
5W HF PA kit SIMPLIFIED assembly instructions

1. Introduction

This is a Power Amplifier kit (PA) for CW or FSK modes. The output power is approximately 5W in the middle of the HF frequency range, using a 13.8V supply. A single inexpensive IRF510 MOSFET is the amplification device. An unusual feature of this PA is the built-in facility for envelope shaping, which can create a precise raised-cosine keying envelope shape. This greatly reduces key-clicks when using on/off keyed modes such as CW or at the commencement/completion of an FSK mode transmission.

I highly recommend building the full kit as described in the assembly instructions. The kit has a discrete component power modulator (voltage regulator) which is controlled by an 8-bit R-2R Digital Analogue Converter, and allows an external microcontroller to control the amplitude of the output by loading the on-board 8-bit shift register using three I/O signals, and thereby create the raised cosine shape.

These instructions are for a simplified assembly of the PA kit, which omits raised cosine envelope shaping, or the power modulator with fold-back current limiting. It is easier to build this way, but the functionality is less.

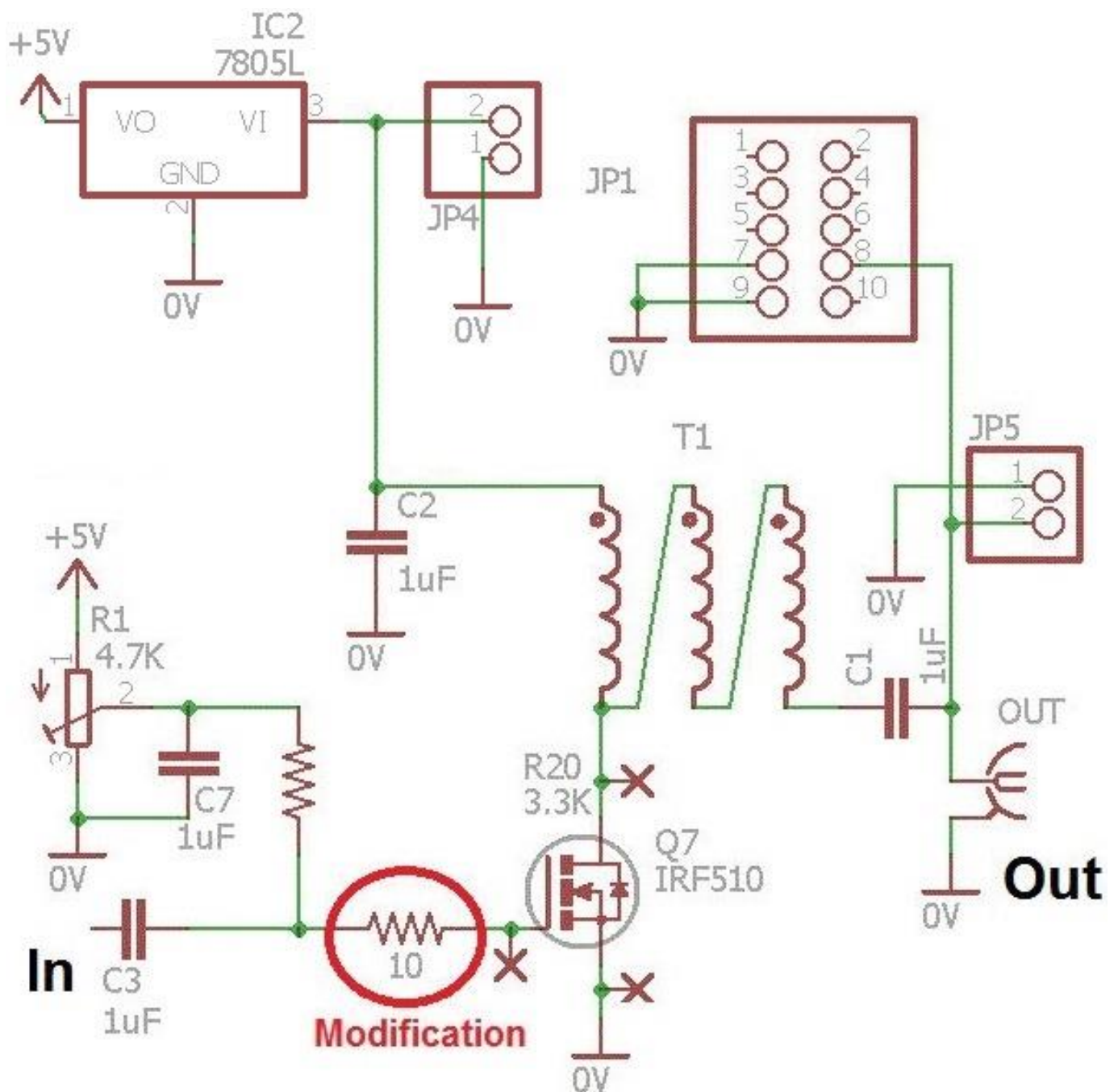
The kit has a PCB of size 80 x 37mm, which is the same size as the other QRP Labs modules such as the Ultimate3S QRSS/WSPR transmitter kit, the VFO kit and the Relay-switched LPF kit. It is therefore physically (as well as electrically) compatible with the other QRP Labs kits and can be bolted behind them in the familiar PCB sandwich. Alternatively this PA can be used with your own homebrew projects. The PCB has space for SMA connectors (not supplied by default with the kit), if you wish to use SMA cables.

The PA kit must always be followed by a low pass filter to attenuate unwanted transmitter harmonics, as usual for RF power amplifiers.

Carry out an inventory of the components according to the parts list to make sure all the components required are present. Remember that there will be many surplus components that are required only for the full build and will not be used here. Read the assembly instructions first before starting the assembly, understand everything, and then finally start the assembly, following all the steps carefully!

The following diagram shows the simplified circuit diagram of this HF PA.

This diagram includes a 10-ohm resistor modification which is highly recommended, and will be described later in this document.



2. Parts list

Unused parts are coloured grey – these are used only in the full build.

Resistors

R27	0.33-ohm, 2 watt resistor
(none)	10-ohm resistor
R2, 19	15K resistor (2 pieces)
R4..10, 28	1.1K resistor (8 pieces)
R3, 11..18, 24	2.2K resistor (10 pieces)
R20, 22	3.3K resistor (1 pieces used, 1 piece not used)
R21, 30	330-ohm resistor (2 pieces)
R23	8.2K resistor
R29	47K resistor
R1	4.7K trimmer potentiometer resistor
R26	3.3K resistor (not supplied)
R25	4.7K trimmer potentiometer resistor (not supplied)

Capacitors

C1, 2, 3, 7, 8	1uF capacitor (5 pieces)
C5, 6	1uF capacitor (2 pieces)
C4	1nF capacitor

Semiconductors

IC1	74HC595 8-bit shift register, 16-pin DIP package
IC2	7805L 5V regulator, TO92 package
Q3, 4	2N3904 NPN transistor, TO92 package
Q1, 2, 6, 8	2N3906 PNP transistor, TO92 package
Q5	2SC4242 NPN power transistor, TO220 package
Q7	IRF510 N-channel power MOSFET, TO220 package
Q9	BS170 N-channel MOSFET, TO92 package

Miscellaneous

16-pin socket	16-pin DIP socket for IC1
10-pin header	10-pin 0.1-inch header
Heatsink	65mm long PCB-mounting heatsink and pins
Insulation sets	2 pieces silicone rubber insulation pads + washers for the TO220 transistors
Nut and bolt	12mm long M3-size bolt and matching nut
FT50-43	FT50-43 toroid
Wire	100cm 0.33mm diameter wire
PCB	80 x 37mm Printed Circuit Board (PCB)

Theoretical circuit explanation

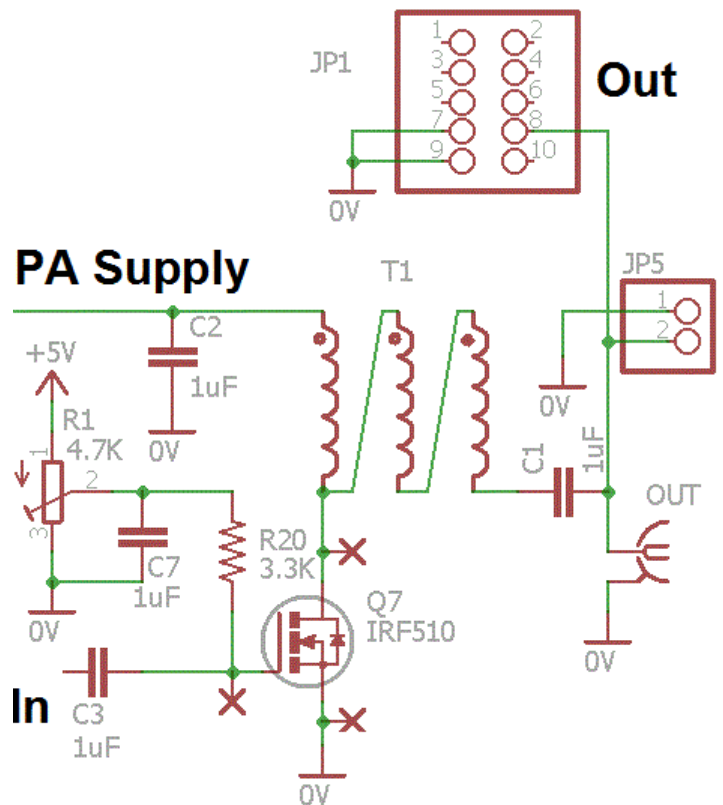
The chosen amplification device is the IRF510 MOSFET. It is inexpensive, robust, easily able to handle the power requirements, and in a convenient TO220 package. On the other hand, the IRF510 does have high gate capacitance. It is originally intended as a switch for switched-mode power supplies and other such industrial switching requirements. Using it as an RF amplifier wasn't the manufacturer's original intention! But it works well on HF, nevertheless! The power output does drop off at the higher frequencies.

For this reason the PCB has been designed to also accept the RD15HVF1 transistor (and similar devices) which are intended and designed for RF applications. They perform very well right up into VHF, 2m band etc. So if you wish to use this PA kit for 6m and 2m you may want to replace the supplied IRF510 with a RD15HVF1 or one of its siblings. The pinout of the RD15HVF1 is different to that of the IRF510. The PCB has a second set of pads to suit the RD15HVF1.

The incoming RF is coupled to the IRF510 gate via a 1uF capacitor. The largish 1uF value is intended to help the PA work well on LF and MF. A DC bias voltage must be applied to the IRF510 gate, this is supplied by 4.7K preset potentiometer R1 via the 3.3K resistor R20.

A trifilar output transformer wound on an FT50-43 toroid provides matching to the 50-ohm output. There are pads/holes on the PCB for an optional SMA connector. This is not supplied in the kit but is available in the QRP Labs shop. You can also fit an SMA connector at the PA kit's RF input instead of the 2-pin header. The RF output is also available at the 2-pin header JP5, and at a 2 x 5-pin header JP1 (not supplied). The 2 x 5-pin header matches the headers on the Ultimate3S QRSS/WSPR Transmitter PCB and the 6-band relay-switched filter kit PCB. This option may be used when using this PA kit with Ultimate3S, and is described in the application note AN004.

The PA kit also contains a TO92-package 5V regulator IC type 78L05, IC2 (also equivalently called 7805L by some manufacturers). Note that this is shown on the main circuit diagram but in not the sub-block above. This 5V is used for the PA bias. Providing the regulator on board simplifies the use of this PA kit module because you only need to provide a single PA supply e.g. 13.8V. However do not be tempted to power other circuits from this 5V regulator output, such as the Ultimate3S kit or other. The 78L05 is only a low power voltage regulator and has no heatsink. The 78L05 is rated for 100mA maximum supply current.



3. Assembly

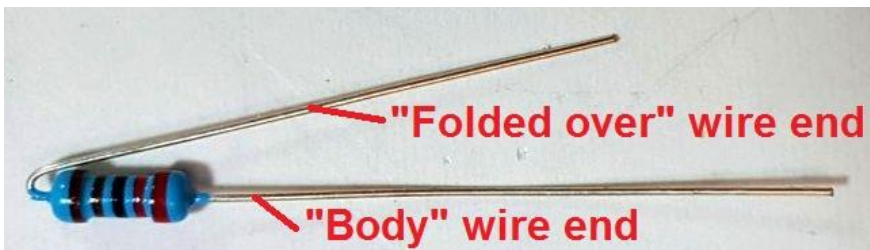
Assembly of this kit is quite straightforward. The usual kit-building recommendations apply: work in a well-lit area, with peace and quiet to concentrate. **Some of the semiconductors in the kit are sensitive to static discharge. Therefore observe Electrostatic discharge (ESD) precautions.** And **FOLLOW THE INSTRUCTIONS!!**

A jeweller's loupe is really useful for inspecting small components and soldered joints. You'll need a fine-tipped soldering iron too. It is good to get into the habit of inspecting every joint with the magnifying glass or jeweller's loupe (like this one I use), right after soldering. This way you can easily identify any dry joints or solder bridges, before they become a problem later on when you are trying to test the project.

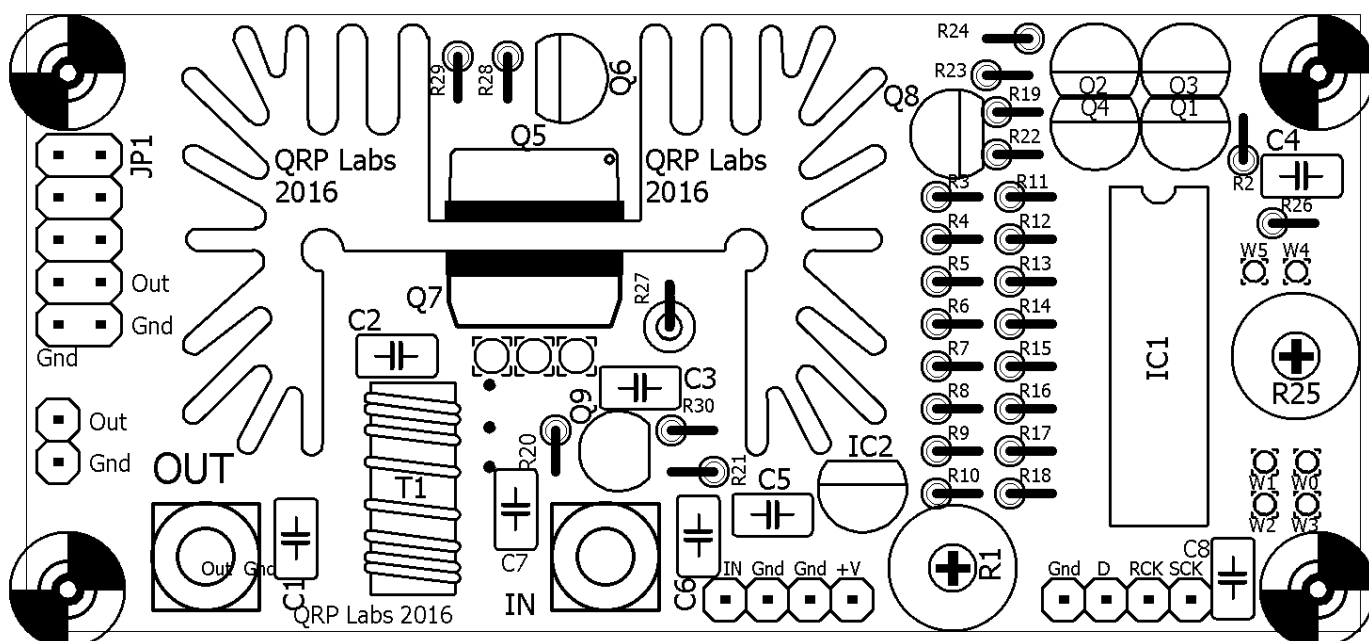


It is always best to detect and correct any mistakes as early as possible (immediately after soldering the incorrect component). The board is quite compact, to fit the required 80 x 37mm PCB dimensions. Removing a component and re-installing it later is often very difficult!

The resistors in the kit are installed vertically, because PCB space is limited. It was important to design it to fit on an 80 x 37mm PCB for potential use with other QRP Labs kits such as the Ultimate3S QRSS/WSPR transmitter. You will need to bend the resistor wires as shown in the picture below. On the parts layout diagram there is a small circle around the hole where the body end of the resistor should be installed. This is not critical (resistors don't care which way around they are) but it is recommended, just to try to ensure that the folded over wire-end of the resistor doesn't touch any other wire or metal part.

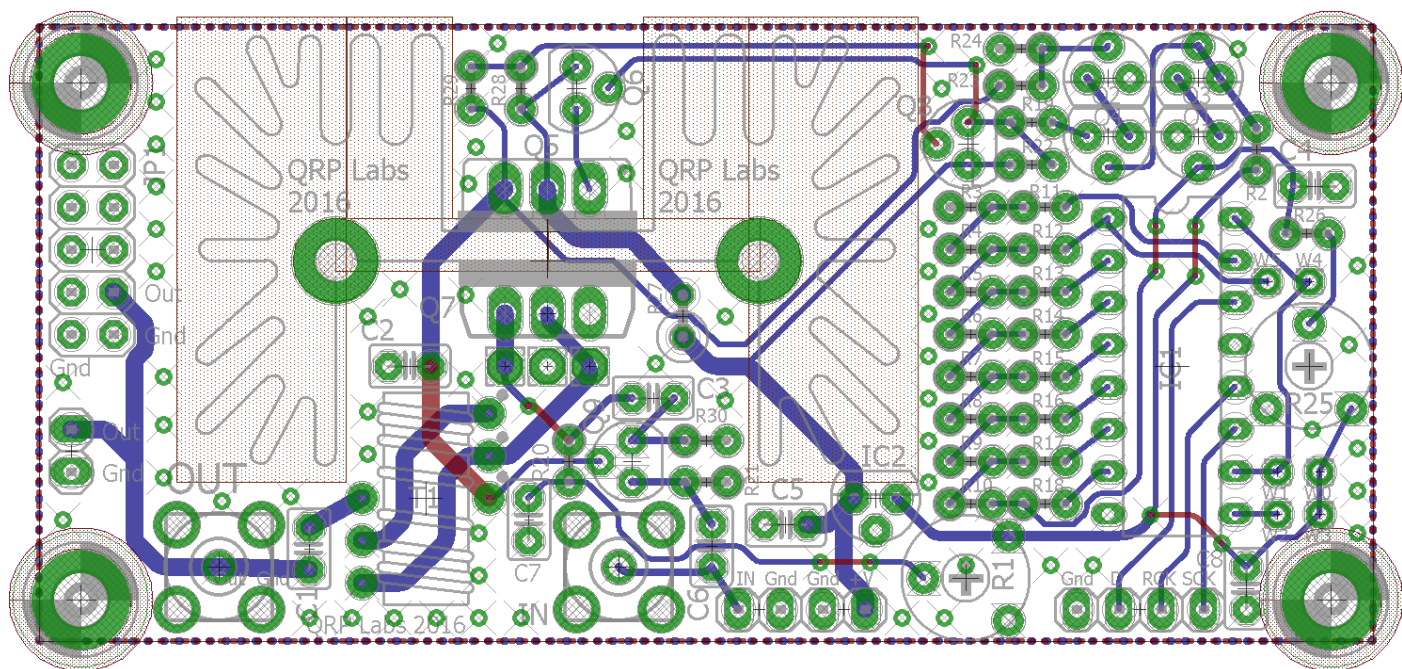


Please refer to the layout diagram and PCB tracks diagrams below, and follow the steps carefully.



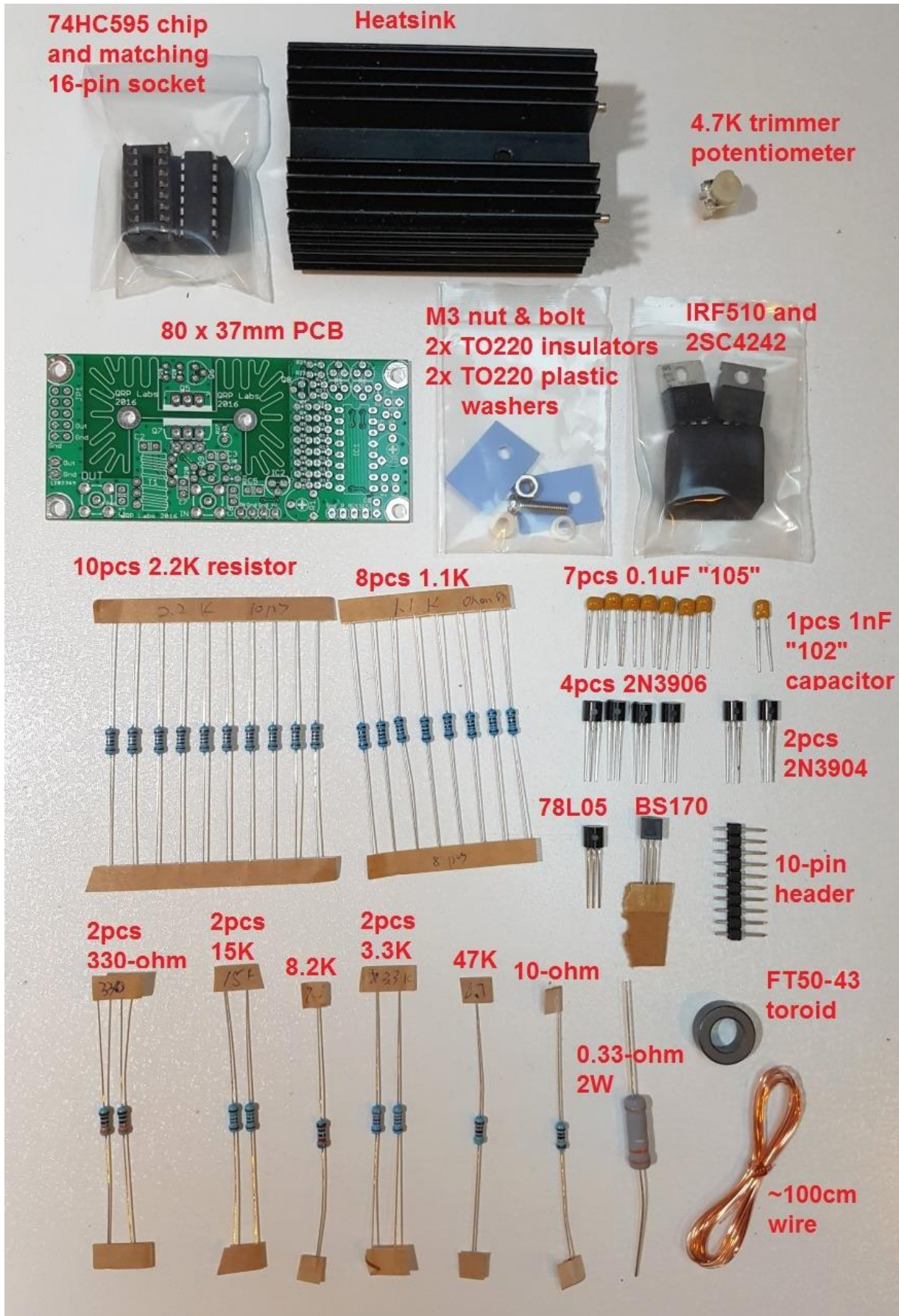
PCB track diagram. Tracks shown in BLUE are on the bottom layer. Tracks shown in RED are on the top layer. There are only two layers (nothing is hidden in the middle). Not shown in this diagram are the extensive ground-planes. Everything on the bottom layer that isn't a RED track, is ground-plane! Large areas of the top side are also ground-plane, connected to the bottom ground-plane layer at frequent intervals by vias.

Note that the heatsink is not electrically connected to ground or anything else. The area right under the heatsink has no ground-plane on the top layer. This is to prevent the heatsink potentially scratching the soldermask and connecting to a ground-plane if there was one. For the same reason there are no tracks on the top layer under the heatsink. The metal tabs of the TO220 transistor is NOT connected to ground, and is insulated from the heatsink, so long as all the insulating hardware is properly installed. The heatsink itself is therefore connected to nothing at all.



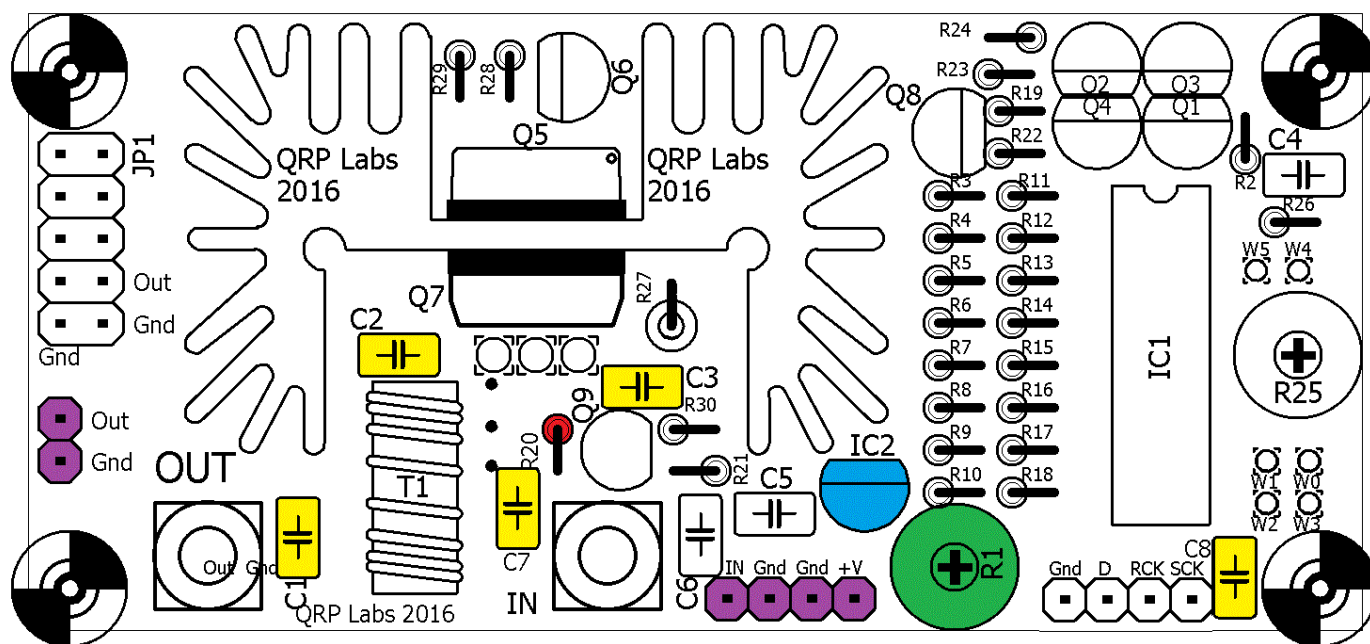
3.1 Inventory parts

This is the full list of parts. Many are not used in this simplified build. Please refer to the parts list.



3.2 Install required components

Install and solder the components indicated in this diagram and described as follows.



YELLOW: Capacitors C1, C2, C3, C7 and C8 are 1uF capacitors. The writing on the capacitor is “105”. Be careful – the kit also contains one 1nF capacitor labelled “102” – do not mix them up!

RED: Resistor R20, 3.3K, with colour code with colour code orange-orange-black-brown-brown.

BLUE: 78L05 voltage regulator IC2. Be careful to install this with the same orientation as the white silkscreen printing on the PCB. Also check the label on the component – there are many TO92-style transistors which look similar – do not mix them up!

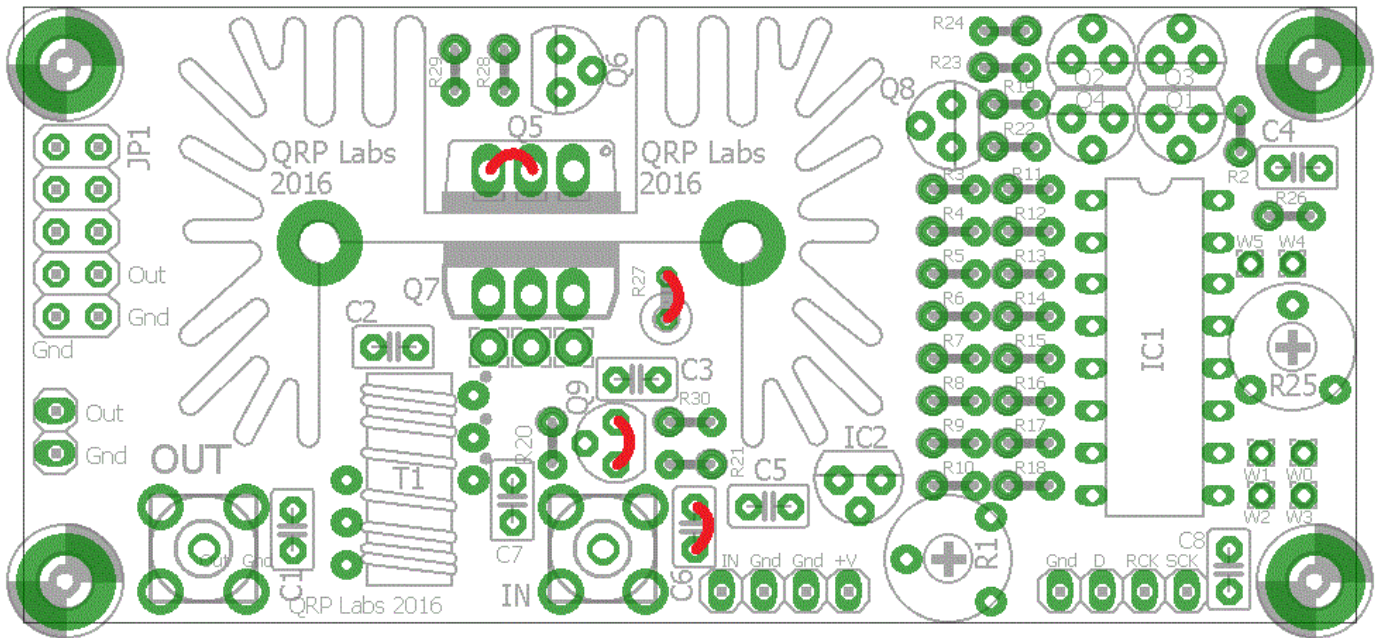
GREEN: The 4.7K preset bias adjustment potentiometer, with label “472”.

PURPLE: Optionally you can install header pins. Many people prefer to solder wires to header pins, rather than in holes. Or you may wish to use header socket connectors. In this case snap off a 2-pin section and a 4-pin section from the supplied 10-pin header, and install them as shown.

3.3 Install jumper wires

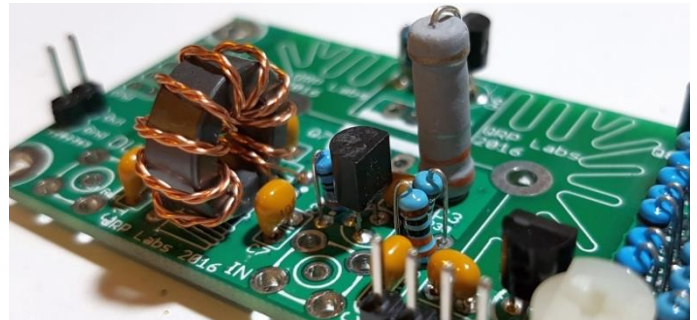
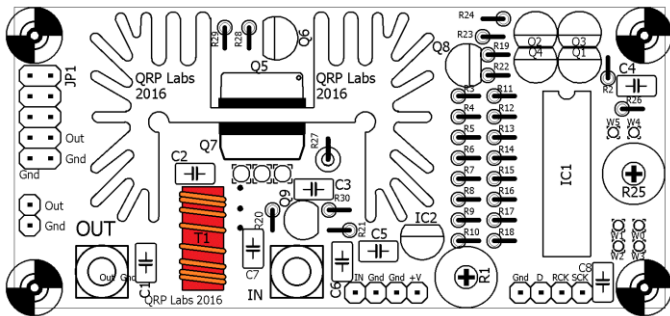
The jumper wires are necessary to bypass the power modulator circuit, and to bypass the leakage gate circuit. These parts of the full PA kit assembly are not undertaken in this simplified build.

Four jumpers need to be installed as per the following diagram. This diagram shows the PCB holes/pads in green to make it clear where the jumper wires need to be installed. These jumpers can be made using wire offcuts from the installed components or surplus components.



3.4 Install trifilar transformer

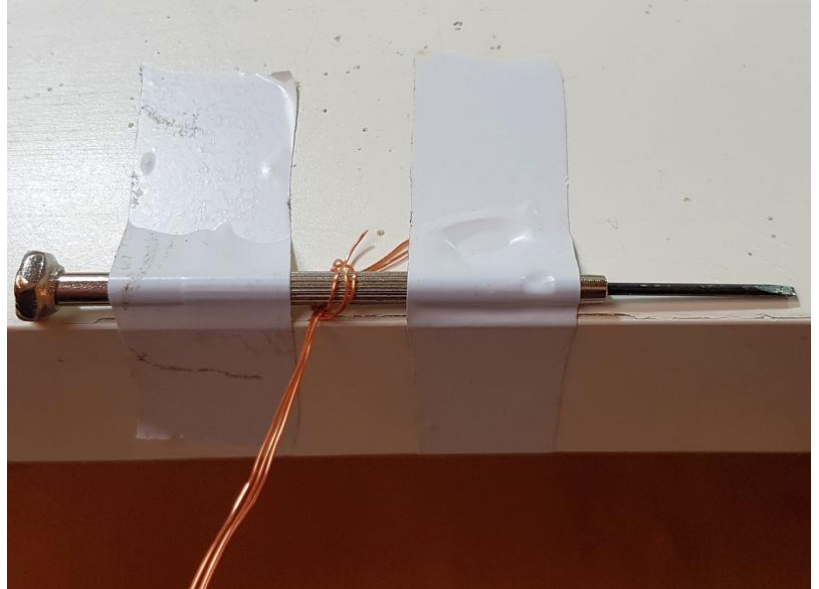
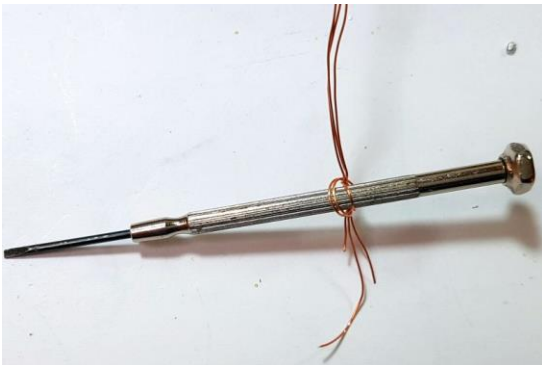
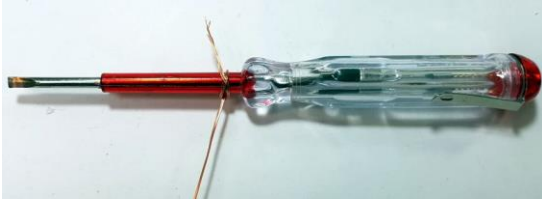
The trifilar transformer is installed in the position coloured red in this diagram. The photo (right) shows the board after installing the trifilar transformer. But it is a tricky part of the assembly, so please read and follow these steps carefully.



Firstly, the wire. The best way to un-wind it, without tangling it up, is to think of what the kit-packing person that wound it up did. Then reverse his steps. So, first unwind the tightly wrapped part in the middle where the end of the wire has been secured. Then, open out the spool of wire so that it is a circle. Then unwind the spool, around your fingers, reversing the process of winding it in the first place.



When you have unwound the wire and straightened it, cut it into three approximately equal pieces. These three pieces now need to be tightly twisted together to make the trifilar wire. My method for this is to tie one end in a knot around a small screwdriver shaft. Similarly tie the other end around another small screwdriver. Now clamp one end somehow to something solid. You could use a vice, if you have one. If you don't, then you have to get creative and think of something. Here I taped it to the edge of the desk. Now you can twist the screwdriver at the free end, repeatedly until you twist the three wires together thoroughly. You need to keep the wire under a little tension to keep the twists evenly spaced.

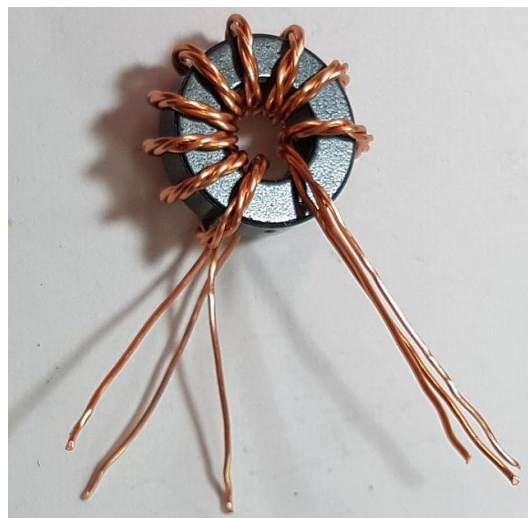
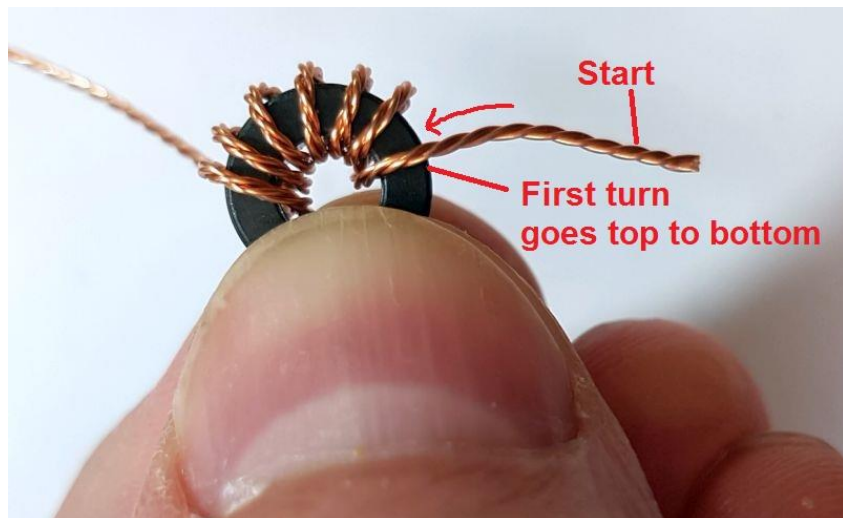


I put about 70-90 twists into a 25cm length of wire. The end result is something like the photo (right). The measurement scale is in cm.

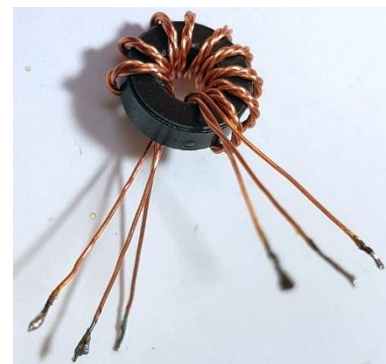
Now cut off the untidy ends, and this is the piece of wire that will be used to wind the FT50-43 toroidal core as a trifilar transformer.



Hold the core between thumb and finger. Pass the wire first from above, to below. Then take the wire from below, and bring it around to pass through the toroid again to form the second turn. After each turn, ensure the wire is fitting snugly around the toroidal core. Wind 10 turns on the core. Each time through the toroid's central hole counts as one turn. Cut off the excess wire, leaving about 2.5cm remaining.



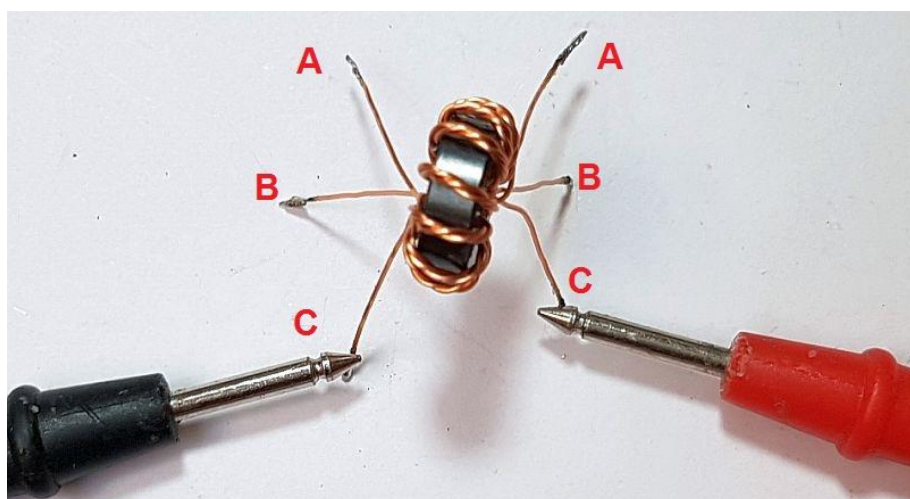
Now it's necessary to identify which wire belongs to which winding. You have three windings twisted together, they all use the same wire. The only way to do this is with a DVM as continuity tester. First, untwist and straighten the wire ends that are not wound around the toroidal core.



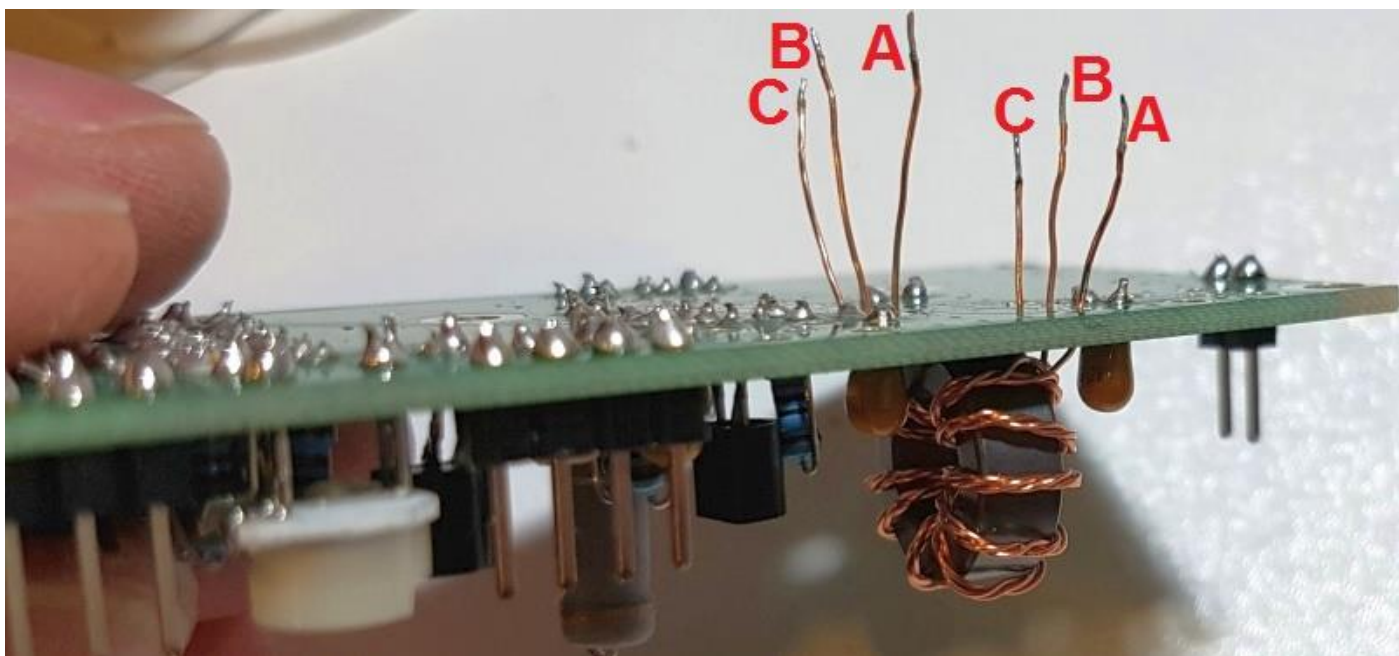
Now tin the last few mm at the ends of each wire. You can do this by scraping off the enamel then tinning with the soldering iron; or, hold the wire end in a blob of molten solder for a few (maybe 10) seconds, until the enamel burns off.

Now use a DVM to test for continuity. Re-arrange the wires so that there is continuity from A-A, B-B, and C-C in this photo.

Carefully keep this orientation of wires and insert the transformer this way into the PCB. You can carefully cut off those few mm of tinned section of wire, if it won't fit through the PCB holes. But **BE CAREFUL** not to lose the orientation of the wires! The right wires must be in the right holes, so that the windings are connected correctly in the circuit!



It's a good idea to check for continuity A-A, B-B, C-C again with the DVM, just to make sure that you didn't accidentally mix up the wire orientation while inserting the wires.

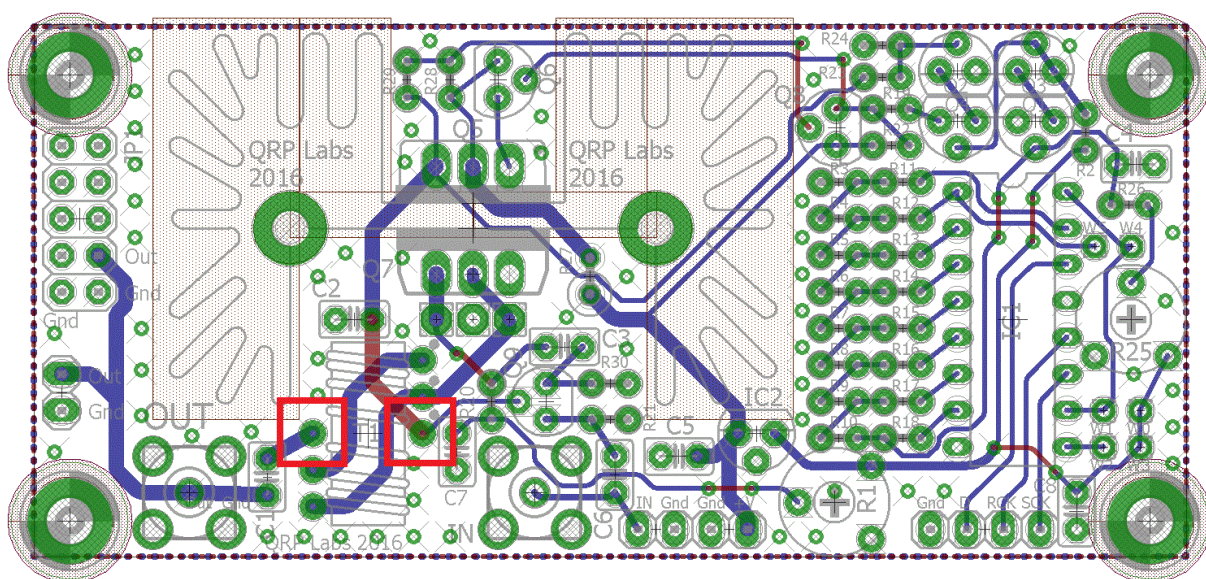


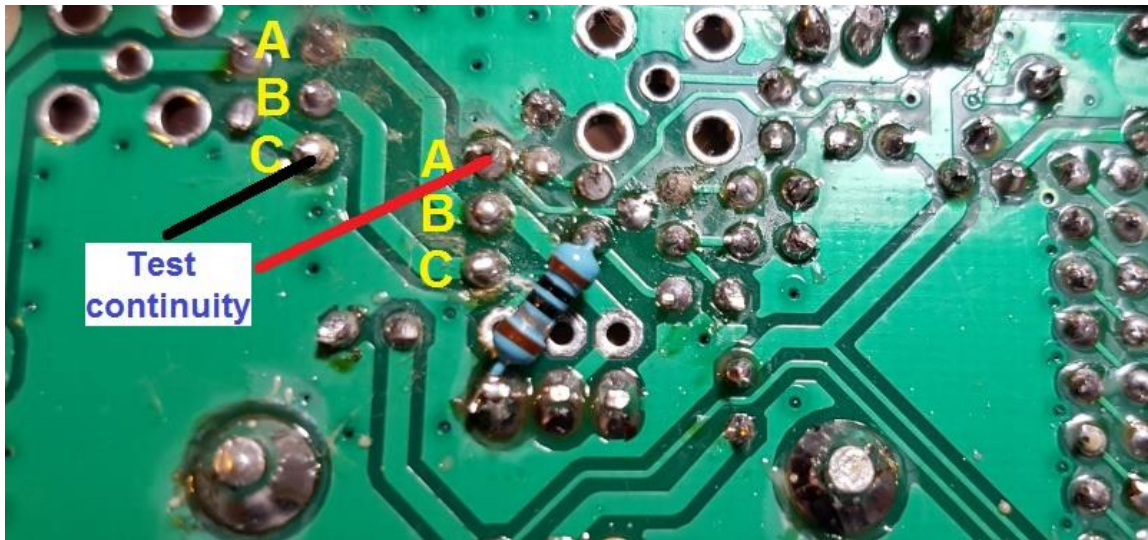
Now trim the wires underneath the board, and tin the ends again. The EASIEST way to do this is simply apply solder so that it sits in the hole and surrounds the 1mm of wire ending, and hold the soldering iron in that position for a few seconds until the enamel is burnt away. This tins the wires and solders them to the PCB pads.

You can inspect the joints with a magnifying glass or jeweller's loupe. The photograph (right) shows a joint where the soldering iron has not been held long enough on the joint. The enamel has not properly burnt off the wire, and there will be no electrical connection to the copper wire. The circuit will not work! So fix it!



You can also test that the wires are properly soldered. Use a DVM to check for continuity (zero ohms resistance) between the indicated points C and A in this diagram and photo. If there is continuity it means that the copper wire is all properly soldered. If not, then go back and check again. You can then check the individual windings to see where the fault lies.

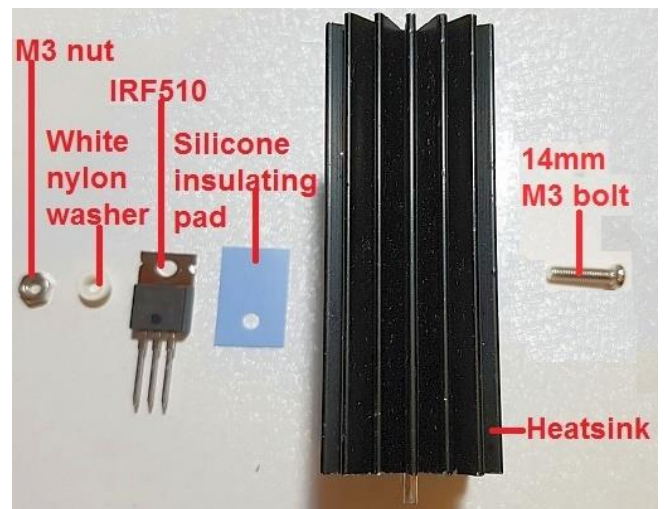




Note that this does NOT necessarily check that you correctly orientated the windings. The only way to do that, was with the DVM continuity check before inserting the transformer; and after identifying the windings, being careful not to mix the wires again while inserting the transformer in the PCB; finally checking again once the wires are inserted but before soldering.

3.5 Install heatsink assembly

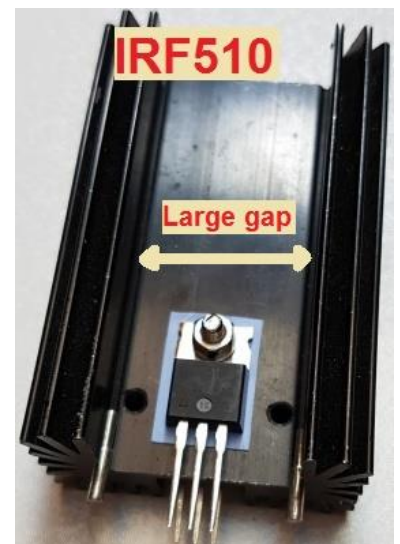
In this kit the IRF510 transistor final (Q7) is fitted to the metal heatsink. The metal tab of this transistor must not short to ground or to other parts of the circuit. Therefore insulating silicone rubber pads are used, and insulating white plastic washers. In this photo (right) the heatsink is viewed side-on before assembly. The picture shows how the transistor assembly must be put together before soldering.



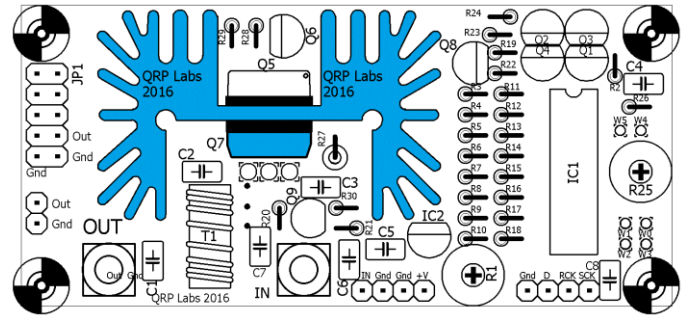
On the side of the heatsink with the large gap, the silicone pad is placed on the heatsink where the IRF510 transistor will sit. The transistor is placed on the silicone pad. The white nylon insulating washer is pushed into the hole in the transistor tab. The bolt then fits through the hole. The metal bolt does not touch the metal tab of the transistor, and the tab does not touch the heatsink.

In the prototypes I put the bolt on the far side and the nut on the IRF510 side, as shown. Then it is easiest to grab the bolt with pliers while tightening the screw from the other side.

If you have some heatsink compound then this would be a good idea (though the prototypes development and testing did not use it). Take care to align the transistor accurately and tighten the bolt/nut well. You will be rewarded by an assembly which fits easily into the holes on the PCB.



It is difficult to remove and replace transistors later! So before soldering, check once again that the Q7 transistor (IRF510) is in the correct place on the side of the wide opening of the heatsink. Check that everything matches the PCB silkscreen and this diagram (right).



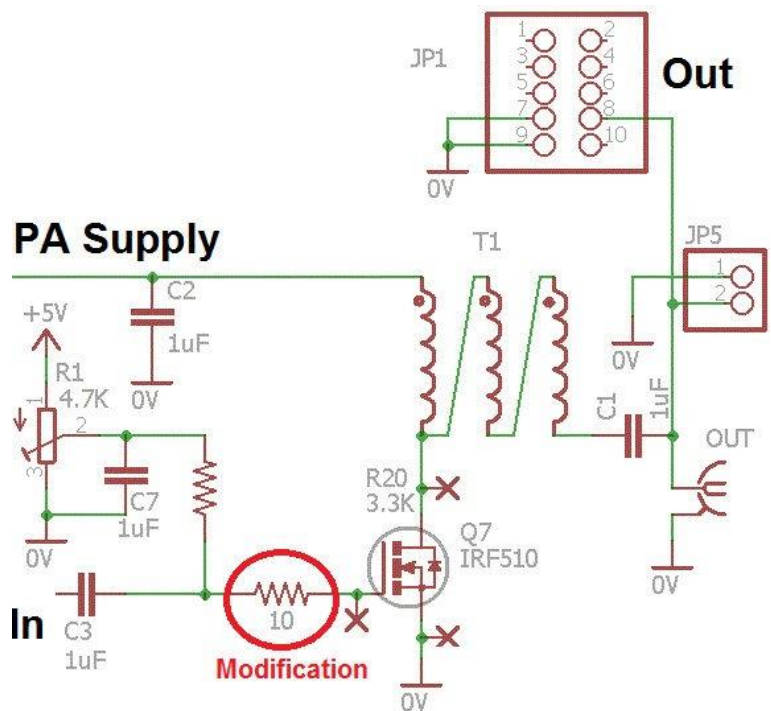
Once the heatsink assembly and transistors are fitting perfectly into the PCB, you can solder first the heatsink mounting pins, then the transistor component leads themselves. A high wattage soldering iron may be needed for soldering the heatsink pins, as the heatsink will try to conduct away heat which may lower the temperature of the joint below the melting point of solder. You could leave the heatsink pins unsoldered if it seems troublesome. After soldering the transistor leads, cut off the excess lead length.

Note that the pads for the heatsink mounting pins are not connected to ground (or anything else). The PCB top side has no copper or tracks of any sort under the heatsink; this is to ensure that even if the soldermask accidentally got scratched, there would be no contact between the heatsink and ground or any other electrical connection.

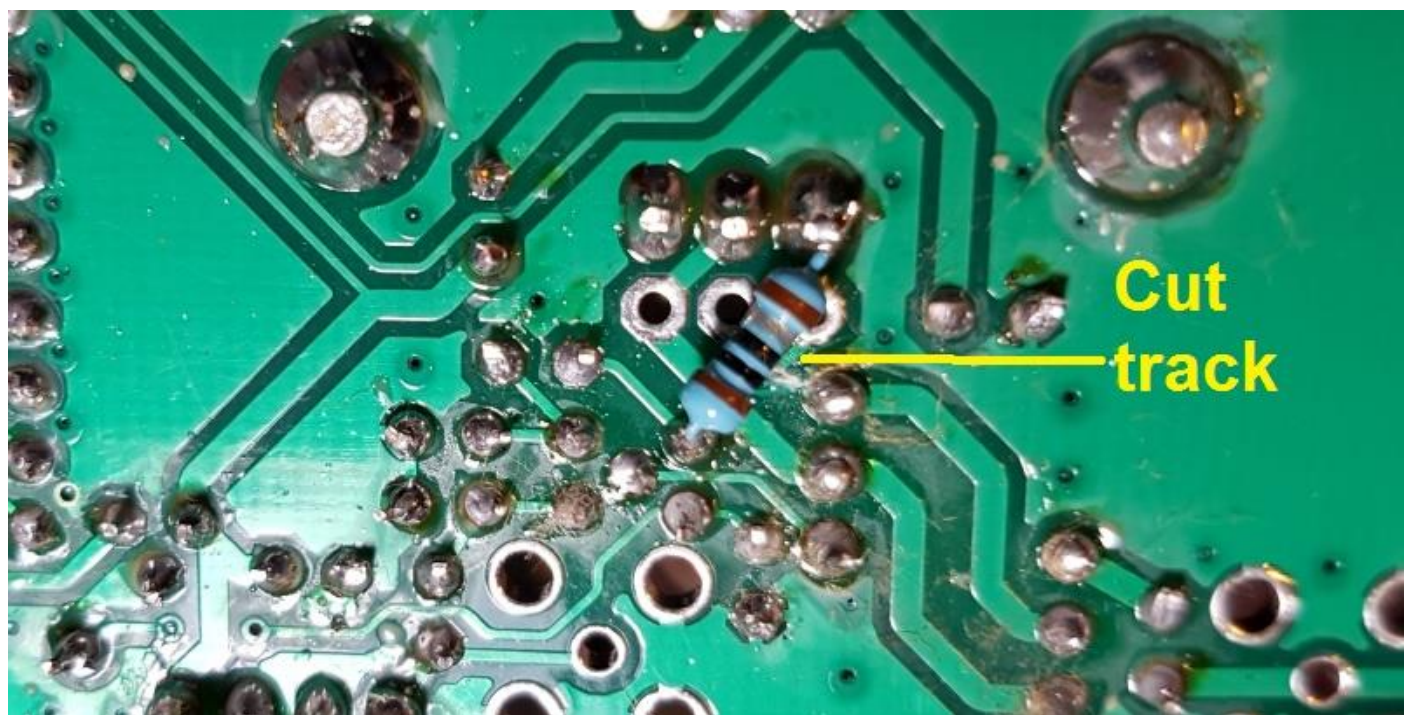
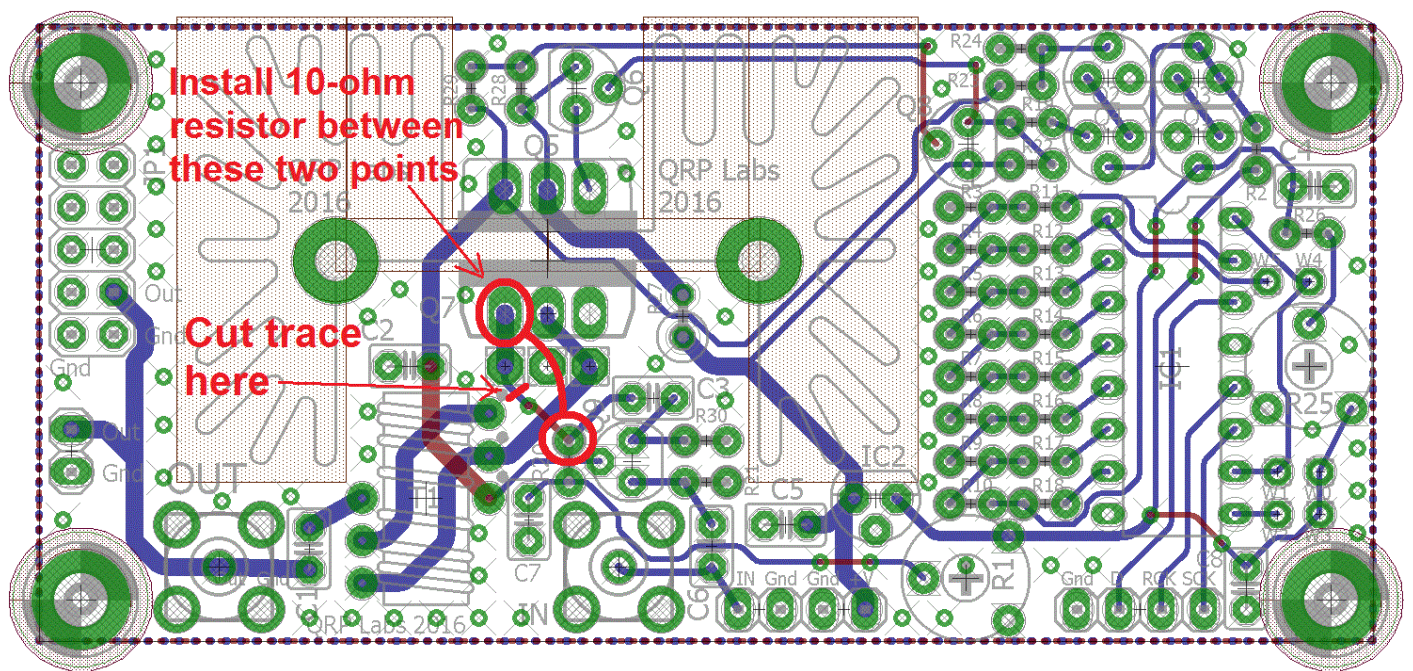
3.6 A recommended modification

This modification will be included as standard on any future PCB revisions. It involves the addition of a 10-ohm resistor at the gate of Q7, the IRF510 final PA transistor. The PA does work without this resistor, and indeed it will produce slightly higher power output. However at certain supply voltages and frequencies, instability can occur. When this happens the amplifier superimposes a low frequency oscillation envelope on the wanted RF output. Fitting this 10-ohm resistor resolves this potential problem, at the cost of some power reduction. The measurements made later in this document were made with this 10-ohm resistor fitted.

The modification involves cutting one track on the BOTTOM side of the PCB, and soldering a 10-ohm resistor on the bottom side of the PCB. The resistor location is shown in the above circuit diagram fragment which shows the IRF510 PA. The 10-ohm resistor is supplied in the kit and has colour code brown-black-black-silver-brown.



The modification is illustrated in the following diagram and picture.

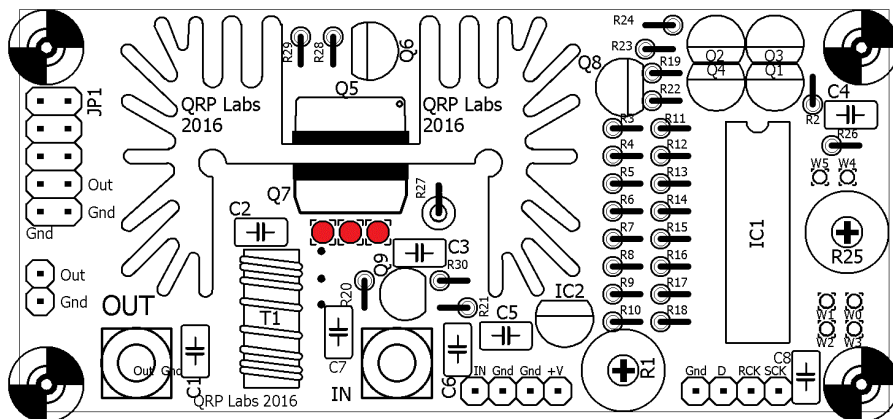


3.7 RD15HVF1 Substitution for VHF operation

The supplied IRF510 transistor works well at HF. However for the VHF bands 6m and above, the gain of the IRF510 in this circuit is very low. If you wish you may substitute the RD15HVF1 transistor or one of its close relatives. These transistors are more expensive but are designed for VHF/UHF power amplifiers and should work well in this circuit.

The pinout of the RD15HVF1 is different to the IRF510! The PCB has a position for the

RD15HVF1 transistor if you wish to use it. If you wish to use the RD15HVF1 in this circuit, insert its leads into the set of three holes shown in RED in the diagram. You will need to bend the leads of the transistor outwards slightly, away from the heatsink, so that they are aligned with this set of holes. Take care to insert the transistor leads into the correct holes.



4. Connecting and configuring the Power Amplifier kit

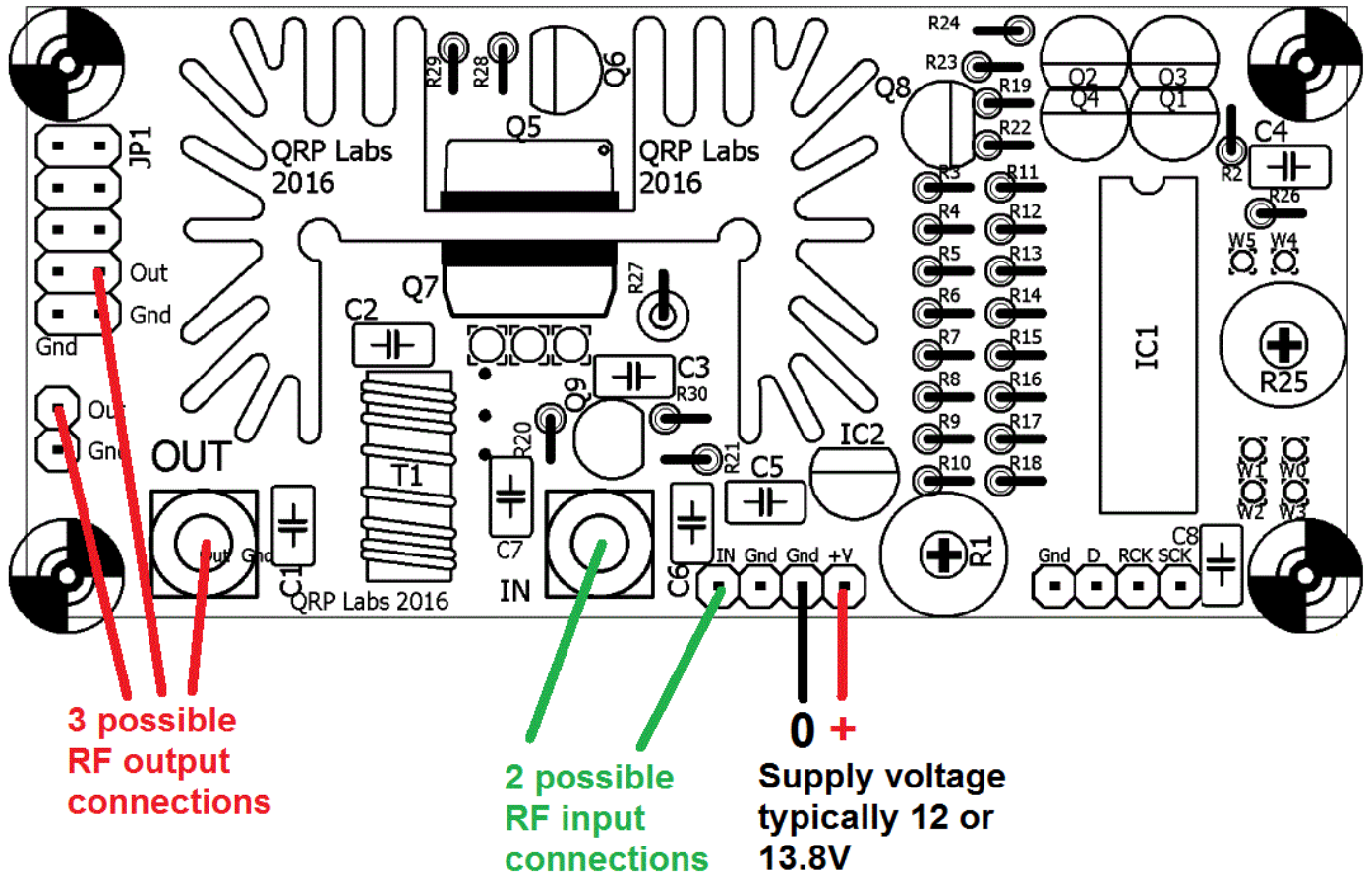
4.1 Basic connections

The power amplifier kit requires a supply voltage of typically 12 or 13.8V. The amplifier may draw 1 or 1.5A of current so remember to use a well-regulated good quality power supply capable of this. Use thick wires to the PA to avoid voltage drop in the wiring. You may wish to connect an electrolytic capacitor close to the PA kit PCB, particularly if the wires to your supply are long.

The RF input to the amplifier may be connected at the pin header, or you may install an SMA connector for it. If using the pin header, it is a good idea to use a ground connection wire as well as the RF signal connection wire. Thin coax is suitable.

The RF output may be taken from a pin header, or an SMA connector, or the 2 x 5-pin header pads provided. The footprint for the 2 x 5-pin header is provided to facilitate connection to the Ultimate3S kit – if you are using this then please refer to App Note AN004. As usual, remember to connect a low pass filter at the PA output, to attenuate transmitter harmonics.

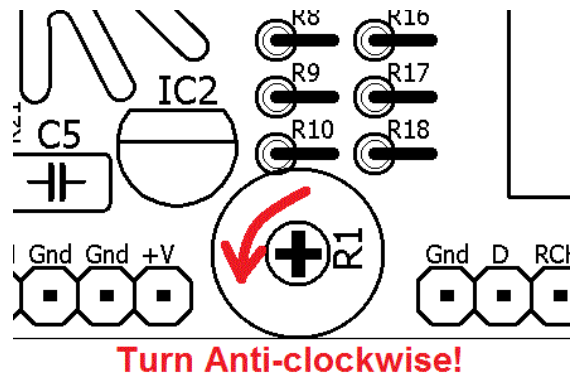
The 4-pin header with the microcontroller signals that control the 8-bit shift register, DAC and power modulator are NOT used in this simplified construction. They may be left unconnected.



4.2 Bias adjustment

Correct bias adjustment is very important! Before connecting power, turn the R1 bias potentiometer completely anti-clockwise (zero volts bias)!

R1 adjusts the bias at the gate of the IRF510 final PA transistor Q7. If the bias is too low, the gain (and power output) of the amplifier will be low. If the bias is too high, the current through Q7 will flow even when there is no signal; this can result in excess power dissipation (though the power modulator circuit removes power to the IRF510 PA final in any case). Efficiency is also reduced and gain/power output may be reduced also if bias is too high.



Theoretically the ideal bias point for the gate of the MOSFET, is where there is zero idle current through the IRF510 transistor, and where increasing the bias voltage any further would result in idle current starting to flow. This point has optimal power output, if the input signal amplitude is optimum, and it has best efficiency as well as spectral purity of the output. Of course in the real world, everything can (and does) change!

The zero idle current point can be found quite easily if you connect an ammeter (typically a DVM in current measurement mode) in series with the PA kit supply. The adjustment is carried out in the key-up state, or in other words, no RF input (you could disconnect the RF input, for example).

Start with R1 completely anti-clockwise. Observe the current consumption of the PA kit when “idle” (key-up state, not transmitting, no RF input). Then slowly turn the R1 trimmer potentiometer

clockwise until you observe a very slight increase in the current consumption. The point where the current just starts to increase is the zero bias point.

An alternative (and arguably simpler) method of bias adjustment is to transmit into a 50-ohm dummy load, measuring power with a power meter or observing on an oscilloscope. Turn the R1 trimmer potentiometer clockwise until maximum power output is obtained, then back off slightly. The bias setting using this method is higher than the zero idle current method. The power output will be higher too.

The gain of the IRF510 amplifier is less at the upper end of the HF bands particularly 28MHz (the 10m band). The input signal is also typically lower, when using for example an Ultimate3S kit as the driver. In these cases, adjusting the PA with a higher bias voltage can improve the gain/power output at the high frequency end of its range of operation.

If using this PA in a multi-band transmitter and desiring maximum power output, you could adjust the bias for best power output on the highest frequency that will be used (for example, 28MHz) where the bias is most critical. The bias setting is much less critical at the lower end of HF.

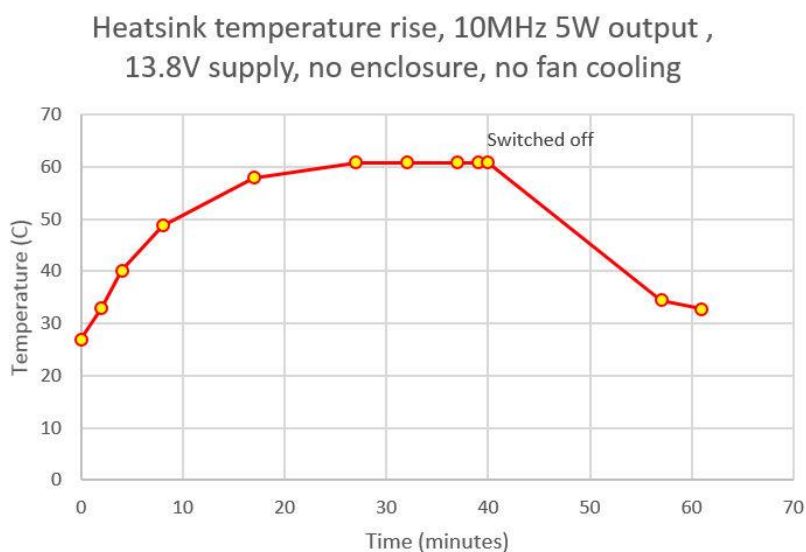
4.3 Heatsink temperature rise; PA kit installation in enclosure

The desired output power of this PA kit in your application has a significant bearing on how you enclose the project. Remember that the heatsink will dissipate a considerable amount of heat. The heat dissipation will cause the temperature of the heatsink to rise. You need to take this into account when deciding what enclosure to use. You may wish to bolt the heatsink to the back of a metal box, for example; or consider a fan to cool the heatsink.

In operation the power modulator transistor will dissipate some heat as it is an imperfect switch; the IRF510 final PA will operate at perhaps 50% efficiency or something like that (dependent on many factors). For a power output of 5W you will therefore be dissipating at least 5W, maybe somewhat more.

Another factor to take into account is the transmission mode you will be using. A continuous key-down transmission using FSK modes such as WSPR, will dissipate a much higher average power than an on/off keyed mode such as CW.

As an example, one prototype here was operated on continuous key-down on 10MHz, with 13.8V supply using an Ultimate3S transmitter as the driver. The power output was set to 5W using the maximum DAC value (meaning excess power was also dissipated in the power modulator). An overall current consumption of 1.06A was recorded. The assembly was lying on the workbench with no enclosure, and no forced air cooling. It took about half an hour for the temperature of the heatsink to stabilise. By that time it had reached



a temperature of 61C which was a rise of 33C above the ambient temperature of the lab. The transmission was switched off after 40 minutes (see chart).

In summary: Enclosing the PA kit in an enclosure will increase the temperature rise; using fan-assisted cooling would reduce it. There are many factors that will influence heat dissipation. The above discussion should be taken as a guideline only – your mileage may (WILL) vary!

5. Power Amplifier characteristics

Please refer to section 5 of the full PA kit assembly instructions. The measurements there were made with the full assembled kit. This simplified kit assembly does not suffer voltage drop across the power modulator, nor does it have any attenuation in the leakage gate. Due to this, the output power will be slightly higher with this simplified kit assembly.

6. References

- App Note AN004 explains how to use this PA kit in conjunction with an Ultimate3S QRSS/WSPR kit to increase the output power to around 5W, and apply raised cosine RF envelope shaping for a beautiful clean click-free signal. Refer to <http://qrp-labs.com/appnotes>
- For updates relating to this kit please visit the QRP Labs PA Kit page <http://qrp-labs.com/pa>
- For any questions regarding the assembly and operation of this kit please join the QRP Labs group, see <http://qrp-labs.com/group> for details

7. Document Revision History

- 02-Jan-2017 1.0 Initial revision
- 09-Mar-2017 1.01 Corrected typos in toroid core type
- 04-May-2017 1.02 Corrected section 3.3 to say four jumper wires (not three)
- 29-Nov-2018 1.03 Corrected BS170 in parts list, it is TO92 not TO220 package