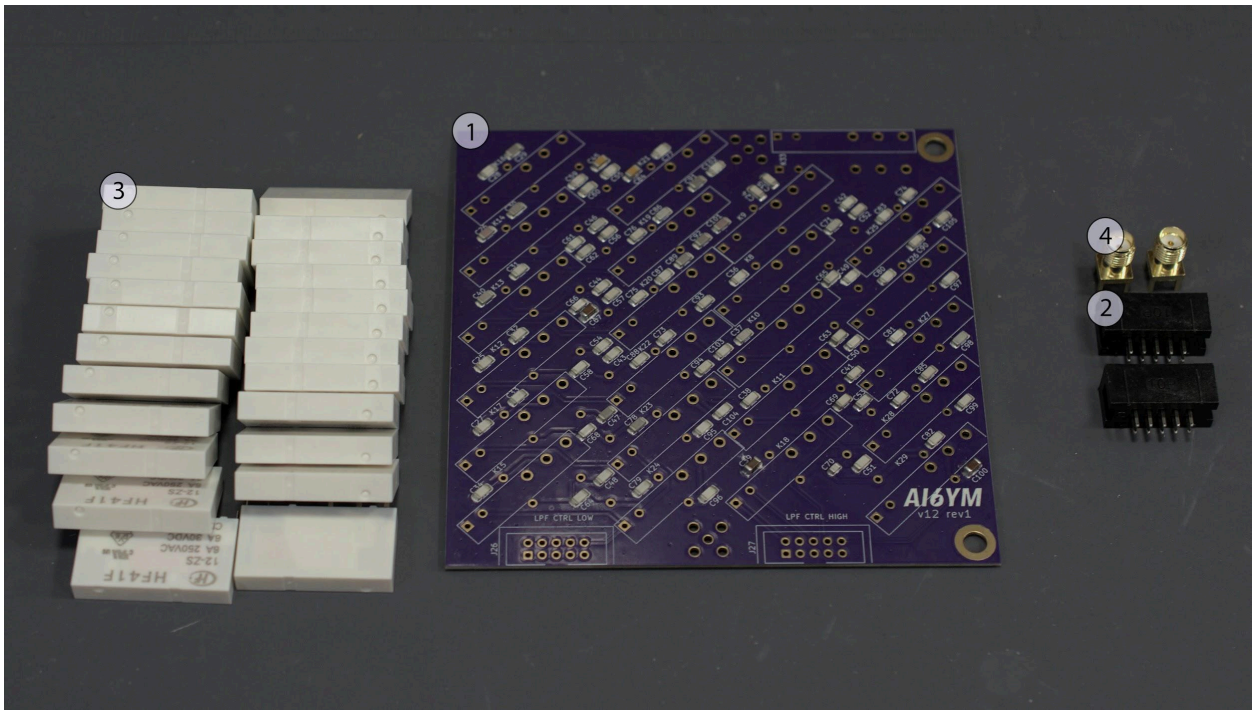
T41-EP SDT v12 LPF Module Assembly Manual



The T41 V12 LPF board filters out harmonics generated by the PA (power amplifier), ensuring a clean transmission in-line with FCC spurious emissions requirements and good operating practice.

The board consists of eleven independent low pass filters and a bypass channel which are relay switched on the input and output side. My kit includes the parts necessary to build filters capable of handling 100W. Control of the relays is provided by the LPF Control Board via two 10-conductor ribbon cable connections. The relays may also be controlled by any system providing 12V (30mA) on the appropriate pin. No other source of power is required.

The typical response of these filters is better than -60dB at the second harmonic with an insertion loss better than 0.5dB.

What's Included (Parts List)

1. (1) LPF Board
2. (3) 2×5 IDC Box Header

3. (24) 12V Relays
4. (2) SMA PCB Connectors
5. (3) T68-17 (Blue) Toroid Cores (not pictured)
6. (21) T68-6 (Yellow) Toroid Cores (not pictured)
7. (9) T68-2 (Red) Toroid Cores (not pictured)
8. 14M (45') of #20 Magnet Wire (not pictured)

Missing a part? Send an email to justin@ai6ym.radio.

You Will Need

1. Soldering Station, hot air or separate heat gun optional but recommended.
2. Multimeter
3. PCB Vise or Helping Hands
4. Jewelers Loupe
5. Wire cutters
6. Sandpaper or Hobby Knife
7. Solder of your preference, 60/40 tin/lead is recommended.
8. Flux Paste
9. Polyimide (Kapton) Tape
10. Solder Wick
11. Bench Vise (optional)
12. Crochet Hook (optional)
13. NanoVNA (or comparable)

Safety Matters!

Soldering irons are hot. Everything they touch gets hot.

Have a fire extinguisher nearby!

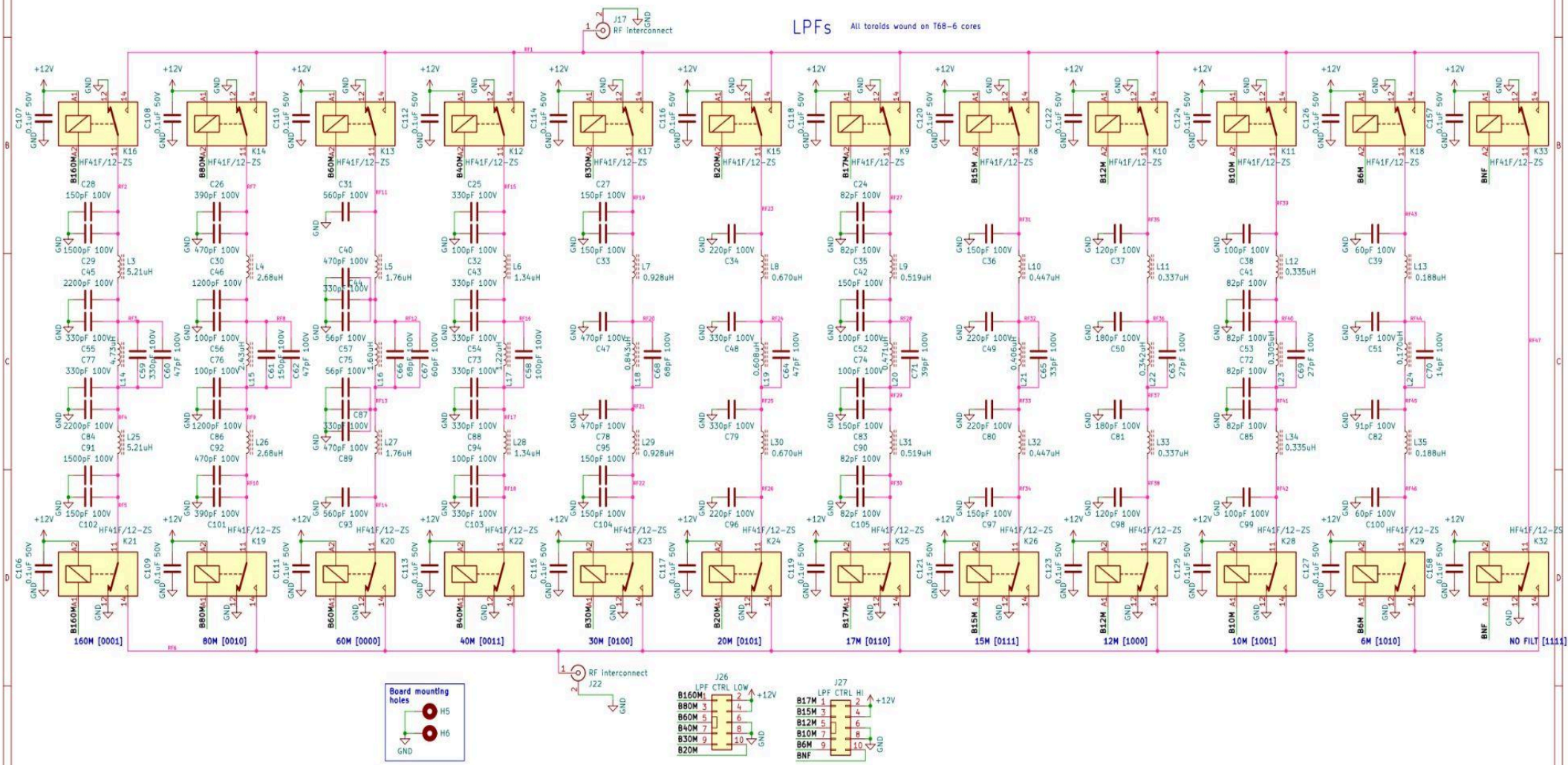
Solder splatters. Your eyes are not easily replaceable.

Wear your PPE!

Fumes from heating the enamel coating on magnet wire can be dangerous.

Work in a well ventilated area!

Schematic



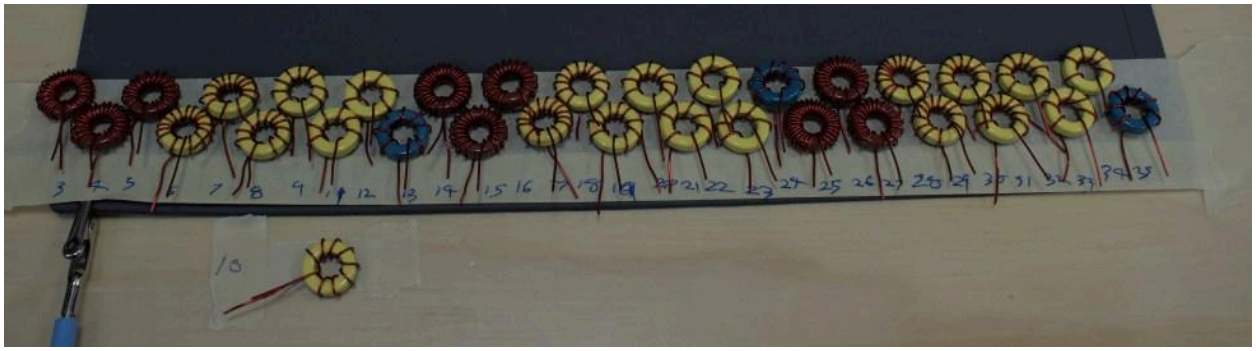
Designed by WJ Schmidt-K9HZ
Layout by OG King-KI3P

Sheet: /
File: lpf.kicad_sch

Title: K9HZ 100W 11 Band LPF: Filter board

Size: A3	Date: 2024-01-17	Rev: V1.00
KiCad E.D.A. 8.0.4		Id: 1/1

Prepare Your Inductors



Before you begin this process ask yourself if you can count, try to be objective. Are you sure? This process may show that you can't. Be prepared to accept that fact.

For a quick method of toroid winding check out my tutorial on the twine lock method of toroid winding. Follow the table below, double check the turn count of every inductor, and keep the finished inductors organized.

Feel free to skip inductors for bands you don't plan to use. Keep in mind that the V12 RF Board doesn't actually support 160M yet and support may not be possible without rework or entirely new boards. I'm assembling all bands so my boards are the most capable they can be.

Band	Inductor	Toroid Core	Turns
160M	L3	T68-2 (Red)	30
	L14	T68-2 (Red)	28
	L25	T68-2 (Red)	30

80M	L4	T68-2 (Red)	21
	L15	T68-2 (Red)	20
	L26	T68-2 (Red)	21
60M	L5	T68-2 (Red)	17
	L16	T68-2 (Red)	16
	L27	T68-2 (Red)	17
40M	L6	T68-6 (Yellow)	16
	L17	T68-6 (Yellow)	15
	L28	T68-6 (Yellow)	16
30M	L7	T68-6 (Yellow)	13

	L18	T68-6 (Yellow)	12
	L29	T68-6 (Yellow)	13
20M	L8	T68-6 (Yellow)	11
	L19	T68-6 (Yellow)	10
	L30	T68-6 (Yellow)	11
17M	L9	T68-6 (Yellow)	10
	L20	T68-6 (Yellow)	9
	L31	T68-6 (Yellow)	10
15M	L10	T68-6 (Yellow)	9
	L21	T68-6 (Yellow)	7

	L32	T68-6 (Yellow)	9
12M	L11	T68-6 (Yellow)	7
	L22	T68-6 (Yellow)	7
	L33	T68-6 (Yellow)	7
10M	L12	T68-6 (Yellow)	7
	L23	T68-6 (Yellow)	7
	L34	T68-6 (Yellow)	7
6M	L13	T68-17 (Blue)	8
	L24	T68-17 (Blue)	8
	L35	T68-17 (Blue)	8

Strip the leads of each inductor by sanding lightly or scraping with a sharp blade. If using a blade be careful not to nick the copper wire which may cause it to break during assembly.

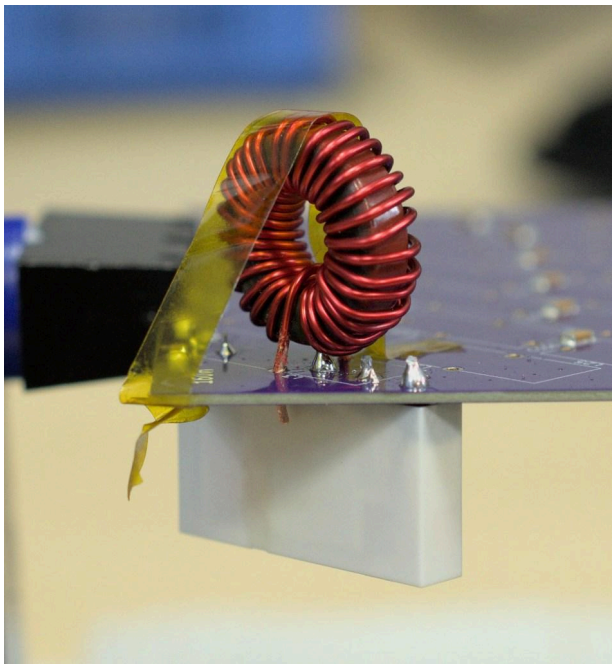
Note: The wire included in my kits is high-build, high-temperature enamel. This is a great choice for long-term durability but it makes stripping the enamel coating off the wire a bit more difficult. Heating the wire with your soldering iron will NOT be sufficient.

It's ok to rewind coils. I made several mistakes building this board and rewound several toroids. I've included extra wire in my kits for this purpose but additional wire is available inexpensively from many fine retailers.

Pro-Tip: Organize and label your inductors carefully, double-sided tape can be a great help for this.

Assembling the Filters

The low pass filters (LPFs) require little, if any, tuning. In this manual, the complete board is assembled before any testing or tuning, if you prefer you may assemble each filter individually and test it before moving on to the next filter.



This board is densely populated, the relays are placed on the opposite side of the board as the inductors with solder joints from each directly under the component on the opposite side. This can make assembly quite challenging.

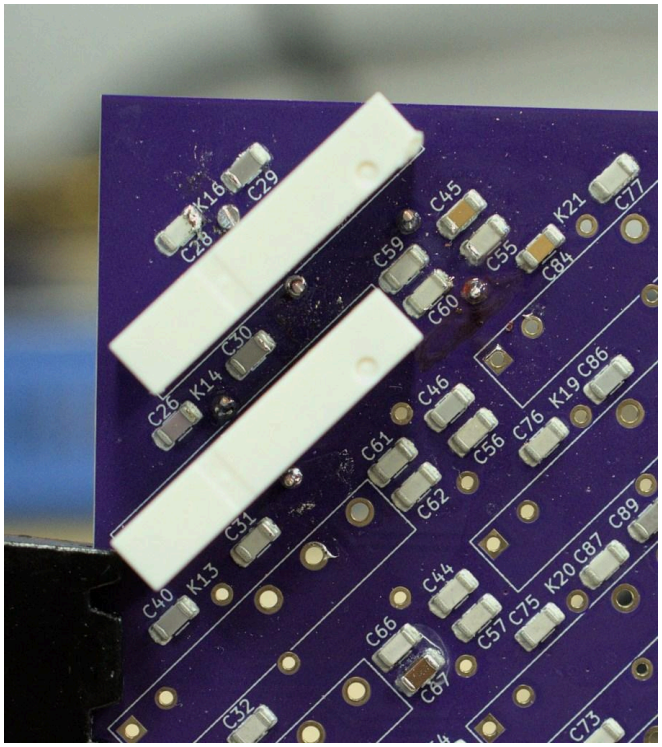
Alternate assembly between inductors and relays, giving yourself the greatest amount of clearance around the joints you are soldering. Place inductors first, these are easier to work around and less susceptible to damage from the soldering iron.

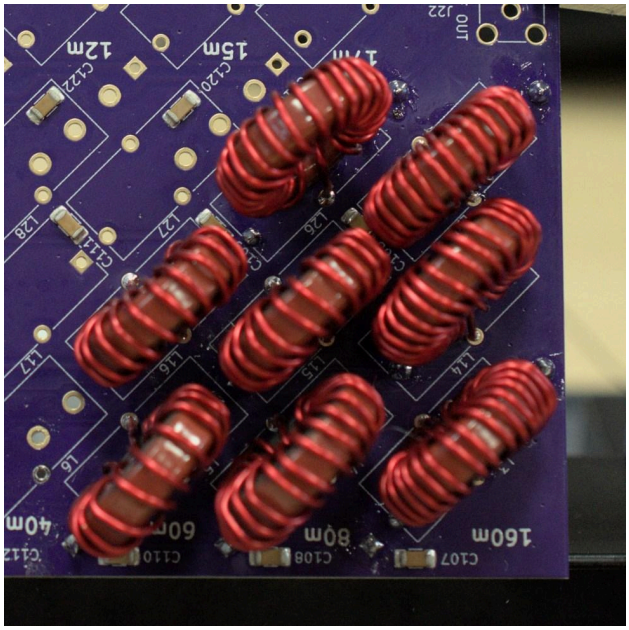
Pro-Tip: By leaving the leads of the inductors slightly long the inductor can be moved slightly allowing clearance to reach relay pins. This is critical for some of the relays, where a pin is directly under the core of an inductor.

Start at one corner of the board, place the first inductor, secure it with tape, and solder it in place. Use a multimeter to check continuity across the inductor (between the solder joints) before trimming off any excess wire.

Pro Tip: Use a bit of extra heat (my iron is set to 370C / 700F) and a lot of flux to help break through the remaining enamel coating on the wire.

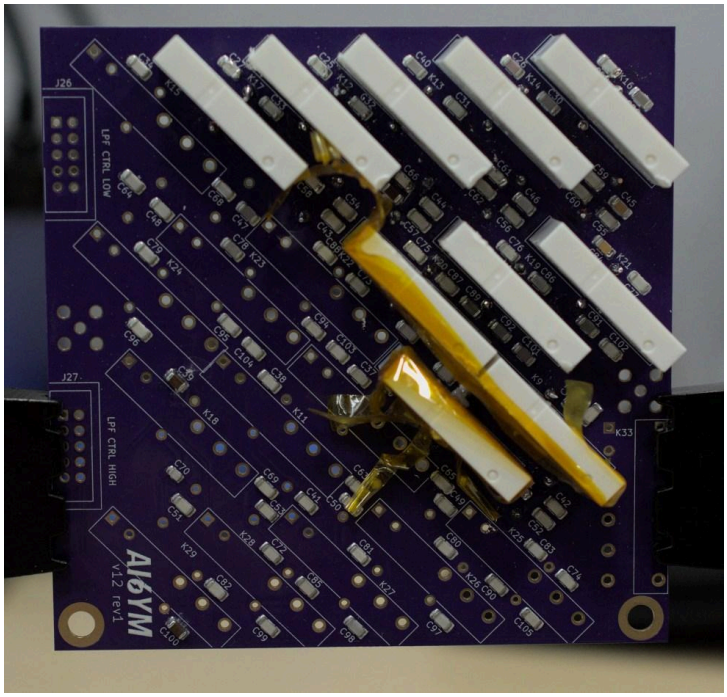
On the opposite side of the board, place the relay which is in the same position and secure it with tape. Solder one pin then check alignment of the relay. It should be flat against the board, not tilted or otherwise askew. Solder a second pin and check the alignment again before soldering the remaining pins.

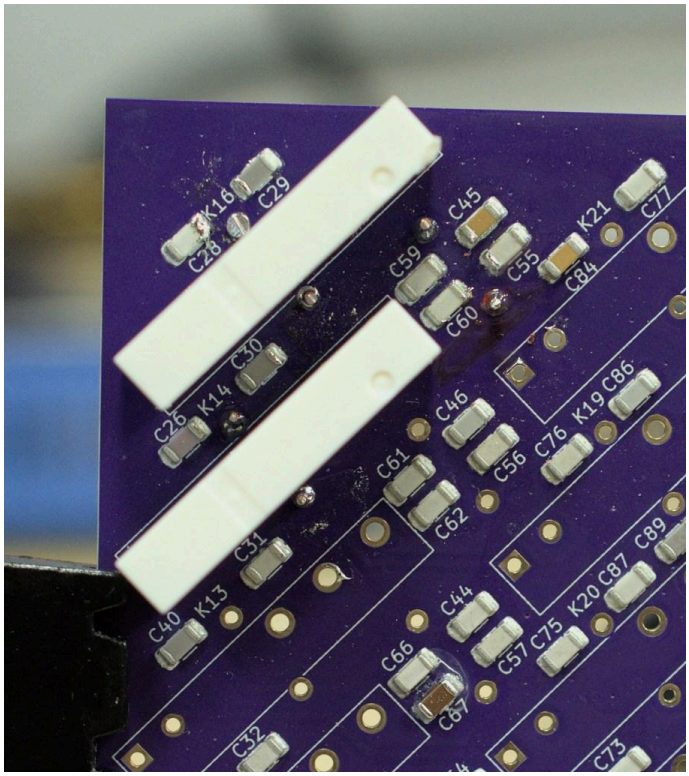




Continue alternating between inductors and relays, soldering inductors first when relays utilize the same board space. Work in whichever direction is most comfortable for you (e.g. right to left may be easier for a left handed person while left to right is easiest for someone who is right handed).

Pro-Tip: If you need to touch up a joint after relays are in place around it, use a heat shield to protect the plastic casing of the relay. A couple layers of aluminum foil or 3-5 layers of polyimide tape is quite effective.




K16
C29
C28
C45
C59
C55
K21
C77
C84
C60
C30
C46
K19
C86
C26
K14
C76
C61
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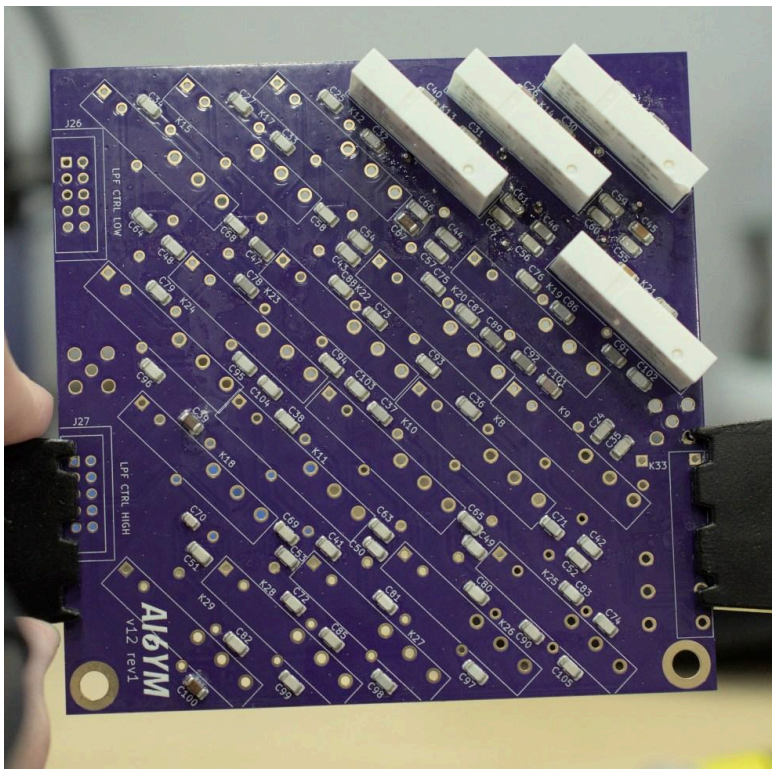
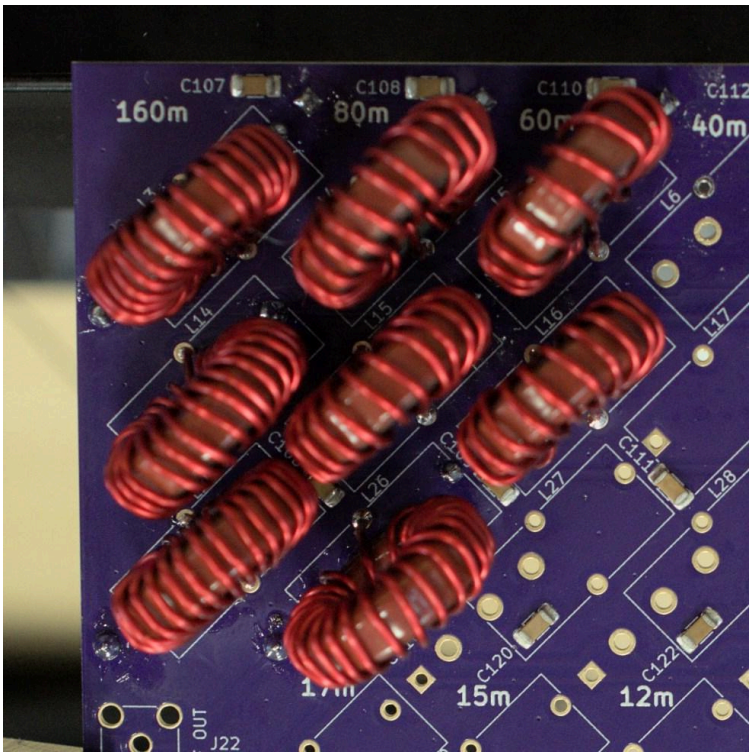
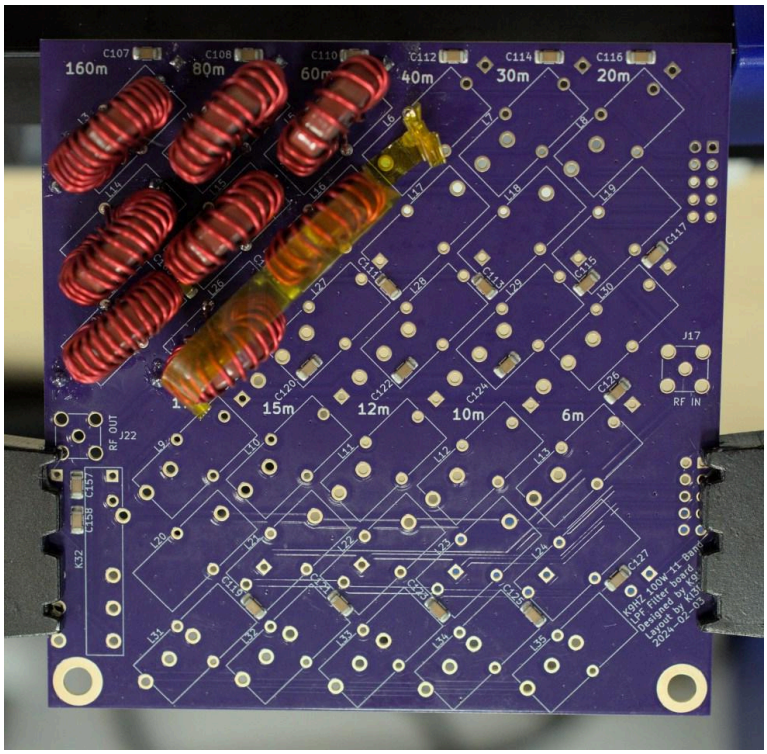
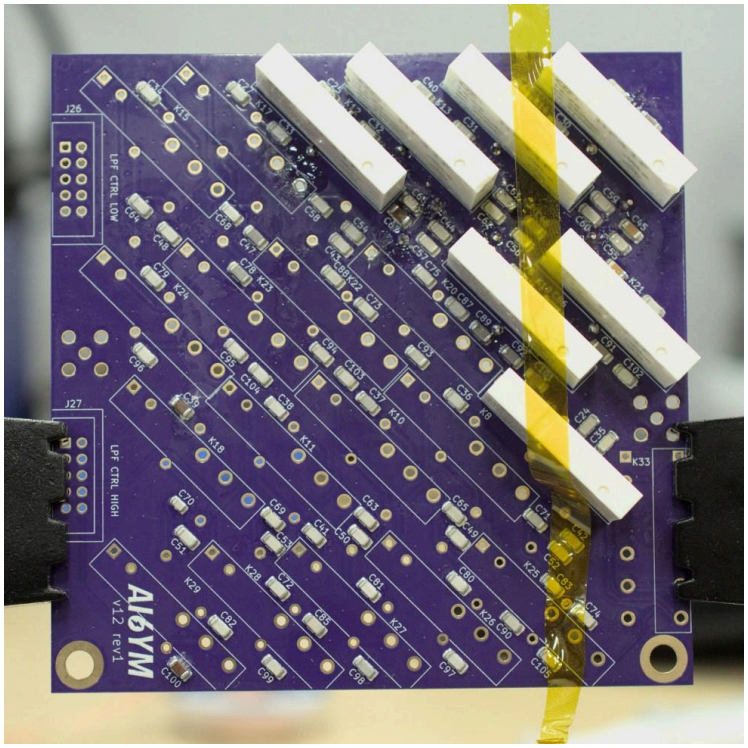
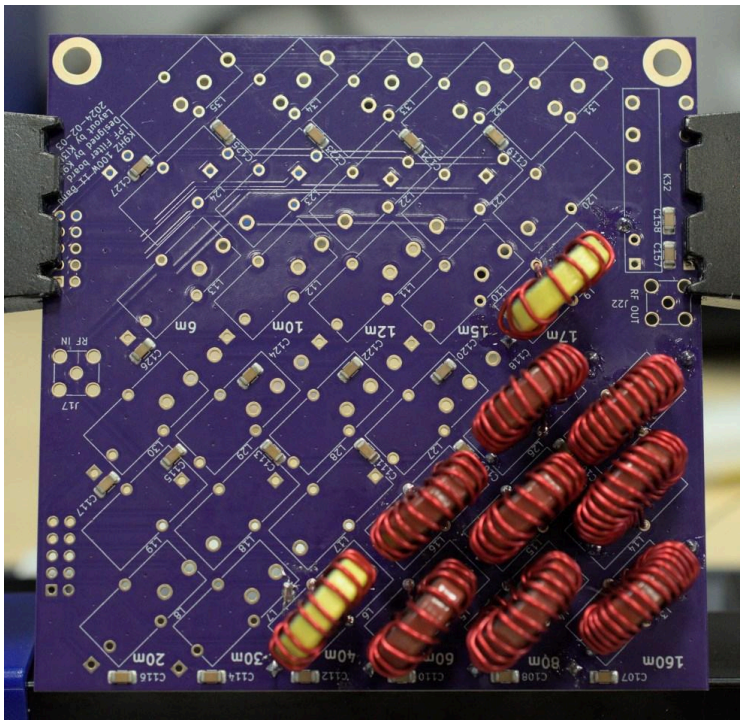
K13
C75
C57
C66
C67
C32
C73

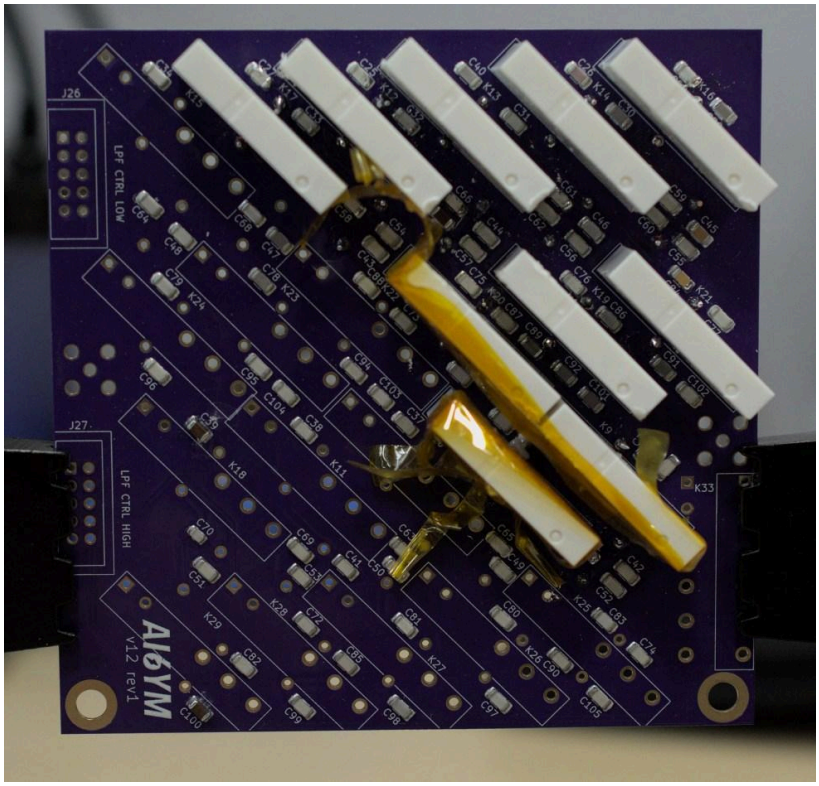

J26
LPF CTRL LOW
J27
LPF CTRL HIGH
AI6YM
V12 rev1

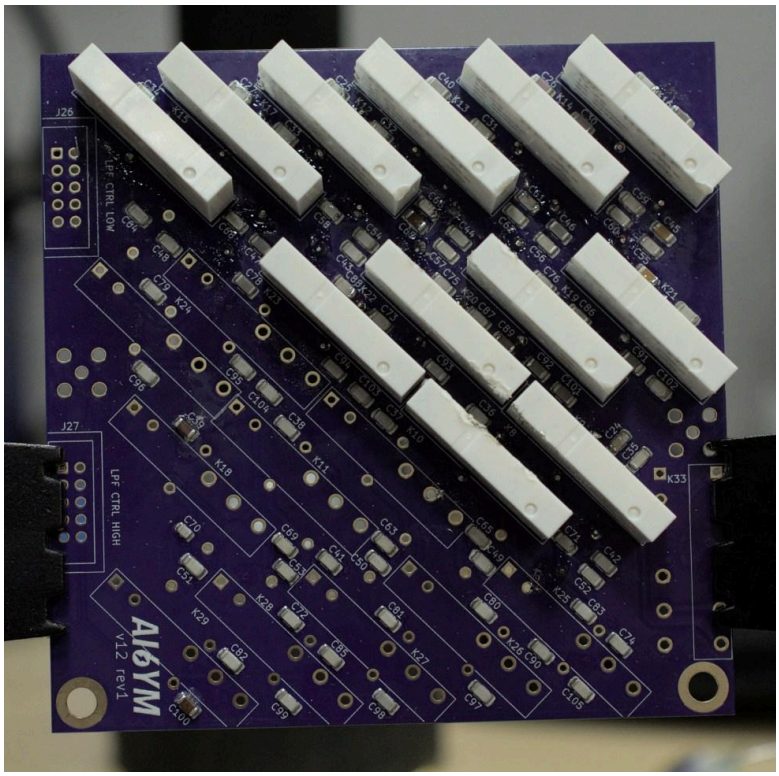

C107
C108
C110
160m
80m
60m
40m
L14
L15
L16
L17
L26
L27
L28
C120
C122
15m
12m
OUT
J22

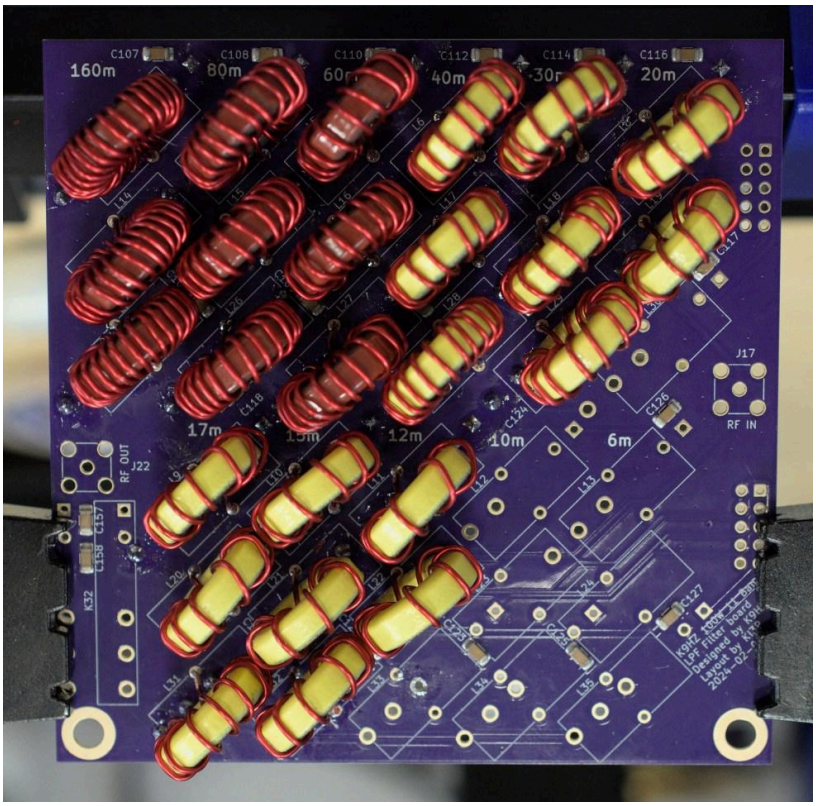

C107
C108
C110
C112
C114
C116
160m
80m
60m
40m
30m
20m
15m
12m
10m
6m
J17
RF IN
J22
RF OUT
K32
C157
C158
C127
KGHZ 100W 11 Band
LPF Filter board
Designed by KG
Layout by KG
2024-02-05

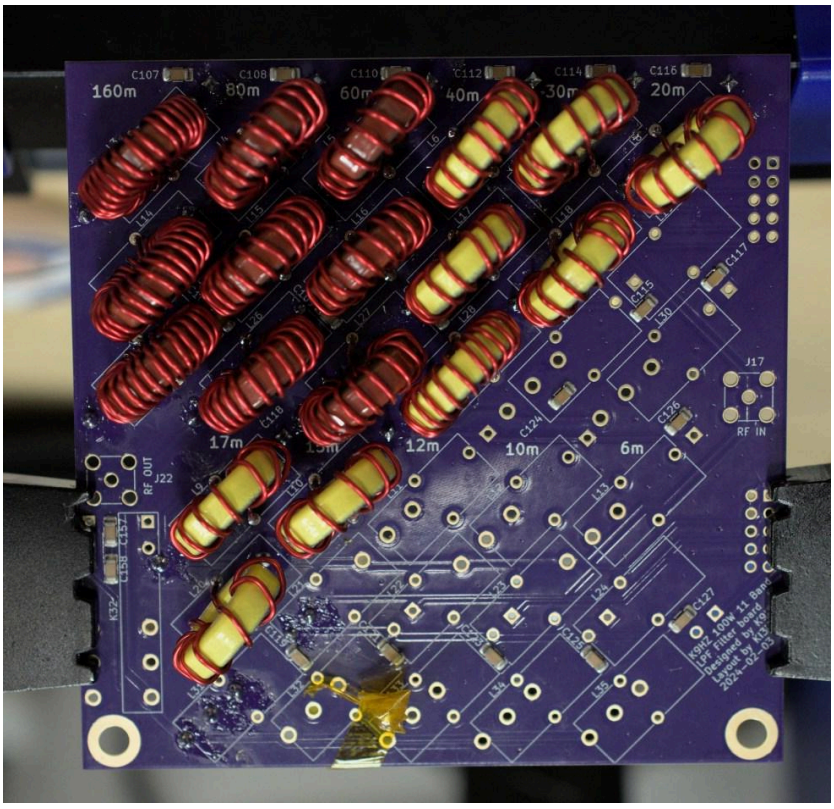

J26
LPF CTRL LOW
J27
LPF CTRL HIGH
AI6YM
v12 rev1

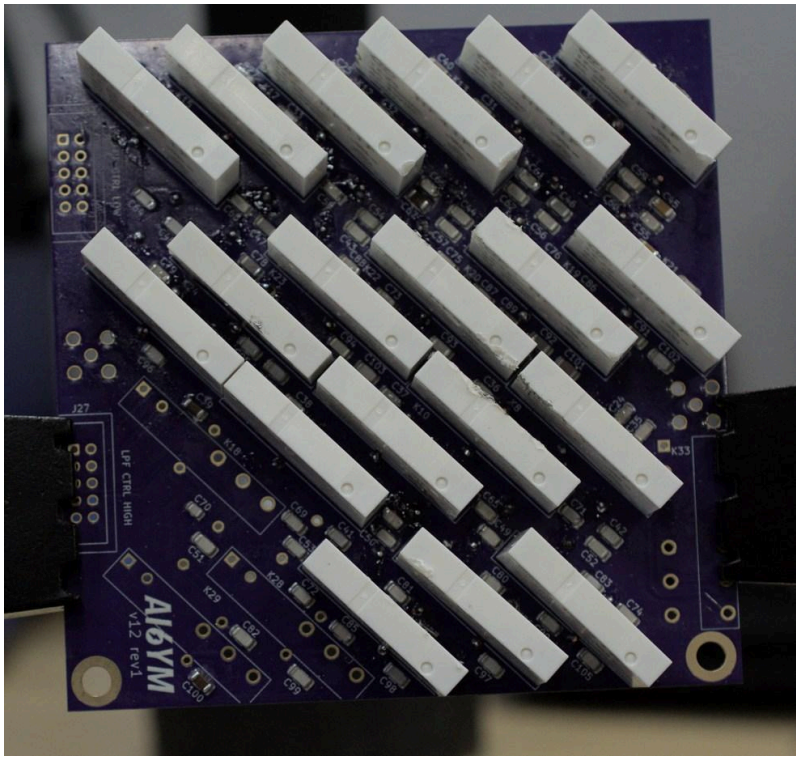

RF IN
RF OUT
160m
80m
60m
40m
30m
20m
17m
15m
12m
10m
6m

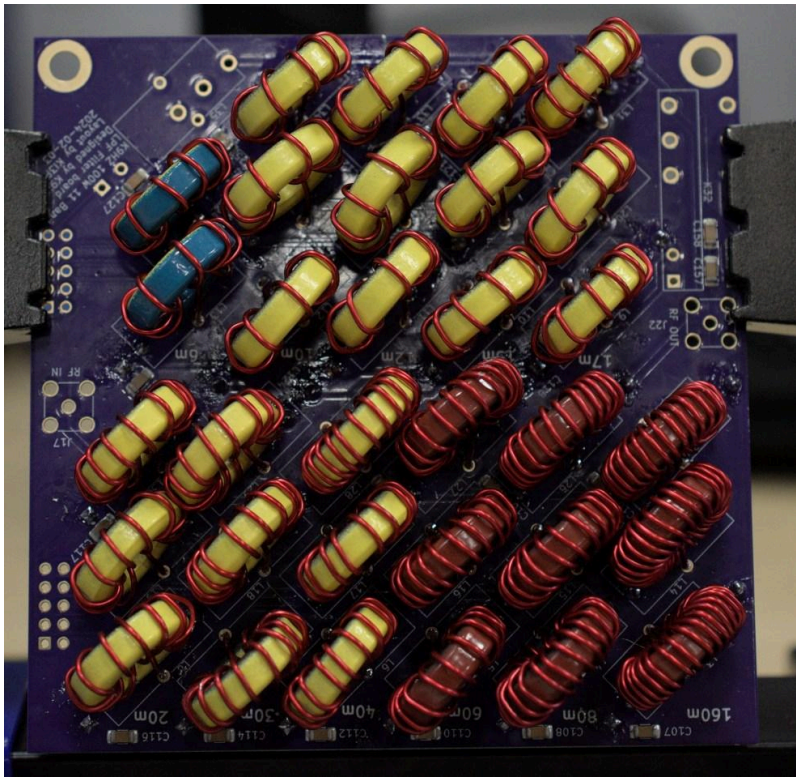

J26
LPF CTRL LOW
J27
LPF CTRL HIGH
K33
AI6YM
v12 rev1

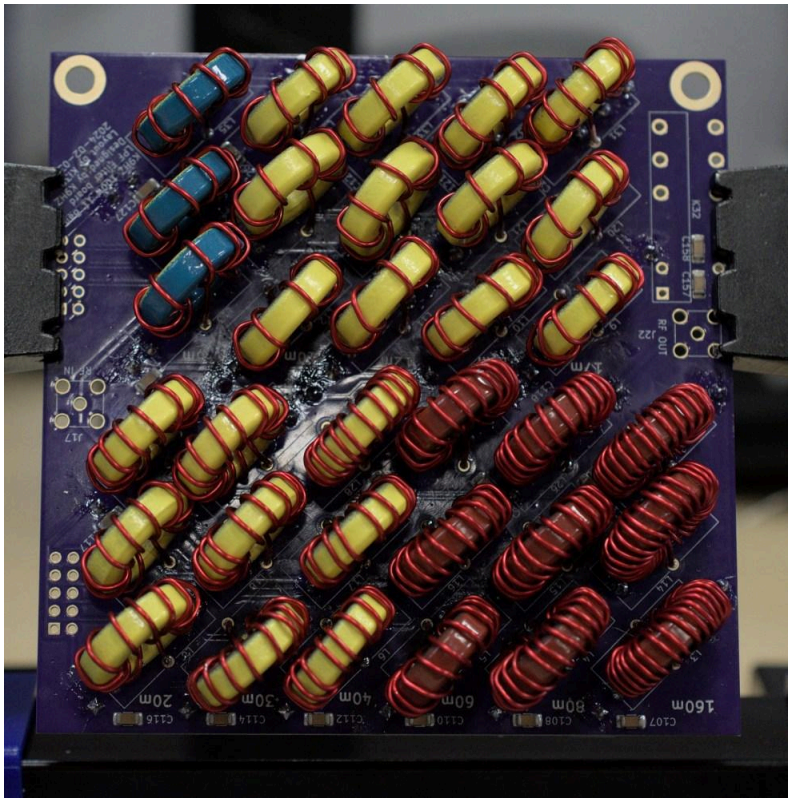

J26
LPF CTRL LOW
J27
LPF CTRL HIGH
K33
AI6YM
v12 rev1

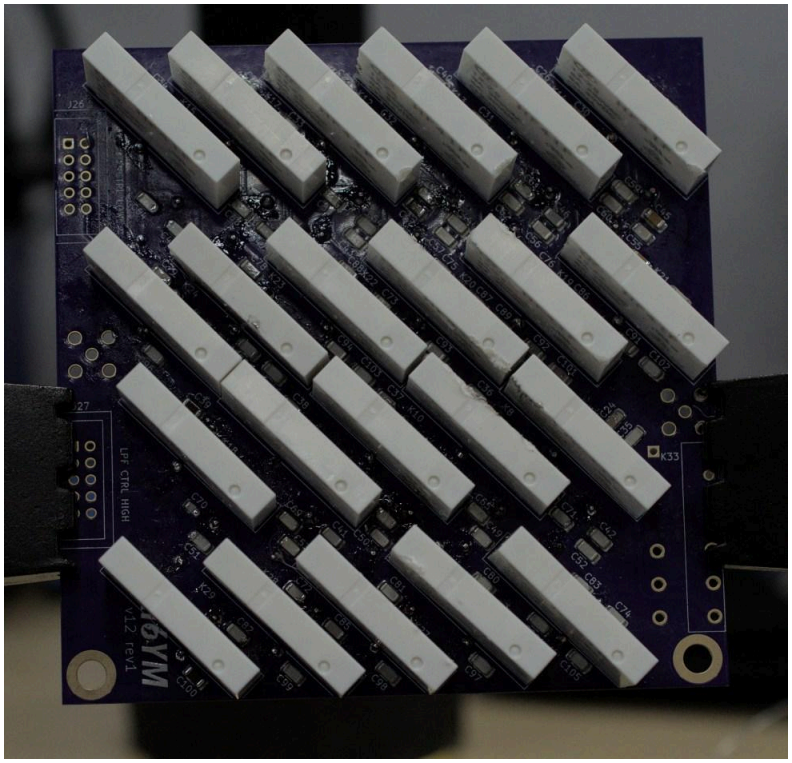

160m
80m
60m
40m
30m
20m
17m
15m
12m
10m
6m
RF IN
J17
RF OUT
J22


160m
80m
60m
40m
30m
20m
17m
15m
12m
10m
6m
RF IN
J17
RF OUT
J22

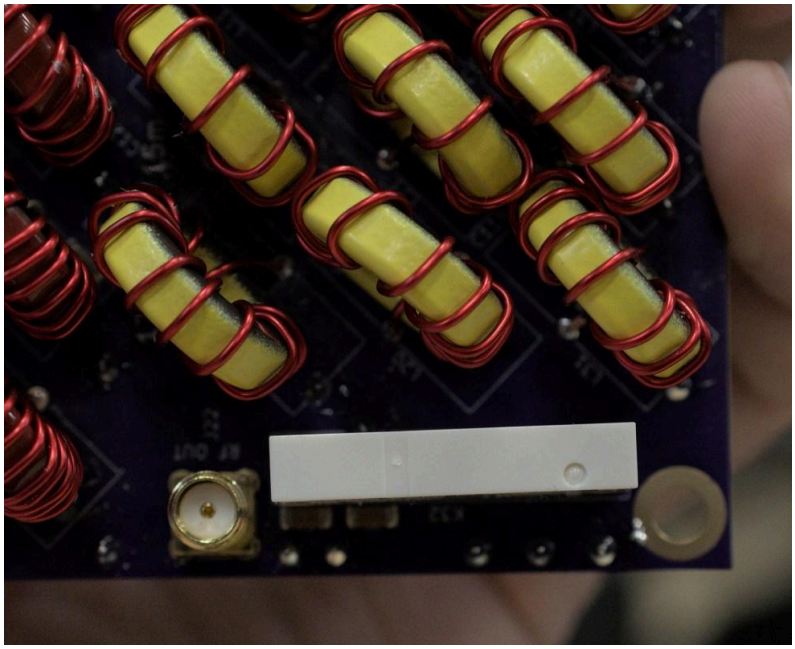

A16YM
v12 rev1
LPF CTRL HIGH

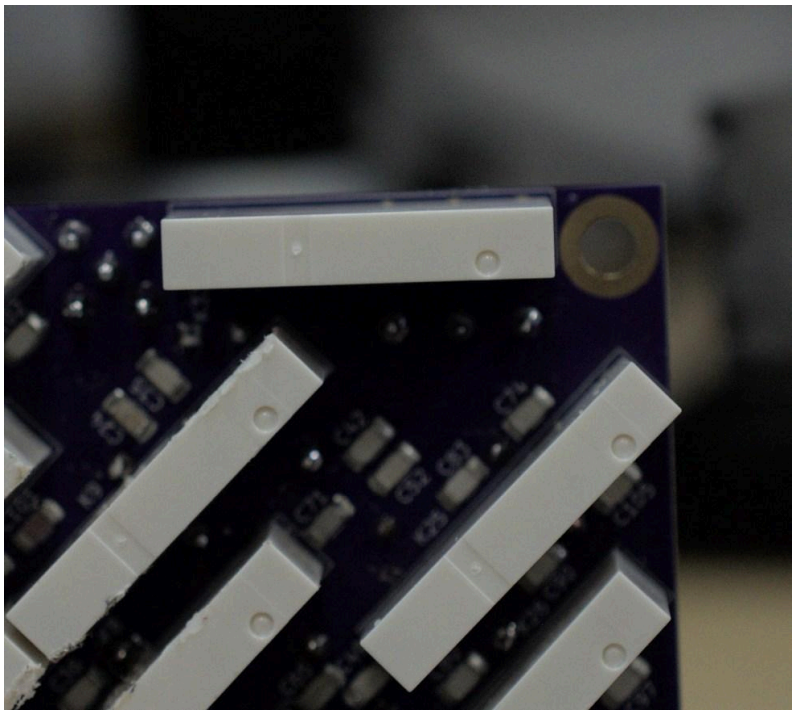

160m
80m
60m
40m
30m
20m
17m
12m
10m
6m
RF IN


160m
80m
60m
40m
30m
20m
RF OUT


LPF CTRL HIGH

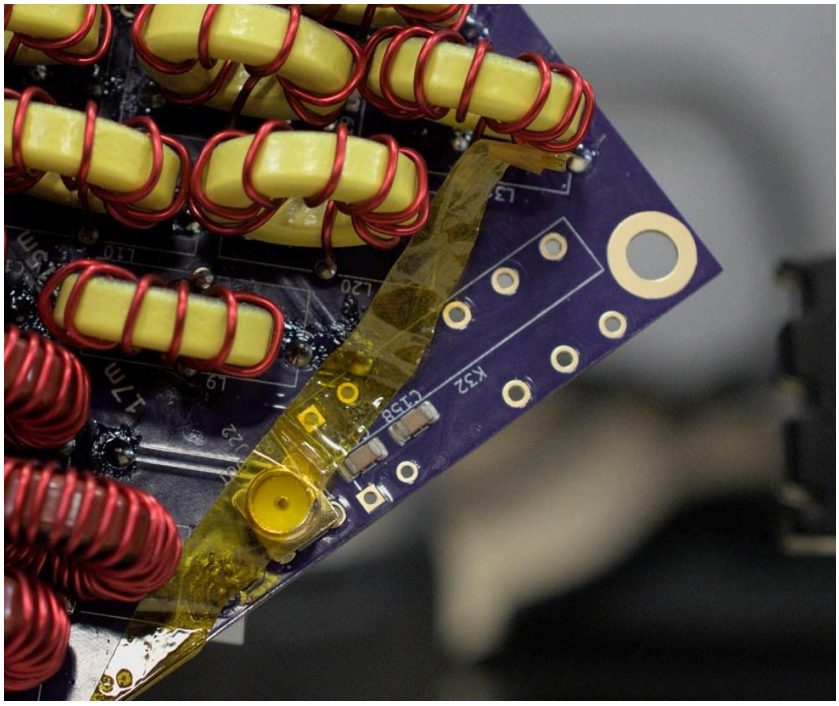
Place the two bypass relays last, these are not part of the diagonal rows of relays which share space with the inductors.





Pro-Tip: It’s not generally necessary to pot the inductors on this board. The inductors don’t require much tuning and the heavy gauge wire doesn’t slip easily on the cores. Feel free to pot the cores anyway, especially if you plan to abuse your radio.

SMA Connectors & Control Headers



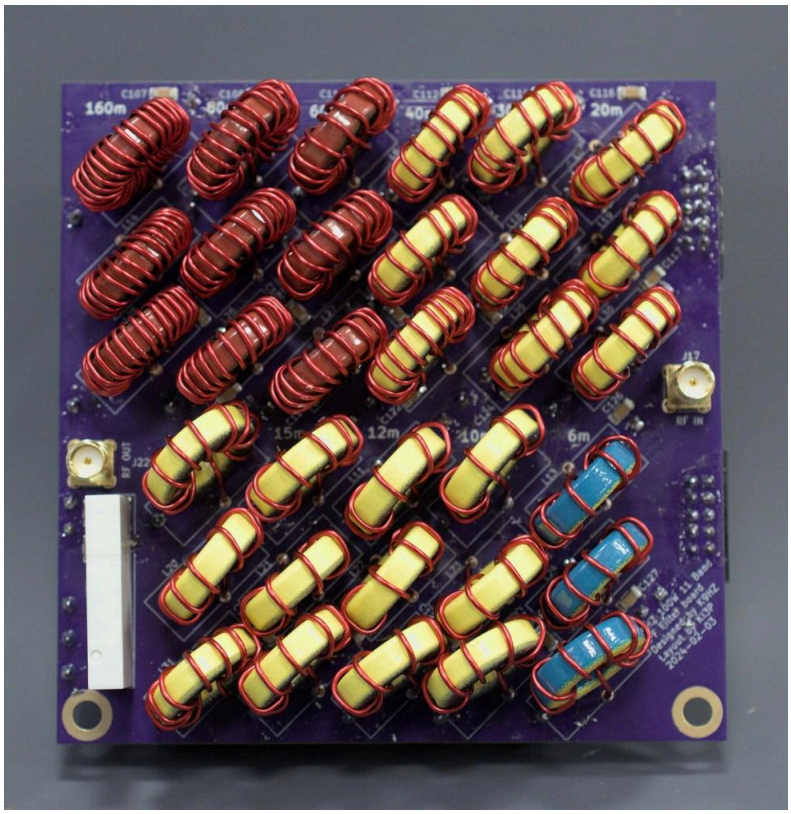
Place the first SMA connector and secure it with a bit of tape. Solder the center pin and check the alignment of the connector. The connector should be straight up and down, sitting flat against the PCB. Once additional pins are soldered, it will be difficult to correct misalignment, so double check before soldering more pins! Repeat for the second SMA connector.

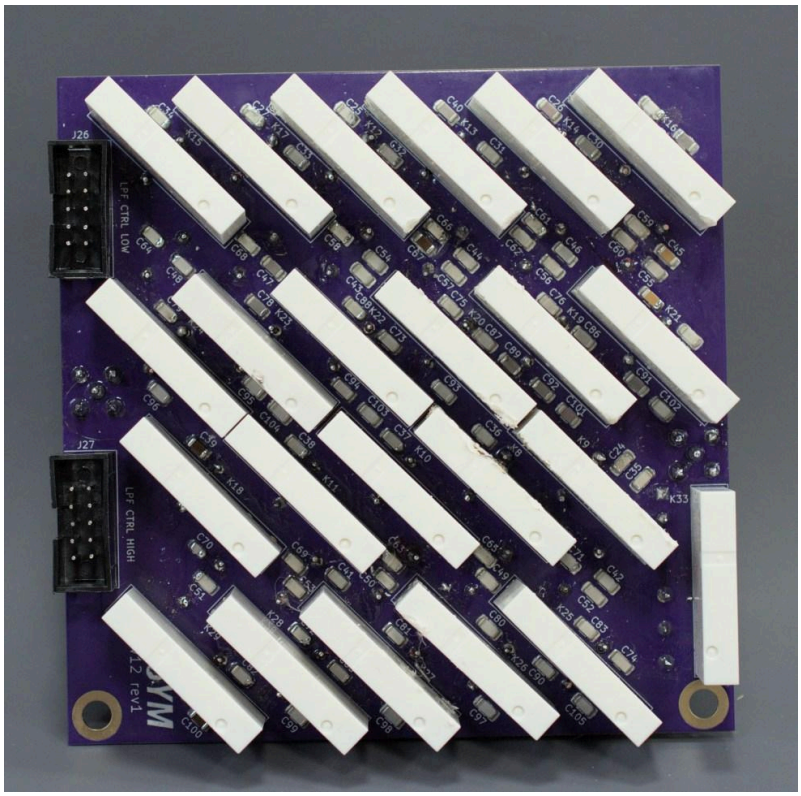
Pro Tip: Hot air and flux is very helpful, these connectors radiate heat away quickly which makes soldering difficult.

Next, place one IDC box header and secure it with a bit of tape. Solder a single pin, check the alignment of the header, solder a pin on the opposite corner of the header, check the alignment again, and then solder the remaining pins. Repeat for the second header.

Finishing Up

Clean your board as necessary to remove excess flux and residue. After cleaning carefully inspect all of the solder joints on your board. Use a jeweler’s loupe to get a good look, touch up any joints that are cold or incomplete.





Testing

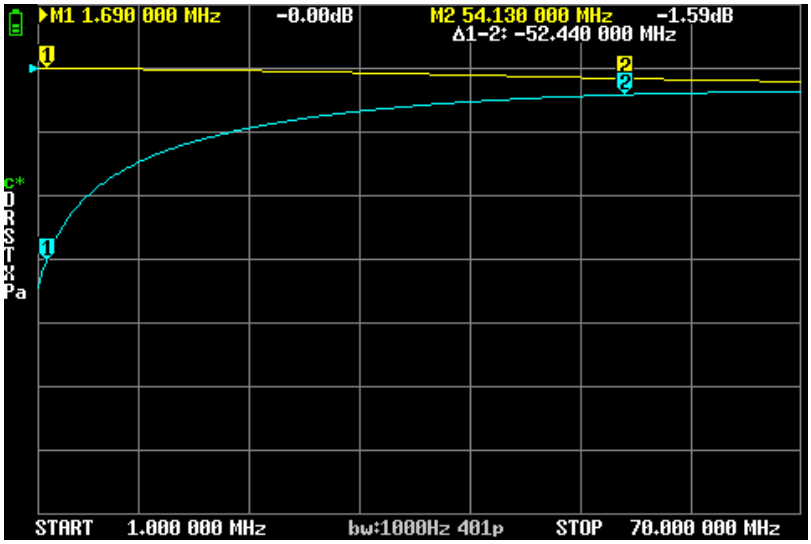
An LPF control test sketch is available in my GitHub repo. This sketch allows you to select each individual filter using the Teensy's serial connection. The LPF control board and T41 main board are required for this sketch.

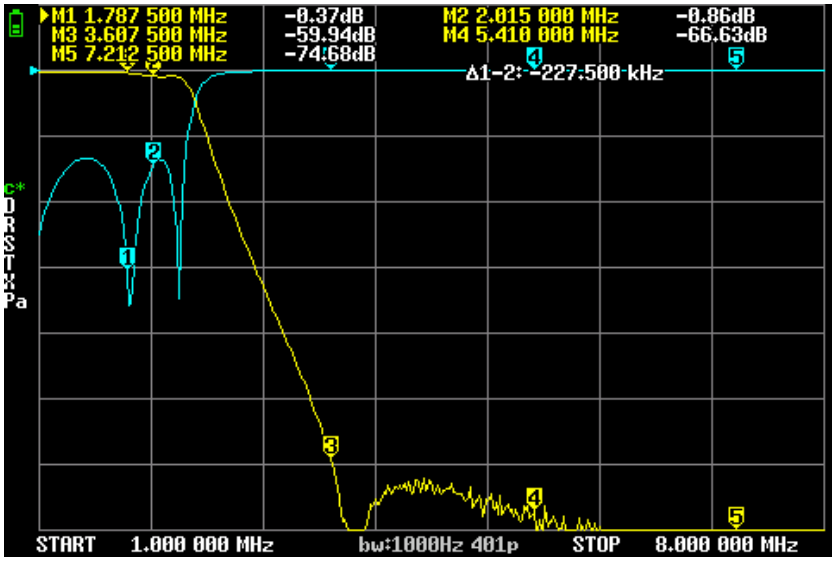
Individual filters can also be selected by applying 12V directly to the header pin which enables the desired filter, see the schematic above for header pinouts.

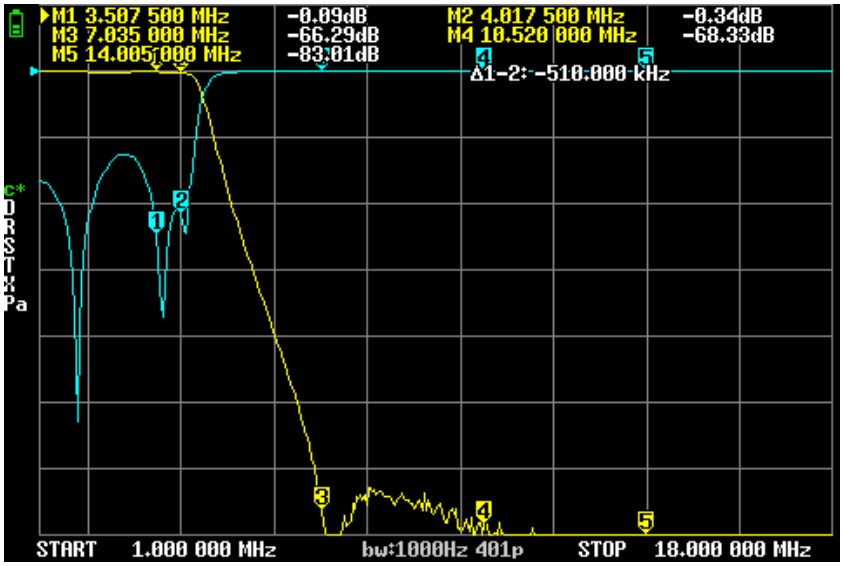
Use a NanoVNA or similar test equipment to generate stimulus signals and measure filter performance. Performance should be measured in the passband and out to at least the fourth harmonic.

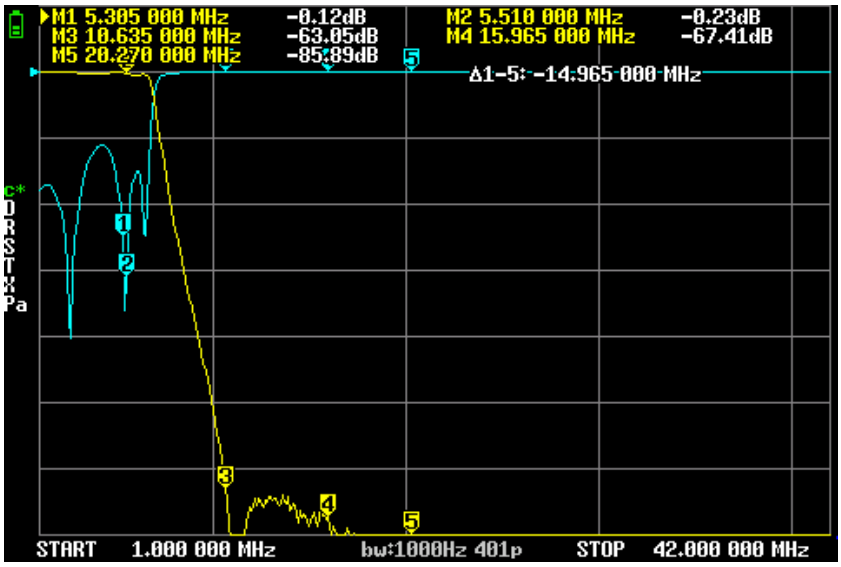
Pro-Tip: Be sure to calibrate your test equipment for each frequency range you test!

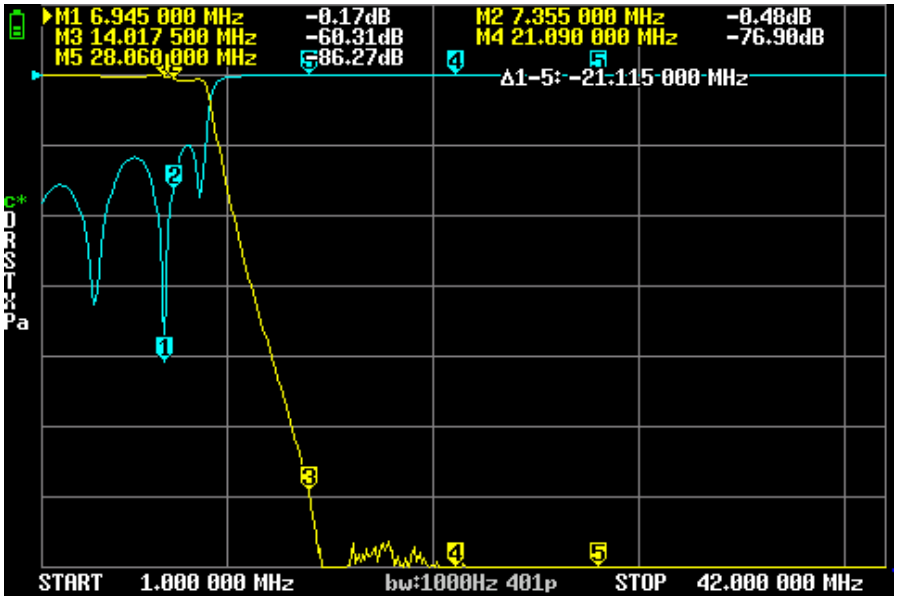
The performance of filters on my board are shown below, no tuning was performed to achieve these results. Be sure to test your PA too to be sure these filters will be sufficient to remove harmonic distortion. In the USA 14 CFR 97.307 requires spurious emissions to be down at least 43dB from the intended transmission on HF and at least 60dB down on VHF (including 6M). Outside of the USA consult your local regulations for spurious emissions requirements.

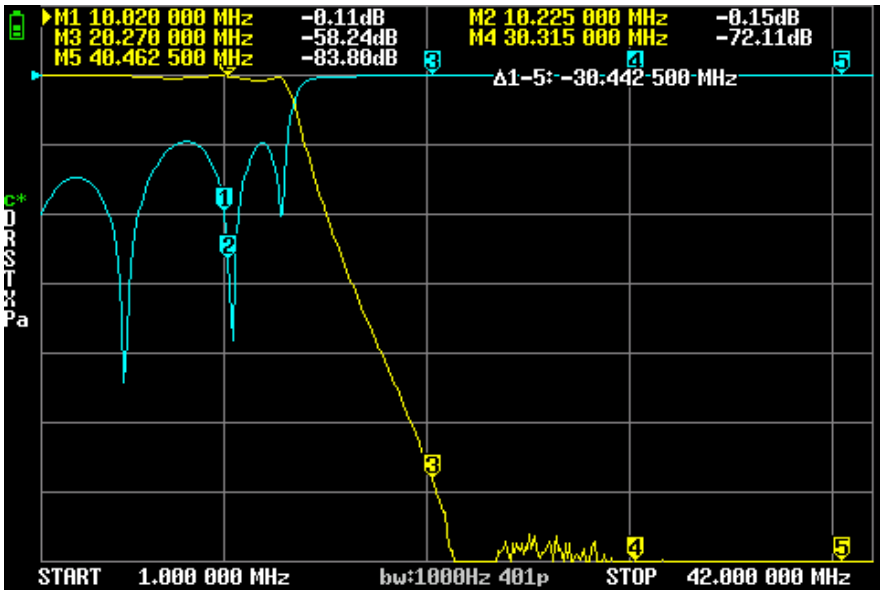

M1 1.690 000 MHz
-0.00dB
M2 54.130 000 MHz
-1.59dB
Δ1-2: -52.440 000 MHz
START 1.000 000 MHz
bw:1000Hz 401p
STOP 70.000 000 MHz

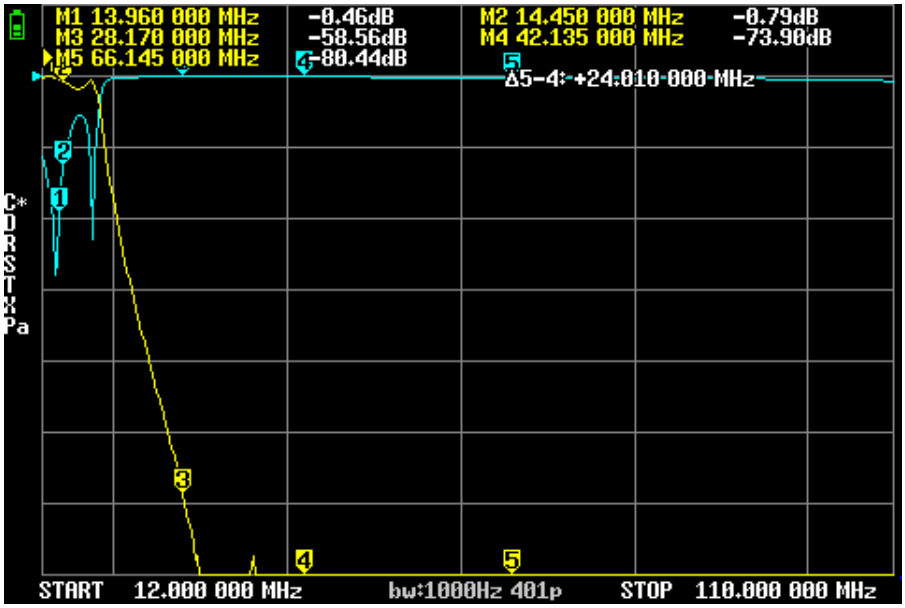

M1 1.787 500 MHz
-0.37dB
M3 3.607 500 MHz
-59.94dB
M5 7.212 500 MHz
-74.68dB
M2 2.015 000 MHz
-0.86dB
M4 5.410 000 MHz
-66.63dB
Δ1-2: -227.500 kHz
START 1.000 000 MHz
bw:1000Hz 401p
STOP 8.000 000 MHz

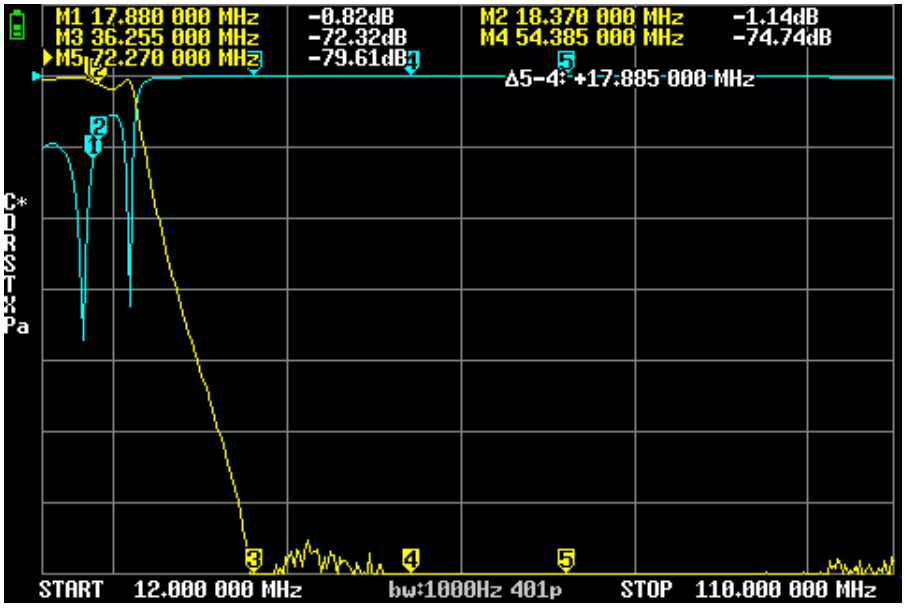

M1 3.507 500 MHz -0.09dB
M3 7.035 000 MHz -66.29dB
M5 14.005 000 MHz -83.01dB
M2 4.017 500 MHz -0.34dB
M4 10.520 000 MHz -68.33dB
Δ1-2: -510.000 kHz
START 1.000 000 MHz
bw:1000Hz 401p
STOP 18.000 000 MHz

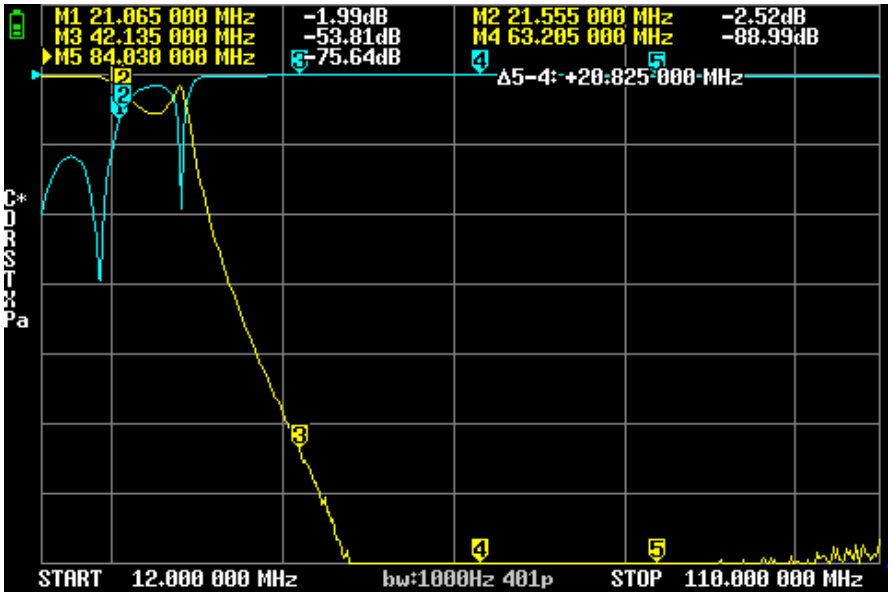

M1 5.305 000 MHz -0.12dB
M3 10.635 000 MHz -63.05dB
M5 20.270 000 MHz -85.89dB
M2 5.510 000 MHz -0.23dB
M4 15.965 000 MHz -67.41dB
Δ1-5: -14.965 000 MHz
START 1.000 000 MHz
bw:1000Hz 401p
STOP 42.000 000 MHz

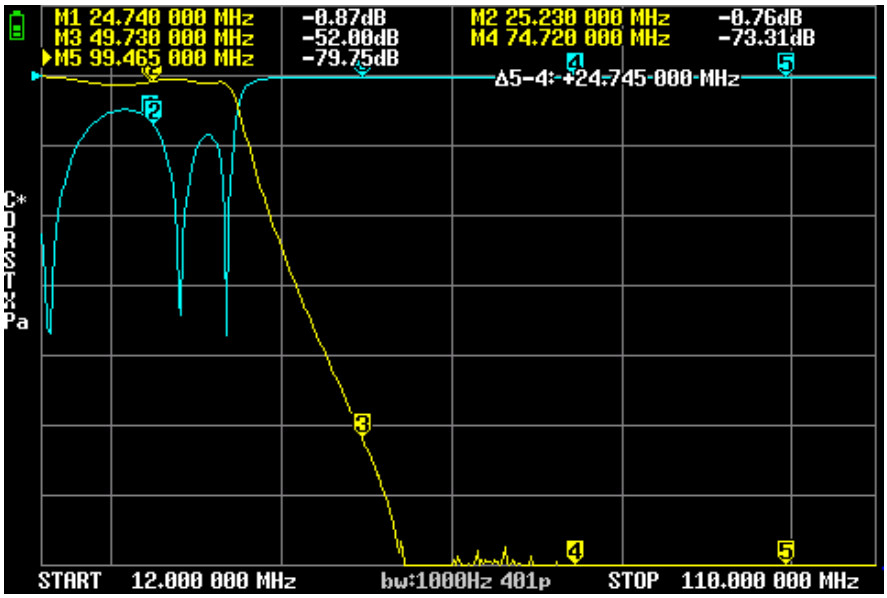

M1 6.945 000 MHz -0.17dB
M3 14.017 500 MHz -60.31dB
M5 28.060 000 MHz 86.27dB
M2 7.355 000 MHz -0.48dB
M4 21.090 000 MHz -76.90dB
Δ1-5: -21.115 000 MHz
START 1.000 000 MHz
bw:1000Hz 401p
STOP 42.000 000 MHz

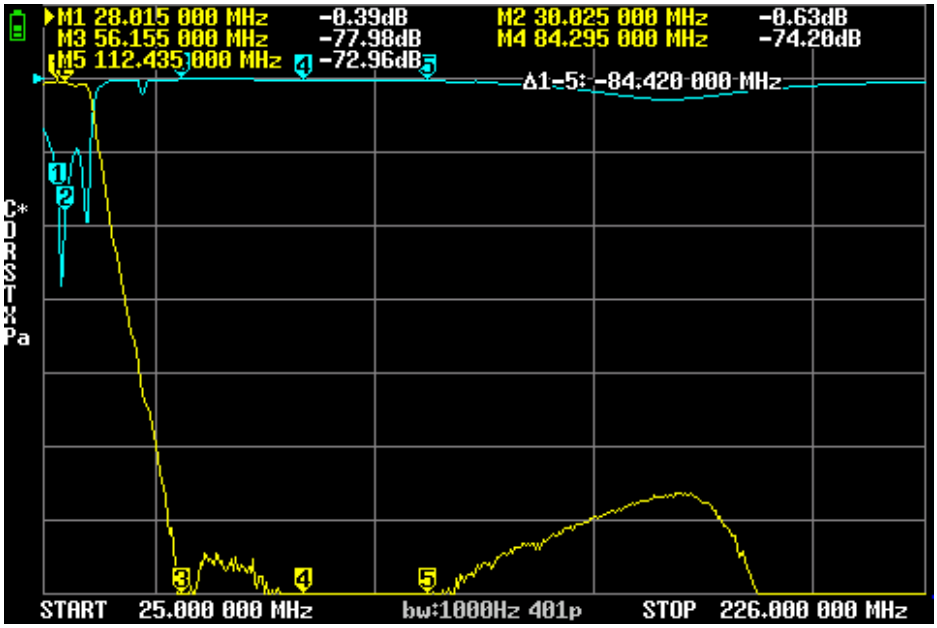

M1 10.020 000 MHz -0.11dB
M3 20.270 000 MHz -58.24dB
M5 40.462 500 MHz -83.80dB
M2 10.225 000 MHz -0.15dB
M4 30.315 000 MHz -72.11dB
Δ1-5: -30.442 500 MHz
START 1.000 000 MHz
bw:1000Hz 401p
STOP 42.000 000 MHz

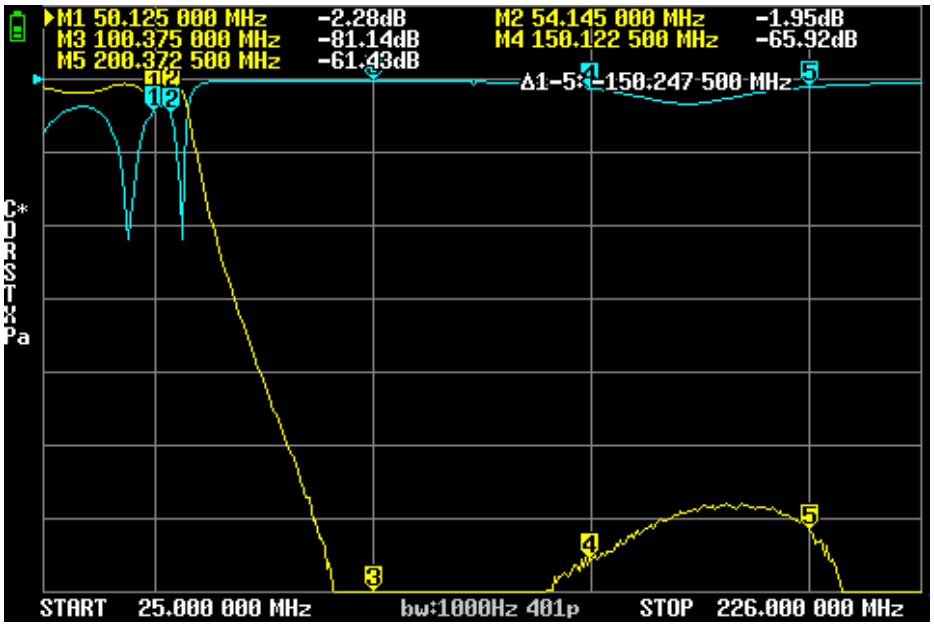

M1 13.960 000 MHz -0.46dB
M3 28.170 000 MHz -58.56dB
M5 66.145 000 MHz -80.44dB
M2 14.450 000 MHz -0.79dB
M4 42.135 000 MHz -73.90dB
Δ5-4: +24.010 000 MHz
C*
DRSTXPa
START 12.000 000 MHz
bw:1000Hz 401p
STOP 110.000 000 MHz


M1 17.880 000 MHz -0.82dB
M3 36.255 000 MHz -72.32dB
M5 72.270 000 MHz -79.61dB
M2 18.370 000 MHz -1.14dB
M4 54.385 000 MHz -74.74dB
Δ5-4: +17.885 000 MHz
C*
DRSTXPa
START 12.000 000 MHz
bw:1000Hz 401p
STOP 110.000 000 MHz


M1 21.065 000 MHz -1.99dB
M3 42.135 000 MHz -53.81dB
M5 84.030 000 MHz -75.64dB
M2 21.555 000 MHz -2.52dB
M4 63.205 000 MHz -88.99dB
Δ5-4: +20.825 000 MHz
C*
DRSTXPa
START 12.000 000 MHz
bw:1000Hz 401p
STOP 110.000 000 MHz


M1 24.740 000 MHz -0.87dB
M3 49.730 000 MHz -52.00dB
M5 99.465 000 MHz -79.75dB
M2 25.230 000 MHz -0.76dB
M4 74.720 000 MHz -73.31dB
Δ5-4: +24.745 000 MHz
C*
DRSTXPa
START 12.000 000 MHz
bw:1000Hz 401p
STOP 110.000 000 MHz


M1 28.015 000 MHz -0.39dB
M2 30.025 000 MHz -0.63dB
M3 56.155 000 MHz -77.98dB
M4 84.295 000 MHz -74.20dB
M5 112.435 000 MHz -72.96dB
Δ1-5: -84.420 000 MHz
START 25.000 000 MHz
bw:1000Hz 401p
STOP 226.000 000 MHz


M1 50.125 000 MHz -2.28dB
M2 54.145 000 MHz -1.95dB
M3 100.375 000 MHz -81.14dB
M4 150.122 500 MHz -65.92dB
M5 200.372 500 MHz -61.43dB
Δ1-5: -150.247 500 MHz
START 25.000 000 MHz
bw:1000Hz 401p
STOP 226.000 000 MHz