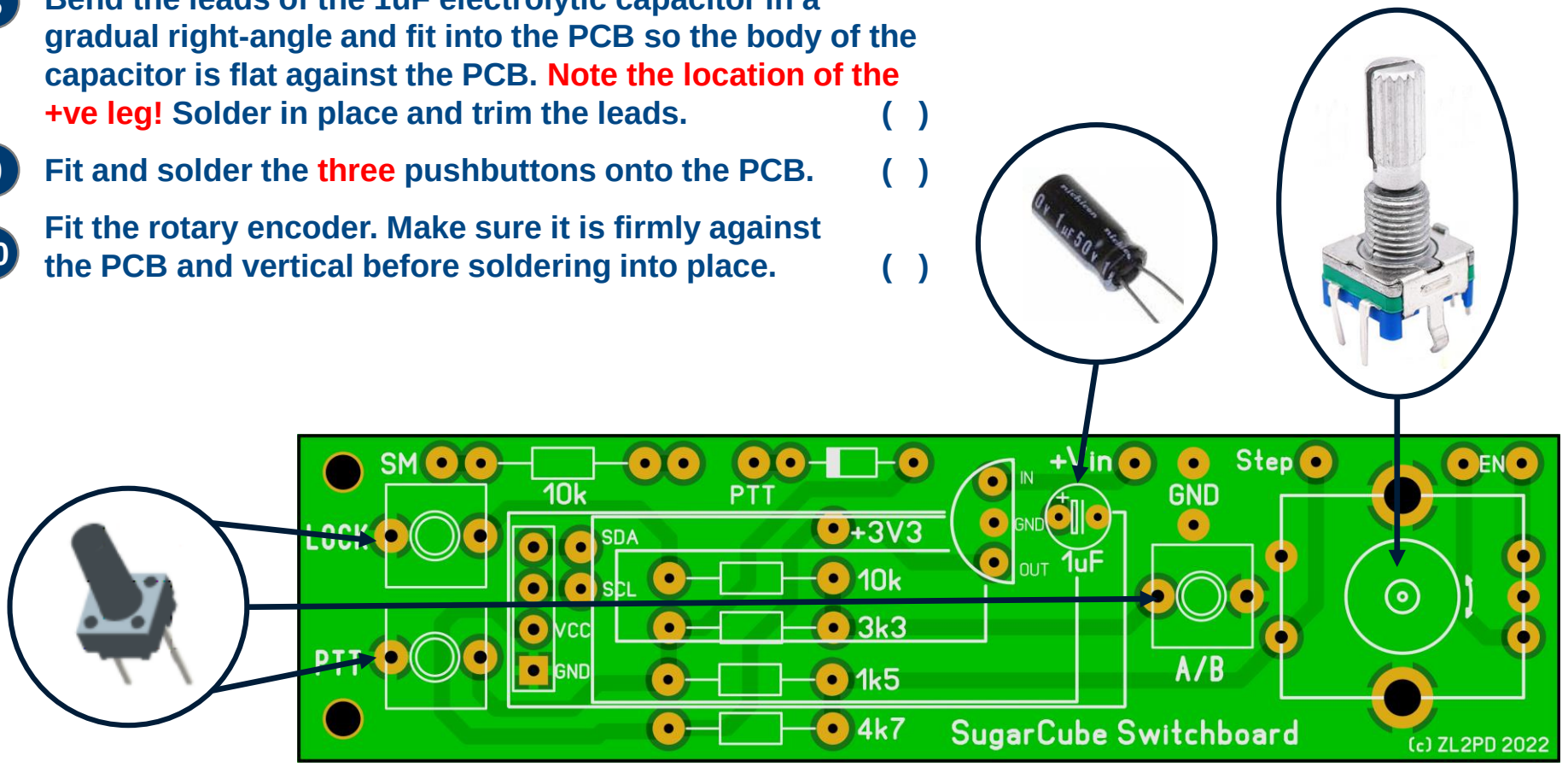
Typical 1/4w resistors

7 **Install the diode (1N4148) making sure the diode's band matches the band printed on the PCB overlay** ( )

Construction (cont'd)

2. Switchboard …

8. **Bend the leads of the 1uF electrolytic capacitor in a gradual right-angle and fit into the PCB so the body of the capacitor is flat against the PCB. Note the location of the +ve leg! Solder in place and trim the leads.** ( )
9. **Fit and solder the three pushbuttons onto the PCB.** ( )
10. **Fit the rotary encoder. Make sure it is firmly against the PCB and vertical before soldering into place.** ( )



Construction (cont'd)

3. Final assembly of the Switchboard PCB

11. **Bend the leads of the regulator in a gradual right-angle so the flat face is upwards. Solder and trim the leads.** ( )

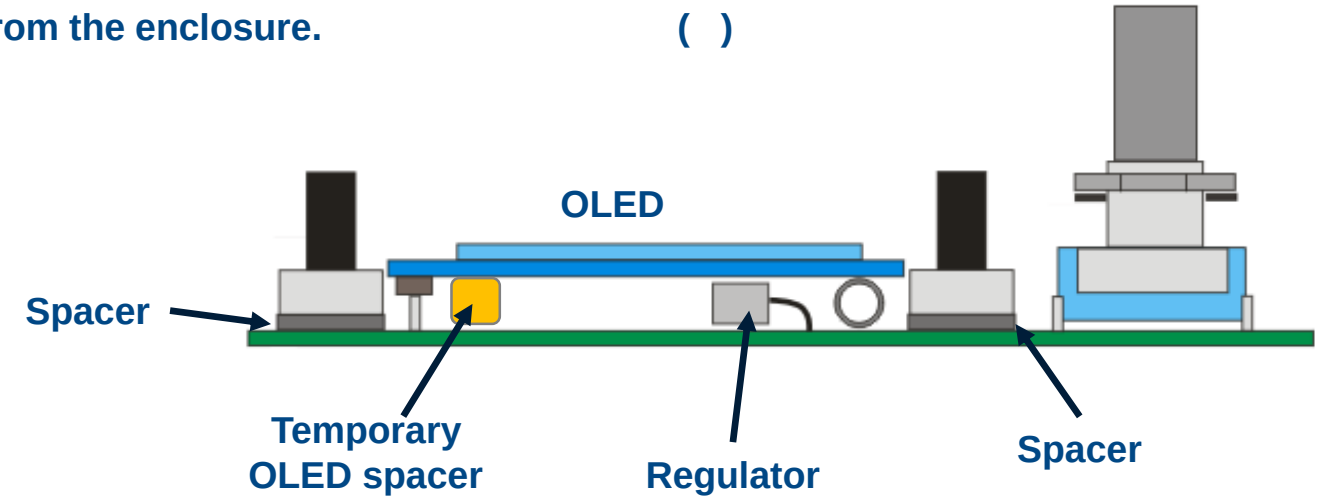
12. **Fit the OLED into place – DO NOT SOLDER IT YET!**

    Temporarily fit the switchboard and OLED using the encoder nut and ONE M2.5 nut/washer/ bolt. DO NOT OVERTIGHTEN. ( )

13. **As this is done, slide the 4.8x4.8mm OLED spacer between the OLED and the PCB so the spacing is correct** ( )

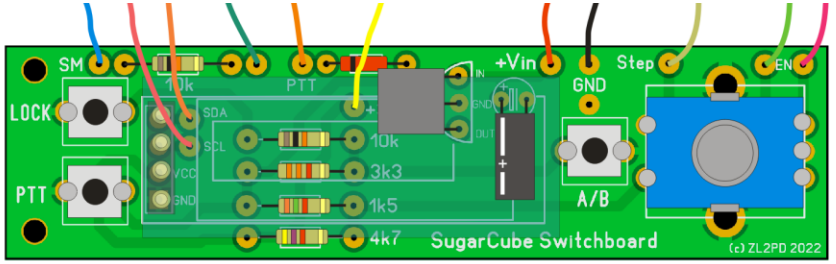
14. **Solder the four OLED pins and slide out the OLED space** ( )

15. **Remove the switchboard from the enclosure.** ( )

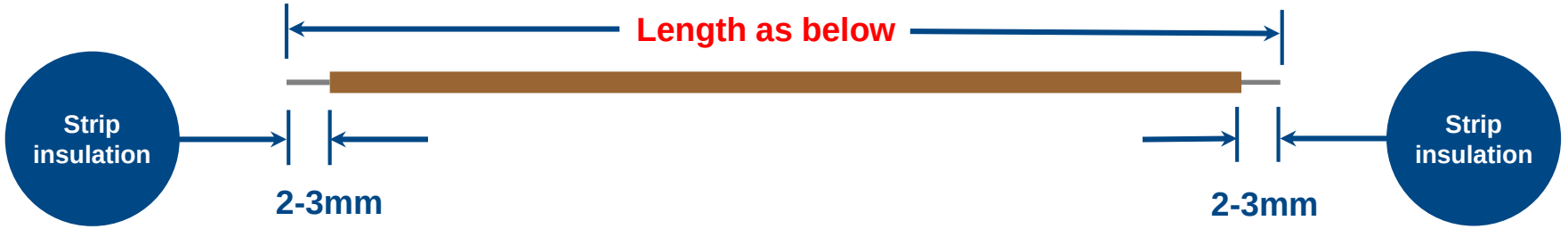


Construction (cont'd)

4. Connecting up the Switchboard



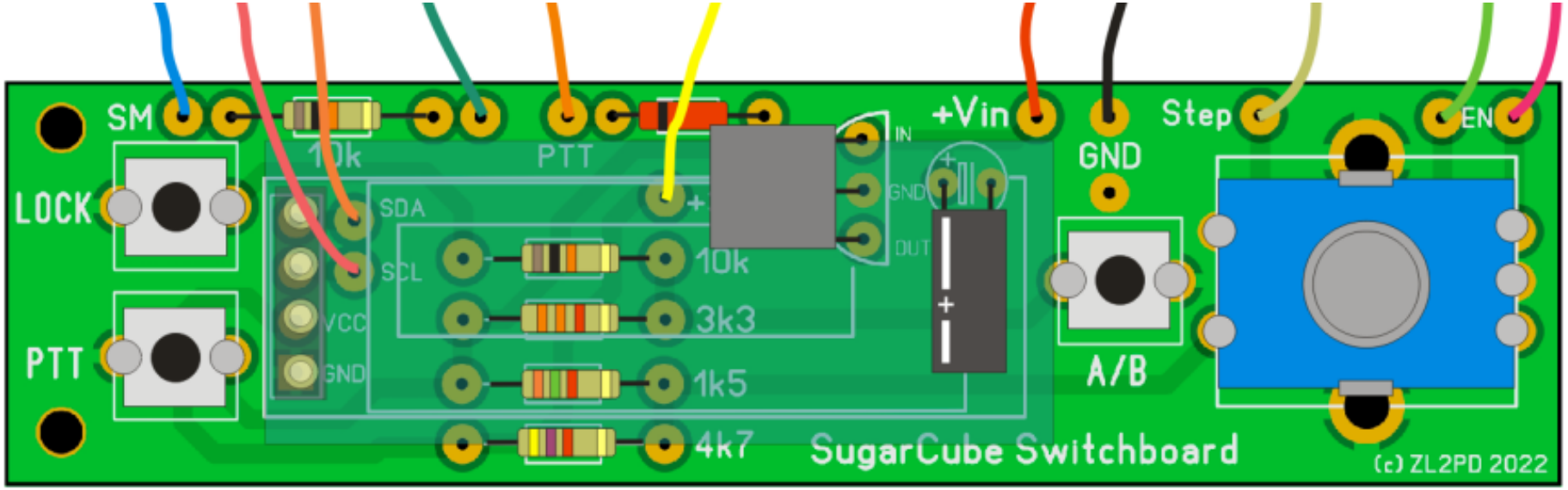
16 **Cut, strip and tin each of the following 13 wires like this:**



1.	50mm	Blue	( )	RSSI from radio	8.	65mm	Black	( )	Ground
2.	75mm	Pink	( )	SCK I2C	9.	65mm	Grey	( )	Step
3.	85mm	Orange	( )	SDA I2C	10.	65mm	Pale Blue	( )	Encoder PhaseA
4.	35mm	Green	( )	RSSI to SC+	11.	55mm	Purple	( )	Encoder PhaseB
5.	65mm	Brown	( )	PTT from radio	12.	70mm	Black	( )	Gnd for SC+ 'e'
6.	40mm	Yellow	( )	Regulated +3V3	13.	70mm	Black	( )	Gnd for SC+ 'f'
7.	7. 85mm	Red	( )	+5V DC In					

Construction (cont'd)

4. Connecting up the Switchboard (cont'd)



17 **Fit the following wires to the SOLDER SIDE (back) of the PCB. These will be connected to the SC+ as well as the RSSI/PTT and USB power connectors in later steps:**

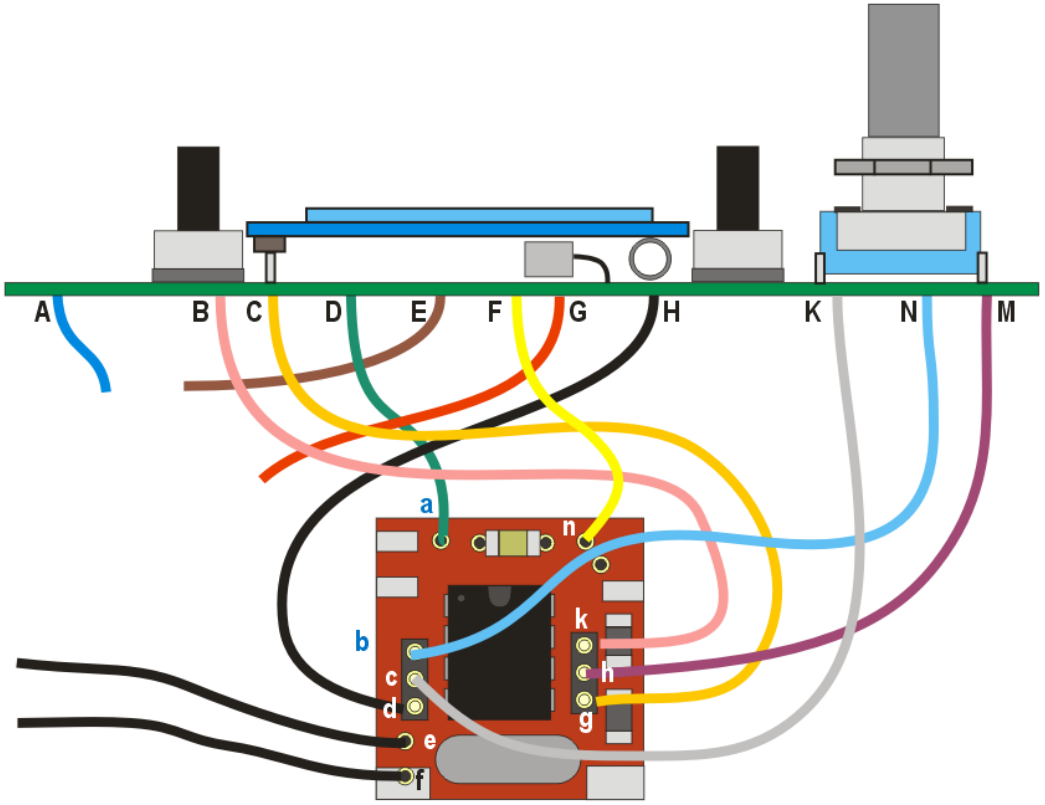
1. Blue	( )	RSSI from radio	7. Red	( )	+5V DC In
2. Pink	( )	SCK I2C	8. Black	( )	Ground
3. Orange	( )	SDA I2C	9. Grey	( )	Step
4. Green	( )	RSSI to SC+	10. Pale Blue	( )	Encoder PhaseA
5. Brown	( )	PTT from radio	11. Purple	( )	Encoder PhaseB
6. Yellow	( )	Regulated +3V3			

Construction (cont'd)

5. Wiring the Switchboard to the SC+

18 **Connect the following wires to the SC+**

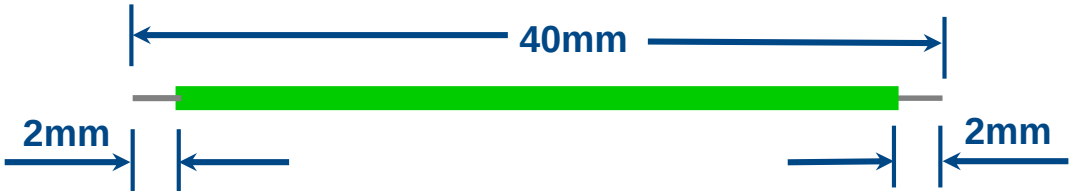
1. Pink	( )	SCK I2C
2. Orange	( )	SDA I2C
3. Green	( )	RSSI to SC+
4. Yellow	( )	Regulated +3V3
5. Black	( )	Ground
6. Grey	( )	Step
7. Pale Blue	( )	Encoder PhaseA
8. Purple	( )	Encoder PhaseB



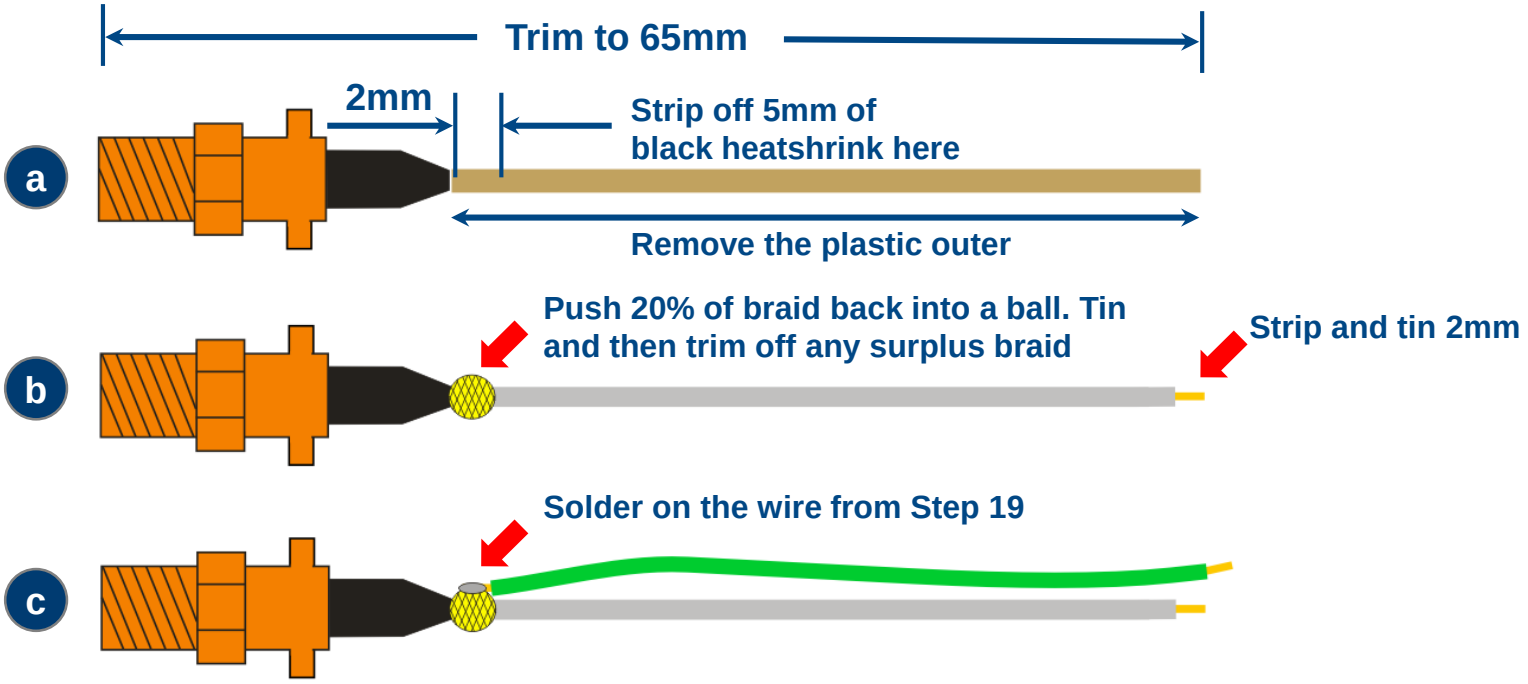
Construction (cont'd)

5. Wiring the SC+ (cont'd)

19 **Cut, strip and tin three green hookup wires like this:**



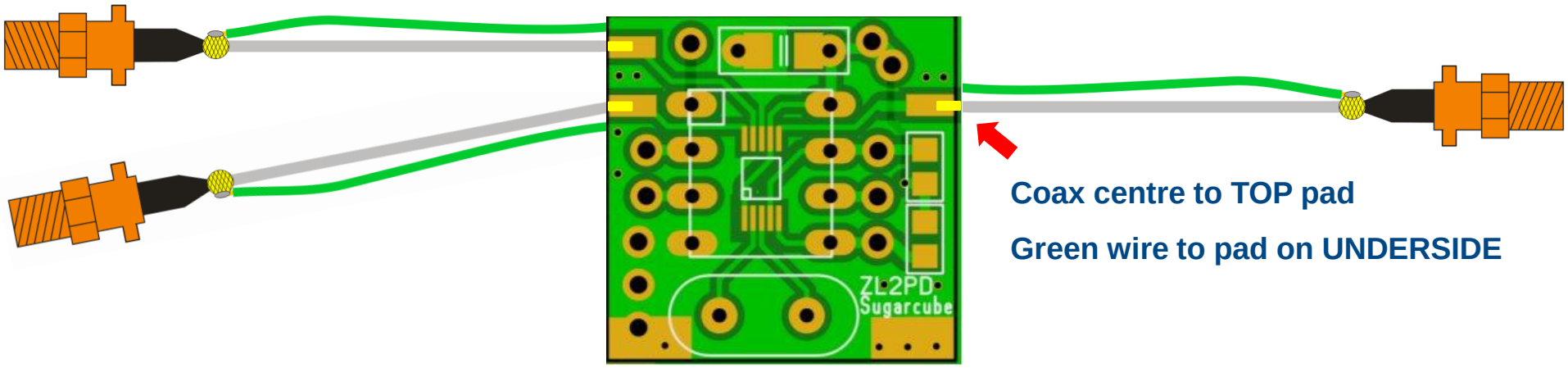
20 **Cut and prepare three SMA cable tails like this:**



Construction (cont'd)

5. Wiring the SC+ (cont'd)

21 **Solder the three SMA cable tails like this:**



Coax centre to TOP pad

Green wire to pad on UNDERSIDE

Construction (Cont'd)

6. Assemble the modules and parts into the enclosure

22 **Use a suitable box or assemble the laser-cut acrylic box placing the bottom cover to one side. Prepare and attach the label to the front panel**

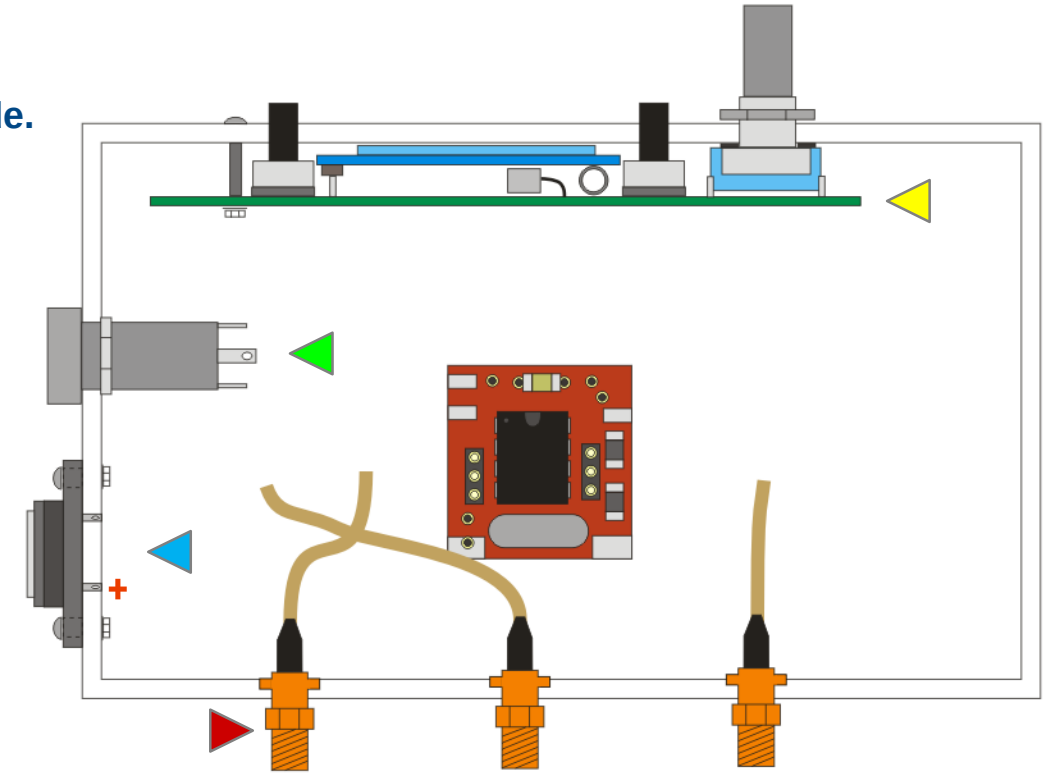
23 **Mount the switchboard on the front panel.** ▶

24 **Carefully mount the SMA tails into the rear panel – Grip the wires at the SC+ end while this is done** ▶

25 **Mount and wire the following items:**

- **PTT/RSSI connector** ▶
- **USB-C connector** ▶

(Check connector polarity BEFORE wiring)



26 Check the Enclosure Wiring

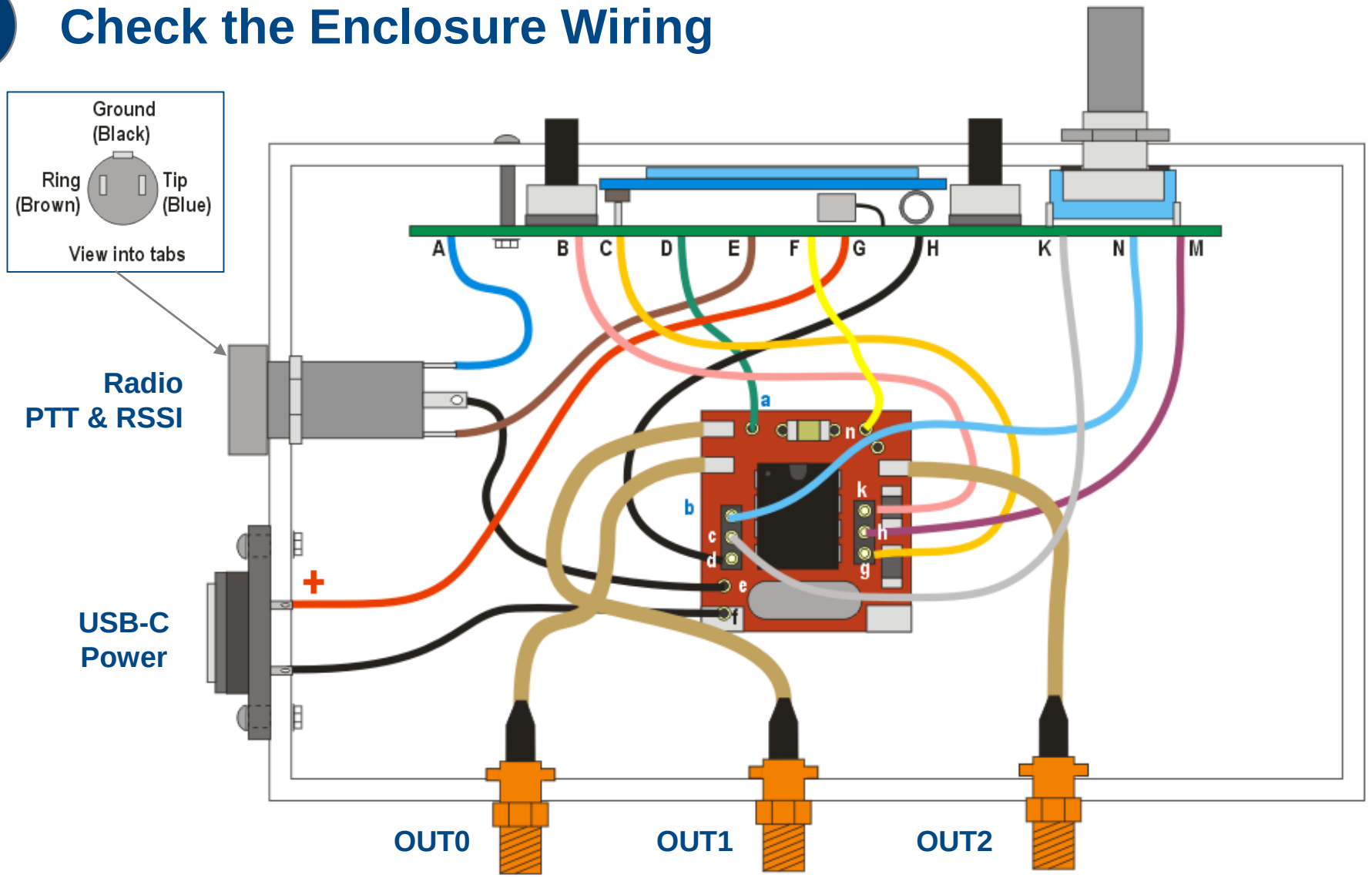


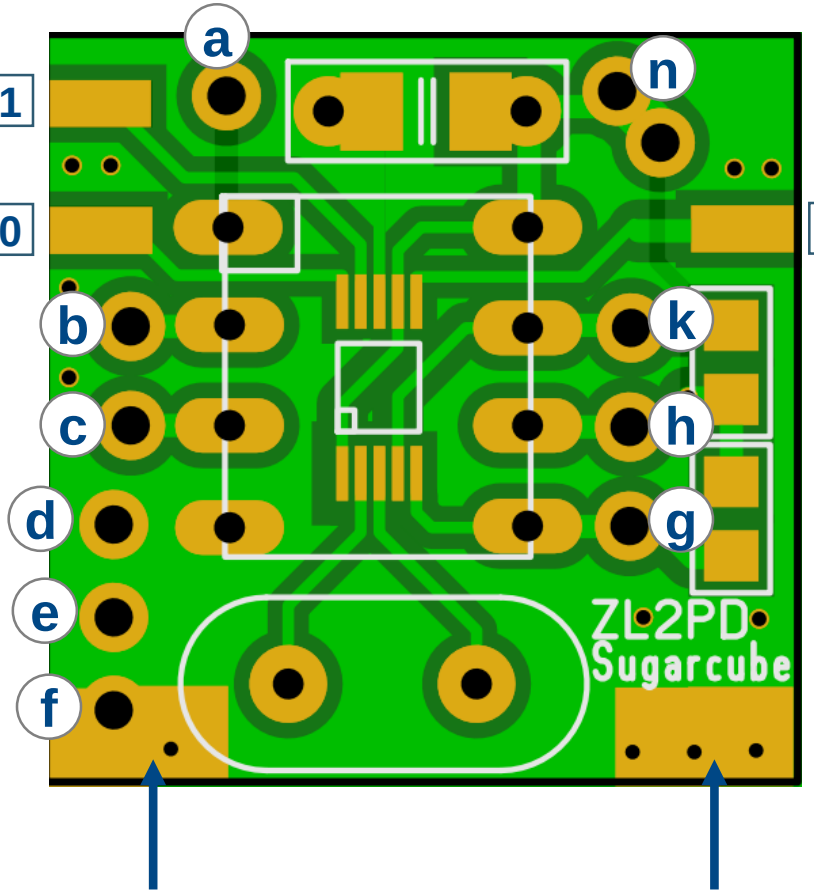
Illustration: SC+ PCB External Connections

RF: Component side pad
GND: Solder side pad

OUT1

RF: Component side pad
GND: Solder side pad

OUT0



OUT2

RF: Component side pad
GND: Solder side pad

These pads may be used to mount the SC+ inside equipment by soldering the assembled and tested module onto a suitable existing PCB groundplane

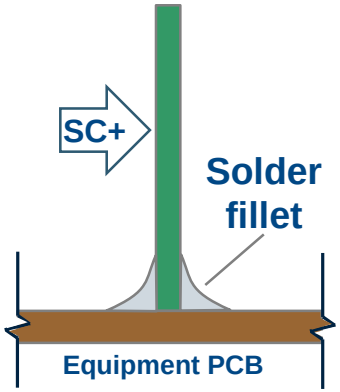


Illustration: Encoder/Switch Board External Connections

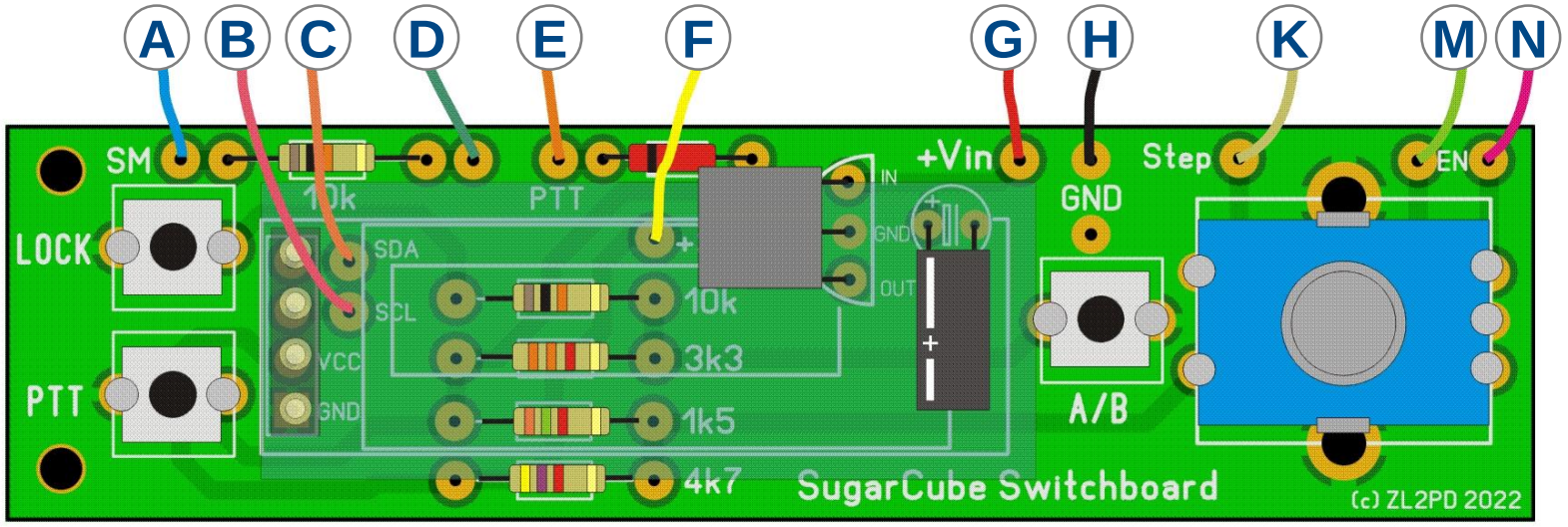
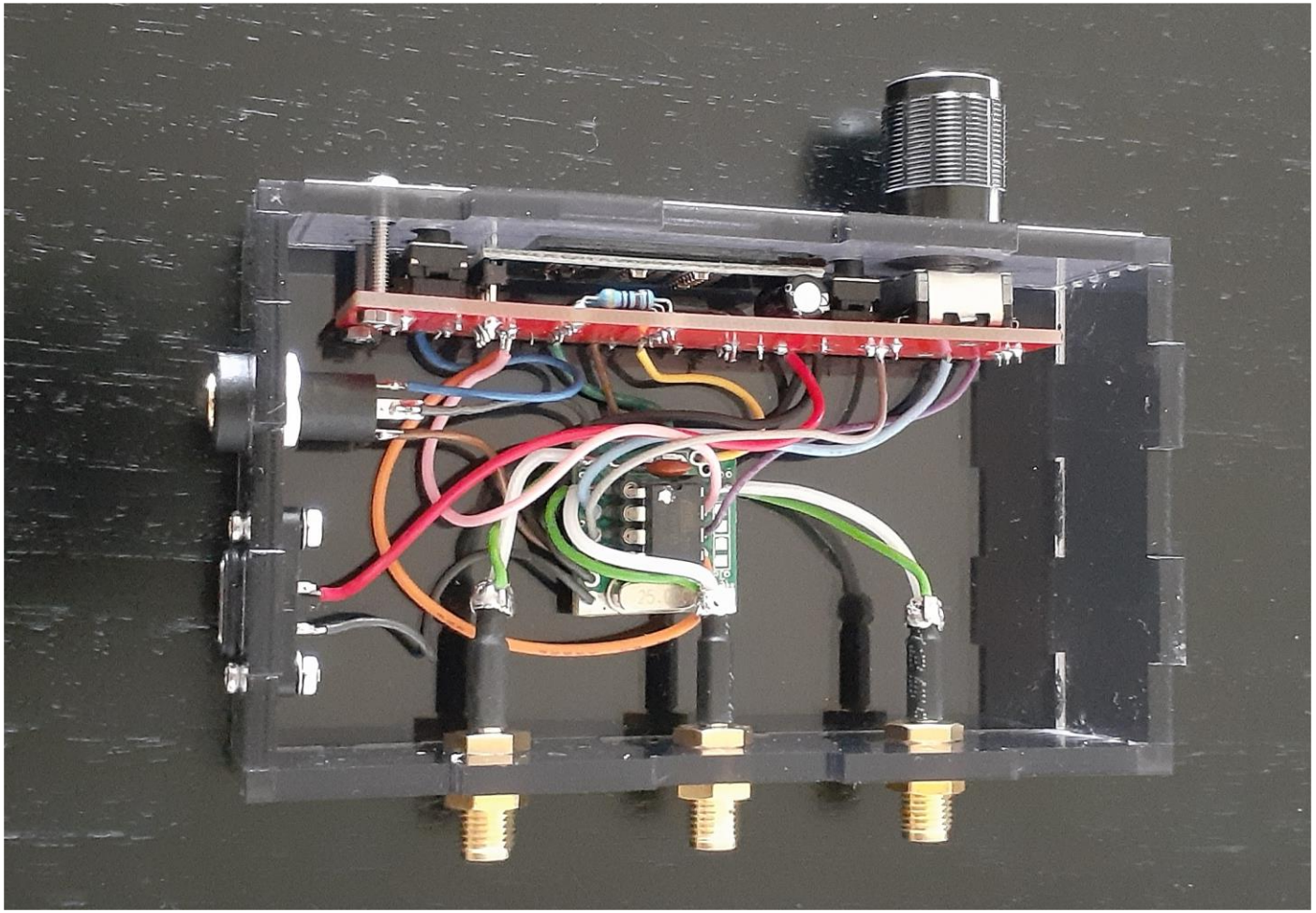


Illustration: Inside View of the Prototype



Testing, Programming, and Powering Up

Let's do a few simple tests before programming the ATtiny85 to check the basic assembly and wiring

27 Do **NOT** insert the ATtiny85 into the SC+ yet ( )

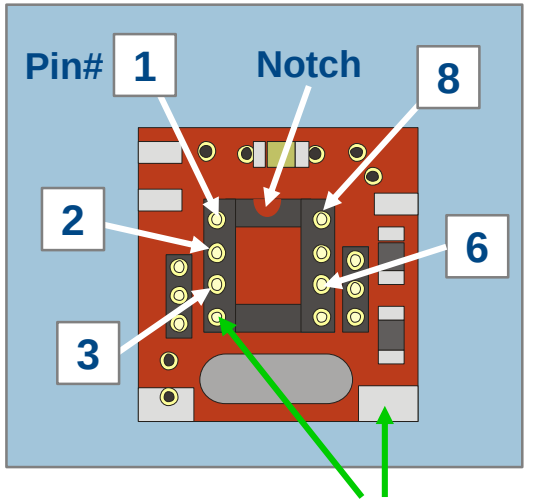
28 As you slowly (slowly!) rotate the rotary encoder knob, check the resistance between pin 2 to ground and pin 6 to ground of the ATtiny85 8-pin DIL socket on the SC+ PCB. You should see momentary shorts to ground as the encoder is rotated. ( )

29 Plug in the USB-C power source and check you have 3.3V (+/-0.1V) on pin 8 of the 8-pin DIL socket on the SC+ PCB ( )

30 Check you have the following voltages on pin 3 of the ATtiny85 8-pin DIL socket on the SC+ PCB (+/-0.2V)

- No button pressed 3.3V ( )
- Press the LOCK switch 2.5V ( )
- Press the A/B switch 1.7V ( )
- Press the PTT switch 0.8V ( )
- Press the Step switch 0V ( )

31 Disconnect the USB-C power source.



Ground is on Pin 4 or here on this tab

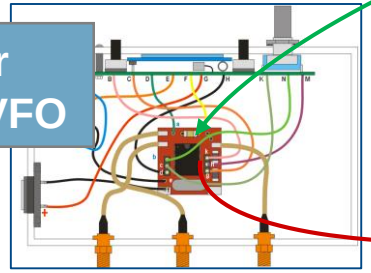
Don't proceed further until you 'tick all the boxes'

The switchboard and SC+ should draw less than 40mA from the USB supply during this test (No ATtiny85 inserted)

These instructions assume you have already downloaded and installed a suitable programming program into your PC e.g. Extreme, Khazama etc

32 Programming Procedure :

1 **Build your SugarCube VFO**



2 **Download the ZL2PD SC+ program firmware**

SC+ Firmware (SugarcubeV10.HEX)

3 **Get the EEP file e.g. Use Excel or download EEP file**

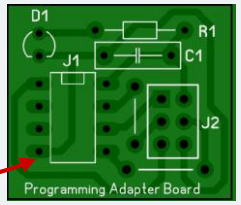
SC+ EEPROM File
This holds your SC+ parameters
(yourfilename.EEP)

5 **Enter settings for ATtiny85 fuses into programming program**
H=&5Fh, L=&E1h

JUST ENTER VALUES !!

6 Put ATtiny85 in adapter

9 Insert ***programmed*** ATtiny into SC+ PCB



4 Load files into your ATtiny85 programming software in PC

7 Connect USBasp to adapter

8 **Program ATtiny85**
a. Flash (*.HEX)
b. EEProm (*.EEP)
c. Fuses

10 **All Done!**

AND…

11 If you want to change VFO settings later…

12 Erase ATtiny ready for new settings and repeat steps 3 to 9

Appendix: How it works

- SC+ starts on the user-programmed start frequency for VFO A
- Start-up takes a couple of seconds (to allow for very slow OLED displays)
- Current VFO A and VFO B frequencies are not saved when the power is turned off

Locks or unlocks VFO tuning

Icons show selected step size (arrow) VFO (A or B), PTT status, and Lock status

Tuning knob selects the frequency on the selected VFO (A or B) in steps selected by pushing and releasing the encoder

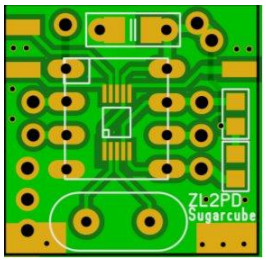
Button for user control of PTT

Bar display can be used to display the S-meter voltage (**Voltage must be 0-3VDC**)

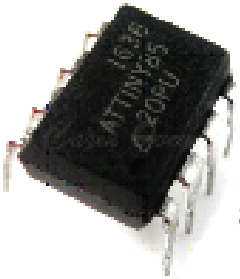
Selects VFO A or VFO B

The SC+ VFO should draw less than 50mA (Typ 40mA)

Appendix: Parts Guide



SC+ PCB



ATtiny85
8-pin DIL

Si5351A
MSOP-10

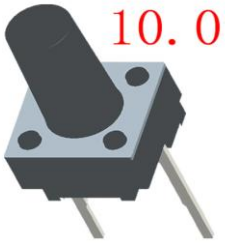
Thru-panel mount
SMA female with
RG-213 tail

0.91” 128x32 OLED

Panel-mount 3.5mm
stereo socket

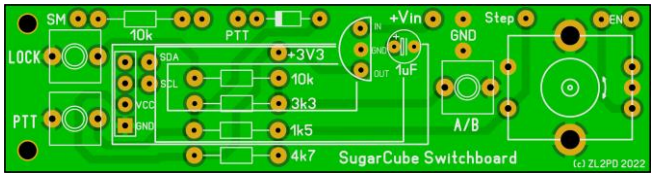
100x60x25mm
plastic box **OR**
laser-cut acrylic box

Panel-mount
USB-C socket



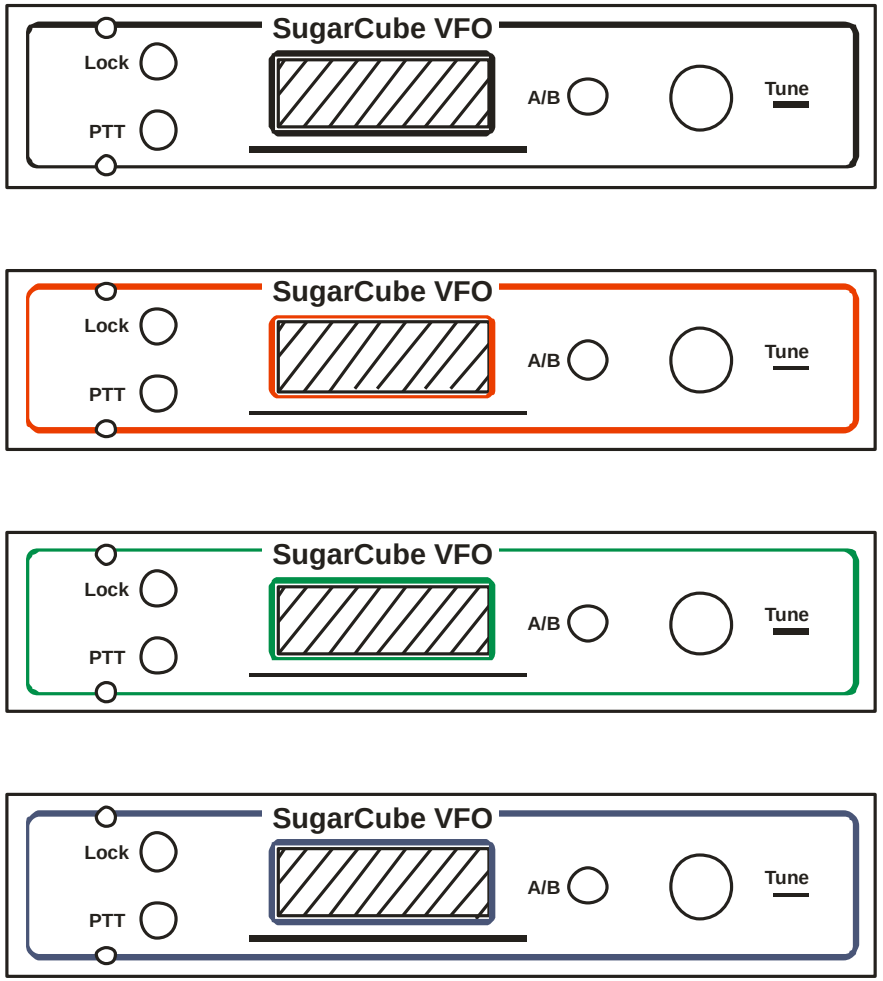
10mm high 2-pin
pushbutton

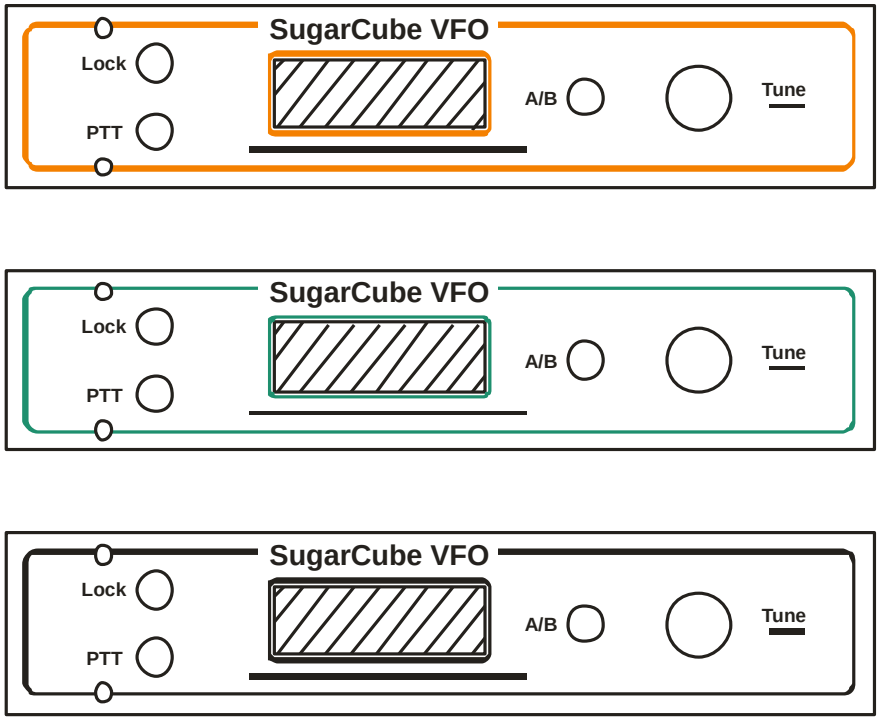
Rotary encoder
c/w switch



80 x 20 mm
Switchboard PCB

Appendix: Plastic Panel Artwork

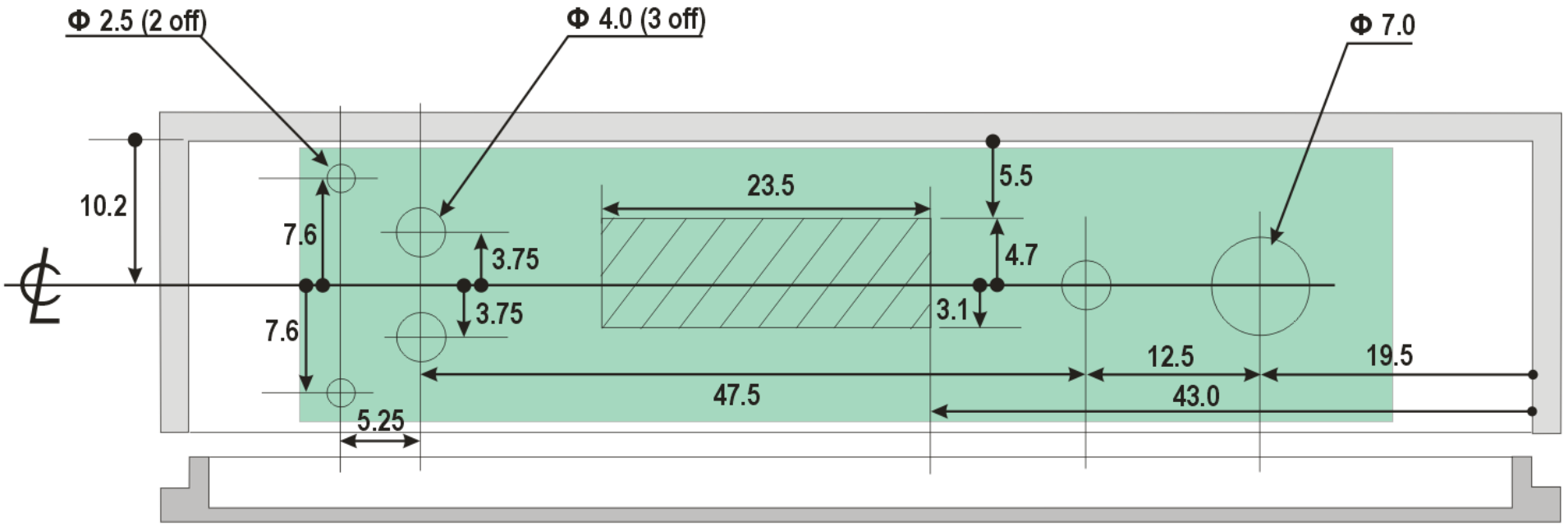




If you are making the acrylic box on a laser cutter, the dimensions are slightly different and the front panel artwork will vary slightly.

Enclosure Preparation – 100x60x25 Plastic Box (1 of 3)

Front face drilling dimensions – View from **INSIDE** Box towards front panel

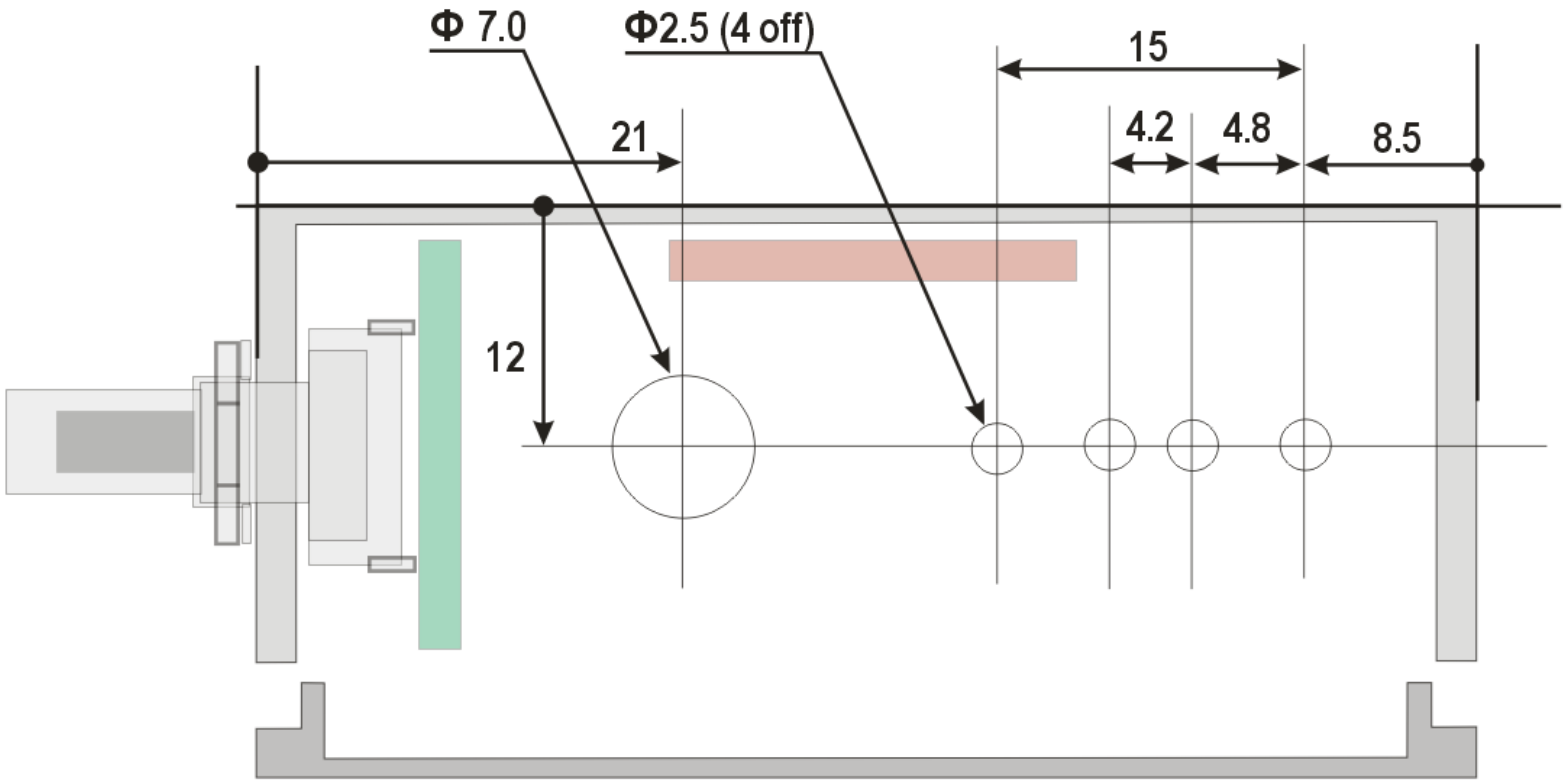


Not to scale - Do not scale this drawing

If you are making the acrylic box on a laser cutter, the dimensions are slightly different and the front panel artwork will vary slightly

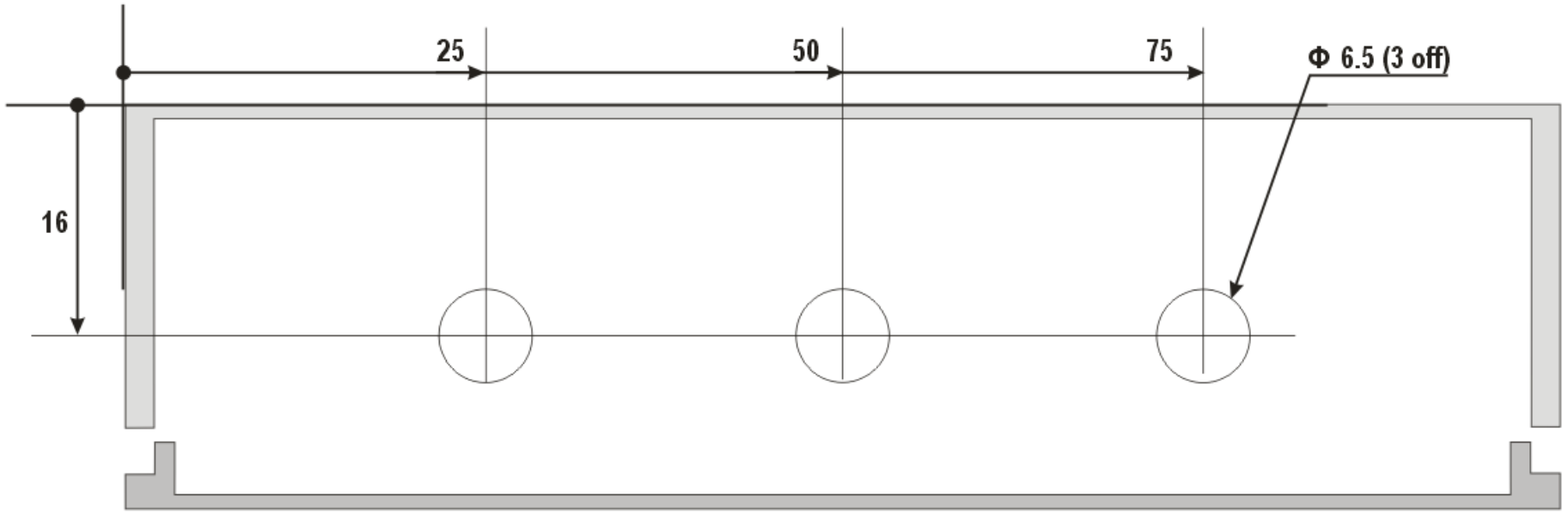
Enclosure Preparation – 100x60x25 Plastic Box (2 of 3)

Side face drilling dimensions



Enclosure Preparation – 100x60x25 Plastic Box (3 of 3)

Rear face drilling dimensions



If you are making the acrylic box on a laser cutter, the dimensions are slightly different and the front panel artwork will vary slightly