13-Transistor Transceiver for Digital Kit Assembly Manual

Rev. B

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PCB Layout by BD4RG

CRKITS.COM
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Change history:
Dec 30, 2021: Add a few links and photos.
April 30, 2023: Add link to VK3YE review and FT8CN operation

Contents

Can we design a useful all discrete component amateur radio transceiver with a single model of transistors, say 2N4401? Many years ago, the NorCal QRP Club did the same thing to hold a 2N2222 design contest and Jim Kortge, K8IQY won the first prize with a CW transceiver design. Now, the digital mode FT8 becomes popular for the non-CW operators, and we've decided to design a kit for FT8 operation. Unlike our popular DSB transceiver D4D, we hope it will be possible to support SSB mode but still keep it simple to build in this design. Our reference is VK3YE's Knobless Wonder and K1SWL's Warbler PSK31 transceiver kit. After several rounds of prototype builds on Choc perfboard, I asked BD4RG to design a PCB and it becomes our new kit product of CRKITS.COM to celebrate the 10-year anniversary (2011~2021).

Specifications

Dimensions: 103mm depth x 88mm wide x 38mm height
Weight: about 235 grams w/o internal batteries
Frequency and Mode: 7074kHz USB
Filter: 4x 7078kHz crystals covering around 7075.5-7077kHz
Audio Pass Band: around 1500~3000Hz
PTT Control: VOX
Receive Current: around 50mA
Transmit Current: around 300~350mA
Transmit RF Power: around 1-Watt
Spurious suppression: -53dBc

Theory of Operation

Please join my group if you haven't and refer to the latest schematic (Rev 1.3 or later) in this directory (https://groups.io/g/crkits/files/13%20Transistor%2040m%20FT8%20SSB). Similar with the BITX design, the bi-directional amplifiers are widely used for both RX and TX chains, and we have added a VOX circuit and replaced a few circuits like the audio amplifier and the transmitter final stage with all 2N4401 transistors. It worked at the first time of the prototype build, but we have encountered a few problems, for example, the headphone background noise impacted the receiver SNR, especially for poor sound cards. We have modified the circuit a little bit to add a switch to split the RX and TX audio channels while in RX, and then combine them while in TX.

Let's review the schematic step by step. First thing first, let's briefly review the connectors.

J3 is the power supply input and it accepts 10 to 14V regulated power supply or battery pack and it requires at least 500mA current capability. In the kit we supply a battery holder of 3x AA size (or 14500 size) which can be used inside the case for 3 pcs 14500 sized Li-Ion batteries (3.7V each cell. Please don't use regular batteries of 1.2-1.5V each cell) to provide 11.1V (max 12.6V) power supply and the normal capability of 800mAh will provide FT8 operation of up to 4 hours. Once the rechargeable Li-Ion batteries are installed inside, J3 will be only used for charging, so please use with proper charger, like 12.6V 0.5A constant voltage constant current charger. Over

charging will cause big problems like smoke and / or fire. If you use Li-Ion batteries, the low voltage status can be detected when the voice operated transmitter (VOX) fails to work even the audio input is correct. When it happens, you'd better switch off the radio by push-push button S1 and recharge it soon. The low voltage detection is achieved by the 12V relay (K1) characteristics. It is not accurate but it prevents over discharging very well.

J2 is the audio input coming from the headphone jack of the sound card. Although the connector and the cable are both stereo type, it only uses the mono channel. The best audio level is designed to be about 150mV RMS on the loading resistor of R43 which just stably triggers the relay and C19 is the decoupling capacitor to reject RF interference. Coupled by C1, the incoming audio is amplified by Q1 by about 20 times. Coupled again by C3, the amplified audio was rectified by D1 and D2 into direct current (DC). C4 holds the DC level and drives Q2 through R5. Q2 is the driver of the relay K1 and D6 is the fly-back diode to prevent damage to Q2 by relay coil. K1 is a DPDT (Dual Position Dual Toggle) relay which switches both the antenna and power supply to work in either RX or TX mode. R4 is the discharging resistor for C4 when the incoming audio disappears so the relay will be released shortly. If you look into the schematic closely, D8 is a switch to connect both AUDIO_RX and AUDIO_TX networks during TX. It is an improvement for receiver SNR as we mentioned earlier.

J1 is the audio output connecting to the mic jack of the sound card. Although the connector and the cable are both stereo type, it only uses the mono channel as well. Q3 is the audio amplifier of about 20 times and the output impedance is about 1k ohm which matches the microphone input impedance well. The best audio level is 50dB on the WSJT-x or JTDX software. You can adjust the microphone gain to achieve the best result.

ANT connector is a BNC connector and it connects to your 50 ohm antenna system when on air or dummy load when in test with a 50 ohm coaxial cable. L1-L3 and C37-C40 are a 3-stage low pass filter to reject harmonies and other spurious generated by the transmitter to comply with RF regulations.

Q4 is a Colpitts type crystal oscillator for the local oscillator (LO). X5 is a crystal with load capacitance of 20 pF. C46 is a capacitor trimmer to fine tune the oscillating frequency. Q5 is a emitter follower to improve the driving capability.

T1 together with D3 and D4 is a balanced mixer for both RX and TX. In TX, the audio comes from J1, coupled by C47, D8 and C8, goes through R10, RF decoupled by C22 and C23 and it mixes with the local oscillator signal in the mixer and feeds into the attenuator by R44, R29 and R30, then it goes into the 1st TX amplifier Q6, the side band crystal filter X1-X4, the 2nd TX amplifier Q9, TX driver amplifier Q10, then the final amplifier Q11-Q13. In RX, Q8 is the 1st RX amplifier, Q7 is the 2nd RX amplifier and the RX signal also goes through the side band crystal filter X1-X4. Passing the attenuator by R44, R29 and R30, it goes into the mixer by T1, D3 and D4, RF filtered by C23, R10 and C22, audio coupled by C5 and amplified by Q3. You can see that it is a direct conversion receiver with a SSB filter in the front end.

Part List

Designator	Value	Quantity
R1/R2/R12-R19/R51-52	1K	12
D6/D7	1N4007	2
D1-D5,D8	1N4148	6
R4/R5/R38-R42/R49	2K2	8
Q1-Q13	2N4401	13
R45-R48	4R7	4
J3	10-14V Power Supply	1
R20-R23	10R	4
C1-C8、C47	10uF	9
K1	12V Relay	1
L4	22uH	1
R8-R11/R43/R44/R50	47R	7
C46	50P TRIMMER	1
R3/R6/R7	100K	3
C41-C44	100P	4
C9	100uF	1
C10-C36	103	27
C45	220P	1
R24-R32	220R	9
C37/C38	390P	2
R33-R37	470R	5
C39/C40	820P	2
X5	7074	1
X1-X4	7078	4
LED	RED/GRN LED	1
ANT	BNC	1
T2	FT37-43 8T Bi-filar, see text and photo below	1
T1	FT37-43 8T Tri-filar, see text and photo below	1
S1	SW SPST	1
L1-L3	T37-2 16T	3
J1	TO MIC	1
J2	TO HEADPHONE	1

Kit Assembly

Let's define a few rules so you can get familiar with the kit soon.

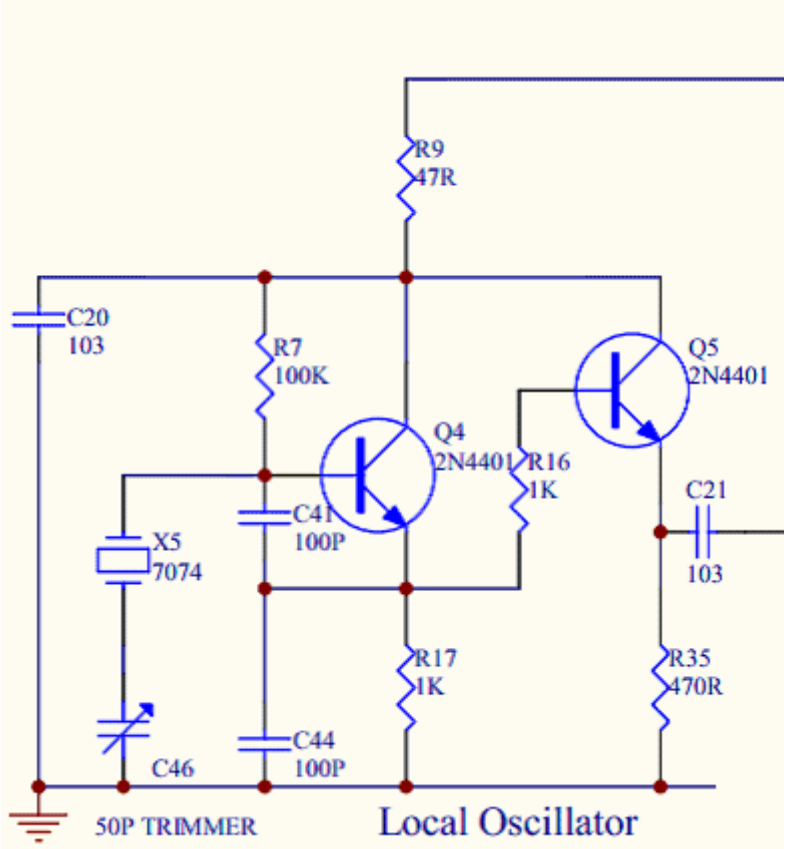
1. All the 103 monolithic capacitors are in 100 mil (2.54 mm) pitch, and other monolithic capacitors are in 200 mil (5.04 mm) pitch. There are no 104 monolithic capacitors in this circuit.
2. All the transistors are 2N4401 in TO-92 package. The pin definition from left to right is E-B-C. It is recommended that you test the hFE first to find 3 closest to use them in Q11-Q13. Others are no difference.
3. All the polarized parts like diodes and electrolytic capacitors have the cathode marked by a short line on the PCB. Make sure you install them properly.
4. All the connectors should be installed without any floating, or it is difficult to put on the panels.

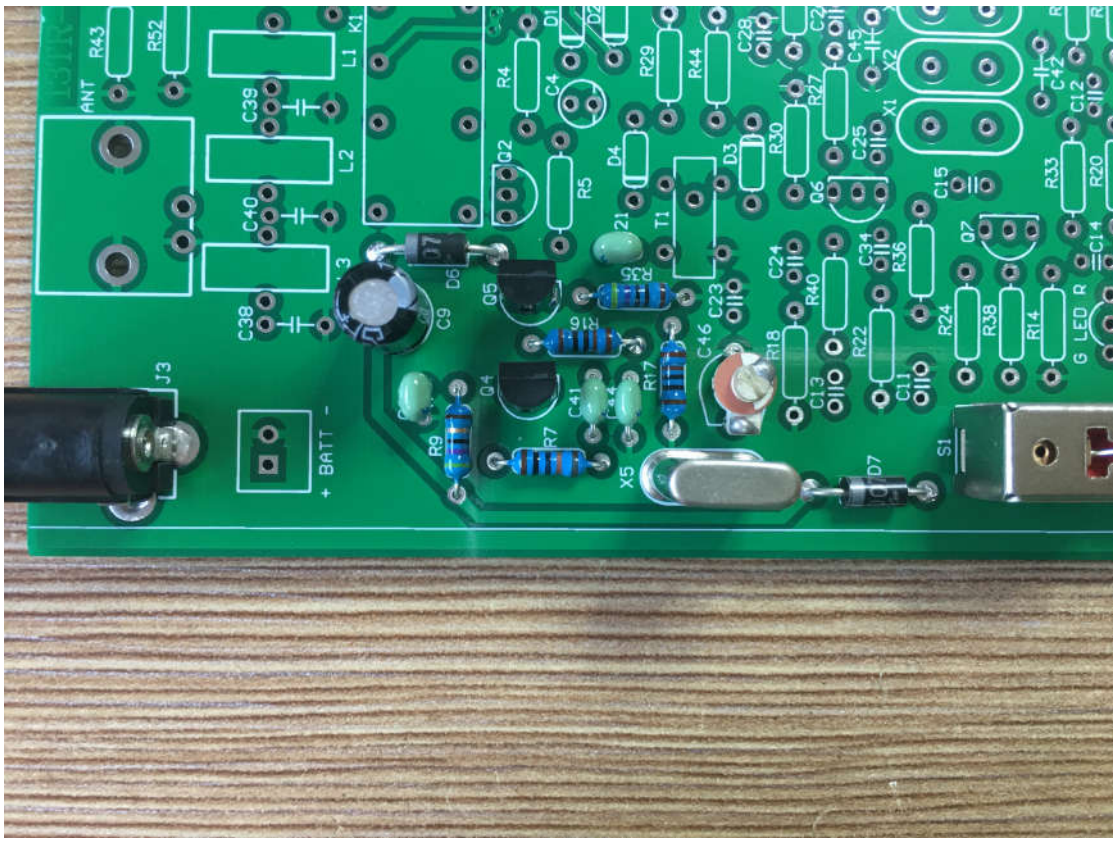
Module based mode

If you are new to the kit, please consider this mode so you can build and test each module.

Step 1: Local Oscillator – X5, Q4 and Q5

Please refer to the schematic. To enable the testing of this step, you will need to install J3, S1, D7 , C9 first. Although the schematic has the correct value marked, it is better that you use together with the part list to double check. If you are not familiar with color codes of the resistors, you can test with your multi meter to double confirm as some of them are very close in color codes.



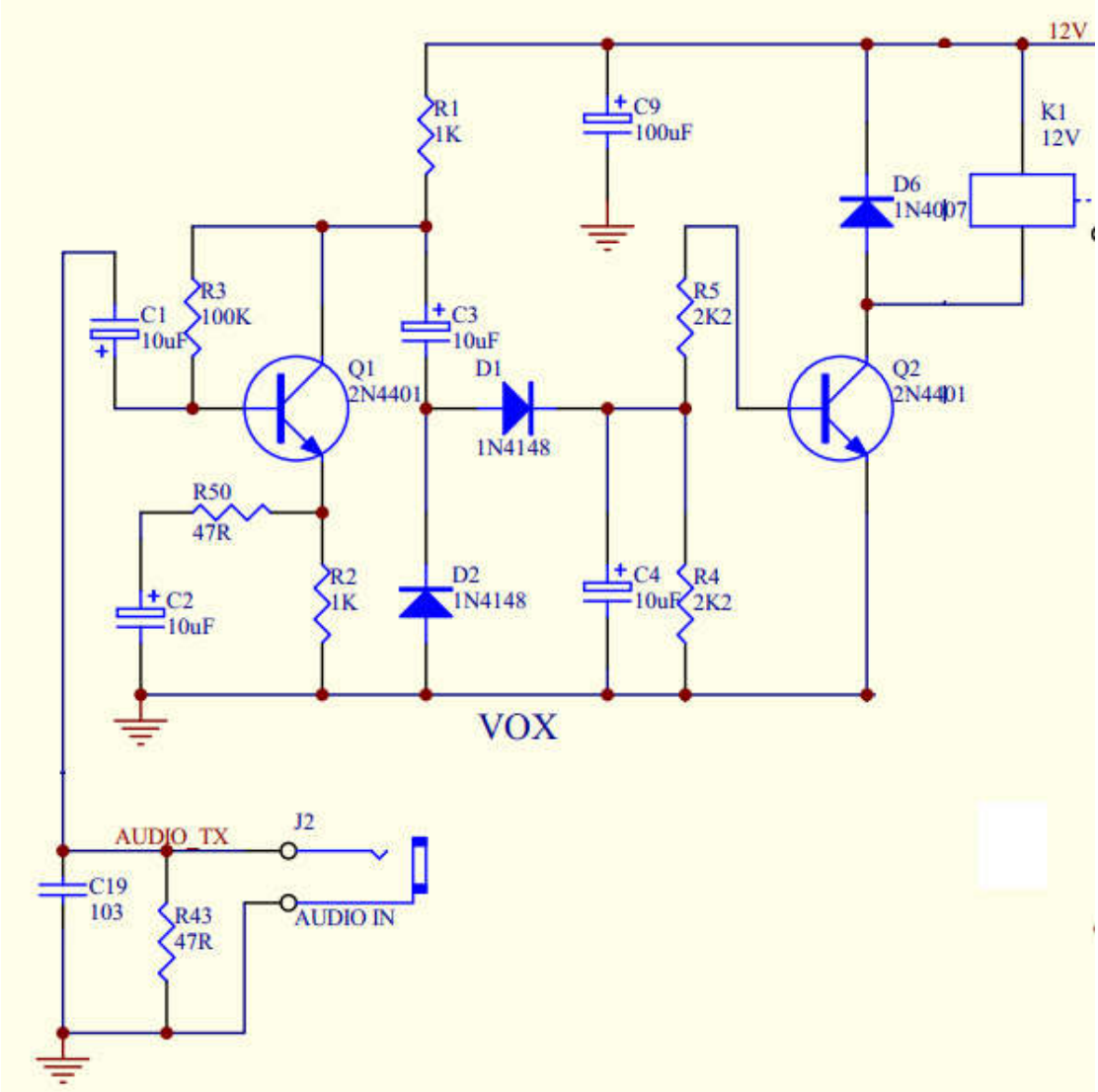


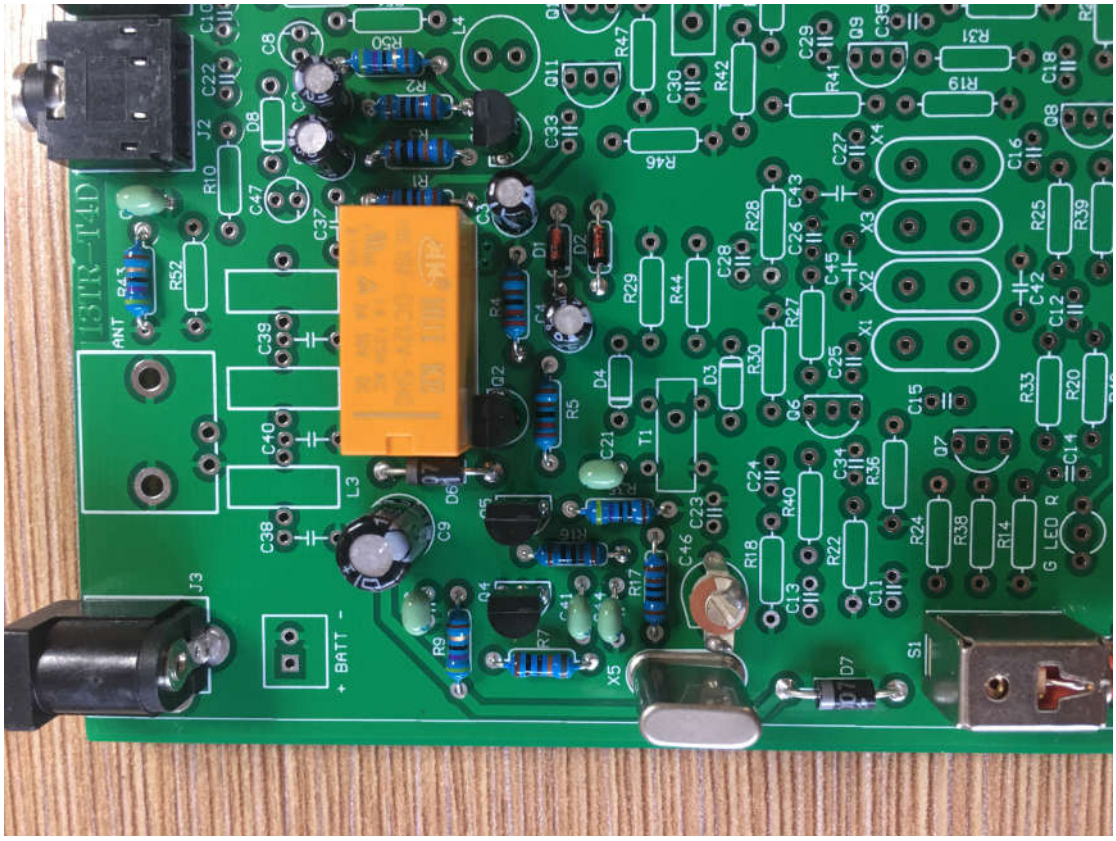
Once you have completed this step, you can apply 10-14V DC power supply to J3, switch on S1, and measure the output of C21 with a frequency counter. Adjust C46 slowly so you get exact

7.074MHz reading. If you don’t have a frequency counter, you can adjust to the position as shown on the photo. If you have an oscilloscope, you can test the waveform at C21 output. Normally it is not a perfect sine wave.

Step 2: VOX – Q1, Q2 and K1

Please refer to the schematic.

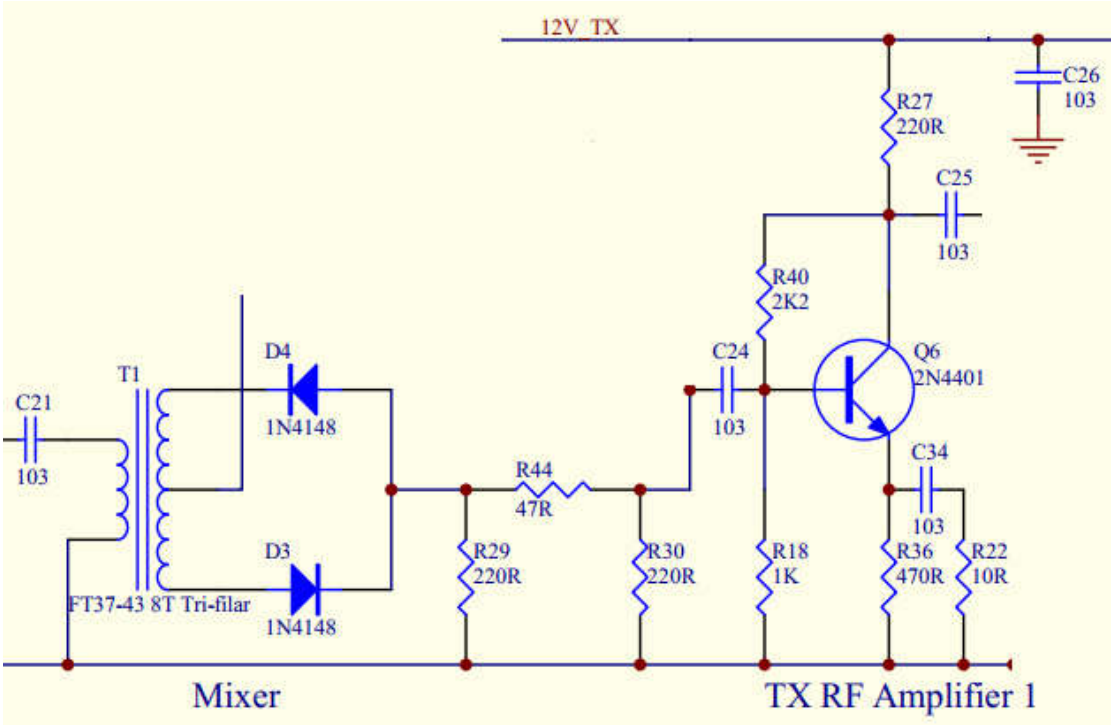


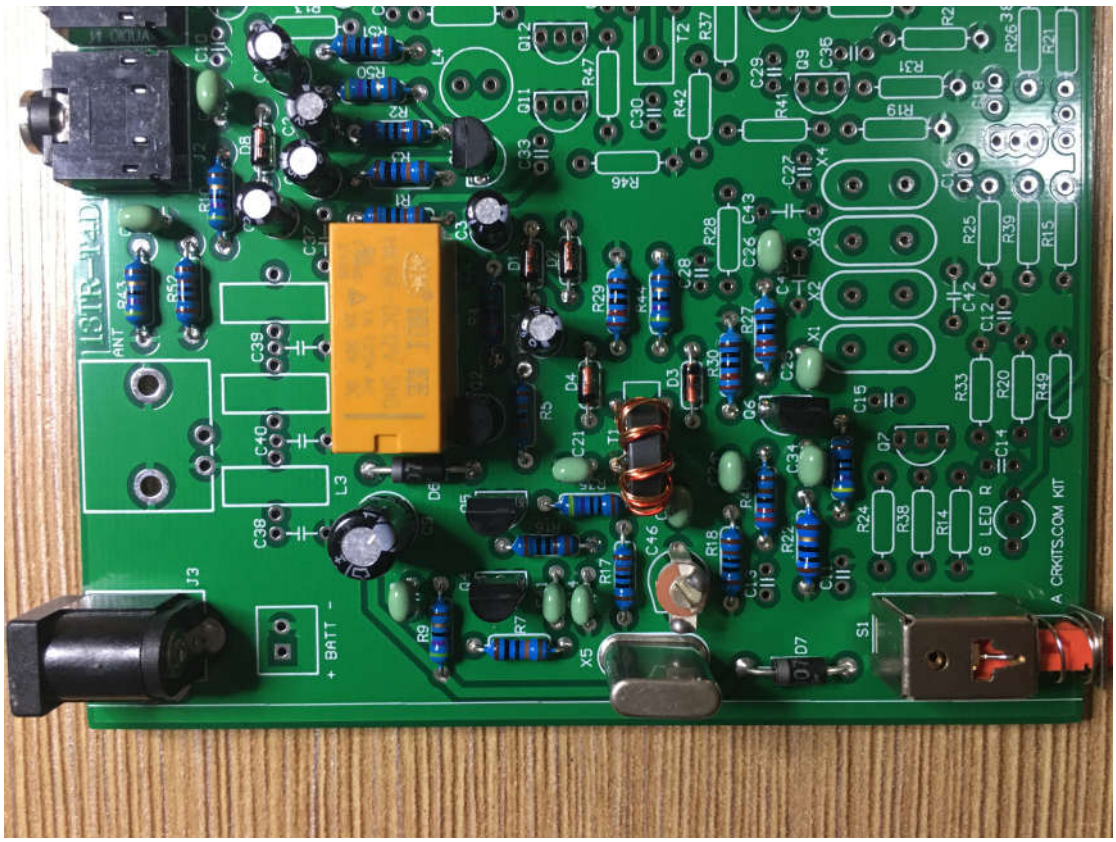


Once you have completed this step, you can apply 150mV RMS 2000Hz sine wave to J2 to check if the relay clicks, and remove the audio source to check if the relay clicks again. If you don't have a signal generator, you can follow my way to download an app (like Sonic Tools on iPhone, choose More - Oscillator) and use your cell phone as the signal generator. You need to set the cell phone volume to the max. To observe the status better, you can install the 3 pin LED and R49 in this step. The shortest pin is for G(Green) and the 2nd shortest pin is for R(Red) and the longest pin in the middle is for common ground. You need to bend the pins so it can protrude outside the panel and install to the same height of the S1 center. You should see solid red when the audio applies to J2.

Step 3: Mixer and TX RF amplifier 1 – T1 and Q6

Please refer to the schematic. You will also need to install R10, C22, C23, R51, R52, C8, C47 and D8 in this step.





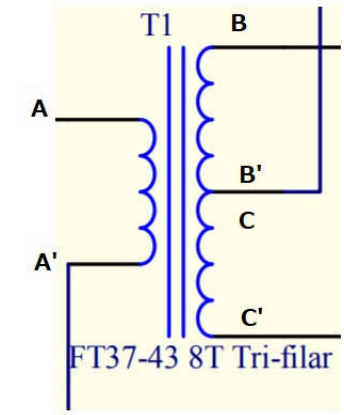
T1 winding is the most complicated part of this kit. It is commonly found in diode ring mixer. W2AEW has a good video to show how you can wind it. The only difference is that we are

winding 8 turns on an FT37-43 toroid using 20 cm red wire and 40 cm golden wire folded in the middle, and the photo might help you as well.

https://www.youtube.com/watch?v=a8ViWS61hsU

I have recorded a dedicated video for T1 and T2 winding in Chinese.

https://mp.weixin.qq.com/s/8dQuNlRKEHyKq9VB69Oynw



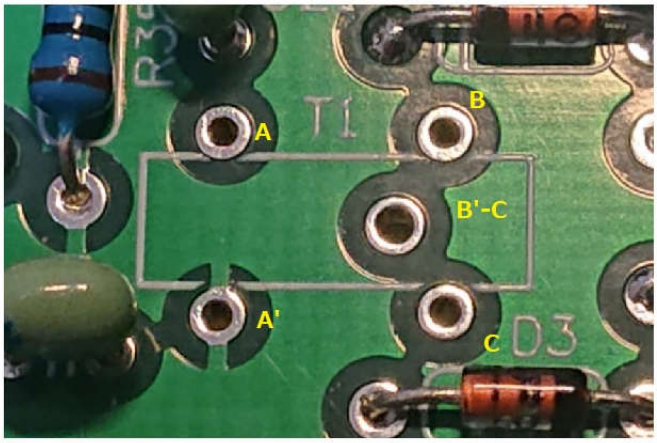
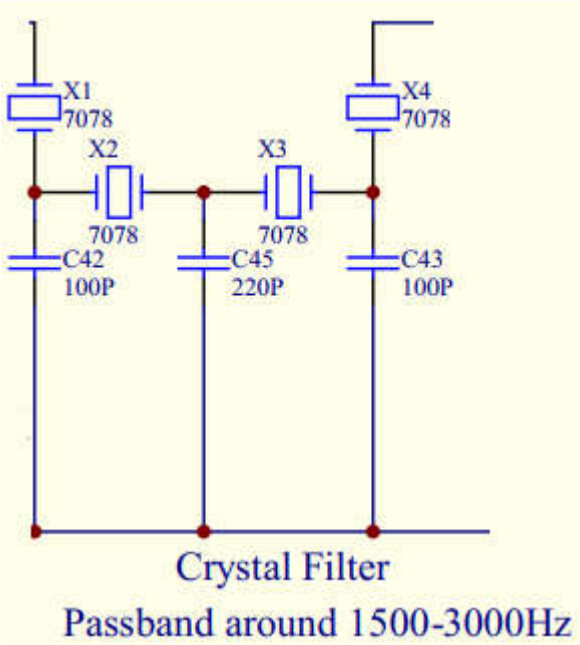
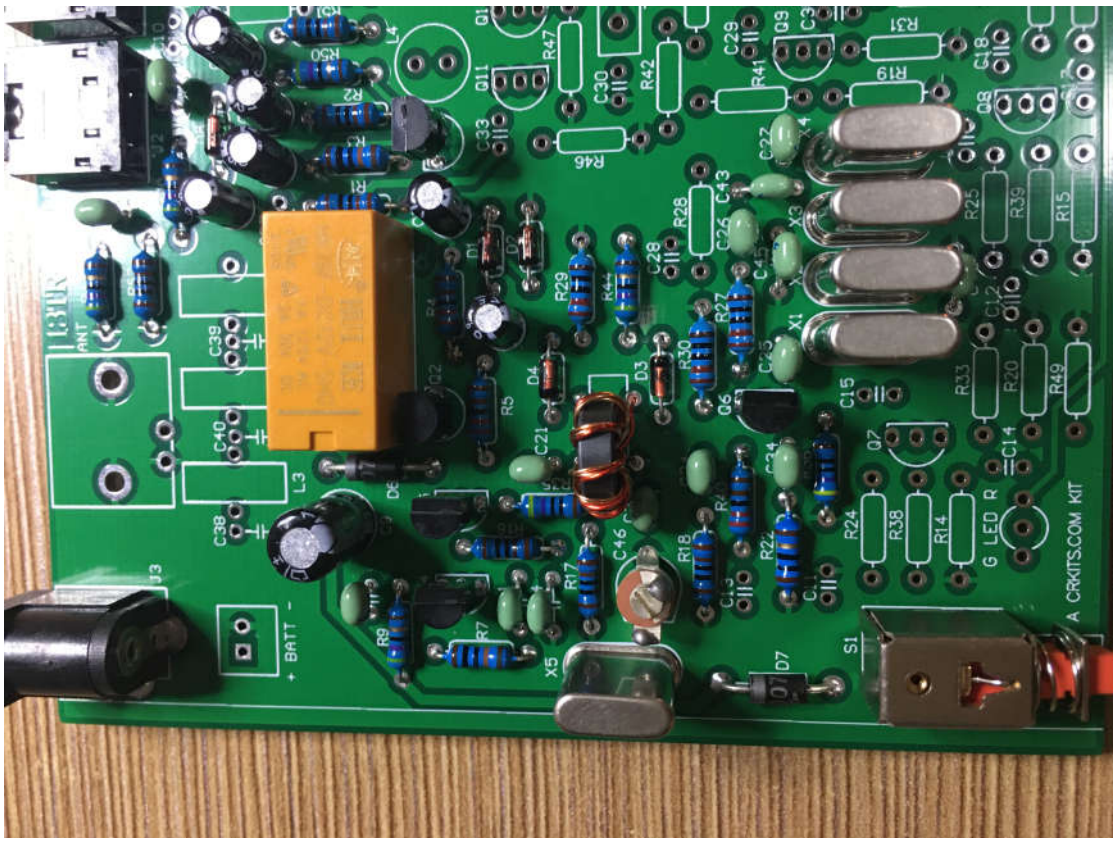


Diagram by JL1KRA. Thanks!

Step4: Crystal Filter – X1-X4

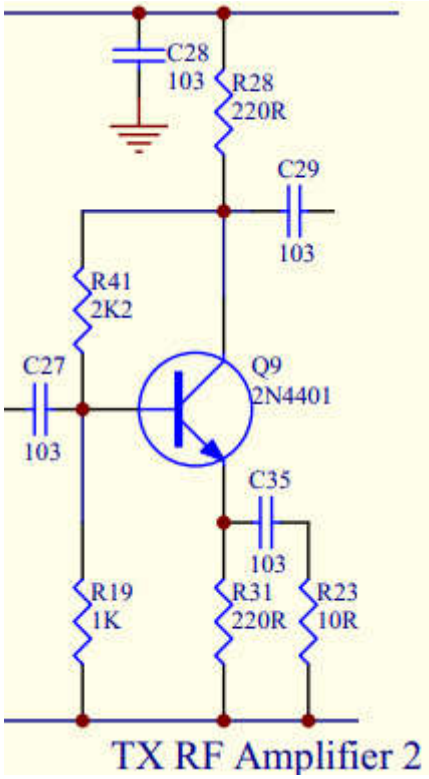
Please refer to the schematic.

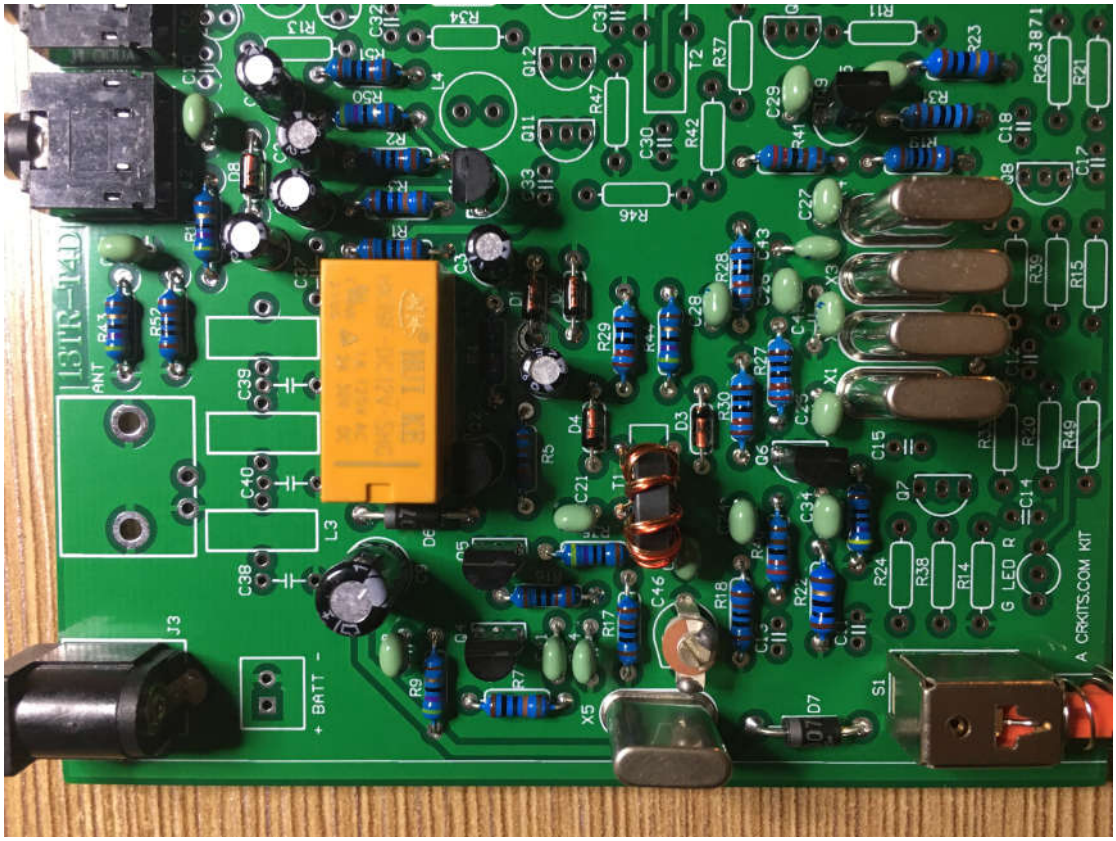




Step 5: TX RF amplifier 2 – Q9

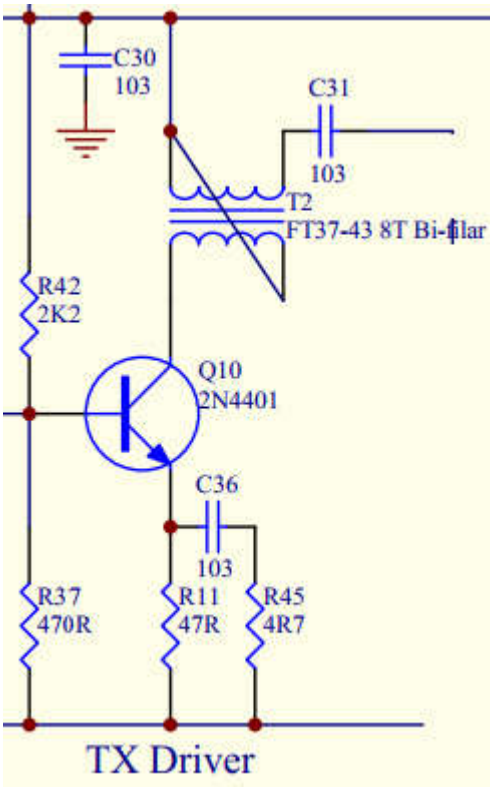
Please refer to the schematic.

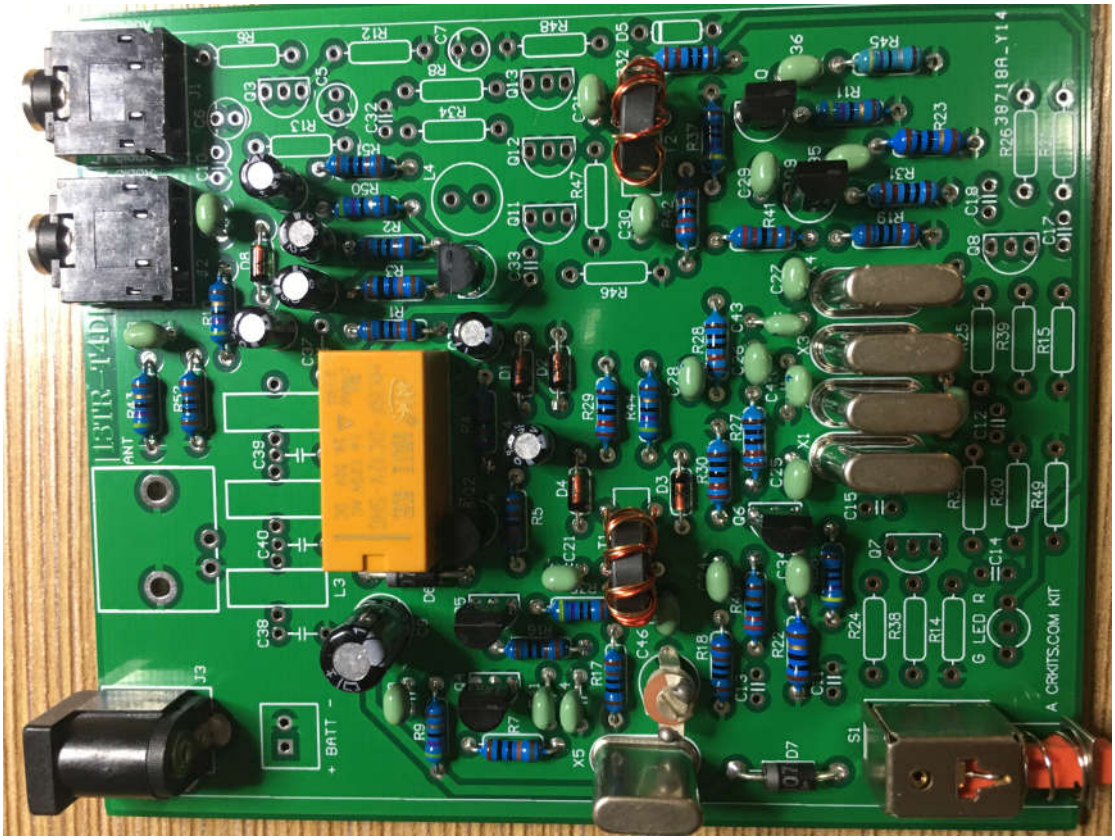




Step 6: TX driver – Q10 and T2

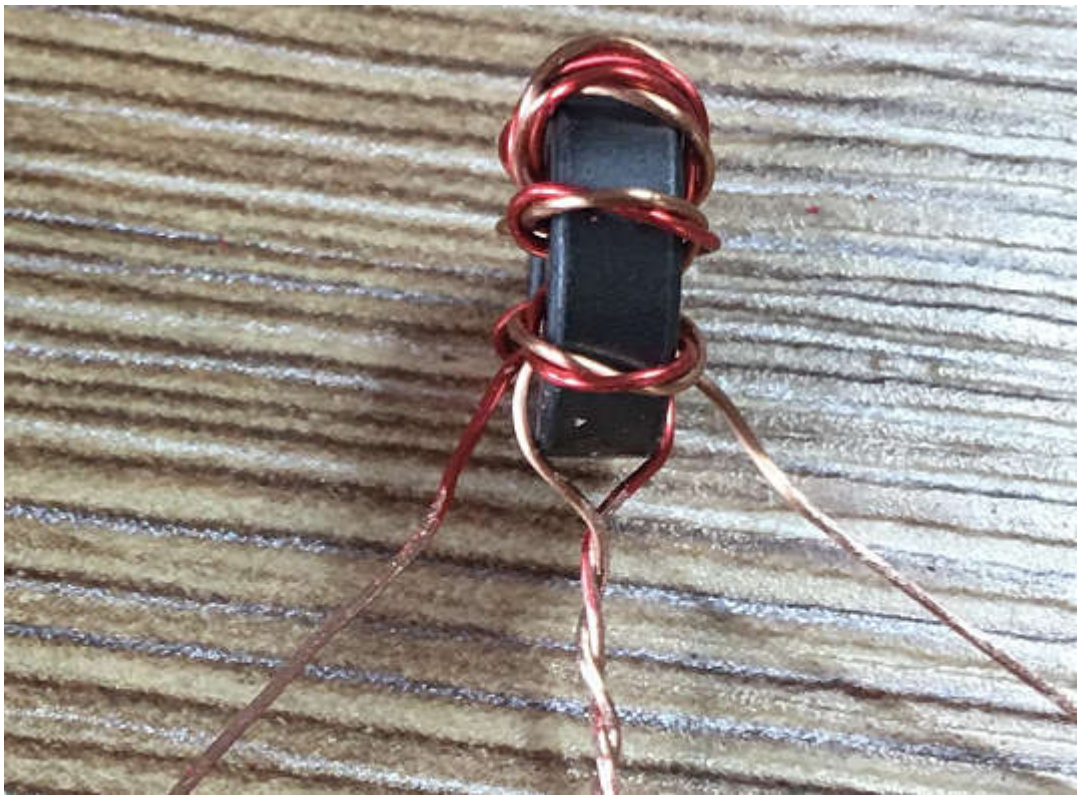
Please refer to the schematic.

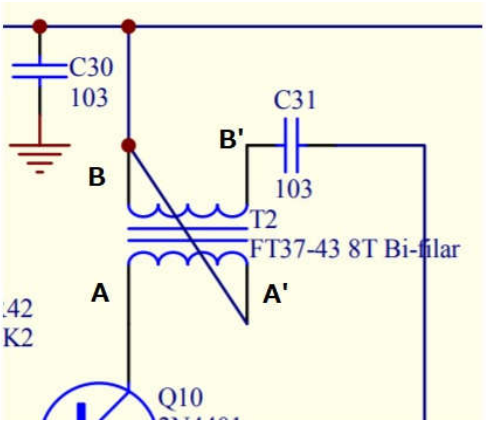




T2 winding is also a complicated part of this kit. We are winding 8 turns on an FT37-43 toroid using 20 cm red wire and 20 cm golden wire, and the photo might help you.

I have recorded a dedicated video for T1 and T2 winding in Chinese.
https://mp.weixin.qq.com/s/8dQuNlRKEHyKq9VB69Oynw





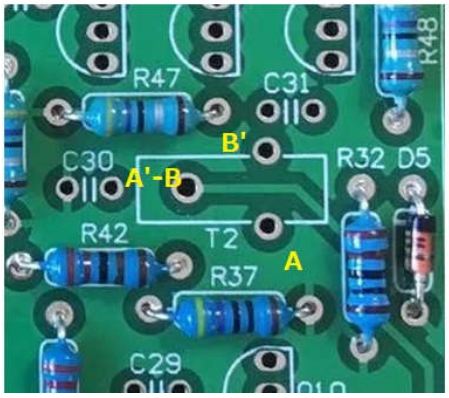
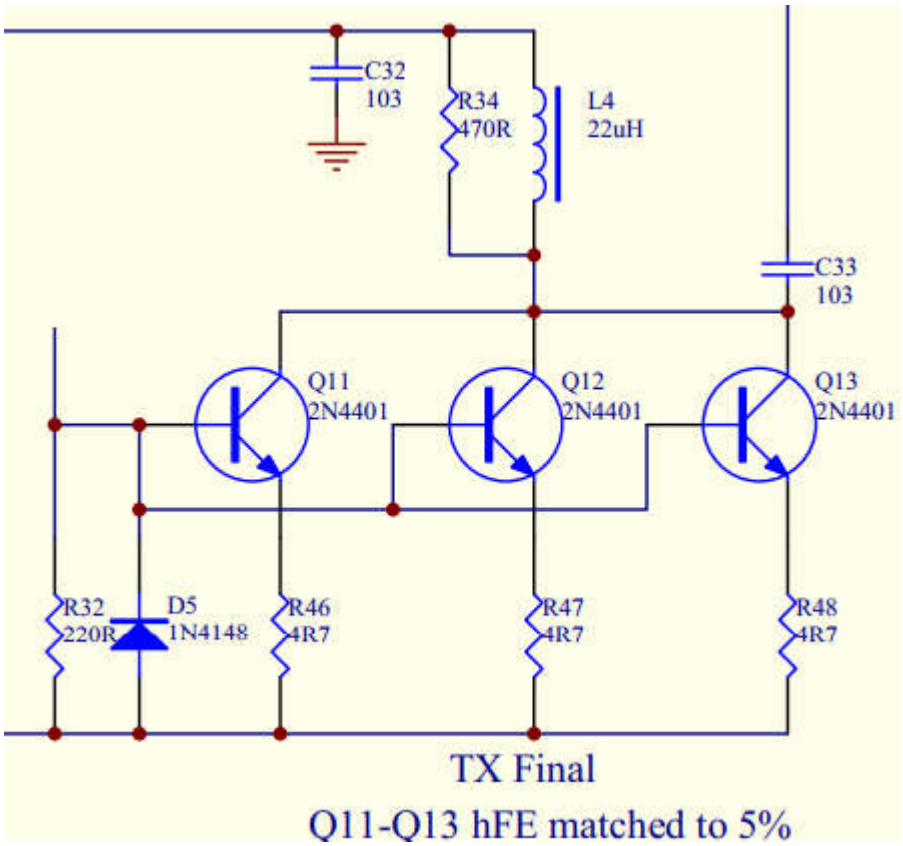
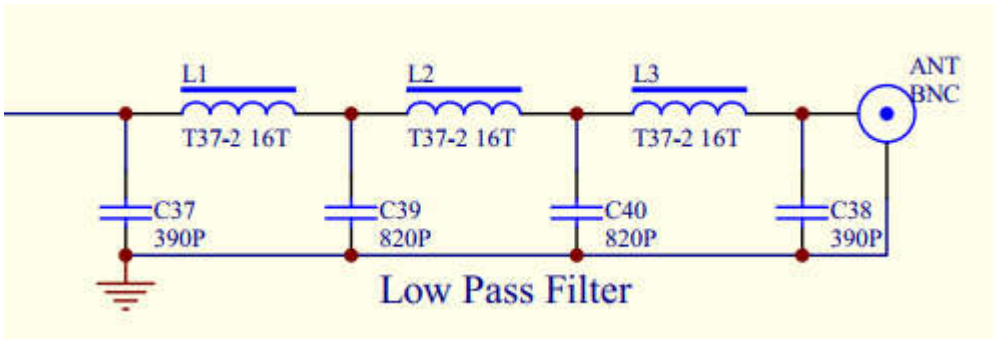


Diagram by JL1KRA. Thanks!

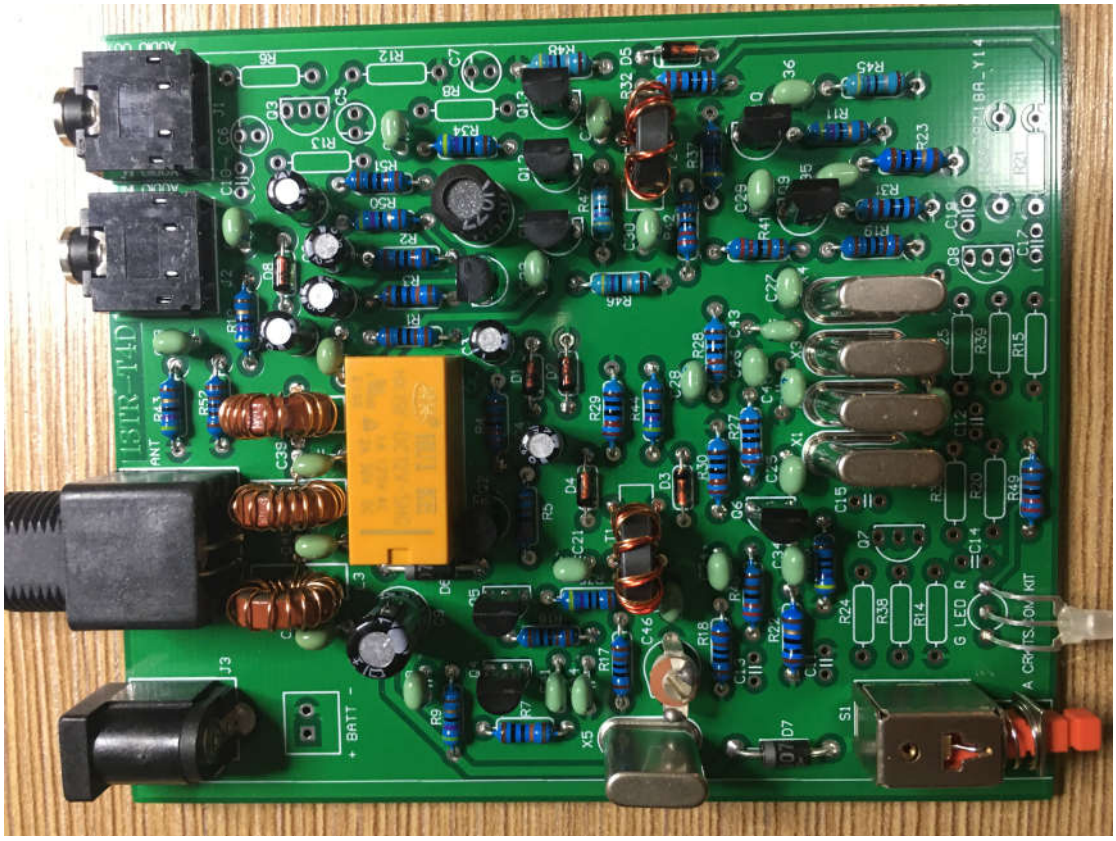
Step 7: TX final and LPF – Q11-Q13 and L1-L4

Please refer to the schematic for TX final and LPF. You will also need to install LED and R49 if you haven't done before.





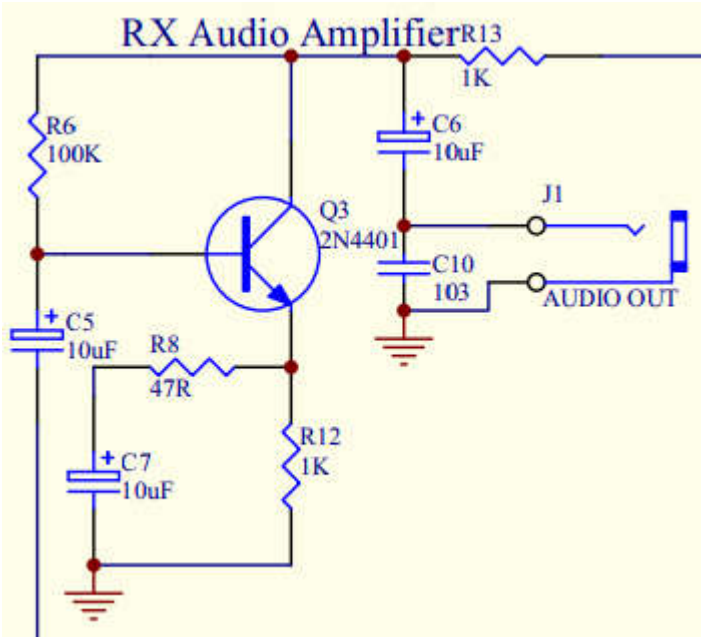
As we mentioned before, it is recommended that you match hFE of Q11-Q13 in 5% range. Normally the hFE is around 200, and the tolerance is 10. Every multi meter has the function. Remember that 2N4401 is a NPN E-B-C transistor. L1-L3 winding is more straightforward. 16 turns on T37-2 toroid using 25cm golden wire.

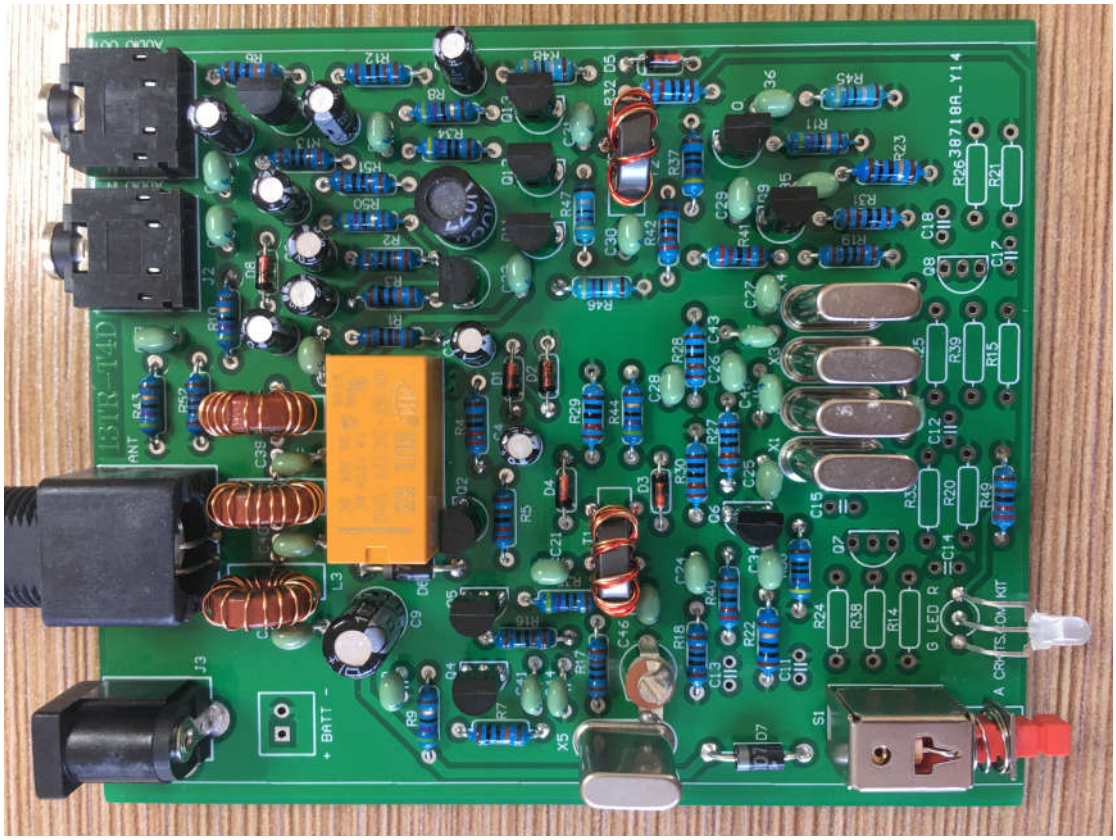


After you have completed this step, you can test the transmitter. Again, you can use your cell phone as the audio generator to generate 2000Hz audio. You will need a 50 ohm dummy load to be connected to the antenna connector. Power on the power supply at J3, switch on S1, and apply audio to J2, and you should hear something in your nearby receiver at around 7.076MHz. If you measure current at S1 when it is off, you can see around 300~350mA current draw in TX.

Step 8: RX audio amplifier – Q3

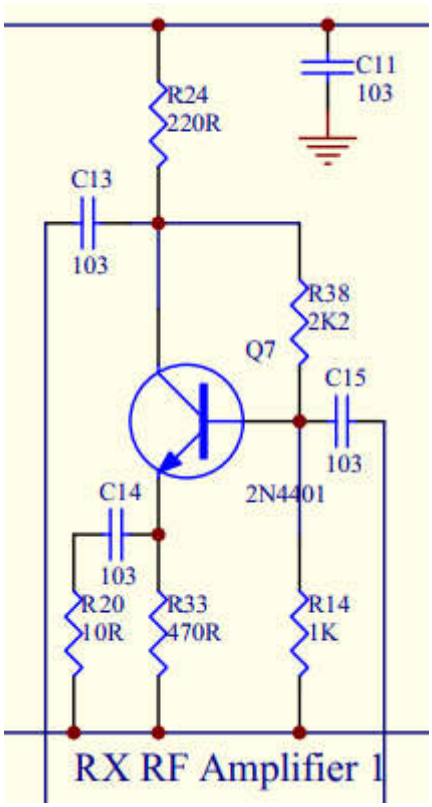
Please refer to the schematic.

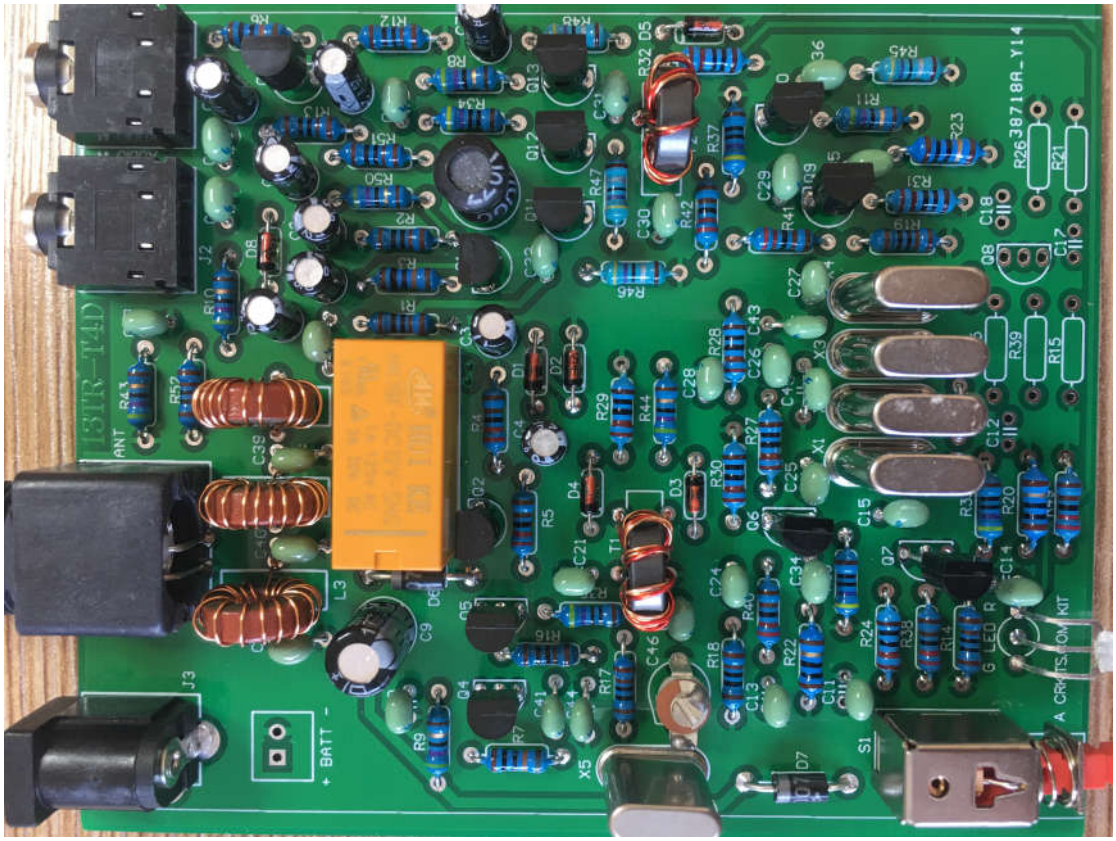




Step 9: RX RF amplifier 1 – Q7

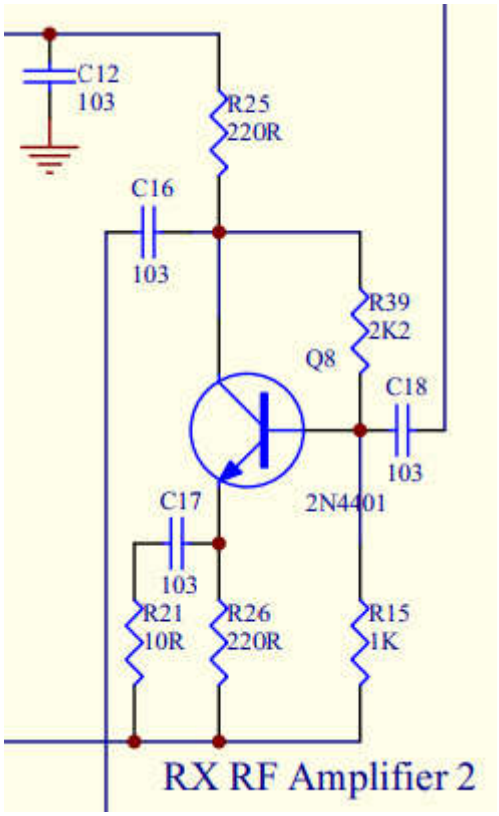
Please refer to the schematic.

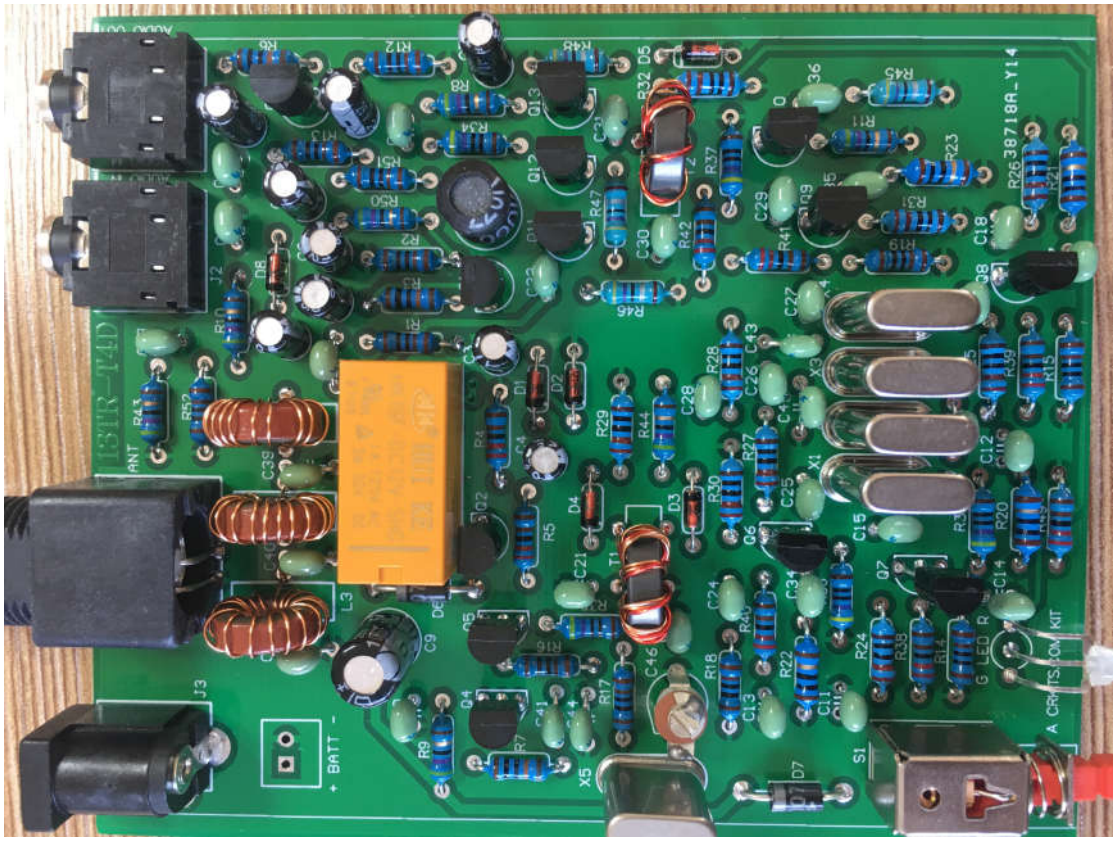




Step 10: RX RF amplifier 2 – Q8

Please refer to the schematic.





After you have completed this step, you can test the receiver. Connect an antenna to the connector.

Power on the power supply at J3, switch on S1, and connect J1 to MIC of your USB sound card. It is recommended to use the sound card with the dedicated jack for MIC. You can use WSJT-x or JTDX to observe the spectrum for on air signals and you should decode something if your computer time is accurate. If you measure current at S1 when it is off, you can see around 50mA current draw in RX.

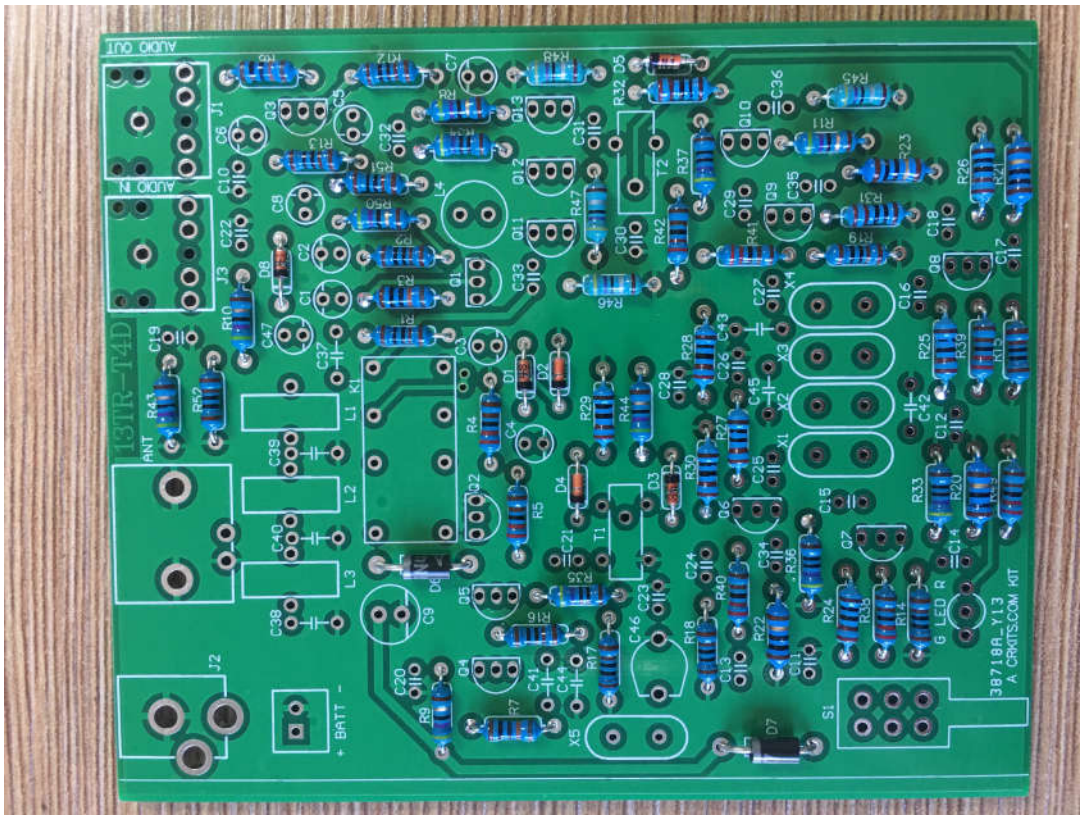
Step 11: Final assembly

Battery installation inside is a bit experimental. If you wish to do so, you'd better understand the potential risk. Just solder the wires to the battery pads (+/-) and stick to BNC and relay surfaces using double sided tape. Don't use double sided tape with foam as the top cover will interfere with the battery holder. Make sure you hold it steady and don't short with any other parts. Make sure you understand the risk of over charging and over discharging. I am not showing the position as this is experimental.

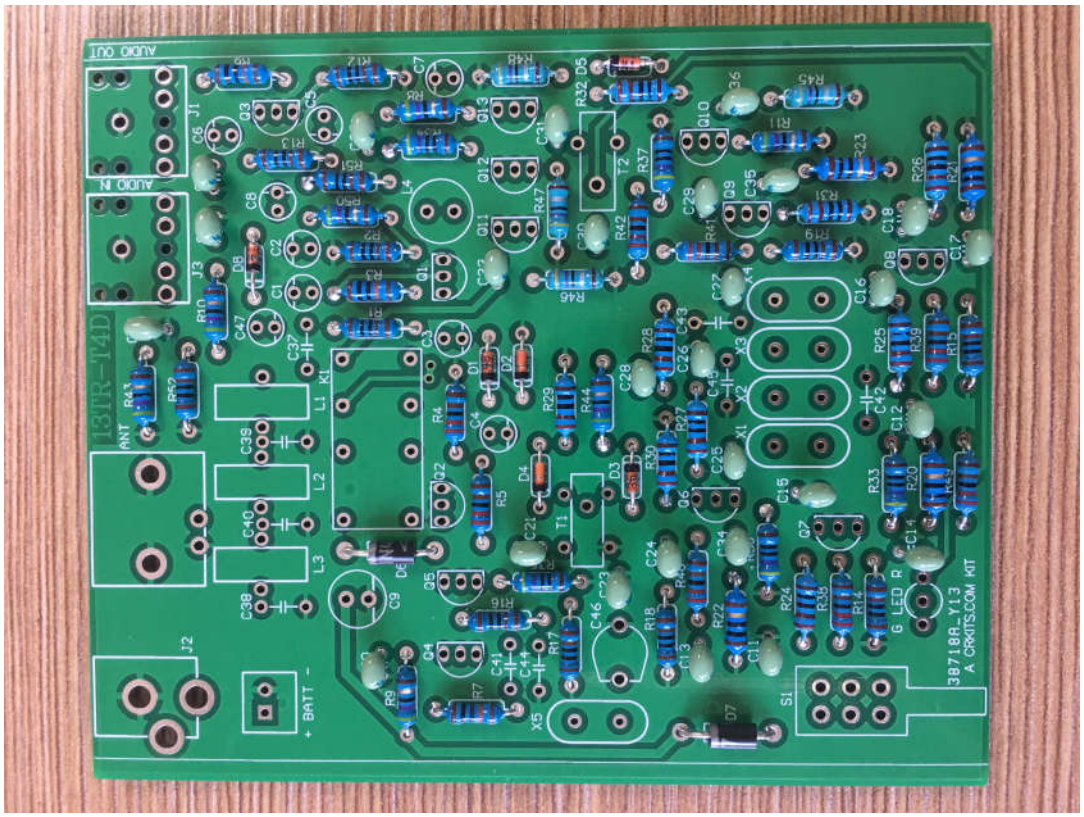
Speed mode

If you are an experienced builder, please consider this mode to save build time.

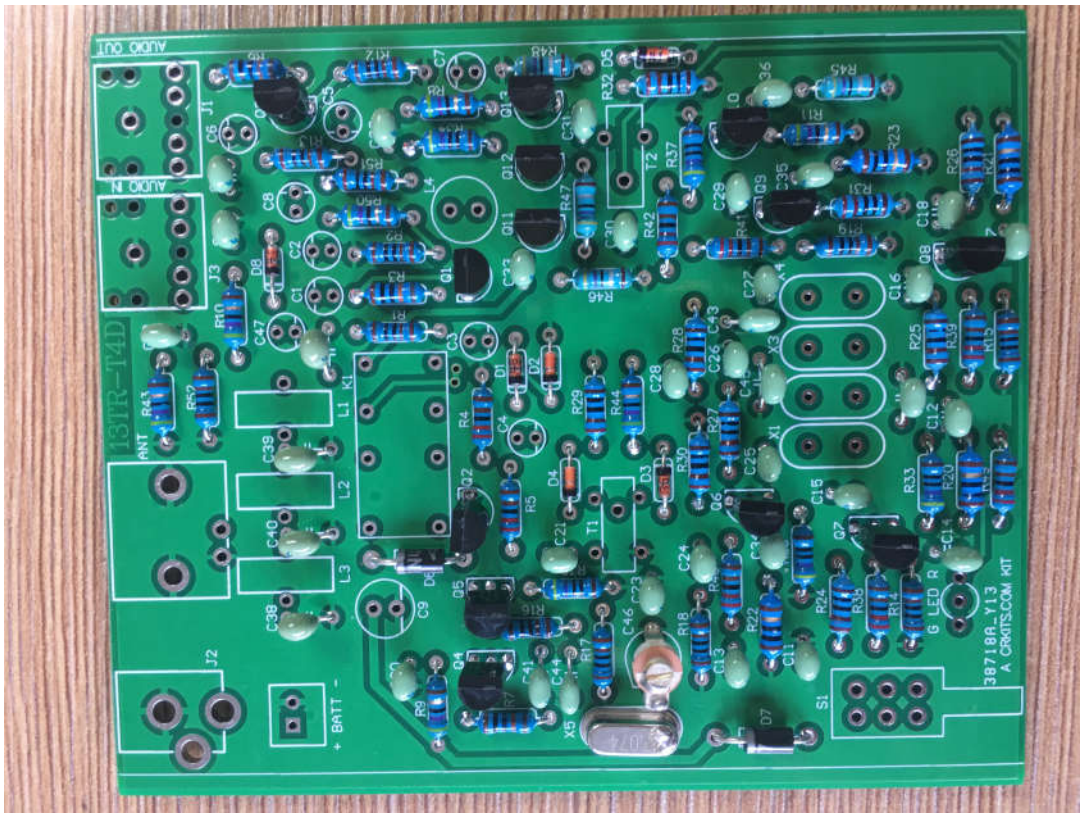
Step 1: Start with all the resistors and diodes.



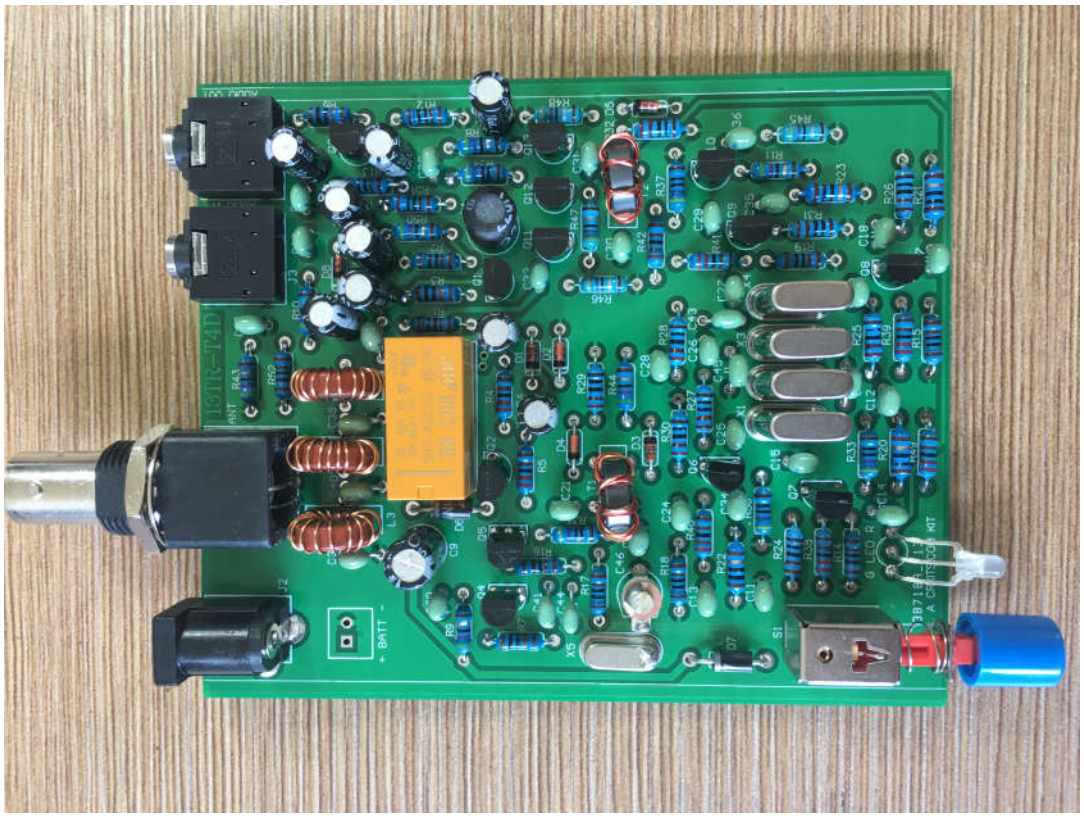
Step 2: Then all the 103 capacitors.



Step 3: Then all the 2N4401 transistors and other parts.



Step 4: Finish the board build with rest of the parts. Please refer to the above for the toroids winding, especially T1 and T2.



Step 5: Put on the case and finalize the kit assembly.


3871BAY11-210626
14V
OUT
IN
AUDIO

Alignment

During the above kit assembly, you already aligned frequency of the local oscillator, and measured both RX and TX current. As the actual working temperature might increase a bit, it is recommended that you fine tune the frequency during actual operation after 3 mins.

I use a known aligned receiver with TCXO. Inject 2000Hz into the kit to activate TX and you can hear a tone in your aligned receiver nearby. Again, use your Sonic Tools alike app to measure the audio spectrum to find the peak of the tone. Adjust the C46 to make the peak as close as 2000Hz and it is good.

Use the TUNE function and always adjust the audio output of your WSJT-x or JTDX software so that VOX is just stably triggered. If you increase the audio level, you will likely get a bit higher RF output, but at the cost of distortion. On some occasion, you may find a specific point where your relay is chattering. You should always avoid that point.

Operation

Cable connection:

- Use a USB sound card with separate MIC and HEADPHONE jacks
- Connect Audio Out to MIC, and Audio In to HEADPHONE

Software setup:

- Set PTT mode - VOX and Radio - None
- Adjust Audio Levels for RX around 50dB and for TX to just stably trigger the VOX

Note: The software setup is very similar to the D4D. Please refer to the D4D kit assembly manual for more information. See Step 8 starting from page 20.
https://groups.io/g/crkits/files/D4D%20Kit%20Documentations/D4D%20Kit%20Assembly%20Manual%20Rev.D.pdf

Fix TX Frequency operation:

- **Notice**: Keep TX frequency in filter pass band or your RF output will be down to zero.
- So it is better you choose a clear TX audio frequency between 1500 and 3000Hz and choose to fix the TX frequency, especially when you answer a call

QRP operation techniques:

- Answer the strong signal and you have better chance to be heard
- When the propagation opens like Gray Line period, you can call CQ as well

Work with your Android phone with FT8CN App:

- Download the latest version FT8CN and install on your Android phone or tablet from https://github.com/N0BOY/FT8CN/releases
- Use an OTG cable and connect a USB sound card with separate MIC and HEADPHONE jacks
- Now you can use FT8CN to send and receive FT8 together with 13TR

Links

- Larry's Manual with BOM in each step

http://www.qrvtronics.com/CatHAM_Radio/files/13_Transistor_DigitalTransceiver.pdf

- JK1EJP's step by step LTspice simulation, building and testing of 13TR (Japanese)

https://jk1ejp.hatenablog.com/

- VK3YE video review

https://www.youtube.com/watch?v=pAJE7IKOuPw

- Further reading about reviews and articles about 13TR

https://groups.io/g/crkits/files/13%20Transistor%2040m%20FT8%20SSB

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