QRP Labs OCXO/Si5351A Synthesiser Module

The QRP Labs OCXO/Si5351A-based synthesizer module can generate up to 3 different square-wave frequencies simultaneously in the range 8kHz to 160MHz with 50-ohm output impedance. Building the kit requires no surface mount soldering. The Si5351A chip is truly tiny (3 x 3mm chip, 10 pins with 0.5mm spacing) but for your convenience, has been pre-soldered already to the PCB by the manufacturer! The chip is set-up using the I2C (two-wire interface) serial data protocol.

The 27MHz reference oscillator for the SI5351A chip is an Oven Controlled Crystal Oscillator. The oven is constructed using pieces of PCB material, broken out from the supplied PCB. This simplified oven therefore can be easily and inexpensively built without needing any additional metal heat-sink or thermal insulation. Yet the performance is still good. On the prototype, I measured under 0.01Hz drift in a 2 minute WSPR transmission on 10MHz in the U3 kit. Less than 1 part per billion. This means the OCXO/Synth kit is more than stable enough even for WSPR on the 2m band.

The OCXO/Si5351A Synth module has a 2 x 10-pin header connector, with a footprint and pinout (see diagram, right) somewhat similar to the popular AD9850 DDS module (from eBay and elsewhere). In particular, the module is directly compatible with the Ultimate3 QRSS/WSPR kits (U3) [see Ref 1], it may be used in place of the original AD9850 DDS module, without hardware modification.

Use with the U3 kit requires firmware versions v3.07 or higher, which are able to drive the I2C programmed Si5351A.

The module may be powered by 5V as it has an on-board voltage regulator to supply the Si5351A chip with 3.3V. A separate voltage regulator is used for the 27MHz OCXO. The SI5351A regulated supply voltage is also made available at pin 18. The circuit also includes level converters to interface to a 5V I2C bus. If desired, the voltage regulator and level converters can be left off the board, converting it for 3.3V operation.

The 27MHz oscillator output is available at pin 2. Ordinarily, this should not be connected to anything. In normal use, you will use one of the three clock outputs of the SI5351A chip.

NOTE! Construction of this module is not trivial. The steps recommended in this assembly manual should be followed very carefully. Do not rush, do not skip any steps. Do not try to be a hero and build the kit without following the steps precisely!

Theory of Operation

Si5351A synthesiser chip

The SiLabs Si5351A chip is a cousin of the famous and popular Si570 chip, but is much less expensive. Unlike the Si570 however, the Si5351A has no quartz crystal inside. An external reference oscillator or crystal must be provided. The reference frequency may be 25MHz or 27MHz.

In this module, a 27MHz crystal oscillator is used. This frequency is chosen because it is possible to configure the chip to produce the exact 1.46Hz tone spacing for WSPR, on any amateur radio band from 2200m (136kHz) to 2m (145MHz). A 25MHz crystal cannot provide WSPR tone spacing on the

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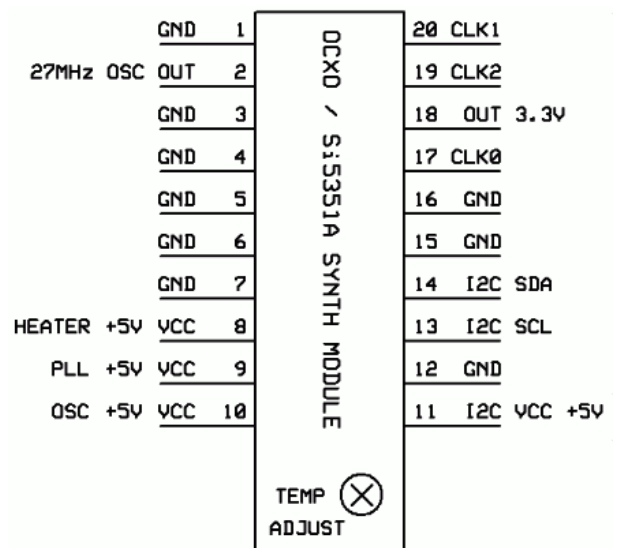
2m band.
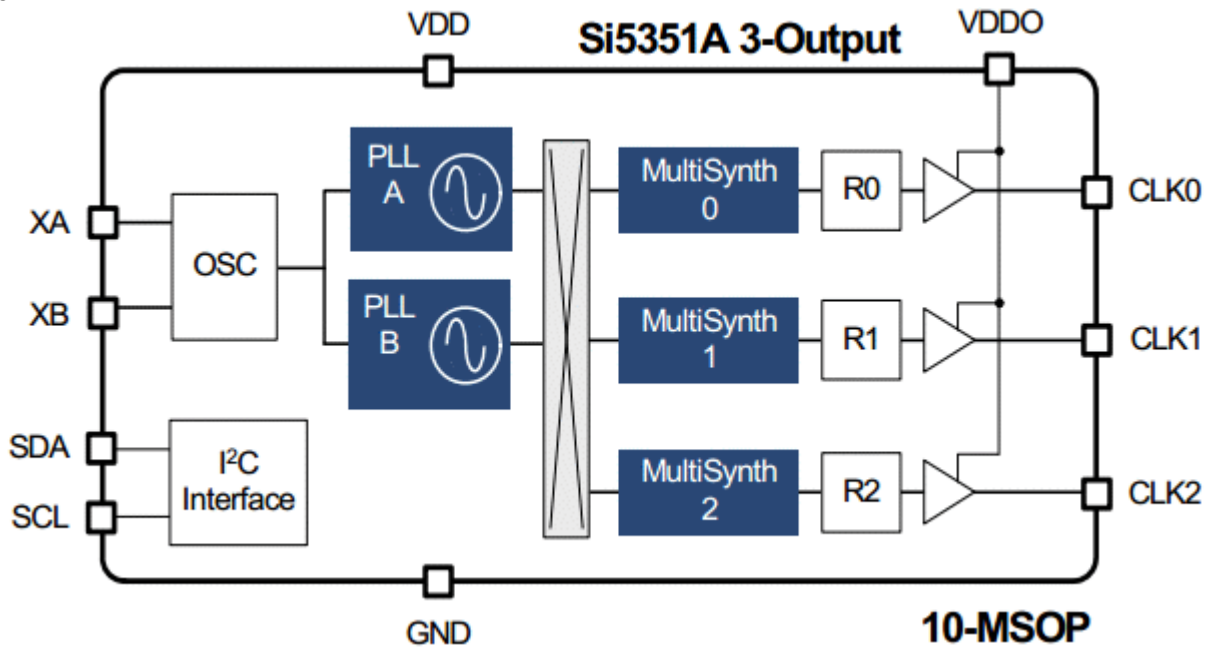
In summary, the Si5351A chip synthesizes output frequencies in three stages. The block diagram of the chip is shown in the above diagram (from the Si5351A datasheet).

First, a crystal reference oscillator is multiplied up to an internal frequency in the range 600-900MHz. There are two PLL's in the chip, each may be selected to choose a different internal frequency. At the second stage one of the PLL frequencies is divided down to each of up to three required output frequencies. Both the upward multiplication to the internal PLL Output frequency, and the division down to the output frequency, use fractional ratios – an integer plus a fractional part consisting of 20-bit numerator and denominator. Optionally a third division stage may be configured to divide each output by a power of 2, for a maximum division ratio of 128. It is used for generating low frequency outputs between 8kHz and 500kHz.

There are a great many other facilities available in this synthesis chip. Please study the Si5351A datasheet for all the details [Ref 2].

In this kit, the Si5351A is powered by an LM317Z variable voltage regulator, set for approximately 3.3V.

The I2C level conversion circuit provides a bi-directional level conversion from the 3.3V levels of the Si5351A chip and the 5V I2C interface of the module. Pull-up resistors are included in the circuit, no external pull-up resistors are required.

27MHz crystal oscillator

The Si5351A chip has an on-board oscillator. All that is required is to connect a crystal externally. However, it is also a potential source of frequency instability, at very fine levels. If the load on the Si5351A output causes varying current consumption in the chip, or variations in heating and hence chip temperature, this could cause the crystal frequency to vary.

Therefore, in order to achieve very high frequency stability, this kit has a separate Colpitts transistor oscillator (Q4) to provide the 27MHz reference frequency. This is so that there is isolation between the crystal and the Si5351A. There is an additional buffer stage (Q5) to even further improve the isolation.

An additional LM317Z voltage regulator set for 3.3V is used to power the transistor oscillator, buffer and temperature control circuit. This ensures that any load change in the Si5351A that might cause a

slight drop in the supply voltage, cannot cause a frequency shift in the 27MHz oscillator, or disrupt the delicate temperature stabilisation.
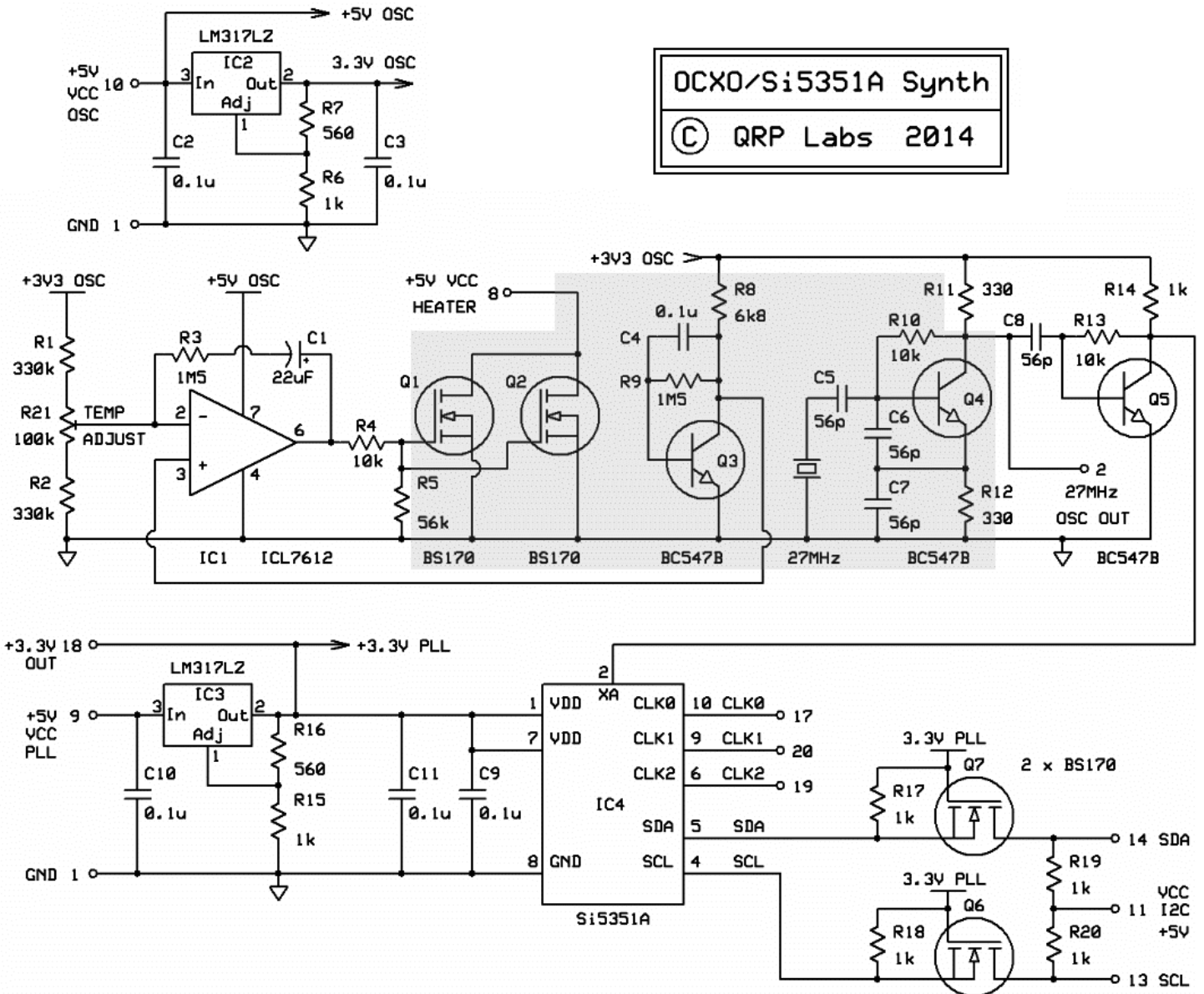
Circuit diagram. The grey shaded section is inside the oven chamber.

Power supplies

All module pins labelled "GND" are internally connected within the module.

Pin 11 is the pull-up resistor positive supply voltage for the level converters. For ordinary use, with a +5V I2C bus, pin 11 should be connected to +5V. The connection is provided separately (not connected to +5V internally) in case you wish to use a different I2C bus voltage.

The +5V pins for the input to the two voltage regulators, and the heater transistors, are all provided on separate pins (8, 9, 10) that are not internally connected. All three pins must be connected to +5V.

The reason for having a separate heater connection is to try to ensure that any voltage drop in PCB tracks caused by the relatively large heater current, does not cause a voltage drop in the supply to the oscillator, that could cause the frequency to be shifted.

In the Ultimate 3S PCB layout, a separate heater connection is provided at the board edge. From this pad to the OCXO/Synth module, the PCB track is as wide as possible. Relatively thick wires from the

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power supply will ensure minimum voltage drop.

Note that in relating the pinout to the physical module, designated pin 1 is near the shorter PCB end of the module.

Oven

The oven heater is very simple. It is just two BS170 MOSFETs in parallel. The rated maximum current of a BS170 transistor is 500mA, and rated maximum power dissipation is 830mW. In the oven heater, the BS170s are connected directly across the +5V heater supply. They will dissipate 830mW when the current is 166mA. The total heater current to the OCXO/Si5351A synthesiser module should therefore not exceed 333mA.

Oven control circuit

The oven temperature control circuit is a Proportional-Integral (PI) controller circuit. It uses a single ICL7612 op-amp circuit with a bridge-circuit to compare measured temperature against set temperature. The set temperature is adjusted via a 100K potentiometer (R21). The temperature measurement uses a BC547 transistor as the temperature sensor.

The "Proportional" term of the PI controller is implemented by feedback resistor R3 (1.5M) which sets the gain of the op-amp. The "Integral" term of the PI controller is implemented by the 22uF capacitor C1 in the feedback path. The op-amp output voltage feeds the BS170 MOSFET heaters (Q1 and Q2), to control the heating current. R4 and R5 limit the voltage at the BS170 gates, to try to limit the current to reasonably safe values at switch on when the oven is cold.

Crystal characteristic, ppm vs temp

This simple oven control circuit has been found to work very well.

This chart shows the measured frequency shift in parts-per-million (ppm) of the crystal type used in this kit. The crystal is a plain common 27MHz AT-cut crystal, not specifically cut for use in crystal ovens in OCXOs. These types of crystal have a minimum frequency dependence on temperature somewhere around 45C. This can be seen clearly on the measured curve. Therefore we are aiming to set the oven temperature at about 45C.

Mechanical/thermal design

An enormous amount of thought went into the mechanical and thermal design of this OCXO/Si5351A synthesiser module kit. There were a number of constraints:

1. Physical dimensions must be compatible with the Ultimate 3/3S kits so that the module can be used in existing U3 kits as a replacement to the previously used AD9850 DDS module. The small size requirement was a significant challenge.

2. The pinout of the module should be similar to the AD9850 DDS module so that the OCXO/Si5351A synthesiser module can be plugged in to the existing U3 kits.

3. The supply voltage and I2C bus voltage must be 5V, again to be compatible with the Ultimate 3/3S kits.

4. The kit must be manufacturable, and not just manufacturable, but manufacturable inexpensively. This means avoiding fancy construction such as machined metal cases, heatsinks, insulation materials. The components used should be readily available and inexpensive.

5. The kit must be build-able by reasonably experienced hobbyists, without expensive tools or highly skilled techniques.

The final design uses a main PCB for the components of the crystal oscillator, oven temperature controllers, Si5351A synthesiser circuit, voltage regulators and I2C level converters. The module has two 10-pin headers, exactly like the AD9850 DDS module.

The dimensions of the OCXO/SI5351A synthesiser module are larger than the AD9850 DDS module, but still small enough to fit the U3 kits. The maximum height of the top of the module, relative to the top surface of the PCB, is 10mm. This could not be exceeded, because the U3 may have the optional relay-switched low pass filter board attached on top. The available headroom was only 10mm. Since the kit uses standard 1.6mm FR4 PCB, the internal height inside the box is only 8.4mm.

The module uses a system of three boxes. One is the main inner oven chamber, fitting on the top side of the PCB, and covering the components inside the oven. The internal height of the components inside the oven chamber must not exceed 6mm. The external height of the oven chamber over the top PCB surface is only 8mm.

On the lower side of the PCB, there is an additional very shallow box. This box is only 3mm high. This is required because this is the maximum space available below the PCB in the U3 kit. The old AD9850 DDS module in the U3 kit sits on top of the Atmega328 processor, which itself is plugged into a standard 28-pin DIP socket. Considering the 1.6mm thickness of the standard FR4 PCB, this means there is only 1.4mm space inside the lower oven chamber box. All the component leads on the bottom side of the board inside the oven chamber must therefore be tightly cropped next to the PCB.

The PCB layout is designed so that no traces lead into or out of the oven chamber on the top side of the PCB. The top oven box is soldered to the top side of the PCB with a complete seal all around. The ground plane is interrupted at the edges of the oven chamber, to minimise the thermal conduction of heat out of the oven chamber. Similarly on the lower side of the PCB. The seal on the lower side of the PCB is only broken to allow the signal and voltage supply traces in and out of the oven chamber.

The crystal is placed on the board in the centre of the oven chamber. It is surrounded tightly by four transistors. The two BS170 heater transistors Q1 and Q2 are placed one on either side. The BC547 temperature sensor transistor is placed in contact with the crystal also. Finally the oscillator transistor Q4 is also placed in contact with the crystal. As much as possible therefore, these components and the crystal should all be held at the same, constant temperature.

The 56pF capacitors in the Colpitts oscillator circuit are NP0/C0G types (very low temperature coefficient), and they are also kept inside the oven chamber. In the circuit diagram above, the oven chamber components are all inside the grey shaded area.

The PCB layout of the main PCB, and the PCB parts that make up the boxes, was carefully designed to 0.01mm resolution, to try to give maximum thermal insulation to the oven chamber in the centre of the module. For constructing the boxes, where the PCB parts have a ground-plane on both sides of the board, the ground plane is interrupted where the seam will be soldered. Without this interruption,

heat dissipation away from the seam would make them very difficult to solder.

The overall outside case also provides an additional layer of insulation for the oven chamber.

Whilst this design has been kept simple to minimise costs, the insulation provided by the FR4 PCB of the inner oven, and the copper plated PCB's providing some heat-sinking effect, result in a simple, inexpensive oven with impressive performance.

Parts List

Resistors (all are miniature 1/6-Watt types)

R11, R12	330-ohm resistor (orange-orange-brown)
R7, R16	560-ohm resistor (green-blue-brown)
R6, R14, R15, R17, R18, R19, R20	1K resistor (brown-black-red)
R8	6.8K resistor (blue-grey-red)
R4, R10, R13	10K resistor (brown-black-orange)
R5	56K resistor (green-blue-orange)
R1, R2	330K resistor (orange-orange-yellow)
R3, R9	1.5M resistor (brown-green-green)
R21	100K preset potentiometer

Capacitors

C5, C6, C7, C8	56pF capacitor (marked "560")
C2, C3, C4, C9, C10, C11	0.1uF capacitor (marked "104")
C1	22uF electrolytic capacitor

Semiconductors

Q3, Q4, Q5	BC547 bipolar transistor
Q1, Q2, Q6, Q7	BS170 MOSFET
IC2, IC3	LM317LZ voltage regulator IC (TO92 package)
IC1	ICL7612 8-pin DIP
IC4	Si5351A IC, already factory-soldered to the PCB

Miscellaneous

1x 10 x 8cm PCB
2x 10-pin 0.1-inch pitch headers
1x 27MHz crystal labelled "27.000"

Construction

READ ALL OF THIS VERY CAREFULLY!

During construction please refer frequently to the parts placement diagram below. It will help to print this page, even if you do not print this whole document. The PCB silkscreen also has the part numbers printed on the PCB. But they are not always easy to read, because the printing is small and the component density quite high. So check very carefully against the parts placement diagram, and make sure that the correct components are inserted in the correct holes, BEFORE soldering.

Pin numbers are indicated in Red, and this image is the board viewed from above. Resistor numbers in red are indicated where the writing is small, to make it easier to see.

Mistakes are difficult to correct. It is better not to make mistakes at all, than try to correct them later! Take the time to avoid mistakes.
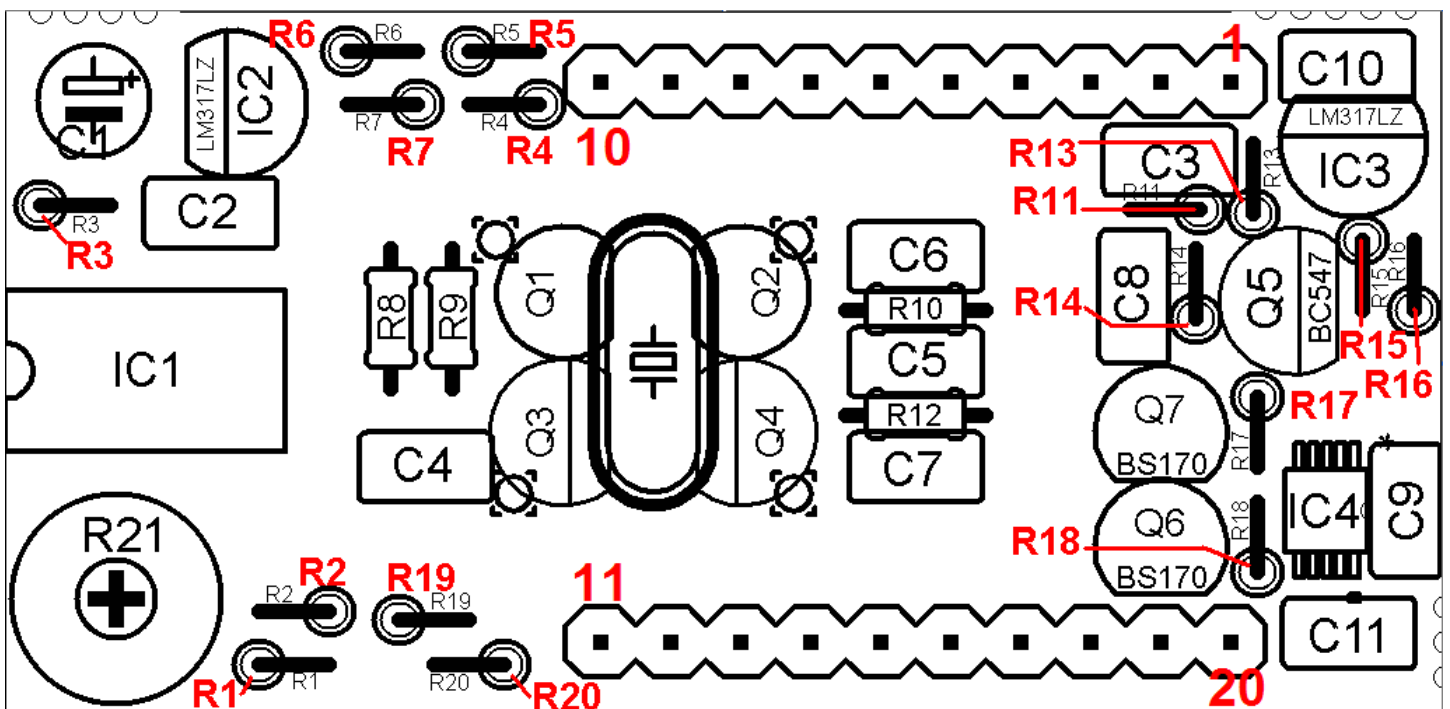
Please follow the sequence of steps listed in this section precisely. Do not try to skip steps. Do not try to be a hero, and build this kit without following the steps precisely. Even experienced kit constructors should follow the steps precisely. Don't be tempted to rush! Go carefully through the listed steps. Tick off each step, as it is completed.

The supplied PCB is broken up into 16 small PCBs. These are used to build three small boxes, and the main PCB for the components. The PCB's are numbered 1 to 15. The PCB part numbers are referred to in the construction steps. However, since some of the PCB parts are tinned (no green soldermask), the silkscreen on these parts does NOT show the part number.

It will help to write the part numbers on PCB pieces where there is no silkscreen.

Refer to the following diagram frequently during the construction! Great care is needed, to select the correct PCB parts for the correct stages of construction. Do not rush, or skip any steps.

The PCB parts are broken off the main PCB using by applying pressure at the rows of drill holes, to break these weak points.

The dimensioned edge of the PCB parts is the centreline of the drilled rows of holes. Some light filing should be done to remove fibreglass splinters. **But do NOT try to remove all sign of the holes!** That will result in making the PCB parts TOO SMALL!

Do NOT break apart all of the PCB parts now. Leave the PCB intact. The list of steps below will tell you when to break off each part. The steps are designed to avoid mixing up PCB parts.
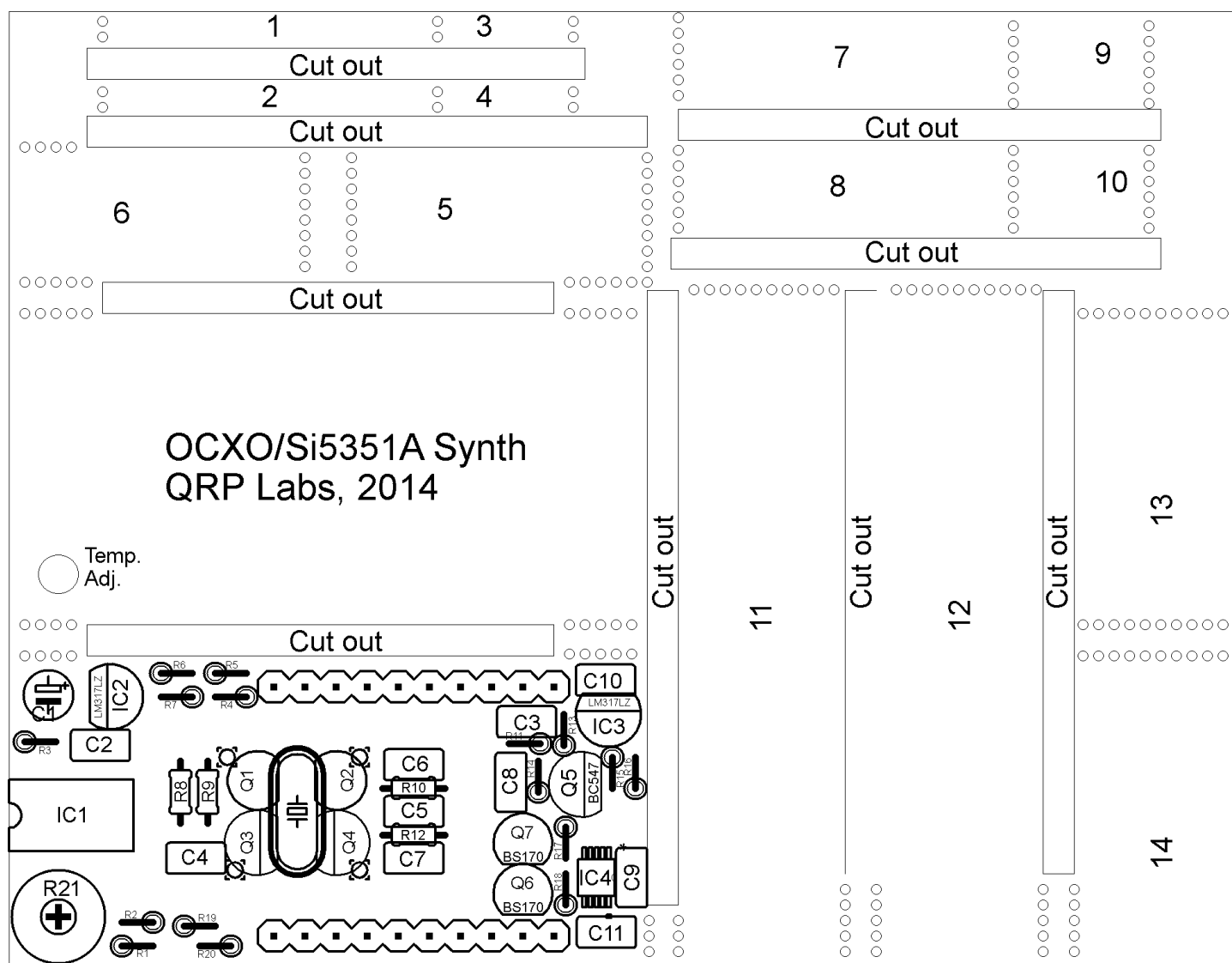
The following image shows the track layout of the main PCB. Red is for top traces, Blue is for bottom traces. I include it here, as it may be useful for debugging purposes, to be able to see what is connected to where.
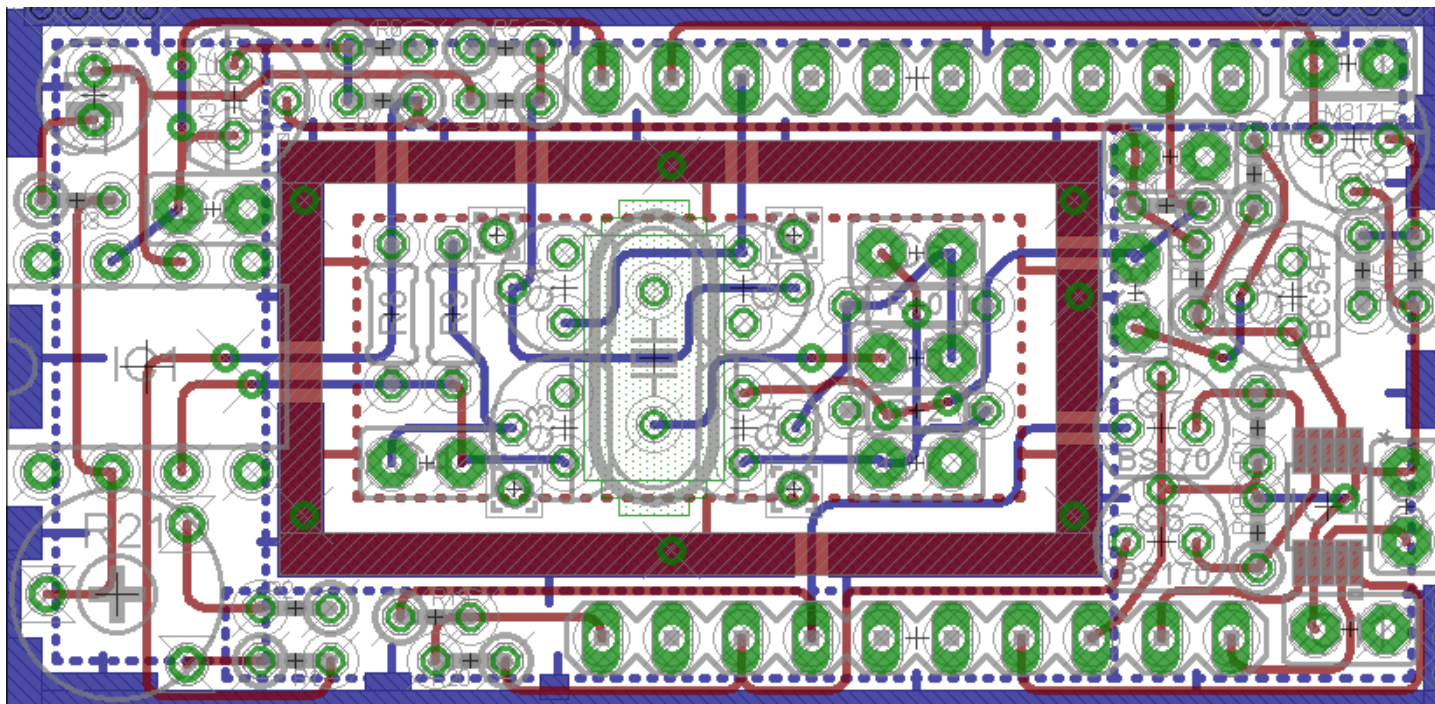
This is the same thing, but with the ground planes filled in:
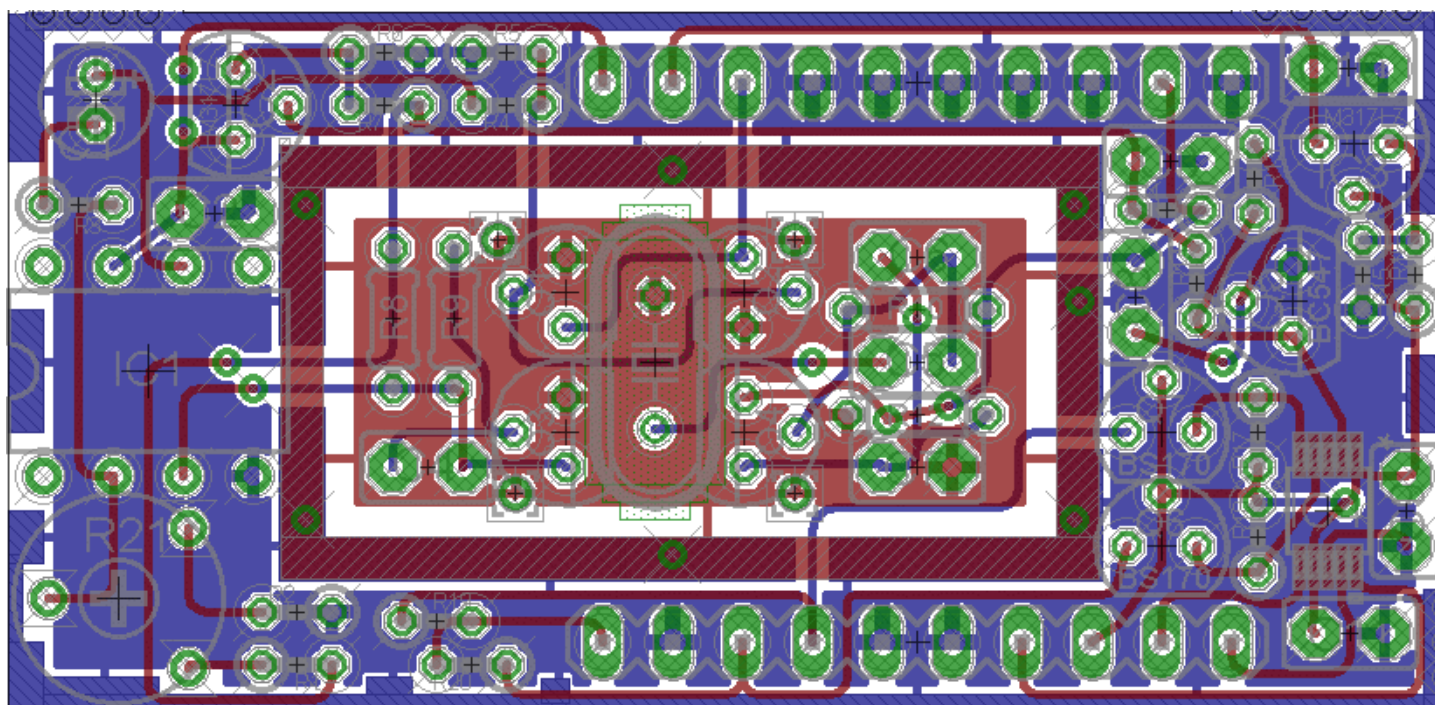
The following sequence of steps will guide you through assembling the OCXO/SI5351A synthesiser module.

Again, even experienced constructors should follow these steps, because this is not a trivial project to build. Follow the steps carefully and patiently, to give the greatest probability of success, and ensure good performance of your oven. Tick the steps, as you complete them.

Proceed, CAREFULLY...

[ ] 1. Familiarise yourself with kit contents

The kit contains one PCB. The Si5351A chip is already soldered on. It is a very small and delicate chip. So be careful when handling the PCB. The PCB will be broken into 16 smaller pieces. One piece is the main PCB where the circuit is built. The other 15 pieces are used to make 3 boxes. The boxes form the central oven chamber, and the outer case.

There are two values of capacitor, 56pF (code "560") and 0.1uF (code "104"). They look similar so be careful not to mix them up! The 0.1uF capacitors are a little fatter. Check the codes and sort them into two piles.

There are several different resistor values in the kit, so please check carefully before installing them. They are tiny 1/6 watt resistors. They have got to be tiny, to fit in the OCXO chamber which is designed to be as small as possible.

There are 9 three-legged TO92 plastic devices. These are: two LM317Z voltage regulator IC's, three BC547 transistors, and four BS170 MOSFETs. They all look very similar! So again: be careful not to mix them up. Keep checking again and again, before soldering.
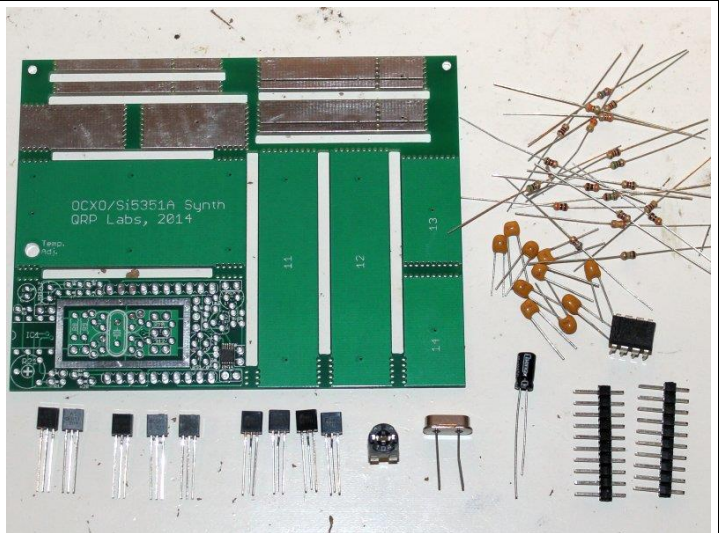
[ ] 2. Get the right tools... wire cutters

You need some tools like a file for smoothing PCB edges, screwdrivers etc.

You also need a good pair of wire-cutters. The underside of the PCB inside the oven chamber, has only 1.4mm of space between the board and the lower oven cover. Therefore you have to trim the component ends, cut them to less than 1.4mm.

The blue wire-cutters pictured here are NOT a good pair of wire-cutters. They are a poundshop (like dollar-store etc) pair. Not sharp. I have a sharp pair of good wire-cutters from Maplin which I keep for wires. I use this old blue set of blunt wire-cutters for other things. In this project: breaking the PCB into the 16 pieces.

[ ] 3. Magnification

A jewellers loupe like this is really pretty useful for checking your soldering. A magnifying glass could be used too. The solder pads in this kit are small and close together. It really is important to check the connections. Particularly, check for short circuits between adjacent pads.
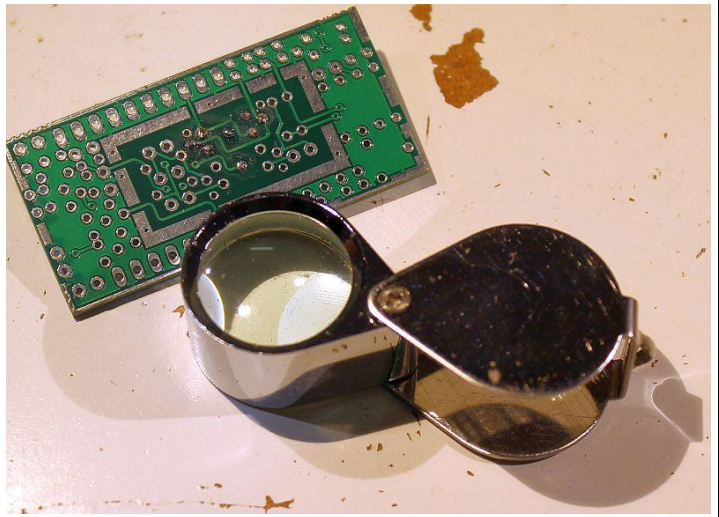
[ ] 4. Soldering iron...

A soldering iron. Personally I have always used an Antex CS 18W iron with 1mm chisel-bit, type 1106. However the 18W power of the iron is marginal, for soldering the seams of PCB boxes. You can do it, I did. I built two OCXO/Synth kits almost entirely with the Antex CS iron. But if you make a mistake, or to make soldering easier, a bit more power can be useful. I happen to have a 100W Weller soldering gun. It makes soldering the seams of the PCB boxes very easy.

[ ] 5. Blu-tack

Blu-tack! Know it? Nasty blue sticky rubbery stuff useful for fixing papers to walls, and many other purposes. Blu-tack was invented in England. I suppose it is available in other countries too. Or something similar, maybe called something else. "Plasticine" would also work, but it's English as well and I don't know what other countries would call it.

Holding together the tiny pieces of circuit board for soldering into the boxes is very difficult. Many times you wish you had four hands. Four tiny hands. Not like the crusty old hands you really have. I managed to build the first OCXO/Synth kit with my two old crusty hands. When I started building the second kit, I had an idea to use Blu-tack to hold things in place. It made everything so easy!

Yes, when the boards are soldered, they get hot. The hot blu-tack gets even more sticky and nasty. But it's Ok, it's easy to rub it off.

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A blob of blu-tack on top of the tiny Si5351A chip during assembly of the module, is not a bad idea! It could help prevent getting an accidental solder splash on the Si5351A. The pin spacing of that chip is only 0.5mm and a solder splash would be hard to remove successfully.

Another way of holding the parts accurately in place for soldering is a V-block, as demonstrated here by Dave G3WUN. Gravity holds the boards at 90 degrees and the magnets aren't really needed.
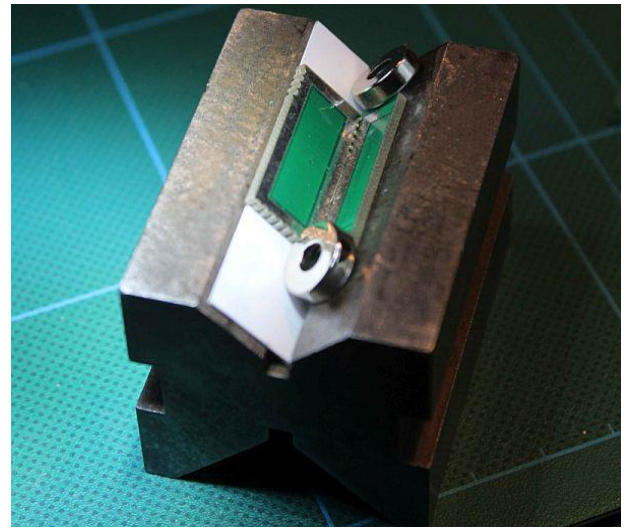
[ ] 6. Break up PCB pieces

The first thing to do is to start cracking up the big PCB. The PCB has slots to separate the PCB's. Lines of holes indicate where the PCB is to be broken. Do not break it into all 16 pieces. It is better to keep all the pieces together until you need them. This way, you have less risk of losing tiny pieces. And less risk of getting confused about which pieces to use.

The first PCB to take out, is the main PCB where the components will be soldered. You need to be very careful, not to damage the tiny Si5351A chip. It is already soldered on the top side of the PCB, at the lower right. My first cut is right there at the lower right of the PCB, as shown in the picture. I use the old wire-cutters to cut along the row of holes.

Be careful NOT to bend the main PCB at all: that could risk breaking the Si5351A solder connections. After that cut, break the row of holes at the top left and top right corners of the PCB. These are further from the Si5351A. Still: be careful.

WARNING: when breaking out the parts of the PCB, be very careful that they do not fly away. When you cut the PCB, the parts can fly. Some of the parts are small. You could lose them easily. I break the PCB parts by bending the PCB, not by cutting (except for the first piece, next to the Si5351A chip). Then they do not fly.

WARNING: Fibre-glass dust is nasty. Make sure you don't breathe it. Clean it up as soon as possible.
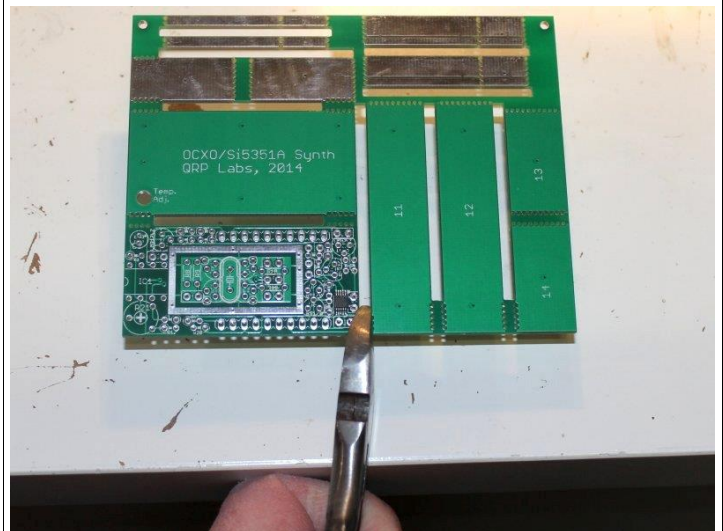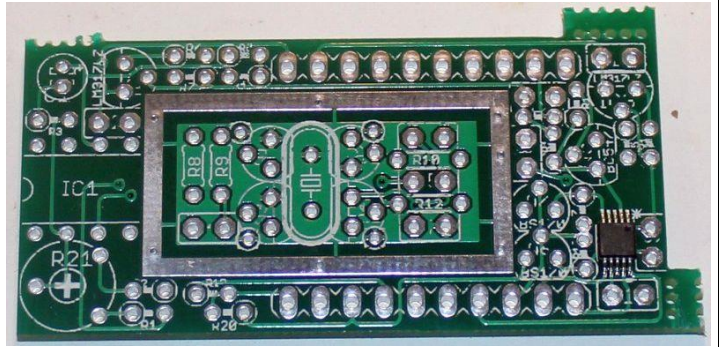
[ ] 7. The result should look like this.	
[ ] 8. Cut stubs Now you can very carefully cut off the stub at the lower right of the PCB, using the wire-cutters and very gentle pressure. Similarly the other stubs. Again, be very careful at the bottom right of the PCB, to not bend the PCB and risk damaging or disconnecting the tiny Si5351A chip.	
[ ] 9. The result should look like this	
[ ] 10. File edges Now **very gently** file off the sharp bits at the row of holes. **Do NOT do too much filing!** You do not have to remove any sign of the holes! Just make it so that the edges of the PCB are smooth, nothing sticks out. The result should be like this.	
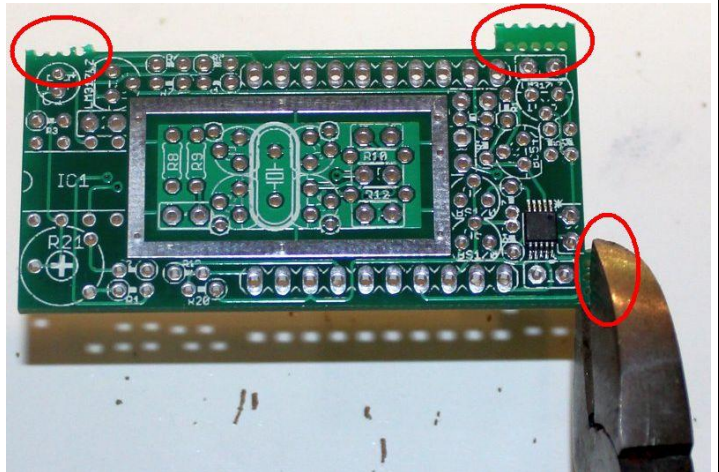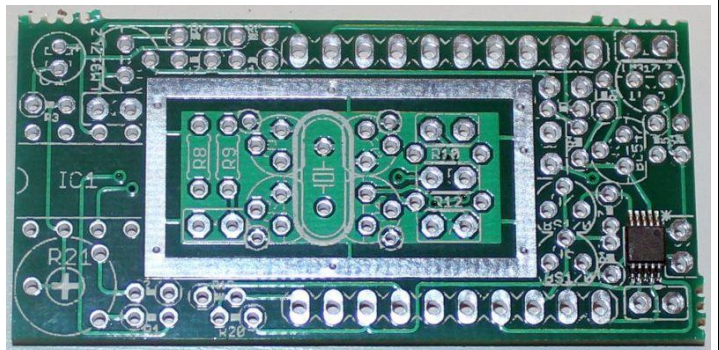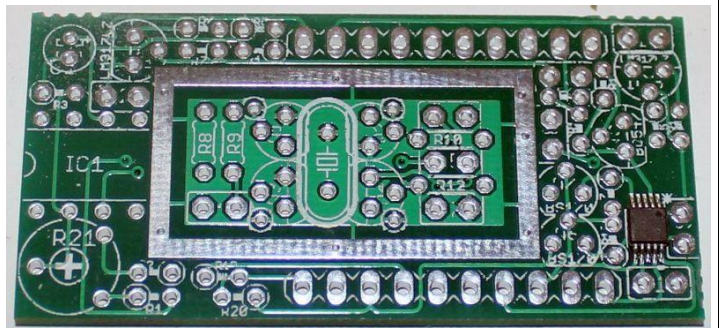
[ ] 11. Snap off box lid

Now you can snap off the box lid too, which is the next large piece.
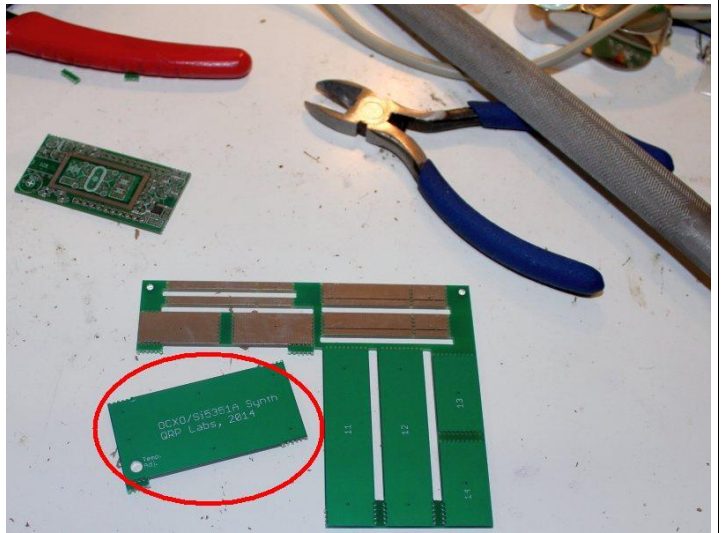
[ ] 12. Snap next piece

Here's the next snap. The pieces we are trying to get to are parts #6, #7, #8, #9 and #10. These pieces make the top inner oven box.
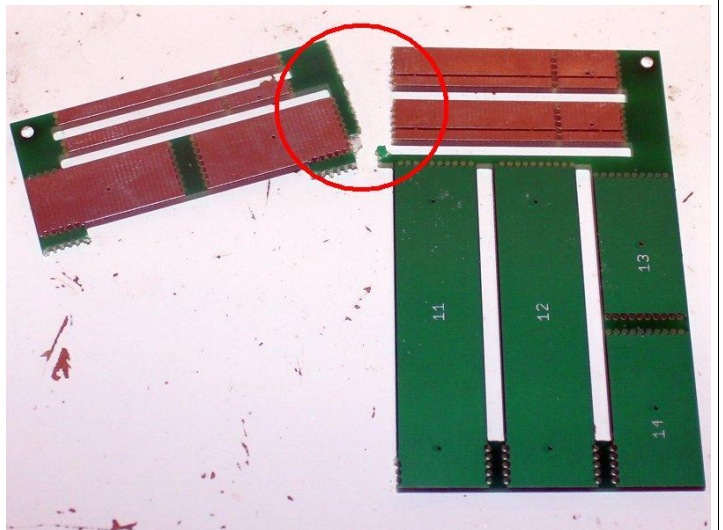
[ ] 13. Snap as shown.
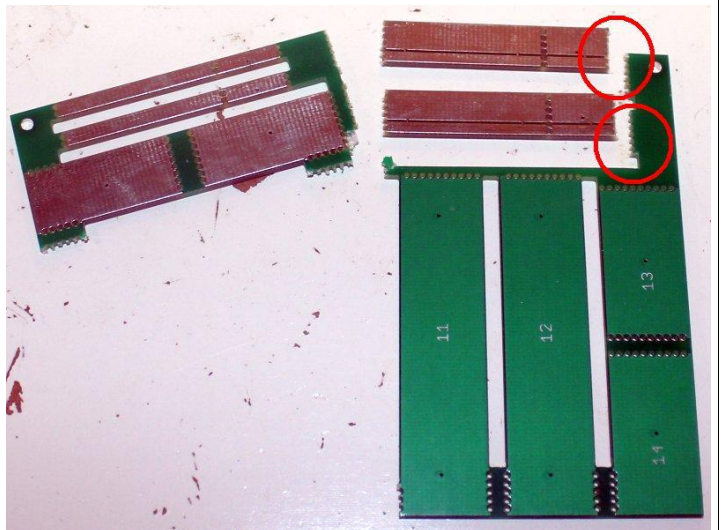
[ ] 14. Snap out piece #6

Now use the old wire-cutters again to snap out piece #6.

[ ] 15. The next snap...

Here's the next snap.

Now we have piece #6 by itself, #7/#9 are still joined together, and #8/#10 are still joined together.
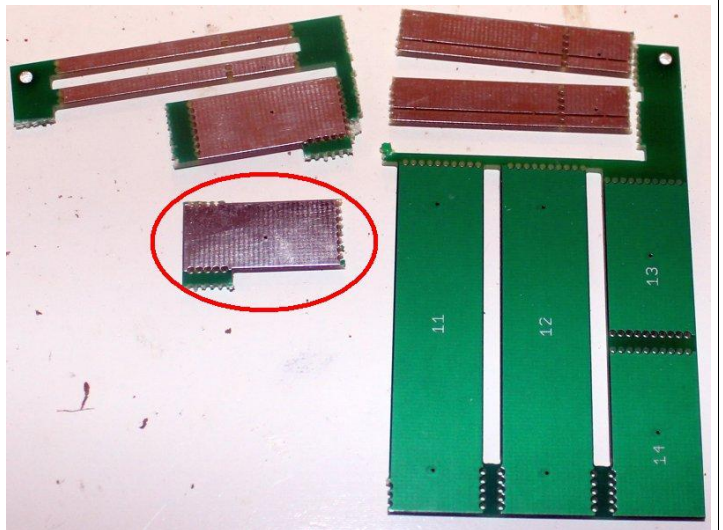
[ ] 16. Break #7/#9 and #8#10

So use the old wire-cutters to break #7/#9 apart, and break #8/#10 apart.
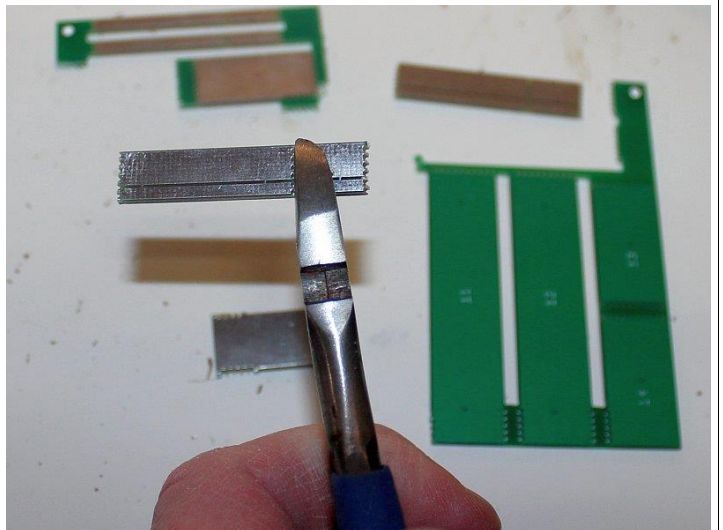
[ ] 17. Parts #6, 7, 8, 9 and 10

Here are all the five pieces that will make the top inner oven box. Parts #6, #7, #8, #9 and #10.

File off the sharp edges.

I'll say it again: file very gently. Do not try to remove the holes. Just remove any obvious pieces that stick out. Later, if you need to, you can always file a little more to make something fit. But if you file too much now, you cannot put it back later!
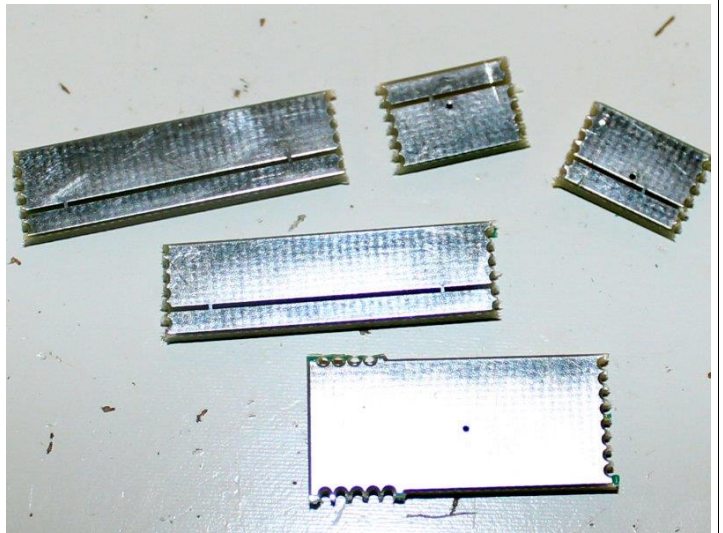
[ ] 18. Parts #6 and #7

The first two pieces to go together are parts #6 and #7, which will be soldered like this.

The rule with this top inner oven box is: the tinned silver-coloured sides are the OUTSIDE of the box. The green-coloured varnished side is the INSIDE of the box.

The seams that you will solder on the INSIDE, are also tinned silver-coloured.
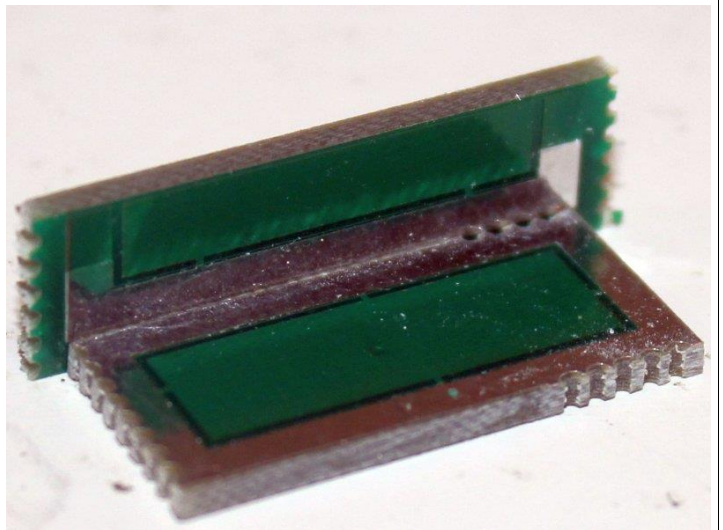
[ ] 19. A solder blob...

My technique is to put a small solder blob on one end of the seam to be soldered.

When you come to apply the solder with the soldering iron, it is easy.
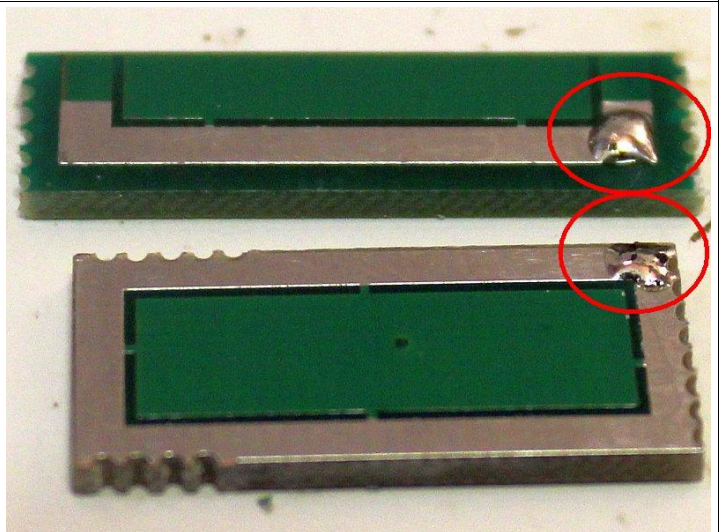
[ ] 20. #6 and #7 joined

Here it is, after soldering those blobs together. With only one tiny blob soldered, you can check the alignment. If necessary, you can still solder again, to improve the alignment.

Be as PRECISE as possible. The boards should be at right-angles. Build on a flat surface. This helps accurate alignment. Make sure the silvered seams are aligned. There should be 1.6mm of board (part #7) overlapping the ends of part #6.
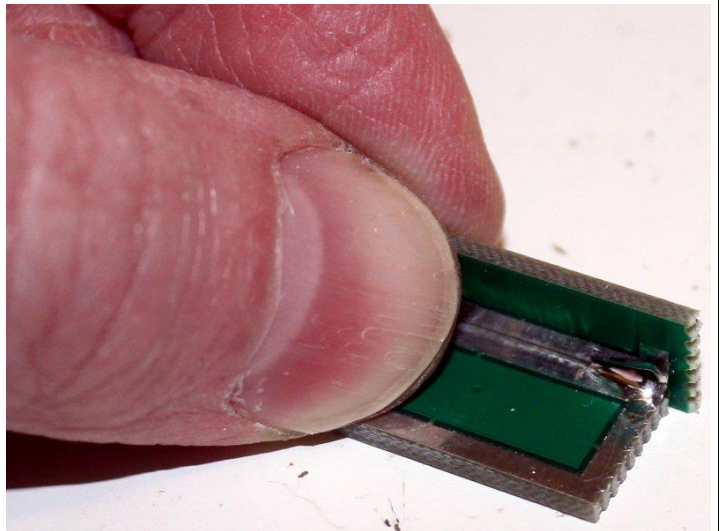
[ ] 21. Another view. Fingers out of the way
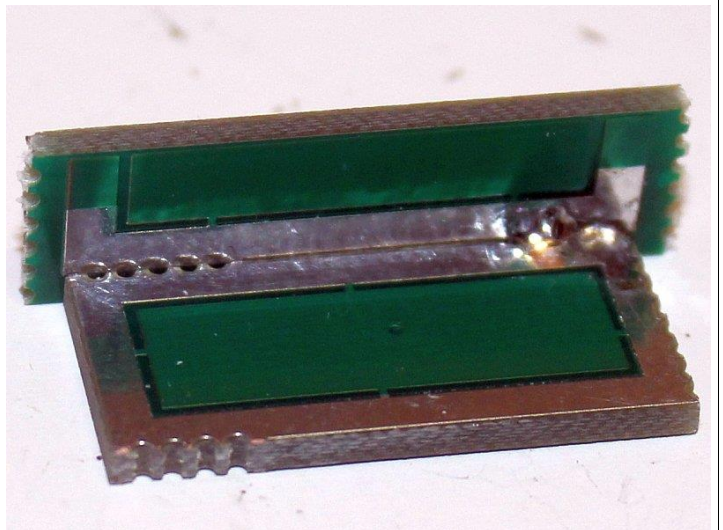
[ ] 22. Solder other end

Next apply a similar blob at the other end. Again, check the alignment.

Check, check, CHECK!

When you are happy that the alignment is accurate, solder along the whole seam.

Be careful not to ruin the alignment, while soldering.

Too much heat, will cause the joint to contract to less than 90-degrees when it cools. Trying to bend the joint back to 90-degrees may lift the copper off the board. So be careful! It may be better to aim for slightly above 90-degree angle. Then when it cools, it will contract back to 90 degrees. In any case, work slowly and a bit at a time. Keep checking everything again and again! Correct any mistakes before they get out of hand!
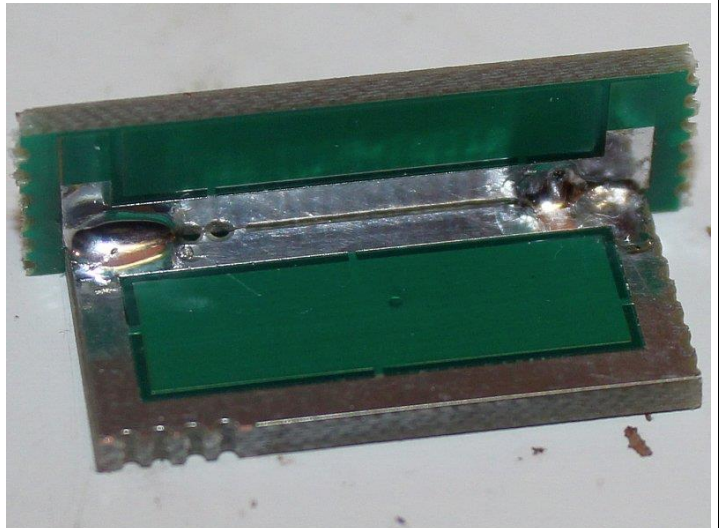
[ ] 23. Add part #9

Now we are going to add part #9. Remember: Green side is the INSIDE.

I put a blob on either side again. If part #9 doesn't quite fit in, at this point you can file the ends a little. Just a little. Until it fits.

This is where I started wishing I had 4 TINY hands instead of these two crusty big old ones. This is where I had the idea that somewhere in the house, is that old packet of blu-tack! That would be really useful! And it is! I strongly recommend it.
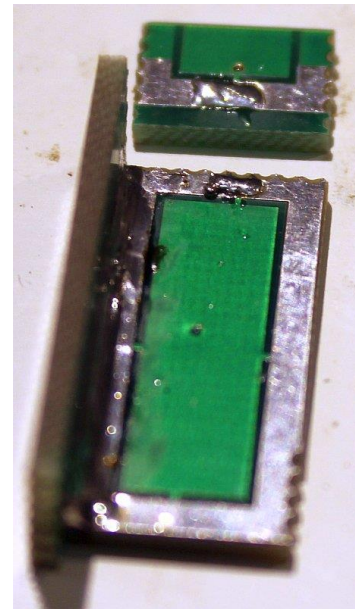
[ ] 24. Solder together

See how easy it is to keep the parts in alignment with the blu-tack, leaving both hands free. One hand to hold the solder in the joint, and one hand to hold the soldering iron.

Again, solder the small blob. CHECK!

When all is aligned, solder along the whole seam.
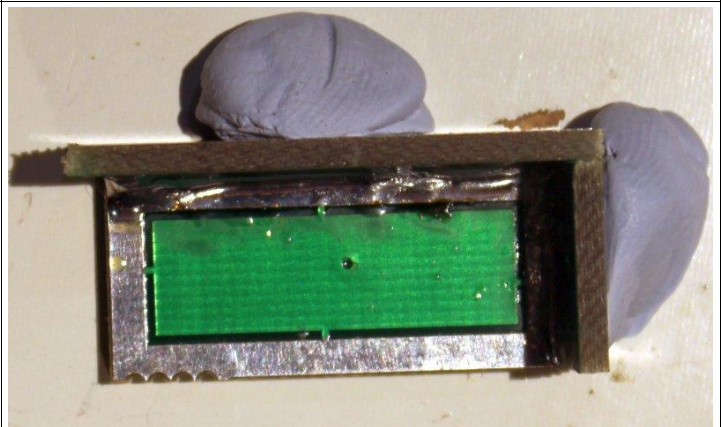
[ ] 25. Add part #8

Next we add part #8. Same method. A blob at each end, then align the parts to be soldered, and stick them to the flat work surface with pieces of blu-tack.

CHECK alignment!

When happy with the alignment, solder the whole seam.
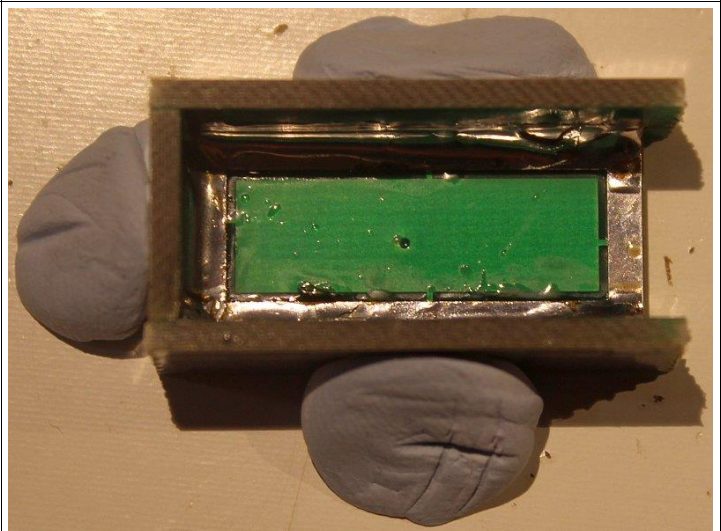
[ ] 26. Another view of adding part #8

[ ] 27. Add part #10

The final part is PCB part #10. Again, if it doesn't quite fit you can file it a little, where the break-holes are. One blob on each side of the seam. Align the parts using blu-tack.

Check the alignment!

When happy, solder the whole seam.
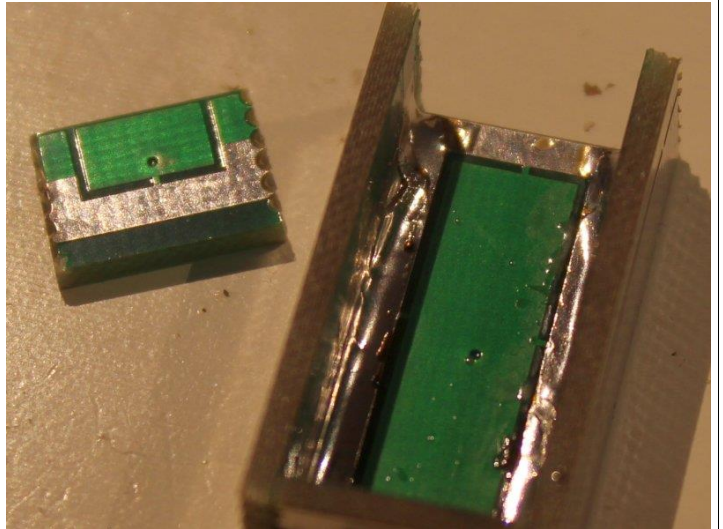
[ ] 28. Completed top inner oven box

Now the top inner oven box is complete, and it looks like this photo.
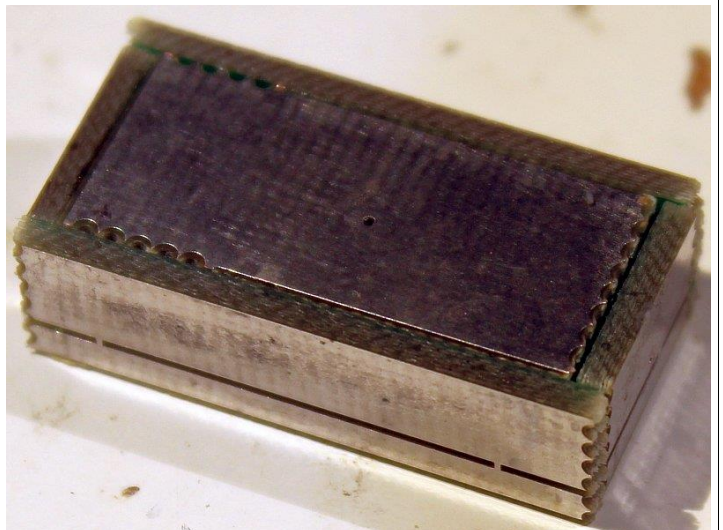
[ ] 29. Lower inner oven box

The next job is the lower inner oven box. This is parts #1, #2, #3, #4 and #5.
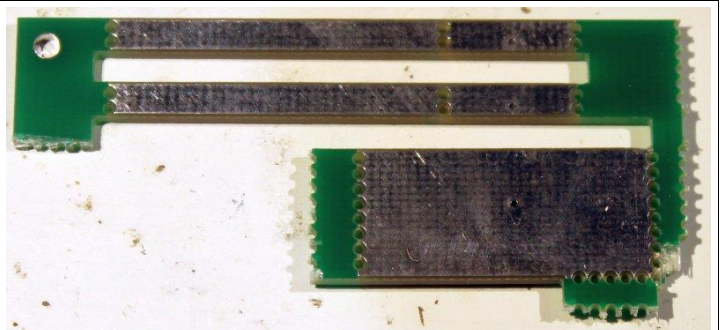
[ ] 30. Break parts apart

Break these parts along the dotted lines. Lightly file any rough bits.

I say again: do NOT file too much! Filing can always be done later. But file too much, and you cannot put back the DUST...

The result should be like the photograph
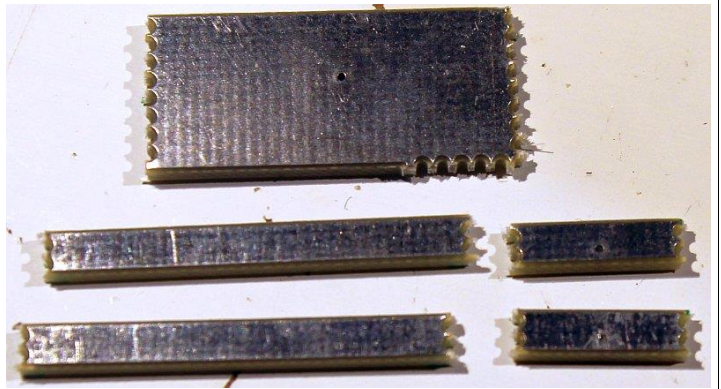
[ ] 31. Join #1 and #5

First we are going to join parts #1 and #5. The alignment must be like this picture. When the top piece (part #1) is stood up, the tinned silver part will line up with the silvered part on the edge of part #5. Again use blu-tack to hold the pieces in place, before soldering. I LOVE that blu-tack.

Note that the tinned edges of part #5 are much narrower than the equivalent part #5 of the top inner oven box. This is because all the cut component leads will be on the lower side of the PCB. There is only 1.4mm of clearance from the PCB's lower side, to the lid of this box. 1.4mm is not much. The component leads need to be cut shorter than this. There is also not much space at the sides.

Because of all this lack of space, the tinned edges of part #5 are narrow. When you solder them, do not use too much solder. Use enough, but not more than enough. Just solder lightly. You do not want to risk any of the component leads on the lower side of the PCB, touching the soldered seam.
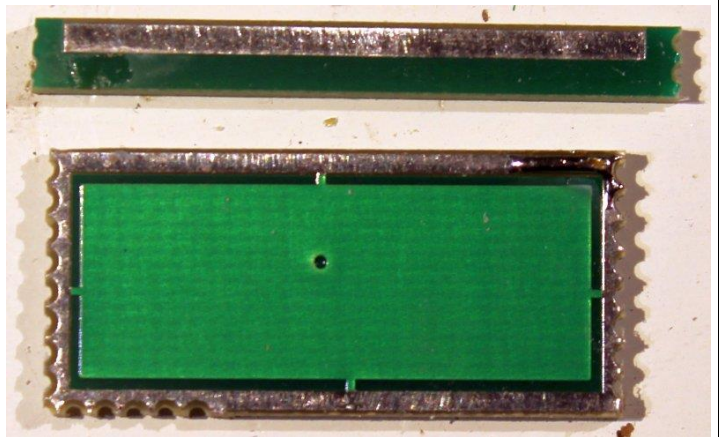
[ ] 32. Add part #3

Next we add part #3. Parts #3 and #4 are the smallest PCB pieces of the whole kit. Be careful not to lose them.

One again: the tinned section is upper. When you stand up this small part #3 on its edge, the green part will be down, the tinned silver part will be up.

The tinned silver part aligns with the tinned edge of part #5. So you can solder it easily.
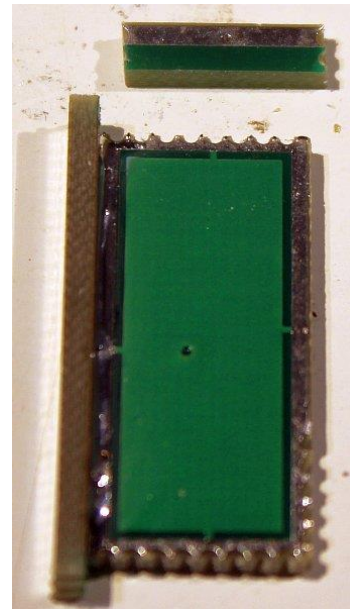
[ ] 33. Solder in part #3
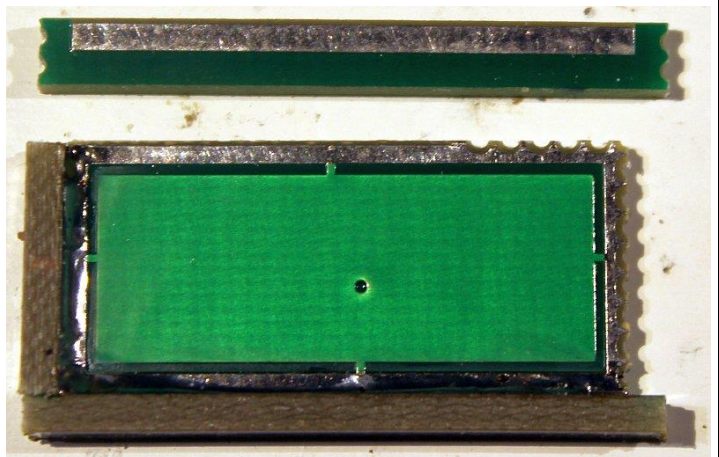
Use blu-tack to hold the parts in place and solder along the seam.
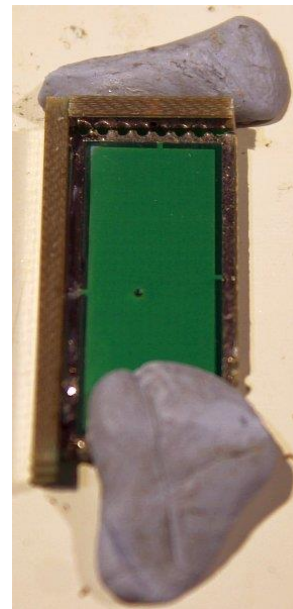
[ ] 34. Add part #2

Now we add part #2.

Once again, the green edge is down, the silvered edge is up.

Use blu-tack to align, and solder the seam as usual.

[ ] 35. Add part #4

The final piece is part #4, it may need a little filing to fit.

Align the silvered edges, use blu-tack to hold in place, and solder along the seam.
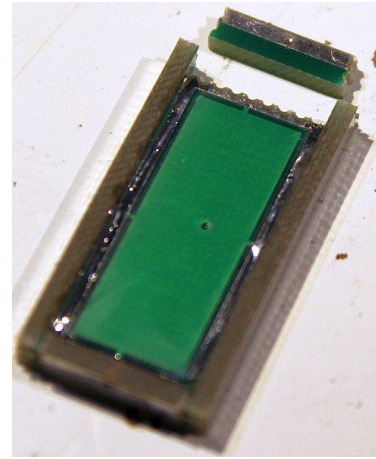
[ ] 36. Completed lower inner oven box

This is a view of the inside of the box. You can see that it is really shallow. You can see that when this is soldered on the lower PCB side, you must have cut the component leads really short, so that they don't touch the box. It was necessary to keep the height so small, because only 3mm are available. This is a constraint of fitting in the sockets of the Ultimate 3S QRSS/WSPR kit, and having the ATmega328 processor sitting in its socket underneath the OCXO/Synth module.

[ ] 37. Completed inner oven boxes

The two boxes (top and lower inner oven boxes) look like this. The outside of the boxes is silvered. You will notice the silvered strip around the bottom of the top inner oven box is separated by 1/2mm from the rest of the metalised box sides. This makes it easy to solder later! If there was no 1/2mm gap, the box side would be a big heat-sink that is very difficult to solder.

The small holes in the boxes are small vias, which connect the ground planes on the inside and outside of the boxes. When completed, all the ground plane surfaces on the insides and outsides of all the boxes, are grounded.
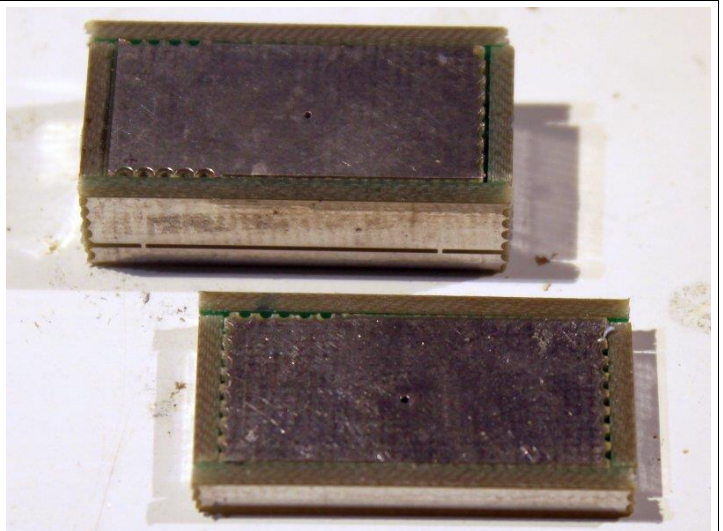
[ ] 38. Checking the seams

We are looking for a complete seal along the box edges, where we soldered along the seam. I like to hold the boxes to the light. You can then easily check for any pinholes of light shining through. That helps to find any gaps in soldering you might have missed.

It's hard to photograph, but this picture is quite a good one.
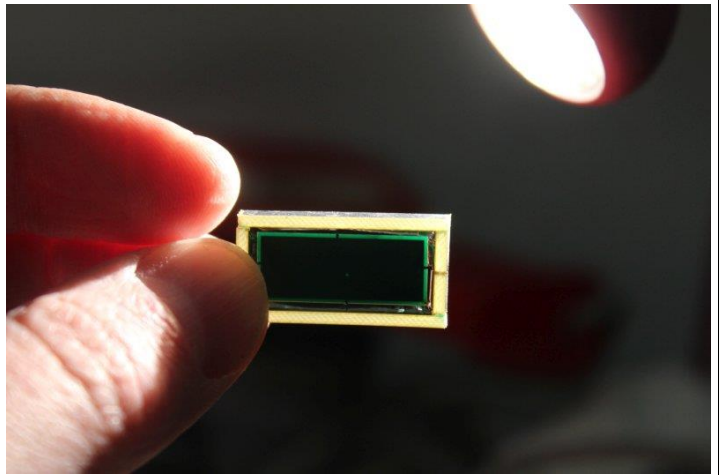
[ ] 39. Outer box construction

The final box to build is the outer box. These are parts #11, #12, #13, #14 and #15 (#15 is the lid).

This photo shows the bottom side of the outer box parts.

Unlike the inner boxes which have a tinned silvered outside, the outer box is green on BOTH sides. However the tinned seams are only on the inside faces of the parts, as shown here.
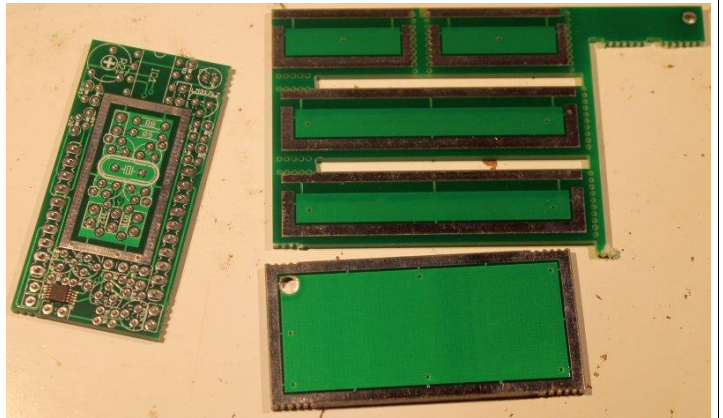
[ ] 40. Break apart parts

Break the pieces apart as shown. As usual, break apart all pieces along the row of drilled holes. Do some light filing to remove any sharp edges. But do NOT file too much.
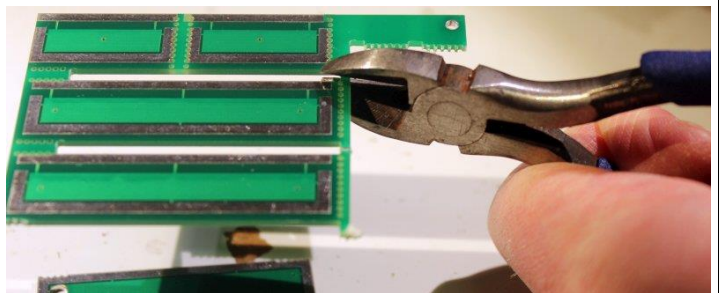
[ ] 41. Join parts #11 and #15

First join part #11 to #15 (the lid). Align them as shown here.

Note the 'U' pattern on the edge of part #11. The bottom of the 'U' will be the seam soldered to the lid (part #15).

Solder blobs at each end of the seams.

U-shaped tinned pattern
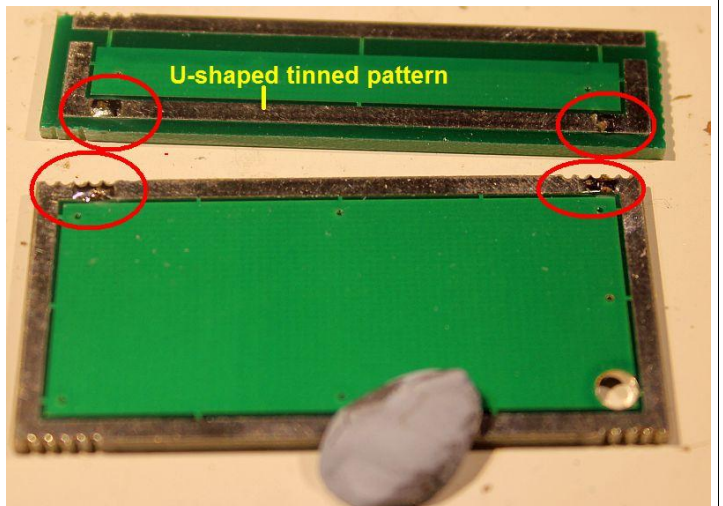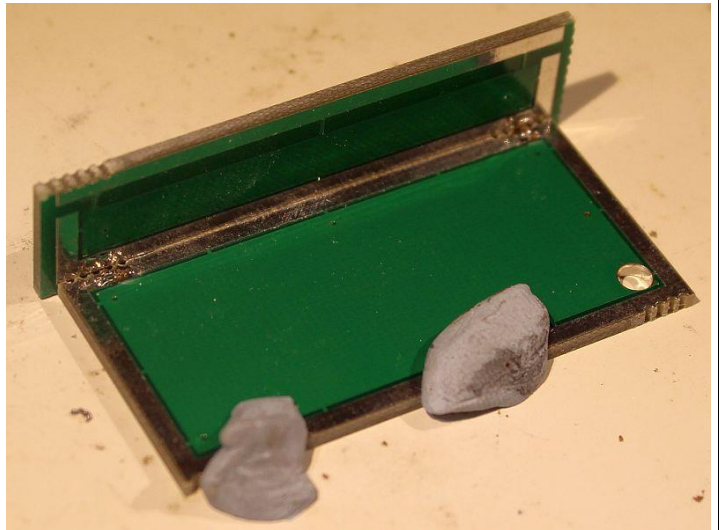
[ ] 42. Align parts #11 and #15

Align the parts with blu-tack stuck to the flat workbench surface.
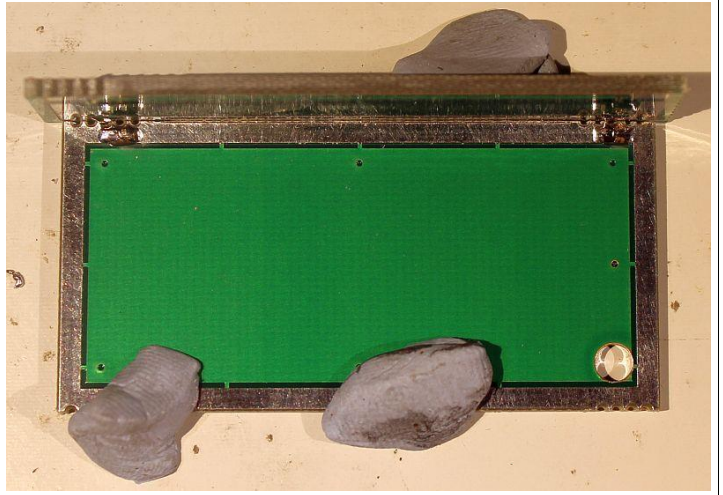
[ ] 43. Solder ends of seams ONLY

When everything is perfectly aligned, solder the end blobs.
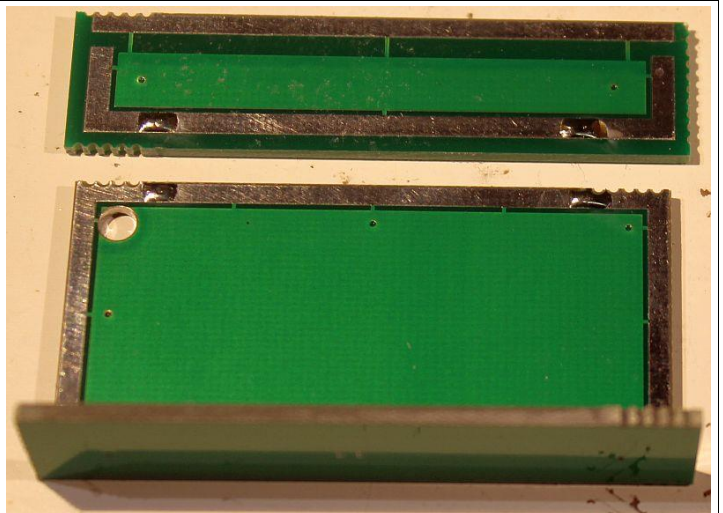
DO NOT SOLDER THE WHOLE SEAM YET!

[ ] 44. Add part #12

Next we will add part #12. Again, the bottom of the U is going to be soldered to the lid (part #15).

Again, put blobs at the seam ends, to make it easy to start the soldering.

DO NOT SOLDER THE WHOLE SEAM YET!

[ ] 45. Note about fitting the PCB!

This is IMPORTANT!

When the outer box is complete, the main PCB with the components on) is going to be soldered in position. It must fit in the gap, as shown in this photo. If the outer box edges are slightly mis-aligned, then the box won't fit.

So it is important to keep checking, that the main PCB does fit!

DO NOT SOLDER THE WHOLE SEAM YET!
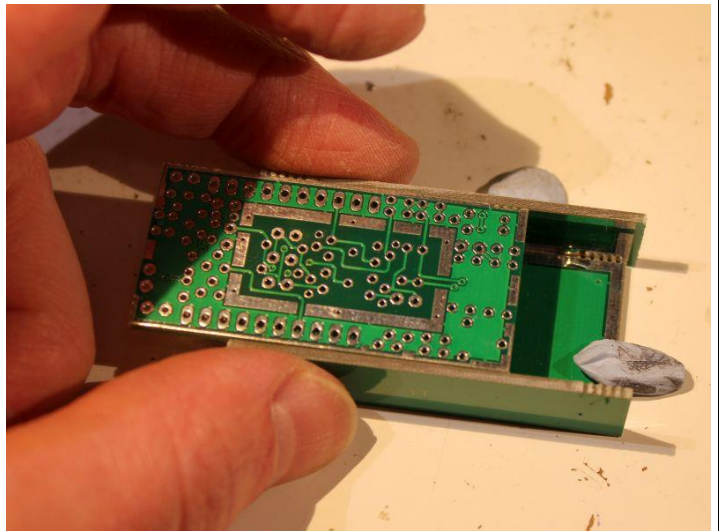
[ ] 46. Check alignment

An easy way to check the alignment is to use the top inner oven box.

Place it on the inside lower face of the outer box, as a spacer. Then you can rest the PCB on top of this lower face. It will be at about the right level where it will finally be soldered.

As you solder the spots and then the seams, the sides somehow close together (reducing the angle below 90-degrees. It will make the PCB not fit. So be careful to keep checking the alignment.

Check check CHECK!
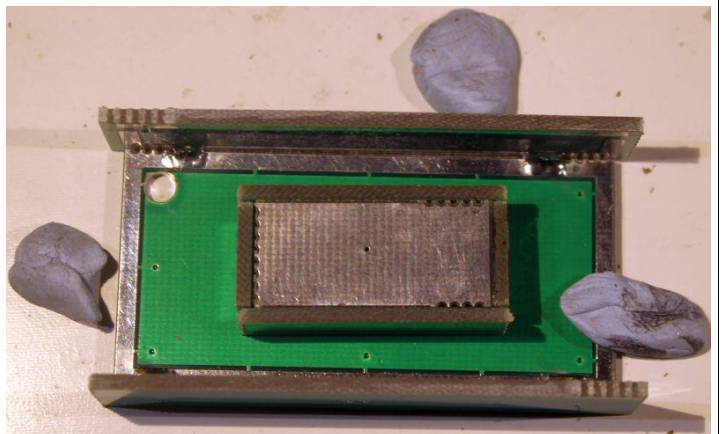
[ ] 47. Add parts #13 and #14

Now we will add parts #13 & #14. Again, note the alignment, and the bottom of the 'U' solder seam. Again use two blobs on each part, and solder ONLY the blobs.

DO NOT SOLDER THE WHOLE SEAM YET!

The reason I keep saying this ("*DO NOT SOLDER THE WHOLE SEAM YET*") is that we have GOT to make sure the main PCB fits in the outer box. If we have only soldered the little blobs, then it is relatively easy to fix any mistakes. If you have soldered the whole seam, it will be very difficult to fix any problems.

25
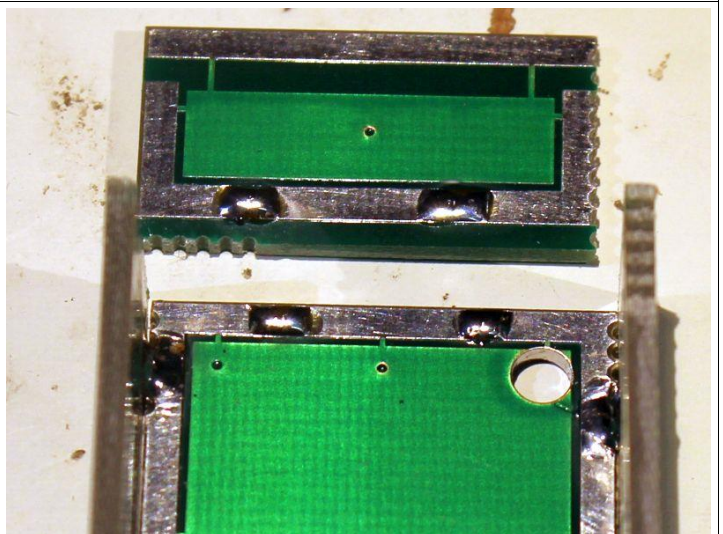
[ ] 48. Check alignment again... and again

Keep checking that the main PCB fits. It should not be too tight. You should be able to remove it easily.

Maybe it is a bit of a tight fit sometimes. Maybe it gets stuck. Mine did. Then you can just poke a small screwdriver (or something) into the temperature adjustment hole, to push out the main PCB.

**Do make sure the Si5351A chip is NOT underneath your screwdriver, when you do that. You don't want to damage the Si5351A chip or its soldering.**

[ ] 49. Solder box seams...

Here's how it should look, with the main PCB resting on top of the top inner oven box as spacer, inside the outer box (**NOT SOLDERED!**). See, it fits!

If the main PCB fit is a bit tight, then a little filing can be done along its edges. Only a LITTLE. It is much better to make sure the soldering of the outer box allows the main PCB to fit properly.

Once you are sure that everything is well aligned, and the PCB fits into the box and can be removed easily – then remove the PCB. **Now solder the seams in the box.** Don't use too much heat or solder. That would cause the board to contract when it cools, and reduce the angle below 90-degrees.

Do NOT solder in the main PCB of course – we have to fit all the components first.
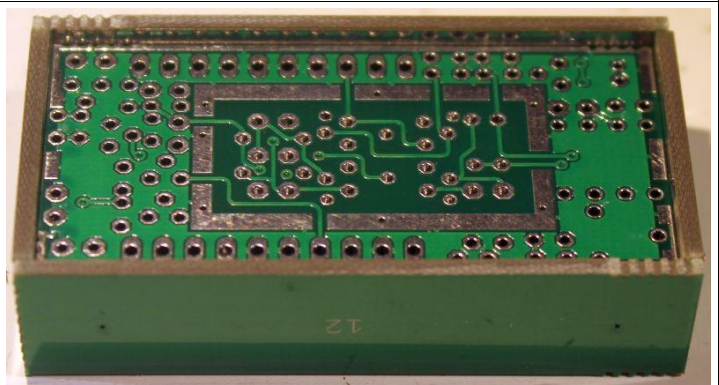
[ ] 50. Admire the three boxes

Finally, here are the three boxes! Outer box (top), top inner oven box (bottom left), and bottom inner oven box (bottom right).
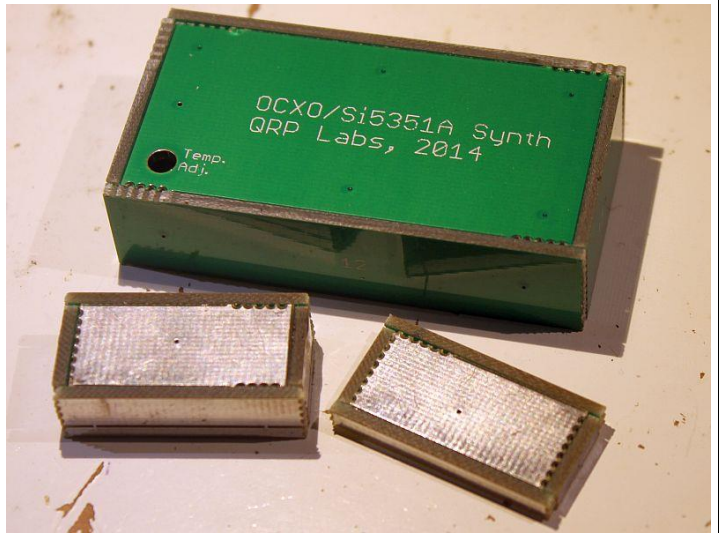

[ ] 51. Start building main board: crystal

Now it's time to build the main board. Starting with the components INSIDE the oven chamber. These components have to fit within a 6mm tall space! So please follow these instructions precisely. **Do not deviate from the instructions!**

First we will start with the 27MHz crystal. Some people like to leave little gaps under crystals but please do NOT be tempted. There is not enough space. There are no bare tracks (or any tracks) on the PCB under the crystal so no danger of any short. Also we want everything to be in close thermal contact. So keep the crystal sitting on the PCB as tightly as possible. I press the PCB down onto the workbench while soldering the crystal wires.

You also need to make sure the crystal is aligned properly. It should fit precisely in the middle of the white silkscreen printing on the PCB. This is so that the heater transistors and other transistors can press against it firmly and evenly. Use only a little solder to solder the crystal wires. Too much solder, will make it hard to cut the wires close to the board.

Cut the wires under the PCB as close to the board as possible. Don't forget, there is only 1.4mm of space on the underside of the PCB, when the lower inner oven box is fitted on.
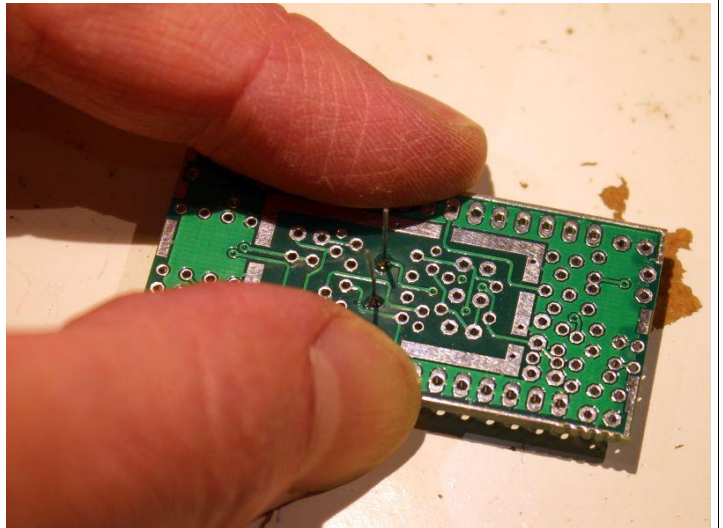
[ ] 52. After soldering crystal

Here's the view of the top of the PCB, after soldering the crystal.
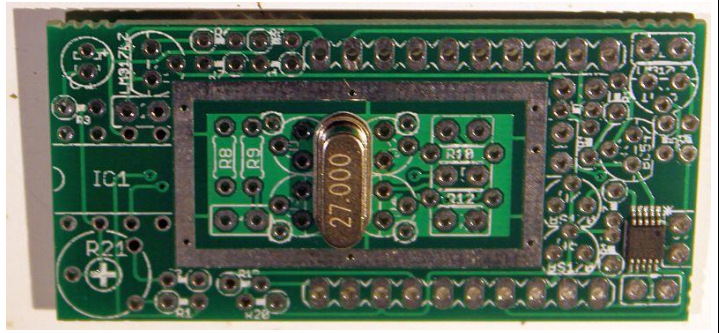
[ ] 53. Install transistor Q1 (BS170)

Now put in Q1 transistor BS170.

Make sure it really **IS** a BS170, not one of the other similar-looking devices (BC547, LM317Z).

The wires of the BS170 must be bent carefully into a triangular configuration.

However as you see here, it won't lie down on the circuit board, in less than 6mm height. We want it to be in UNDER 6mm height, as well as tight contact with the 27MHz crystal.
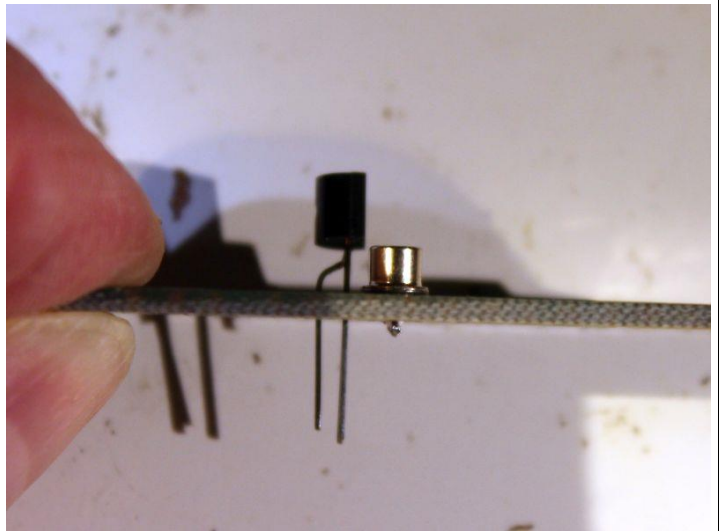
[ ] 54. Press down transistor Q1 (BS170)

So apply some careful pressure to the top of the Q1 transistor, like this. Just squeeze it right down. Press it as far as possible.

Like magic, now it fits in 6mm, and the flat face of the transistor is flat against one side of the crystal! The bottom half of the transistor face is in contact with the crystal. Or at least, close to it.

Don't worry if there seems to be a small gap. Try to ensure the Q1 transistor is standing up straight. Not leaning to the left or right.
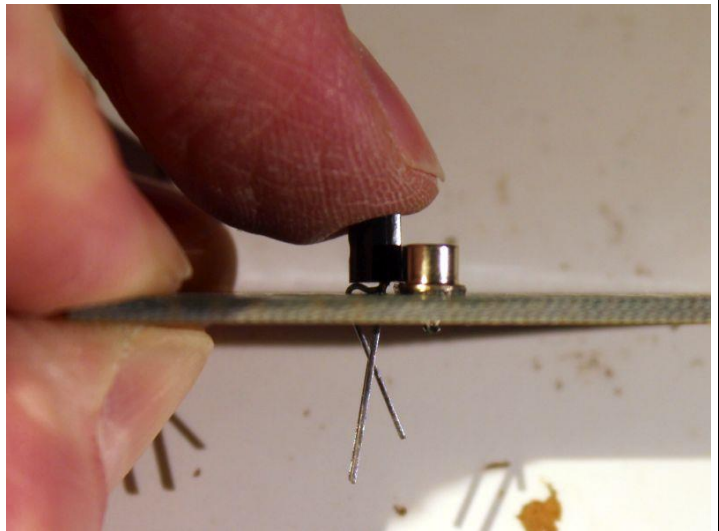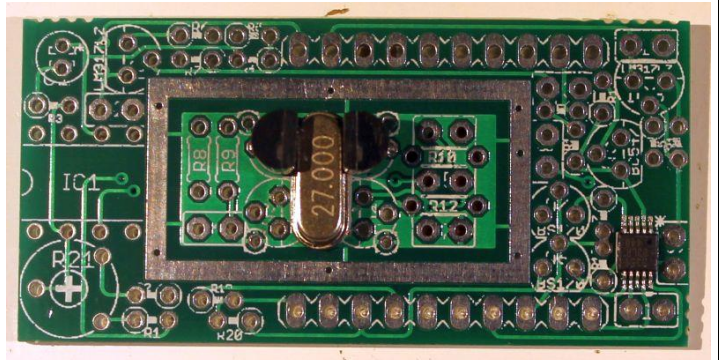

[ ] 55. Fit/solder Q2 (BS170) transistor

Q2, the other BS170, is soldered in the same way.

Clip all the wires under the board as close as possible, and use only a little solder.

When done, this is what it looks like from on top of the PCB.

[ ] 56. PCB side view

This is the side view of the PCB. See how both Q1 and Q2 are close to the crystal, and low on the board.
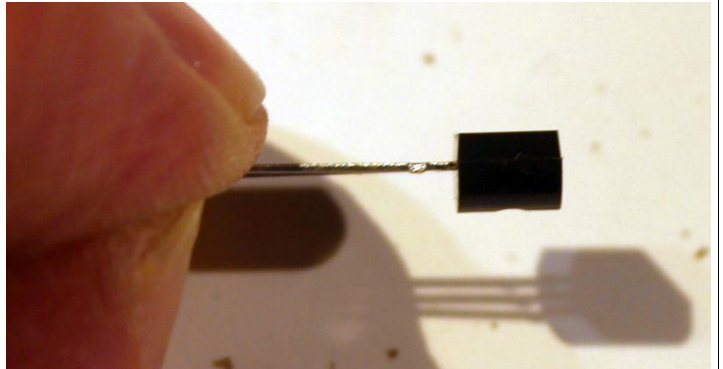
Everything must fit in under 6mm!

[ ] 57. Prepare Q3/Q4 BC547 transistors

Now come Q3 and Q4, two BC547 transistors.

Make sure you select the correct devices. **NOT** the similar-looking BS170 or LM317Z.

As seen in this photo, the wires of the BC547 transistors are all in-line. There is no triangular configuration ready-made.
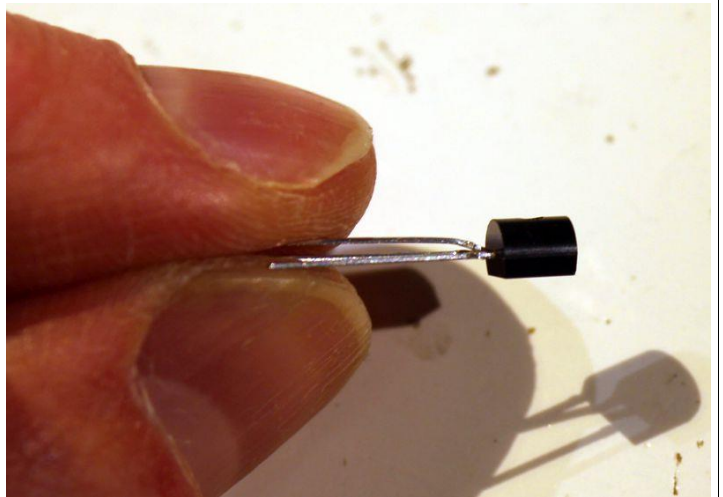
[ ] 58. For creating the triangle...

To create a triangular configuration I use a small screwdriver.

[ ] 59. Bend central wire of transistor

Gently bend the central wire away from the flat of the transistor. Try to bend it right where the wire enters the plastic transistor body.

[ ] 60. Another bent central wire

The other BC547, showing how I bent the centre leg inwards, away from the transistor flat.
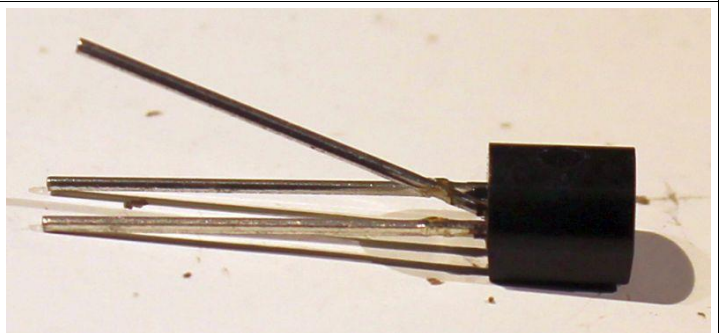
[ ] 61. Push BC547 transistor to board

Now when you push the BC547 transistor into the PCB, again you can use firm (but careful) finger pressure. The centre wire will bend down under the transistor body.
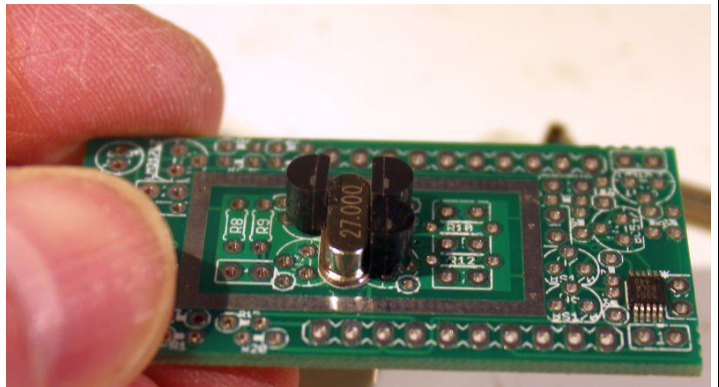
Just like the BS170's, the BC547 transistor will slip magically into the correct position!
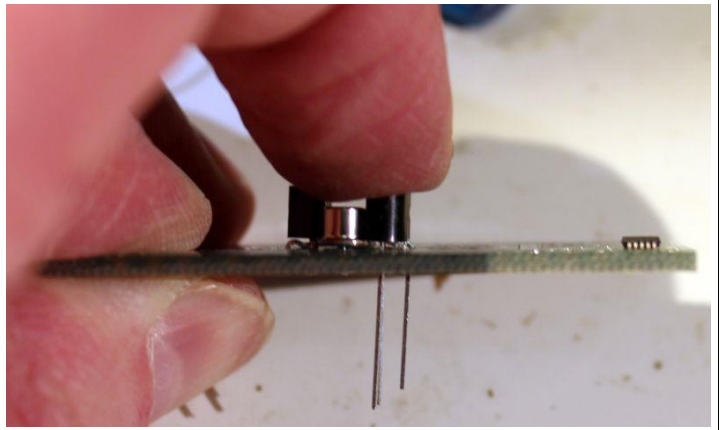
## [ ] 62. Board with Q4 fitted

Here's the board with Q4 fitted.

Notice how the BC547 is tight against the crystal and board, just like the BS170s, Q1 and Q2.

[ ] 63. Install other BC547 (Q3)

Press the BC547 down against the board and solder it, just like the others. Again, clip off the wires under the board very tightly. Use only a little solder, to make this easier.

There is only 1.4mm of height available under the board. All wires must be shorter than this.
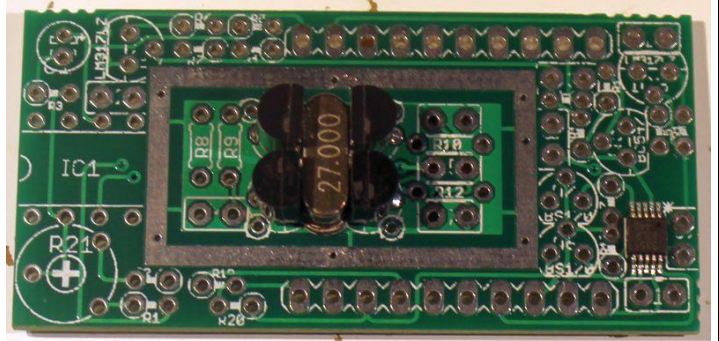

[ ] 64. Install R8, C4, R10, R12, C5, C6, C7

Now install parts R8 (6.8K, blue-grey-red), R9 (1.5M, brown-green-green), and C4 (0.1uF, marking "104"). Cut the wires off under the PCB, very close to the PCB.

KEEP the wires snipped off the resistors, R8 and R9! We will use those wires in the next step.

Also now fit R10 (10K, brown-black-orange), R12 (330-ohm, orange-orange-brown), C5 (56pF, marking "560"), C6 (56pF, marking "560") and C7 (56pF, marking "560").
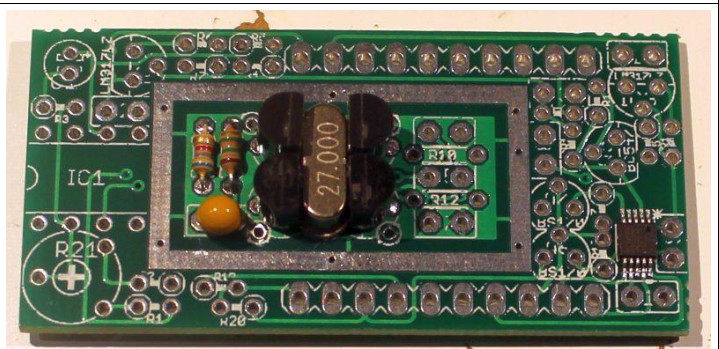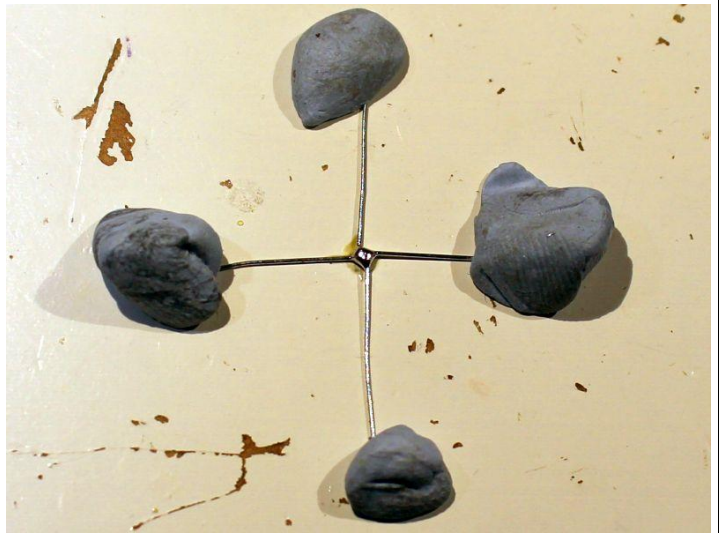
[ ] 65. Build crystal cage

We're going to make a little cage to try to hold the transistors even tighter to the crystal and create good thermal contact.

For this, use the four wires cut off the R8 and R9 resistors just now.

Use the blu-tack to configure them on the workbench in a '+' shape. (Yes, by now, probably the blu-tack is getting a bit dirty). Solder the junction in the middle.

[ ] 66. Build crystal cage, part 2

Bend the wires so that the centre junction is elevated off the workbench.

An alternative method is to put the wires in position on the board as shown in the next step, and solder the centre junction with them in position.


[ ] 67. Fit crystal cage

Insert the 4 wires of the "cage" over the crystal and transistors. There are 4 holes in the corners, as seen here. Press the wires in as tight as possible.

Solder two of the wires, on one side (e.g. next to Q1, Q3). Then try to tightly pull the other two wires tight, using pliers, from the bottom side of the board. Solder them so that the wire "cage" is as tight as possible.

The "cage" should hold the transistors and crystal together, hopefully. Try to make it as tight as possible.
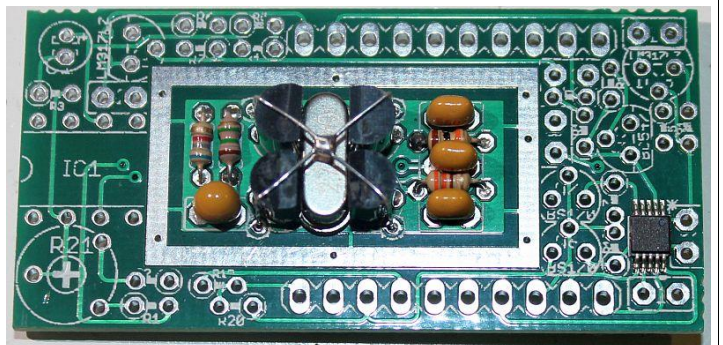
[ ] 68. Fit R11 (330-ohm)

At this stage, I find it encouraging to test that the 27MHz crystal oscillator is working. Before this, fit R11 (330-ohm, orange-orange-brown).

This resistor, in fact ALL the remaining resistors, are mounted standing up on the PCB, not lying down like the resistors so far. The best way to do this, is to bend one wire over. Then insert the resistor, with the body end of the resistor aligned with the white circle on the silkscreen of the PCB. You can also refer to the parts diagram to be clear which end of the resistor that is.
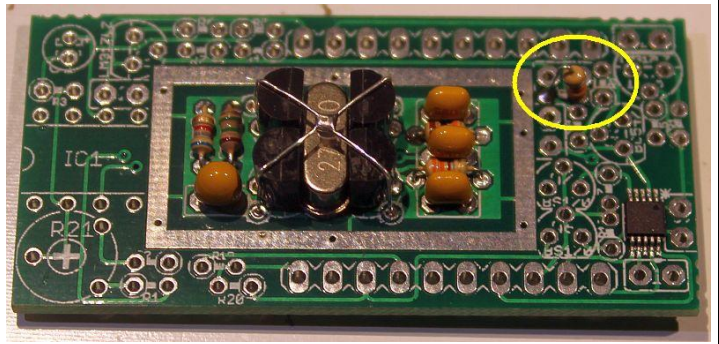
[ ] 69. Check 27MHz crystal oscillator

Now we can test the 27MHz crystal oscillator.

The important point is this: Once you have soldered on the inner boxes to create the oven chamber, it is VERY difficult to open them again. Ideally you hope you will never see inside the oven chamber, ever again. If there are any mistakes, you really want them fixed NOW!

So **check, check, check**. Did you use all the right component values for resistors and capacitors? Did you use the right components for Q1, Q2 (BS170) and Q3, Q4 (BC547)? Count all the remaining transistors too, to make sure you have the right number of each (didn't use any accidentally).

Check all the connections with the magnifying glass, for connection issues and for solder bridges.

Also use a DVM to check for shorts. The tracks leading out of the oven chamber on the bottom side of the PCB, should all measure infinite resistance to ground (or at least, higher than the highest 2M range of my DVM).

To test, I connect a 5V supply. I wire to the Gnd and +5V to the points shown. I did not SOLDER in the wires. Just bend them and push them in the holes. It is good enough to create contact. The Gnd point is pin 1 of the pin-header (BLACK wire on the right). The +5V point is the centre pin of IC2 (LM317Z) at the top left of the PCB. In the final circuit, this voltage will be 3.3V, not 5V. But 5V is fine for testing that the crystal oscillator is working. The oscillator output is presented at pin 2 of the pin-header. In the photo, I have clipped
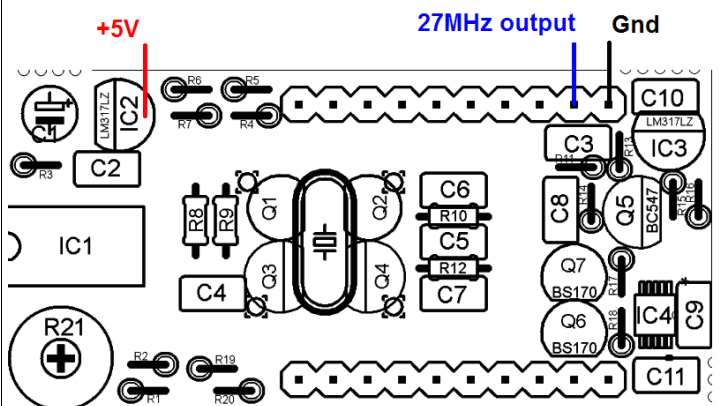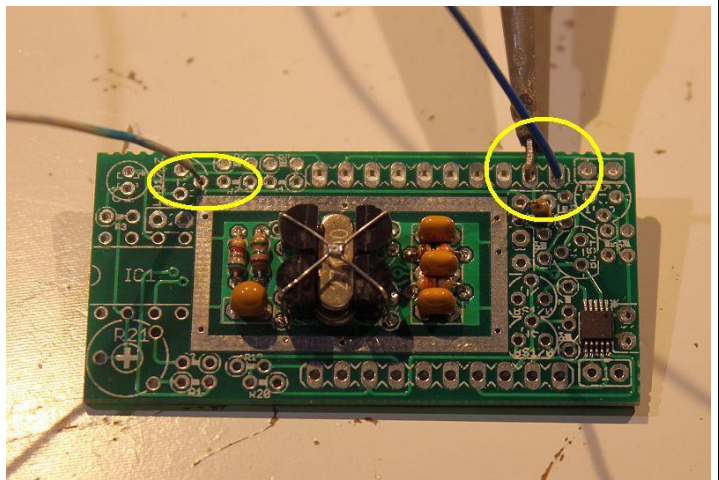
Note: when testing, using the 5V supply, you will need short leads to the power supply, or alternatively, connect a capacitor across the power supply, close to the PCB. This is required to decouple the oscillator (provide a return path to ground). Without this, your oscillator might not work. You could also just fit C3 at this stage (see step 79 below) – fitting it NOW, does no harm and will help ensure the oscillator functions correctly.

on my oscilloscope probe here, to pin 2.

[ ] 70. Testing 27MHz crystal oscillator...

If all is well, when you turn on the power, there will be no smoke or sparks. The oscilloscope screen will show a 27MHz signal like the photo. Or something similar to that. I get 0.6V p-p. The frequency measurement is 26.995MHz which is fine - the frequency measurement on this 'scope isn't particularly accurate anyway.

Typically the actual frequency is about 2kHz lower than 27MHz, e.g. 26,998,000.

If you don't have an oscilloscope, you could try to listen for the 27MHz signal by tuning somewhere around 27MHz on a radio receiver. It is not necessary to attach a wire to the 27MHz output, you should be able to pick it up easily on the radio receiver.

Testing temperature sensor: To perform a basic check of the temperature sensor circuit, you can check that the voltage at the collector of Q3 is somewhere approximately half the supply voltage (2.5V). This can be conveniently measured at IC1 pin 3.
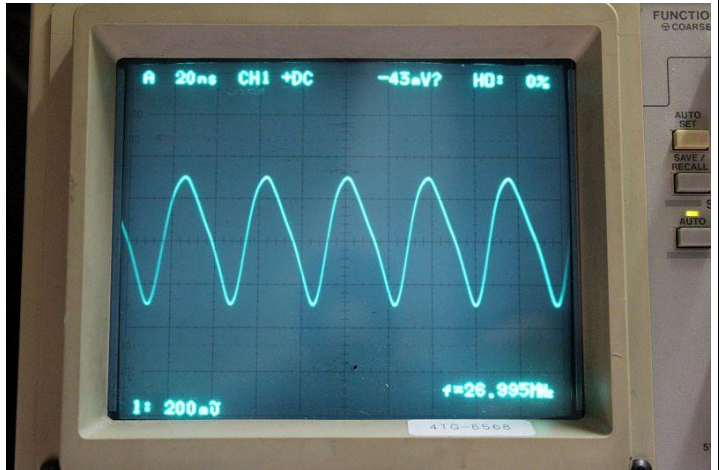
[ ] 71. Fit top inner oven box

Now we fit on the top inner oven box. It may be a tight fit. You may need to press firmly to make it sit tight on the board. Make sure it is fit right in the middle of the rectangular tinned area of the PCB top side. Be as accurate as possible.

Solder the top inner oven box in **only 4 spots**: two at each end of the long edges, as shown.
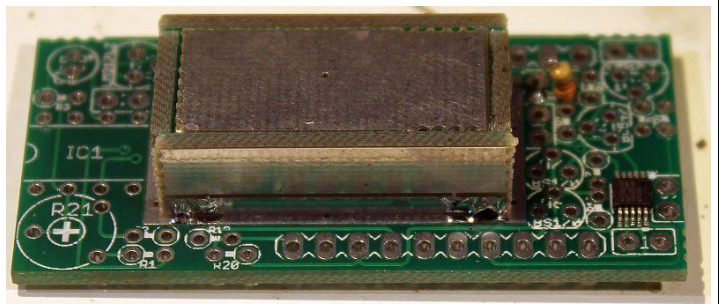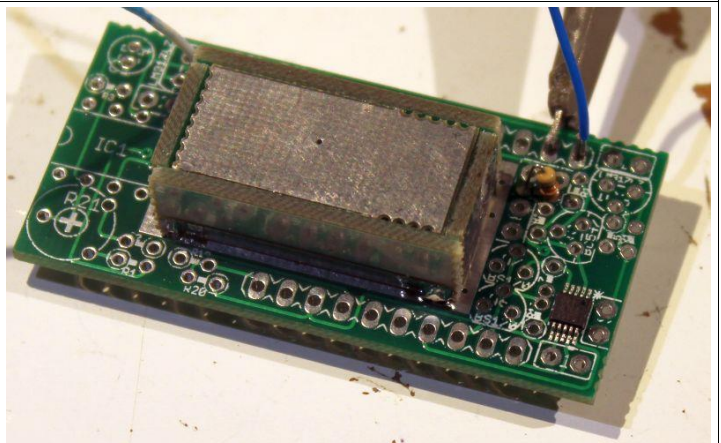
[ ] 72. Test/check again!

Now I like to test again, with 5V and the oscilloscope, to make sure everything STILL works.

Remember: once you've soldered along the seams in the next step, it will be VERY difficult to open the oven lid again!

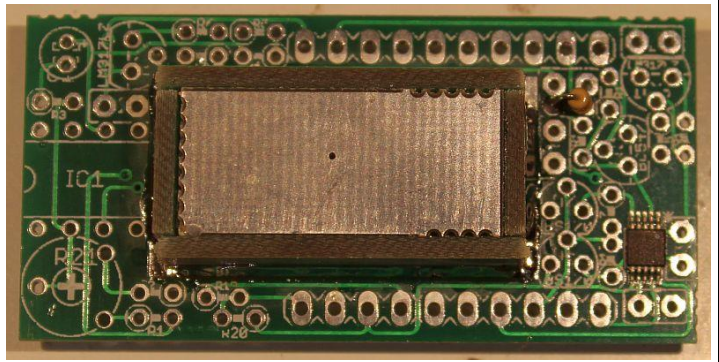Check the temperature sensor too (see above).

[ ] 73. Solder seams

If all is well, you can solder along the whole seams. Aim for a complete seal on the top side, along all the seams.

Test again after that. Let's really hope you still have a 27MHz signal.

Check the temperature sensor too (see above).

[ ] 74. Fit/solder lower inner oven box

Now do the same on the lower inner oven box, on the underside of the PCB. Again, ensure the placement of the lower inner oven box is central in the rectangular tinned area of the main PCB. This one should be initially soldered in 2 spots. Both are in the middle of each of the SHORT sides of the rectangle. Now I like to test again.

Remember that the wires under the PCB must all be less than 1.4mm long, otherwise they will touch the lower lid, and perhaps cause shorts.

If all is well, then you can solder all around the seam of the lower inner oven box, to the underside of the PCB. This time there are gaps in the seam, where the signal traces enter the oven. No problem, no need to solder here.

Finally test the 27MHz and temperature sensor, just one more time, just to be sure. (Or alternatively, test for shorts, there should be open-circuit between all the traces leaving the oven, and Gnd).
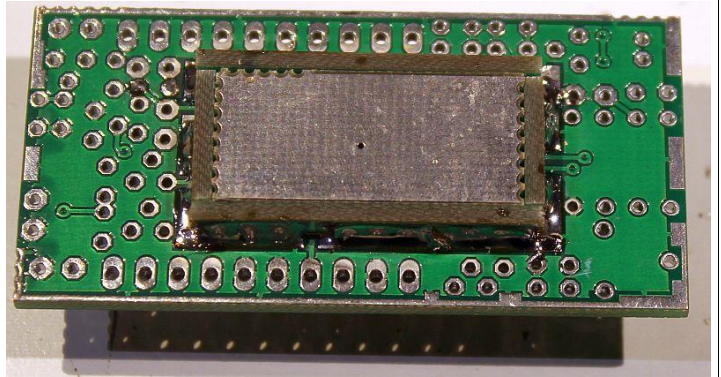
[ ] 75. Fit components around IC1

Solder in IC1 (ICL7612). Be sure to align the dimple on the top of the chip, with the dimple printed on the PCB silkscreen. The pins of the chip will need to be squeezed slightly, as with all new chips, to fit in the holes.

Note that the requirement to cut wires on the board underside is less strict, than the components inside the oven chamber. Still, don't leave them too long. Also, the height available is more. But not much more! Everything must fit inside 8.4mm height! So make sure all the components are inserted into the PCB all the way, seated comfortably on the PCB.
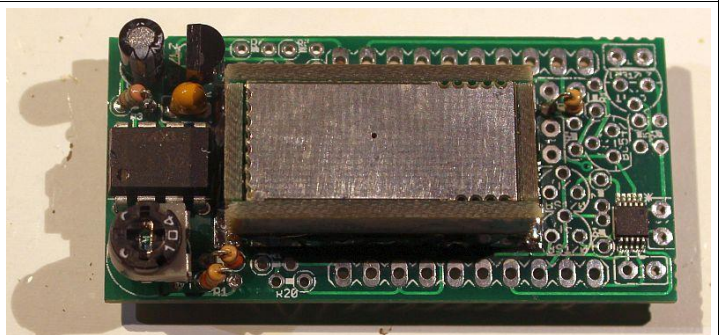
Solder in R3 (1.5M, brown-green-green). Again, R3 is to be mounted vertically. Put the resistor body in the white circled hole, as before. Solder C2 (0.1uF, marking "104"), C1 (22uF electrolytic capacitor), and IC2 (LM317Z). Make sure that C1 is pushed all the way in. C1 is 8mm high, so there is not any headroom (there is only 8.4mm height available inside the outer box, when soldered together). Similarly, for IC2 (LM317Z). It does not have to be pushed right to the board, like the transistors inside the oven chamber. But it still should be pushed reasonably close to the board so that the height is less than 8mm.

Also solder R1 and R2 (both 330K, orange-orange-yellow), and the trimmer potentiometer R21 (100K, marking "104"). Turn R21 fully anti-clockwise.

[ ] 76. Fit components around IC1

Next solder in R19 and R20 (both 1K, brown-black-red).
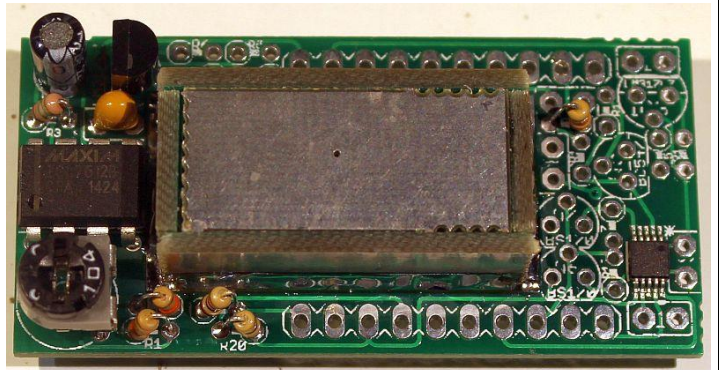
[ ] 77. Fit R4, R5, R7, R6

At the other edge of the board, solder in R4 (10K, brown-black-orange), R5 (56K, green-blue-orange), R7 (560-ohm, green-blue-brown) and R6 (1K, brown-black-red).

Be very careful when soldering these, not to create solder bridges. The pads are close together, and they are very close to the tinned edge strip around the underside of the PCB (see following photo).
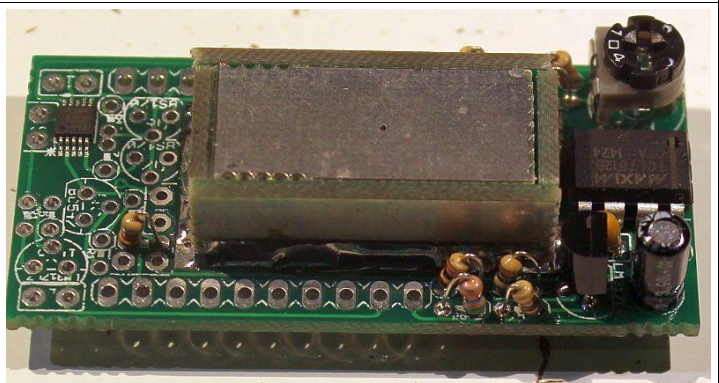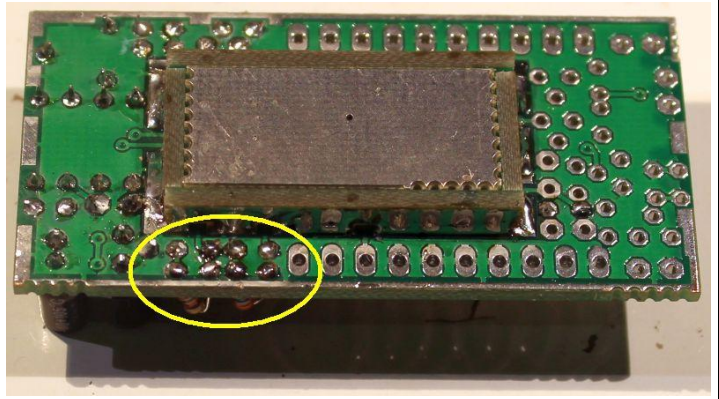

(Board is turned around 180 degrees compared to previous photo)

[ ] 78. Avoid solder bridges...

Here's a photo showing the underside of the PCB so far, and the area near the edge strip I'm talking about.
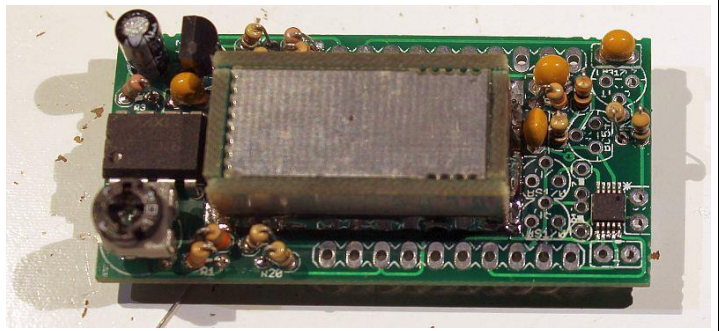
Avoid any solder bridges from those resistor wires soldered in the previous step!

[ ] 79. Fit R13, R14, R15, R16, C3, C8, C10

Fit and solder R13 (10K, brown-black-orange), R14 (1K, brown-black-red), R15 (1K, brown-black-red) and R16 (560-ohm, green-blue-brown).

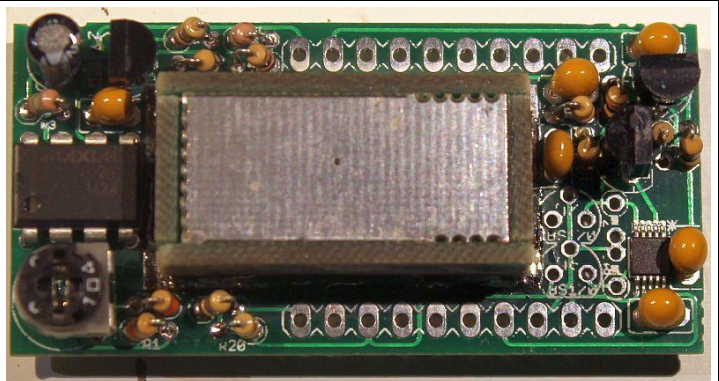Fit and solder C3 (0.1uF, "104"), C8 (56pF, "560") and C10 (0.1uF, "104").

[ ] 80. Fit IC3, Q5, C9, C11

Fit and solder IC3 (LM317Z) and Q5 (BC547). Be careful not to mix them up with each other, and the BS170!

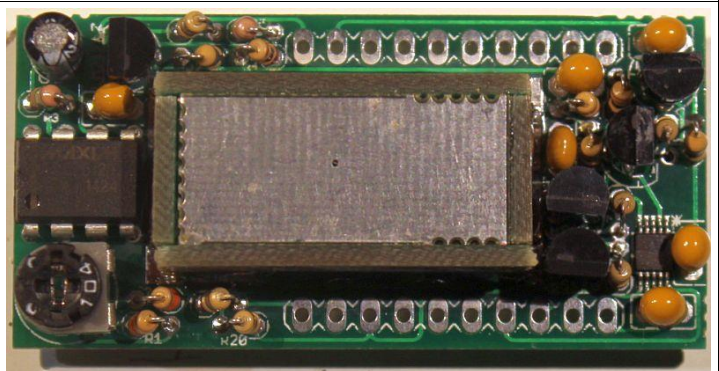Fit and solder C9 and C11 (both 0.1uF, "104").

Check for shorts on the bottom of the board! Everything is quite close together!

[ ] 81. Fit R17, R18, Q6, Q7

Fit and solder R17 and R18 (both 1K, brown-black-red).

Fit and solder Q6 and Q7 (both BS170 transistors).

[ ] 82. Prepare 10-pin headers

For those of you intending to use this module with a Ultimate3 QRSS/WSPR kit [Ref 1], you must remove pin 12 from the pin header, as indicated in the diagram above, and also in the photograph on the previous page.

This is because this pin is grounded on the module, but on the U3 the connection was used for one of the data control signals to the AD9850 DDS module, and is also shared with an LCD data pin. Grounding this connection would prevent anything being displayed on the U3 LCD, so the pin must be removed from the pin header, before installation.

The pin is easy to pull out with plyers or a wire-cutter (see photograph, right).

If in doubt: remove pin 12. It is only a ground connection anyway.

The pin does not need to be removed for use in the U3S kit or other applications.
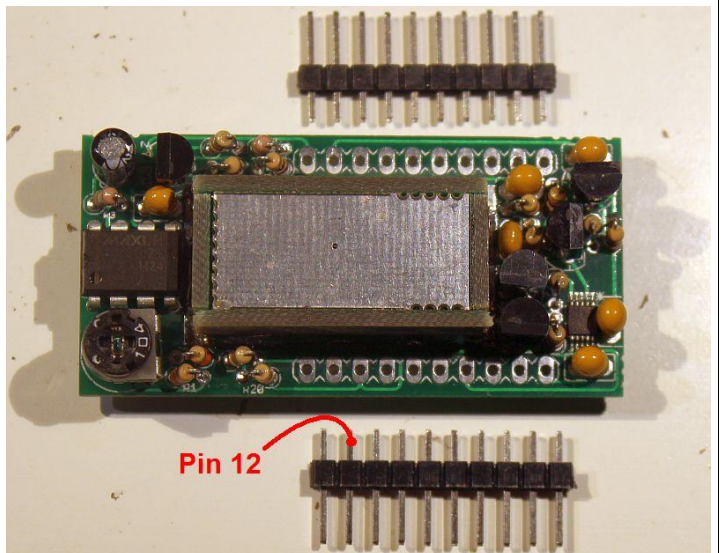

[ ] 83. Fit 10-pin headers

Here's another photograph showing where the 10-pin headers are fitted.

They are pushed in from the underside of the board.
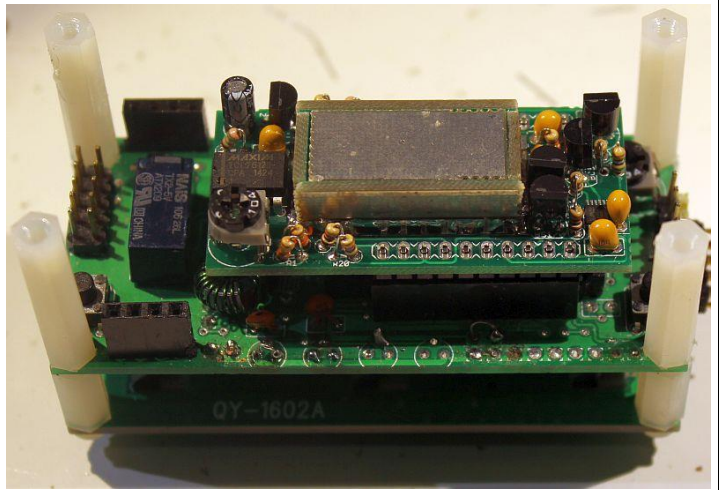
Read the following few steps before soldering!

[ ] 84. Solder 10-pin headers

The easiest way to ensure the correct alignment, is to insert the 10-way header strips in the U3 or U3S kit. Or, a breadboard, or wherever you intend to use the OCXO/Synth module.

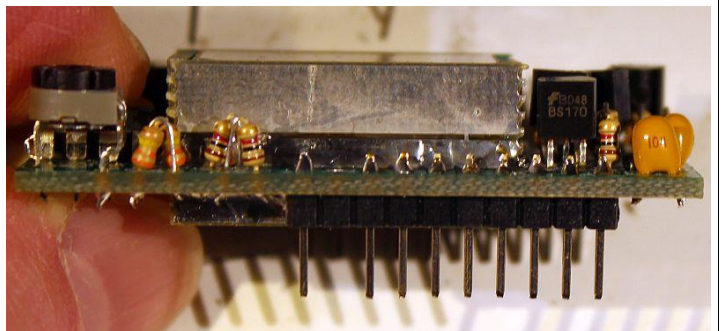The sockets will hold the headers exactly where you want them.

Solder quickly, to avoid melting any plastic!
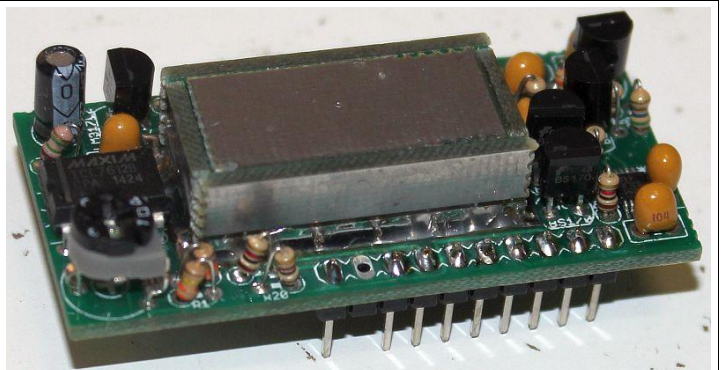
[ ] 85. After fitting 10-pin headers

This is what it should look like, from the side.

Note the pin 12 that has been removed, because I intended to be able to use this module in a U3 kit.
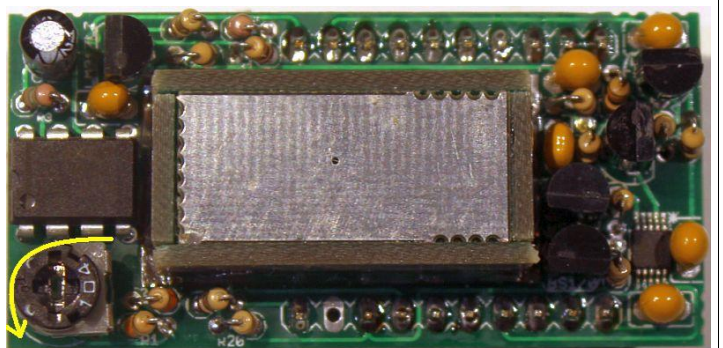
[ ] 86. Another view...

Here it is again from a different angle.

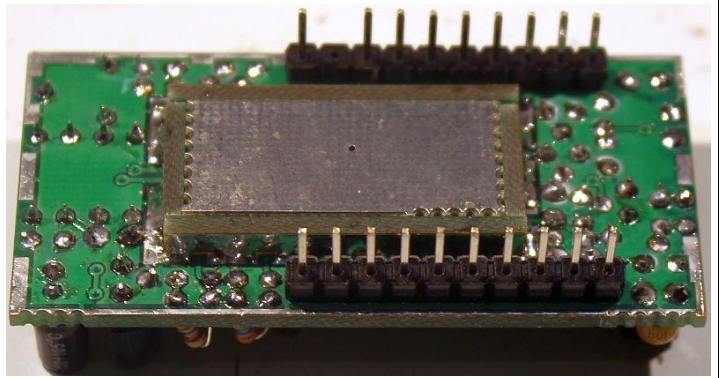## [ ] 87. Ensure R21 is turned anti-clockwise

Please ensure R21 is turned fully anti-clockwise!

This trimmer potentiometer sets the oven temperature. If it is wrongly set, at too high temperature, it can burn out the BS170 heater transistors.

[ ] 88. Photo of the bottom

Here's how the completed PCB looks from underneath.

[ ] 89. TEST EVERYTHING!

At this point you really MUST test everything before soldering on the outer box.

Here's the OCXO/Synth module being tested in a Ultimate 3S QRSS/WSPR transmitter kit.

Only proceed to the next steps when you have verified that the synthesiser is working properly.

On applying 5V power to the board, you should find a voltage of approximately 3.3V (up to 3.5V) at pin 18 of the module (refer to diagram on page 6). No output frequencies are generated until you have programmed the Si5351A configuration registers via the I2C interface.

The U3/U3S kits (firmware v3.07 and above) handle the I2C programming. Simply set up the U3 kit for transmitting on a mode and frequency of your choice and verify that you get approximately the expected output frequency. It may be a few kHz off (probably about 2kHz low) until the 27MHz reference frequency has been calibrated; do not worry about this now.

You should also check the operation of the oven at this time.

NOTE for installation in the U3/U3S:

when you have the L1 toroid in the U3/U3S installed in the vertical position, it may be too close to the bottom layer of the OCXO/Si5351A Synth PCB. I recommend changing the L1 orientation on the U3/U3S to be horizontal.
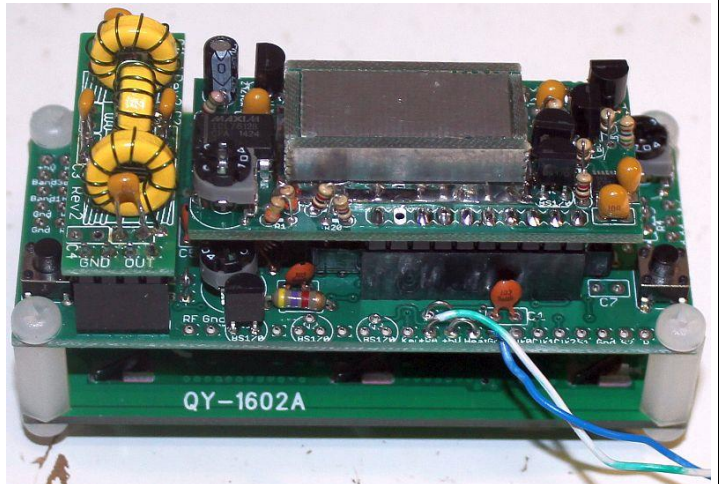
[ ] 90. Find a 0.40mm piece of card

It is important to use some thermally insulating material, to slow down heat getting out of the oven.

So we need a spacer. It will sit on top of the inner oven box. The internal height of the outer box should be 8mm, and the internal height of the inner box is 6mm. The thickness of the FR4 PCB is 1.6mm. Therefore there should be a 0.4mm gap between top of the inner oven box, and the inside surface of the outer box.

Here I am measuring a business card, it is 0.31mm and would be fine, stuck on the inner oven top.


[ ] 91. Or use self-adhesive labels...

Another alternative, is self-adhesive labels. I measure the thickness of one to be 0.08mm.

It does not have to be precisely 0.40mm. If you don't have a micrometer, don't worry either. Just guess. It really isn't very critical.
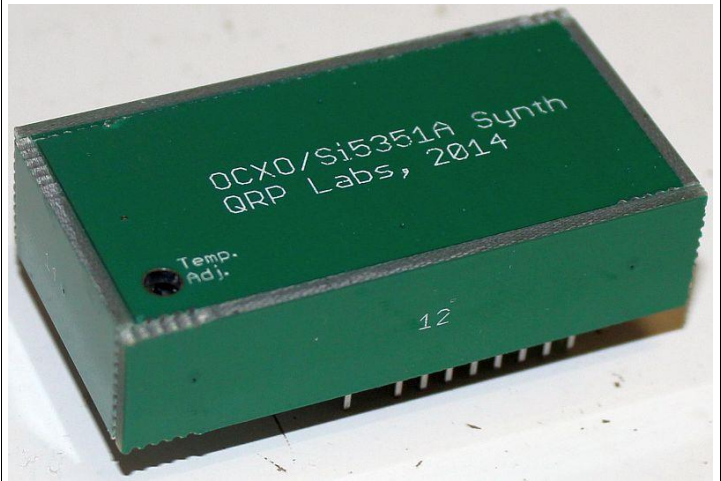

[ ] 92. Stick spacer on top of inner oven

I used the sticky labels. Since each measured 0.08mm thick, I cut out 5 rectangles and stuck them all on.
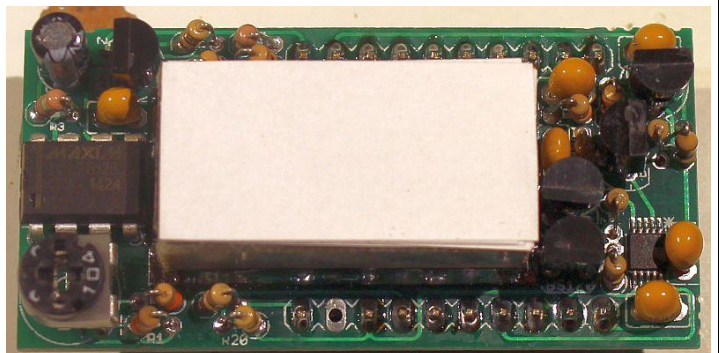
[ ] 93. Put on outer box (module lid)

Now the PCB assembly can be placed in the outer box.

[ ] 94. Underside view

Here's how it should look from the underside. Notice how the PCB assembly sits a couple of mm below the box edge. The solder-tinned PCB seams on the PCB and the outer box line up. We will solder along this seam, to fix the PCB assembly in the outer box.
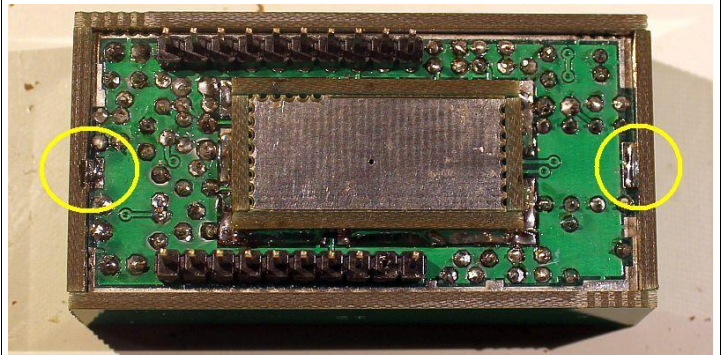
However, nothing is soldered yet.
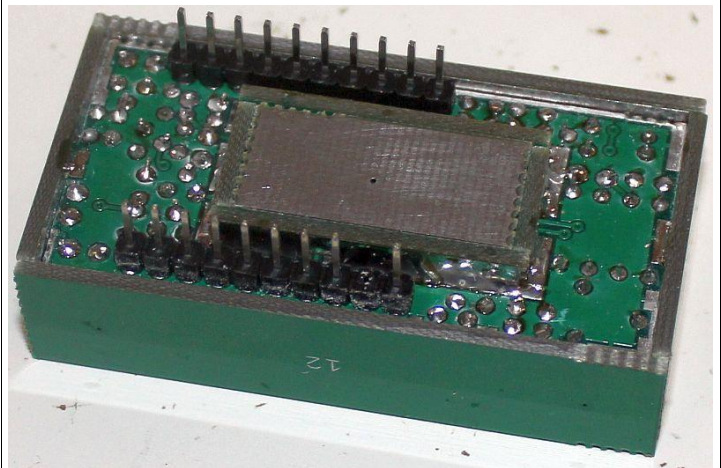
[ ] 95. Solder two blobs, at each end

Solder just two blobs, one at either end.

Now TEST again. Make sure the SI5351A module still works!

If anything needs to be opened for checking, it is much easier to open two blobs, than many!


[ ] 96. Solder remaining places around seam

The tinned exposed seam of the outer box, and the PCB, go ALL the way around the edge of the board. But you will not be able to solder the whole seam. For example, you cannot solder between the plastic of the 10-way pin headers, and the outer box.

So, solder where you can safely solder without creating bridges to components.

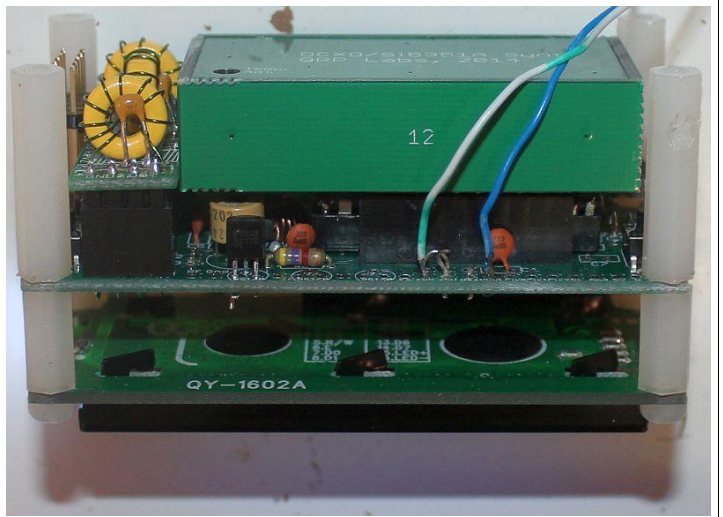These yellow circles show where I soldered the seam on my prototype.
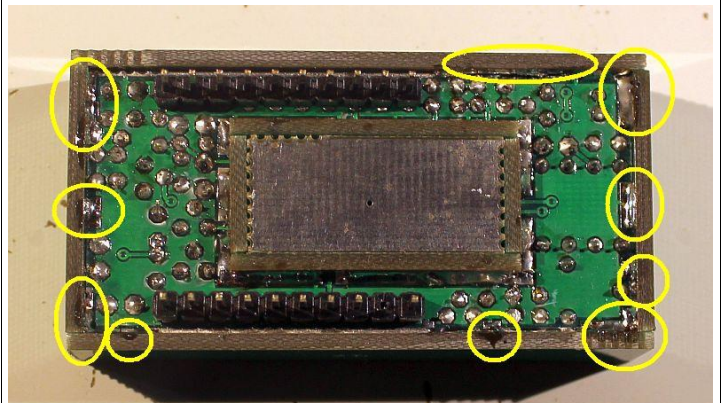
|	
[ ] 97. OCXO/Si5351A in U3S This is a photograph of the OCXO/Si5351A module plugged in to my U3S kit. The module is a tight fit, touching the low pass filter module at the left of the photo. It DOES fit, however. **IMPORTANT NOTE**: in the U3S kit, the power amplifier FT37-43 toroid (L1) can be mounted vertically or horizontally. When the OCXO/Si5351A module is used, toroid L1 should be mounted HORIZONTALLY. If you mounted your toroid vertically, please change it now.	
[ ] 98. OCXO/Si5351A in U3S again Here's the view from above. Note the hole to access the temperature adjustment trimmer. Initially, ensure the temperature adjustment trimmer is turned fully anti-clockwise.	
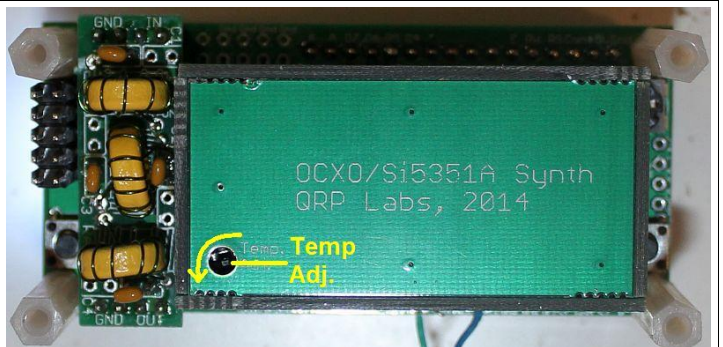
Adjustment

The adjustment of the OCXO consists of setting the optimum temperature, using the Temp Adj trimmer R21. When in the fully anti-clockwise position, the oven is off. As you turn the trimmer clockwise, the oven temperature will increase.

Note: if you use a metal screwdriver to adjust the trimmer, each time the body of the screwdriver makes an electrical connection between the trimmer's metal parts and the metal of the box cover, a short occurs that will pump high current into the heater transistors. It will cause a jump in frequency. This situation should be avoided if possible by using a non-metallic screwdriver or putting some tape around the screwdriver shaft.

DO NOT put the trimmer at the fully clockwise position, it will probably burn the BS170 heater transistors. As I mentioned already: opening up the OCXO for any reason, including to replace burnt components, is very difficult!

Final fine adjustment needs to be made when the OCXO is completely constructed (case put on etc) and using actual power supply arrangement (voltage regulators) you will use.

What we are looking for, is the temperature where the output frequency is MINIMUM.

Configure the OCXO/Si5351A to output a frequency which you can receive on your radio receiver, for example. I use the 30m band for this. You can for example, put the OCXO/Si5351A synthesiser module into a U3 or U3S kit for this, and configure the kit to produce RF Output. A suitable mode would be FSKCW, with FSK 0 and Frame 0. This will just transmit continuously.

Use the Argo software to accurately monitor the output of the synthesiser, by analysing the audio from the receiver. Argo has a "peak" frequency measurement with a resolution of 0.01Hz. It is very useful for the adjustment of this OCXO.

The optimum temperature for the oven is the flat part of the crystal's frequency to temperature curve (see for example, the measurement of one of these crystals, in the following section). The crystal is an inexpensive AT-cut crystal. They typically have their curve flat at about 45C.

To make the adjustment, keep increasing the temperature adjustment a tiny fraction at a time, by turning the R21 trimmer potentiometer very slightly clockwise. A "tiny fraction": I really mean a tiny adjustment, it is very sensitive. You may find the frequency jump suddenly when the adjustment is made.

Wait at least 10-15 minutes for the oven temperature to stabilise at the new temperature. Then observe the new frequency. At some point, the frequency will start to increase again. Then you can back off the temperature a bit, and it should now be sitting nicely at the minimum point.

It's also a good idea to measure the heater current.

The chart to the right shows how the audio frequency output of my receiver changed as I increased the heater current (and hence temperature). In this case the Synth output was set for a little over 10MHz to generate the audio around 1kHz.
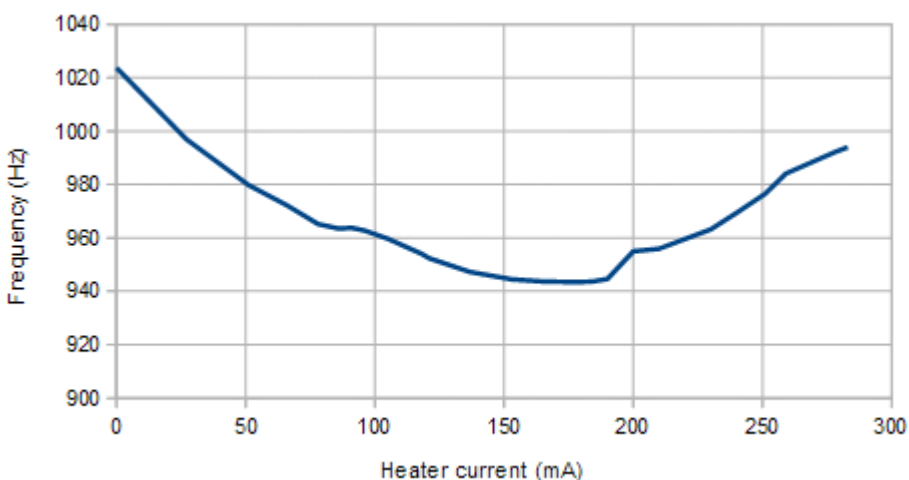
If when you adjust the trimmer potentiometer, the frequency moves in a direction you do NOT expect – for example, if you start from the fully anti-clockwise position and the adjustment to increase heater current makes the frequency increase, rather than decrease – then check that you are listening to the correct sideband. The 27MHz OCXO will typically oscillate at 26,998,000 (approx 2kHz low). So the output frequency will also tend to be proportionately lower than expected.

It is expected that in the final application (such as the Ultimate 3S QRSS/WSPR transmitter kit) the software will allow the register calculation to use the actual oscillation frequency, not the theoretical 27,000,000. This is referred to in the U3S as calibration.

Current also depends on the ambient temperature. The current is proportional to the difference between oven temperature and ambient temperature.

Be careful not to exceed 300mA. Preferably don't even get close to it. The maximum rating of the BS170 transistors is 166mA each (333mA total for two), but you would ideally not get close to that.

Troubleshooting

Please direct queries to the QRP Labs Yahoo group forum:
https://groups.yahoo.com/neo/groups/QRPLabs

Typical performance measurements

The following performance measurements were made on a prototype. Your results may differ from these, perhaps significantly in some aspects. The charts are intended to give an idea of what to expect from the behaviour and performance of the OCXO/Si5351A synthesiser module.

Crystal characteristic

The chart shows the measured frequency shift of the common inexpensive 27MHz AT-cut crystal used, over -6 to +62C temperature range. This crystal is not an expensive type designed for ovens etc.

The curve shows the typical flat point around 45C, which is where we aim to put the oven temperature.


Crystal characteristic, ppm vs temp
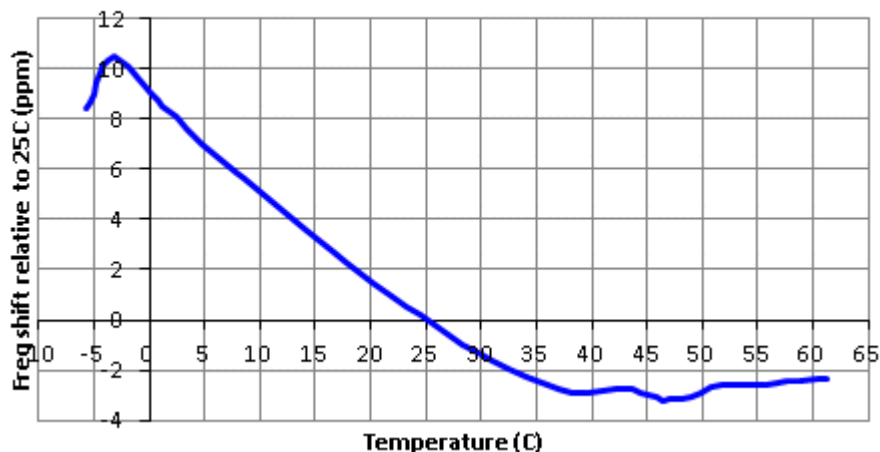
Heater power vs Temperature

The heater current (left axis) or power (right axis) measurement vs ambient temperature, over the range -8 to +33C.

The computed straight-line best fit equation allows us to extrapolate and determine the 0 power point, which should be the operating temperature of the oven. Here it was just under 45C, which is a well-adjusted oven.
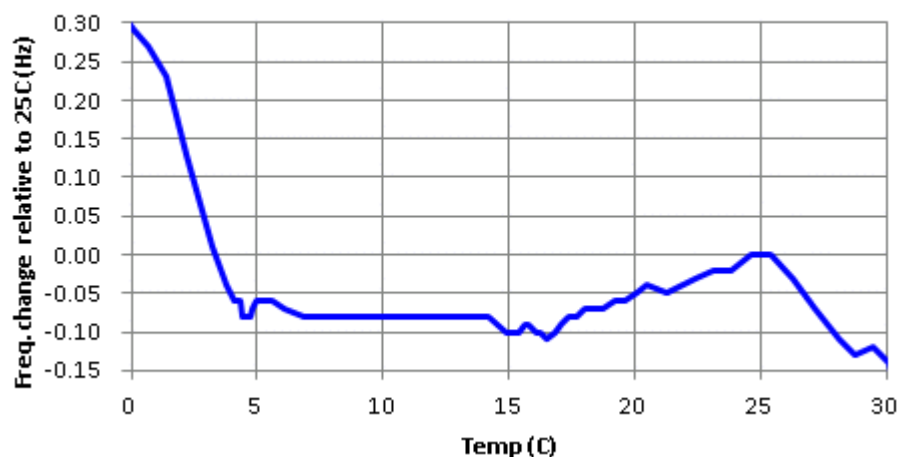

Heater power vs Temp

$y = -0.0192x + 0.8594$
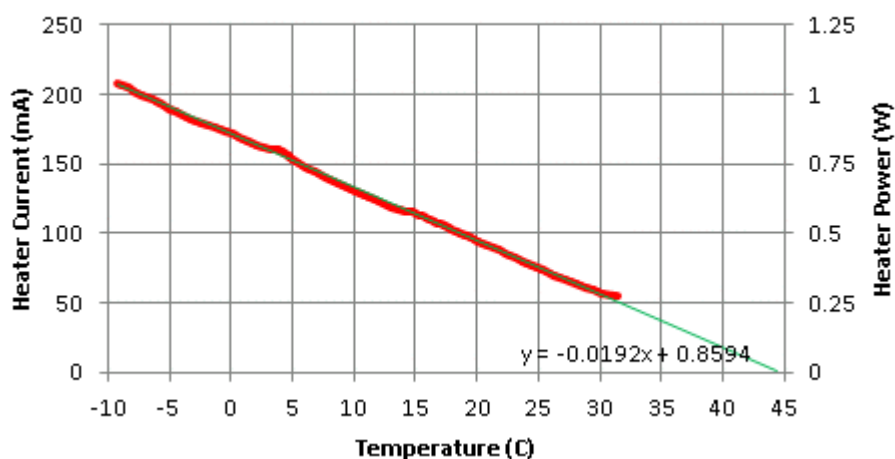
OCXO/Synth output vs Temp

The synth output, when set to 10MHz, over the temperature range 0 to 30C.

Between 3 and 28C, the frequency variation is about 0.1Hz, which is 10 parts-per-billion (ppb).


10MHz out, shift vs Temp

44

Switch-on current

The chart shows typically what happens at switch-on. The heater current rapidly rises, reaching a peak before falling back to a steady stable state.

At the same time the frequency (measured at 10MHz synth output frequency) drops rapidly to start with, over-shoots, and returns to its stable value.

Typically most of the stabilisation has occurred within 10 minutes.
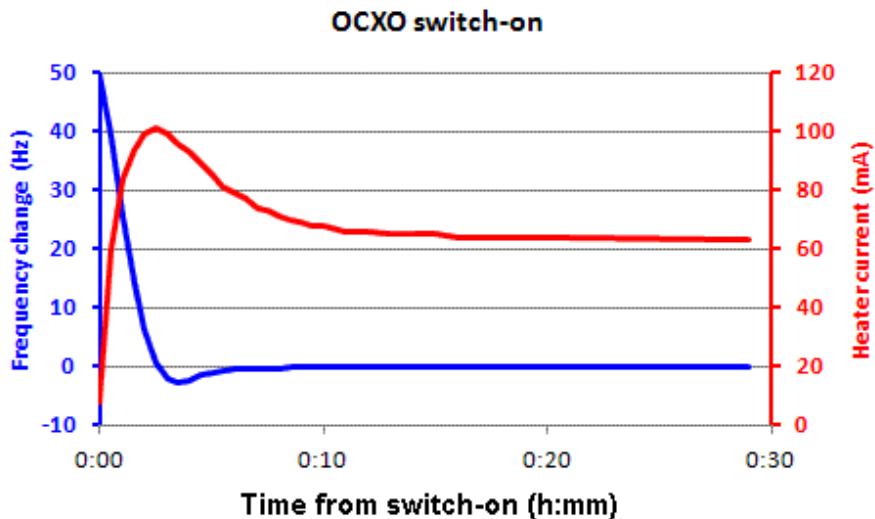
Si5351A output waveform

The Si5351A synthesiser output waveform is a 50% duty cycle squarewave, 3.3V peak-peak.

The frequency here was set to 10.140050 (in the standard QRSS sub-band of the amateur radio 30m band).

Here an X10 probe is used so the 100mV/div indication really means 1V/div.

The "ringing" is an effect of the oscilloscope and probes, and can be ignored.
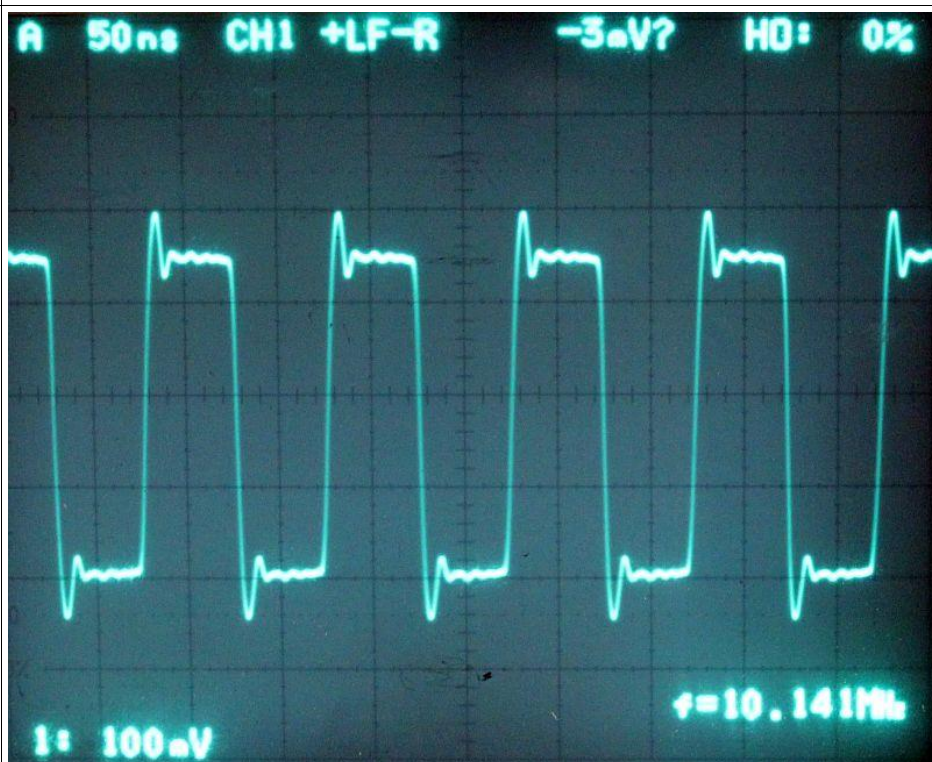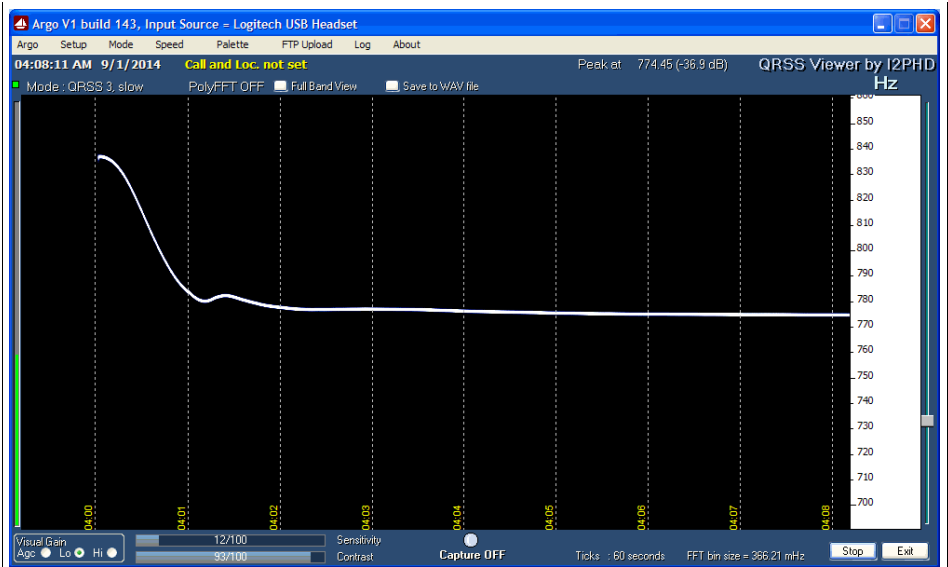
Frequency at switch-on

The OCXO/Si5351A synthesiser is used in a U3 kit, set up to beat against a commercial 10MHz OCXO and produce an audible beat note, viewed in Argo via a laptop sound card.

Vertical lines represent 1 minute of time from switch-on.

After 8 minutes the frequency is within 1Hz (0.1 parts-per-million).

On/off keying stability test

The OCXO/Si5351A synthesiser module again used in a U3 transmitter kit. It is set up on the 30m (10MHz) band and transmitting into a dummy load.

It is keyed on for 2 minutes, keyed off for 2 minutes. This is a harsh test for the OCXO Synth.
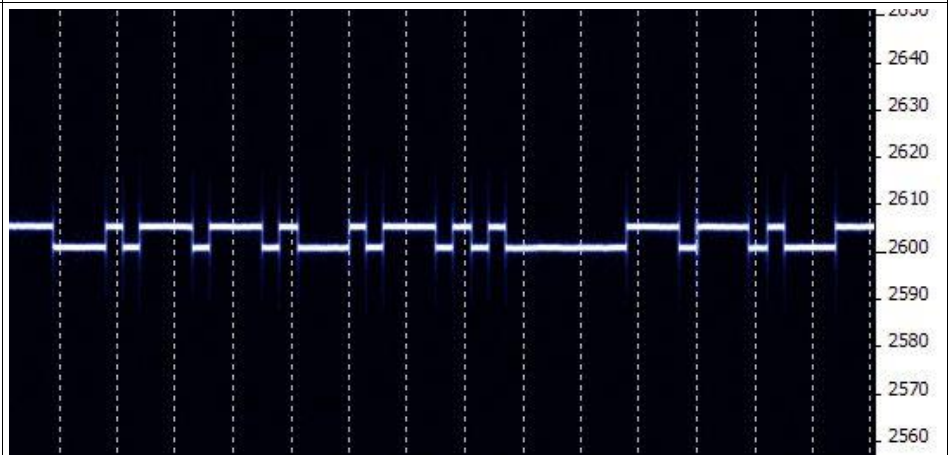
Frequency variation in 2 minutes is so small it cannot be measured in Argo's 0.01Hz resolution of frequency measurement.
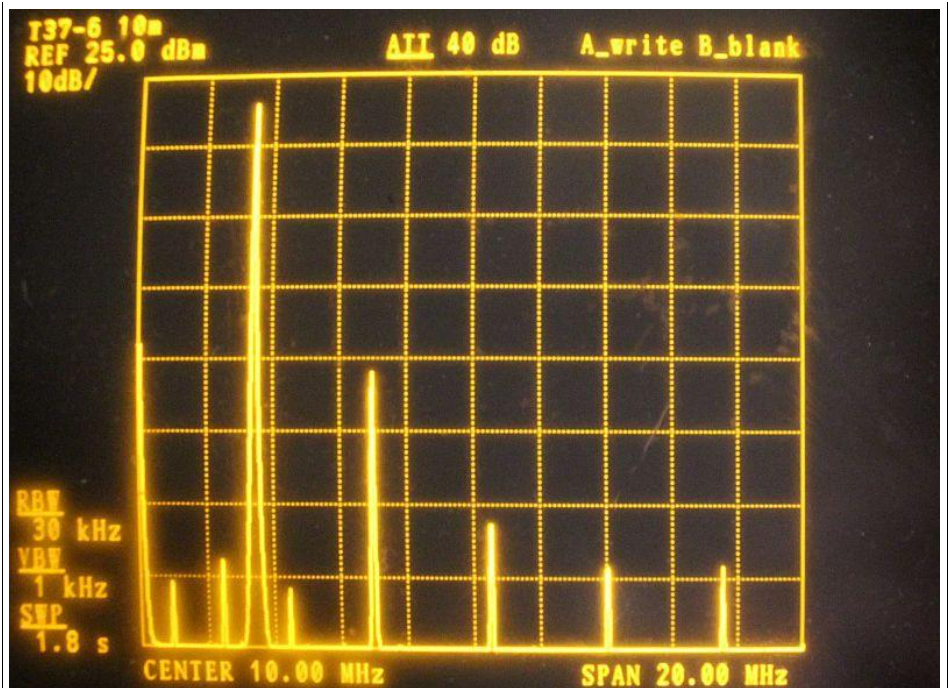

FSK CW test

The OCXO/Si5351A synthesiser module again used in a U3 transmitter kit. It is set up on the 30m (10MHz) band and transmitting into a dummy load.
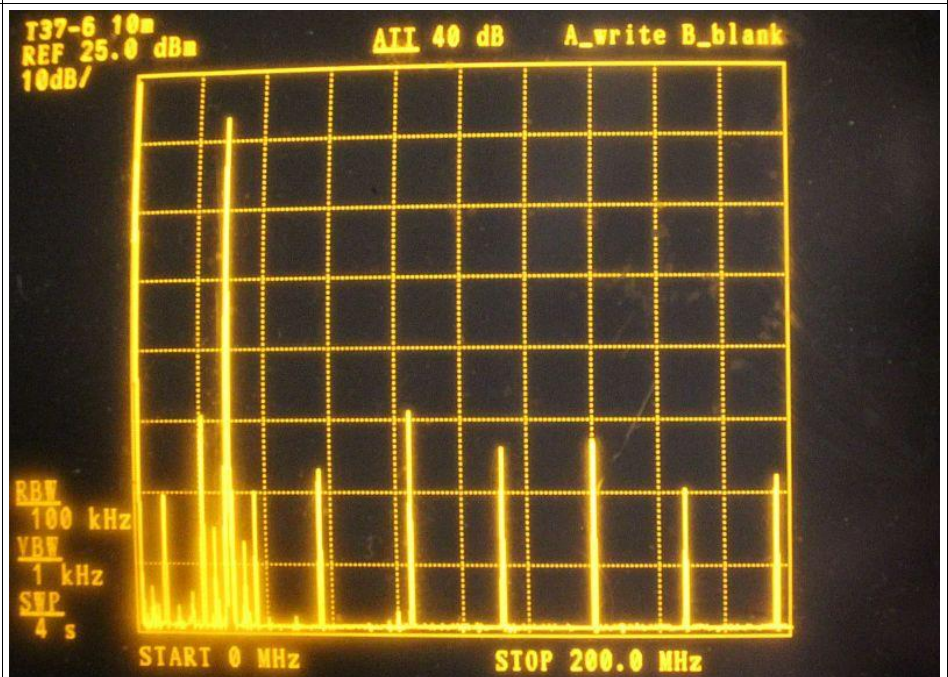
Sending FSK/CW mode with 6 second symbol length.

3.5MHz output spectrum

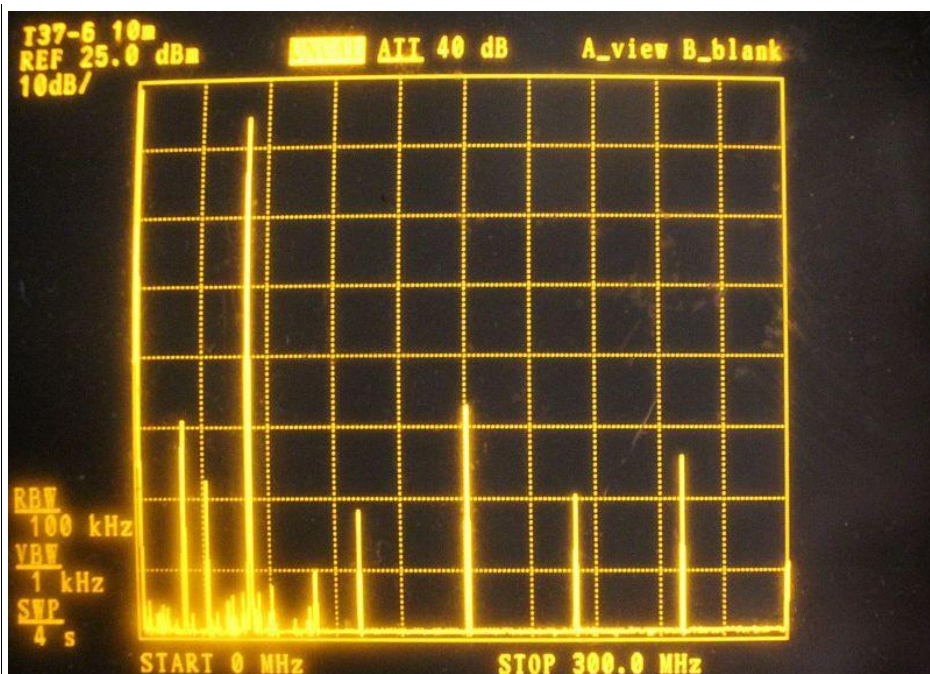OCXO/Si5351A synthesiser module in a U3 with dummy load, frequency set to 3.5MHz with 80m band LPF.

28MHz output spectrum

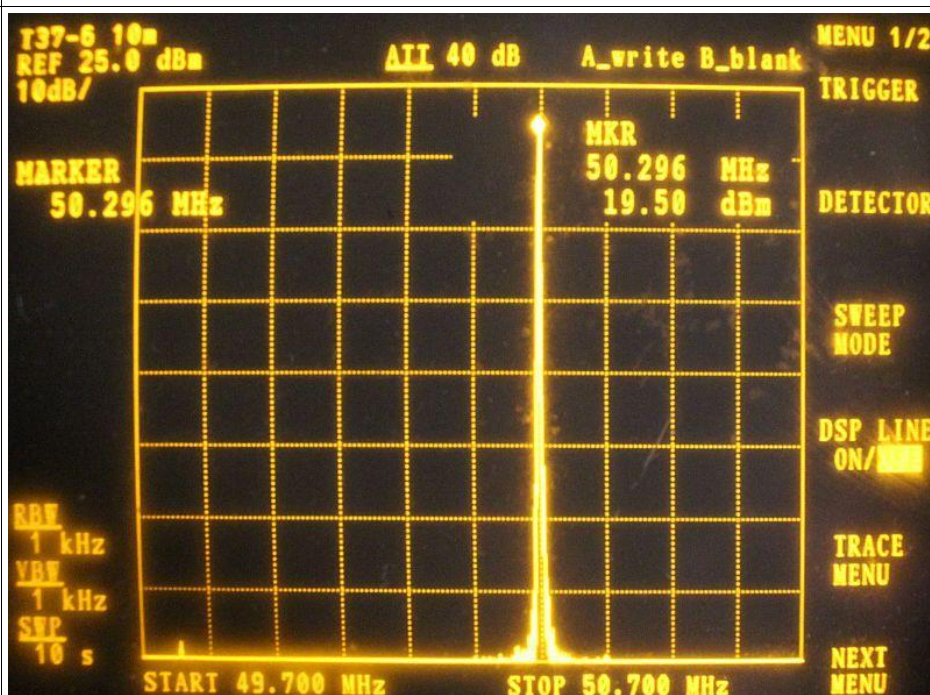OCXO/Si5351A synthesiser module in a U3 with dummy load, frequency set to 28MHz with 10m band LPF.

50MHz output spectrum

OCXO/Si5351A synthesiser module in a U3 with dummy load, frequency set to 50MHz with 6m band LPF.

50MHz close-in spectrum

As above, but zoomed in to a 1MHz slice of spectrum.

References and resources:

1) Ultimate3 QRSS/WSPR kit: http://www.hanssummers.com/ultimate3

2) SiLabs Si5351A page (including datasheet): http://www.silabs.com/products/clocksoscillators/clock-generator/Pages/clock-vcxo.aspx

3) QRP Labs web shop: http://www.qrp-labs.com

4) QRP Labs Yahoo group forum: https://groups.yahoo.com/neo/groups/QRPLabs

5) Follow QRP Labs on Twitter @qrplabs and Facebook http://www.facebook.com/QRPlabs

Document History

1)   17-Feb-2015   First version
2)   19-Feb-2015   Corrected circuit diagram: R6 was labelled R5
3)   25-Feb-2015   Corrected typos, clarified SI570 oscillator, and 27MHz testing
4)   01-Mar-2015   Corrected Q2 in title of step 55, and missing part #14 in step 47.)
5)   12-Mar-2015   Note about not using a metallic screwdriver for adjustment
6)   07-Nov-2016   Added parts list
7)   08-Nov-2016   Minor updates/corrections
8)   09-Nov-2016   Corrected typos in the parts list