Make the basic LIMA-SDR transceiver a full-fledged transceiver by increasing selectivity and HF with the project of DJ0ABR, 10Watt, optional to 100Watt

Author, PA3CVI

Freely translated into English, after a design by DJ0ABR.

Eindhoven, June 31, 2019

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Introduction.

With Bernd's excellent basic LIMA-SDR design, DL9WB, I have made some successful CW-QSOs with the 0.5Watt HF output power. Because I thought the power was very low, I went looking for a design with an output power of about 10 Watt. My choice ultimately fell on a clearly defined design by Kurt, DJ0ABR, with the LIMA-SDR transceiver as the basic concept.

I have made the habit of recording my projects' progress in a well-defined kind of report, manual, or whatever you want to call it, so that I can fall back on that later for any modifications. Hereby I have taken over the "red thread" of DJ0ABR and where useful, supplemented with comments, tips and many clarifying images.

The original site of DJ0ABR can be found at: https://www.dj0abr.de/

This may also enthuse other amateurs to tackle such a project. I learned a lot and had fun while building it. The project is suitable for advanced radio amateurs with some knowledge of electronics.

I have not realized all parts of his project, but the combination chosen below is sufficient for a professional SDR Transceiver. This article consists of:

1. **Customization of the Lima-RX**
2. **Customizing the Lima-TX**
3. **Microphone amplifier from DJ0ABR**
4. **Adjust Microphone PTT Switching**
5. **Preselector**
6. **Power Amplifier, 10 Watt**
7. **Possible Problems and Solutions**
8. **Settings**
9. **Sound card**
10. **PowerSDR Settings**
11. **Low Pass Filter**

1. Modification of the Lima RX PCB.

1.1. Separation of Lima-RX and Lima TX.

It is really advisable to separate the RX and TX from each other and house them in two separate draft-free HF housings. This separation has the great advantage that the prints are much easier to approach. The separation is very simple because only a few pins of the 11-pin pin connector are used.

In that case you have to branch off and run the following lines from the RX PCB, fig. 1.

1.2. Aftakkingen van de Lima RX naar de Lima TX.

- TX Clk

Marked as "TX CLK" in the schematic. It is best to branch off from the 11-pin connector with a coaxial cable and connect the shielding of the coaxial cable directly to ground.

- PTT line.

- supply voltage, max. 13.6V.

The other connections of the 11-pole connector are unnecessary.

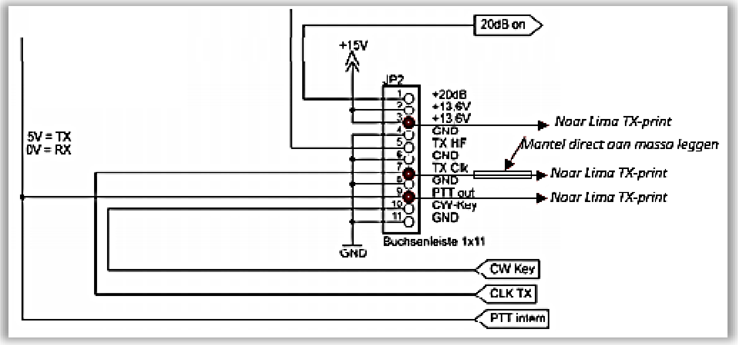


Fig.1, 11-pin branches of the Lima RX connector

1.3. R2 and R4, fig.2.

* remove the R2 resistor.

* remove the R4 resistor and replace it with a jumper.

Fig. 3, R2 remove, bridge R4

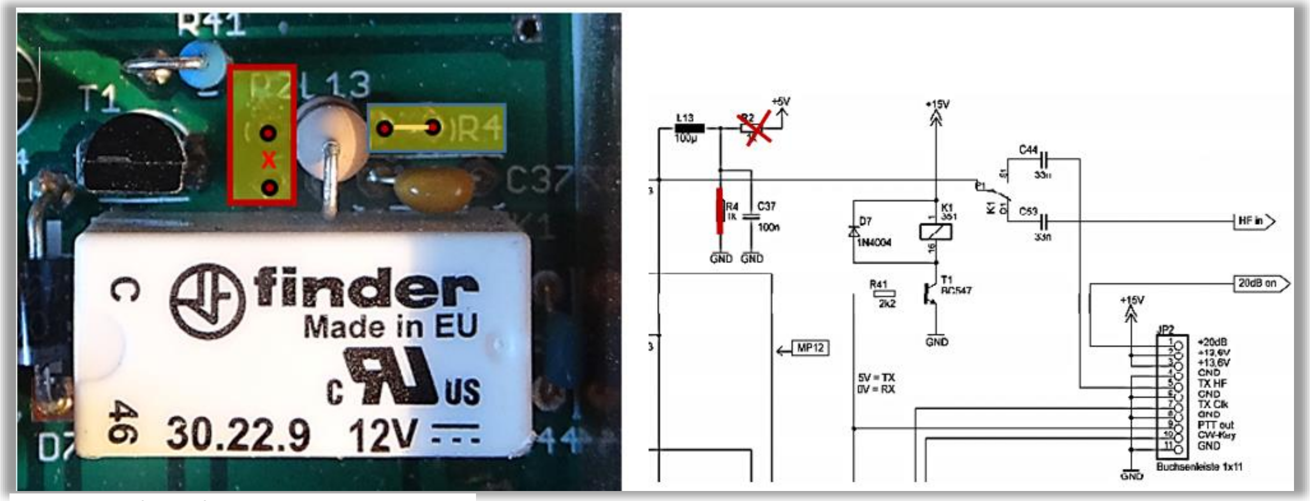


Fig. 2, R3 and R4 adjustment.

1.4. Measures to correct the oscillation tendency of the power supply, fig. 3 to 5.

* place an Elko 10uF/16V in parallel with the 100nF capacitor C4.

* place a tantalum 22uF/16V in parallel with the 100nF capacitor C5.

* place a tantalum 22uF/16V in parallel with resistors R5 or R6.

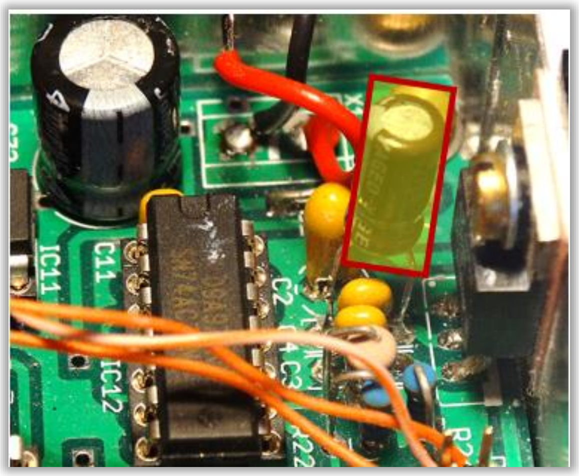


Fig. 3, Elco.

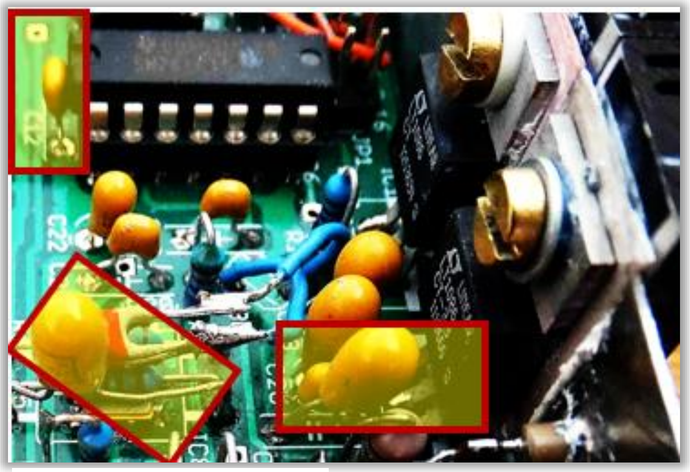
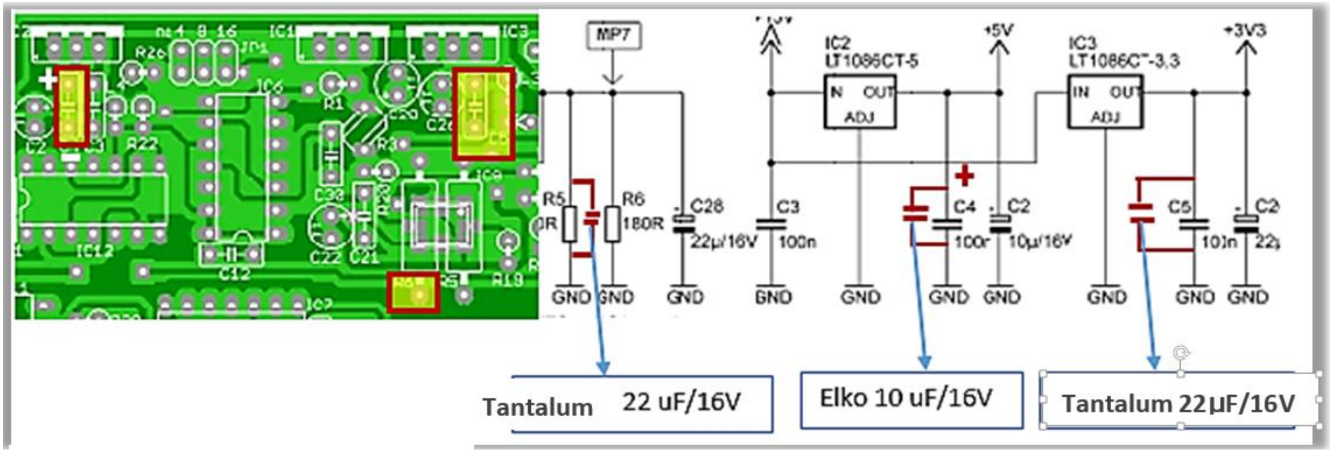


Fig.4, tantalumC's.



If you want to use the U02-SDR-Preselector from DJ0ABR, the Lima-RX Preselector and the Lima-RX pre-amplifier are no longer used. Instead, you need to make the following preparations to connect the U02-SDR Preselector later:

* Remove relay K2.
* Connect the now free pin P2 of the removed relay K2 in fig.6, to the terminal of the U02 SDR Preselector ("RX-mixer") by means of a thin coax, for example RG316 or the like. In the Lima-RX schematic, this cable is labeled "HF in IQ", fig.7. Of course you have to connect the shielding of this cable to ground. In the photo it seems that the soldering point is to the left of P2, In the picture it looks like the soldering point is to the left of P2, but it isn't.

Fig.6, Relay K2 has been removed.

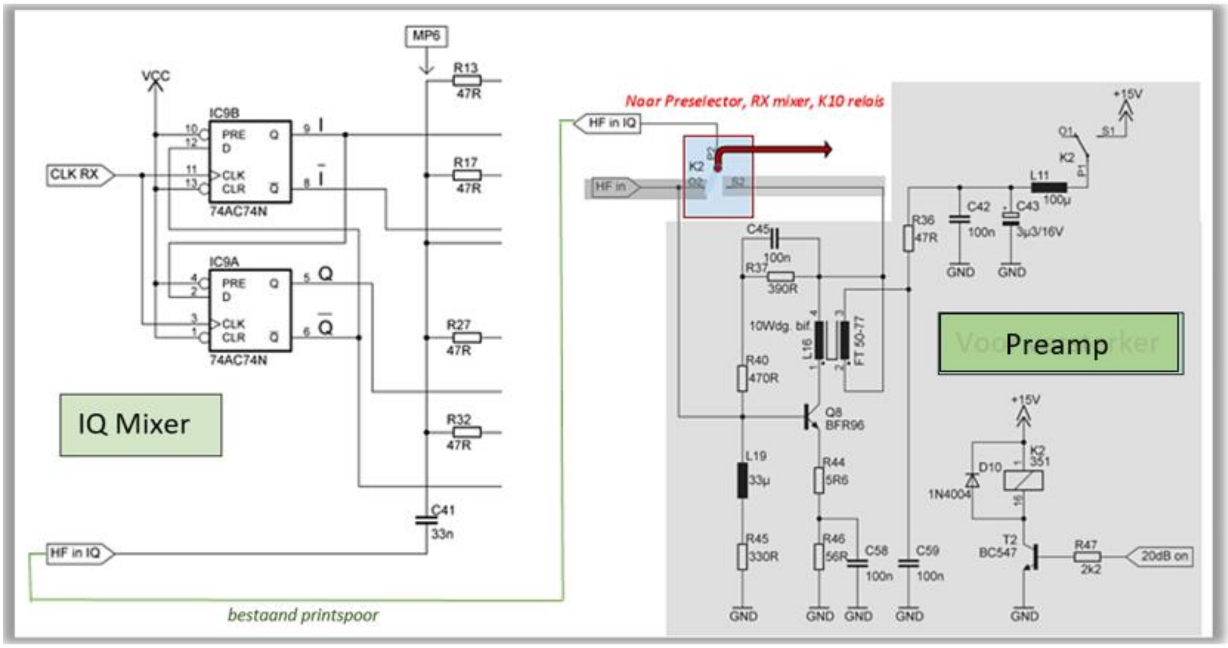


Fig. 7, Relay K2 has been removed.

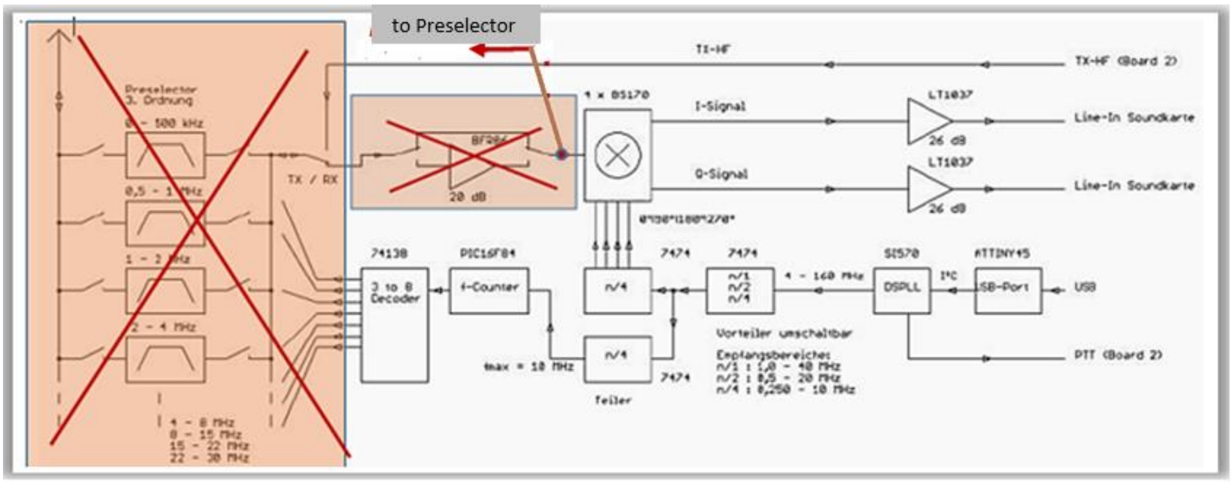


fig. 8, Lima RX scheme, colored rectangles are switched off.

2. Changes to the Lima SDR TX board.

2.1. Modulator output stage.

The modulator is controlled via 4 push-pull stages, consisting of the BC556B BC546B.
In my Lima, that of DJ0ABR, the base current is not enough, so that the BC556B does not work optimally. As a result, only a weak, heavily distorted signal came out of the mixer.
I replaced the BC556B with a BC557C and replaced the BC546B with a BC547C, fig.9. After that, this circuit worked flawlessly. Even with poor quality, the C-types yield double the profit compared to the B-types.

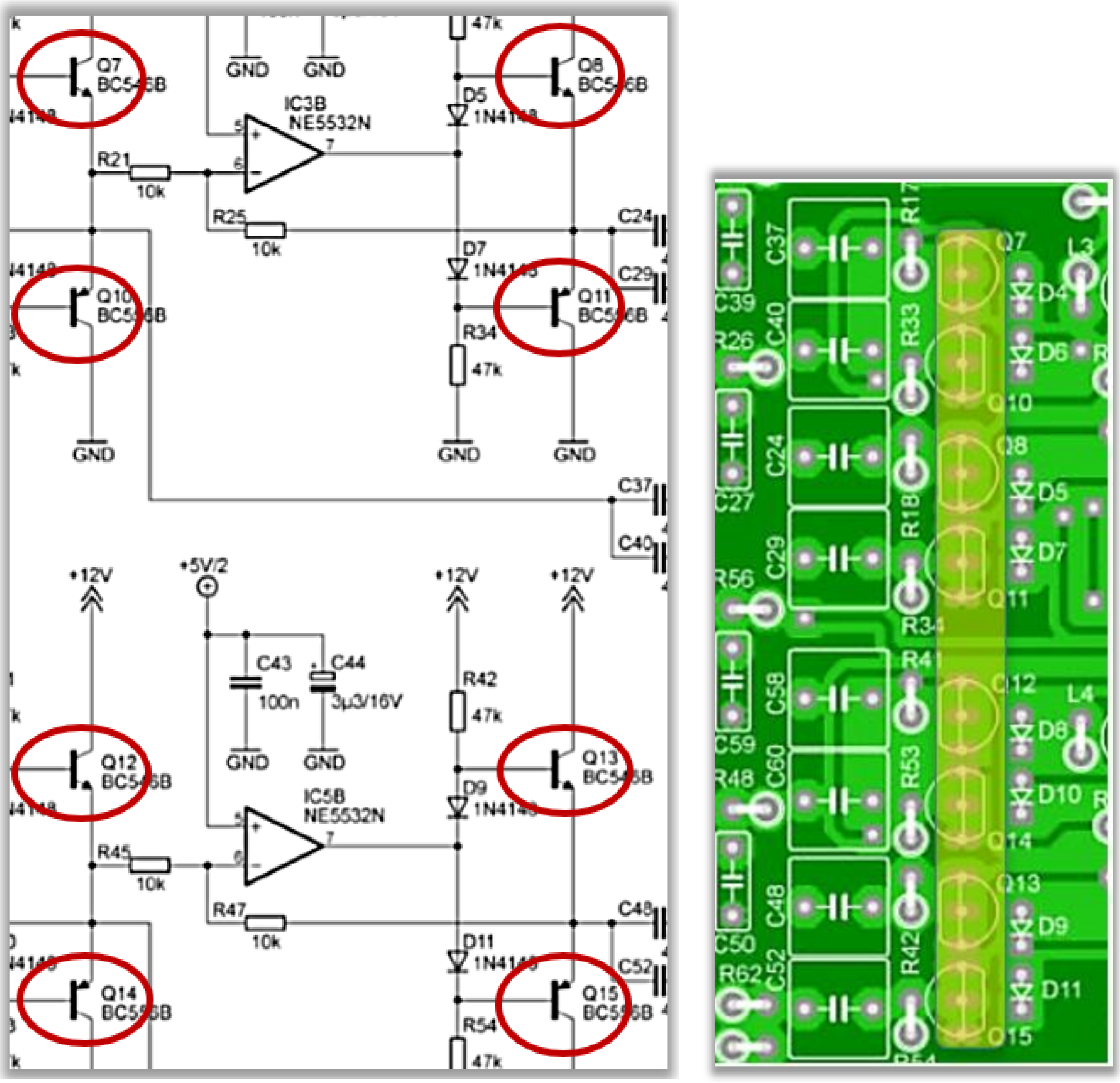


fig. 9, replace transistors of the Impedance converter.

2.1. 1W-PA.

The 1W-PA components were not used. If they were already occupied, you'll need to remove the four BS170 Fets, the two double-hole cores (you may apply and use in the 10W PA) and the relay, which saves power consumption. In addition, you remove the R22, R29 resistors and the transistor T1, freeing up the Mixer output, here you can take the mixer output signal, fig.10. up to 13. With a coaxial cable, it is connected to the TX input of U02-Preselector.

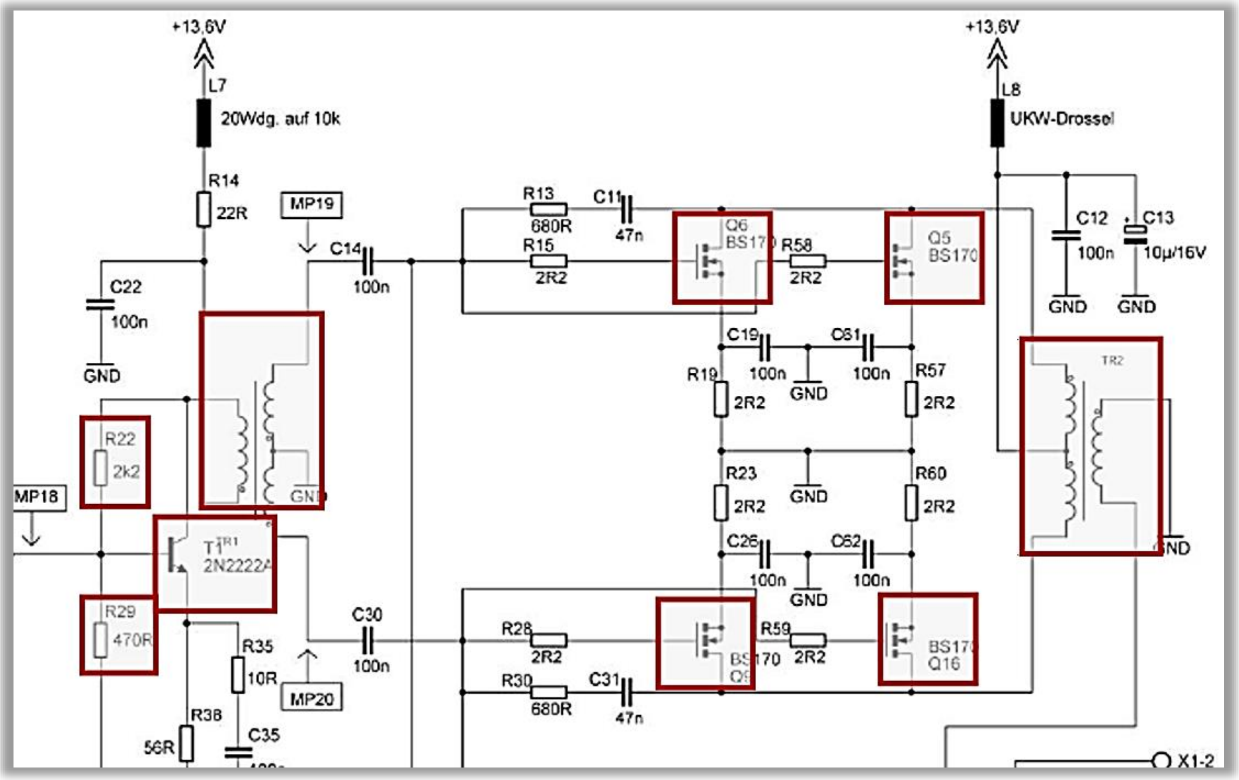


fig. 10, removing peripheral components and the 1W PA transistors.

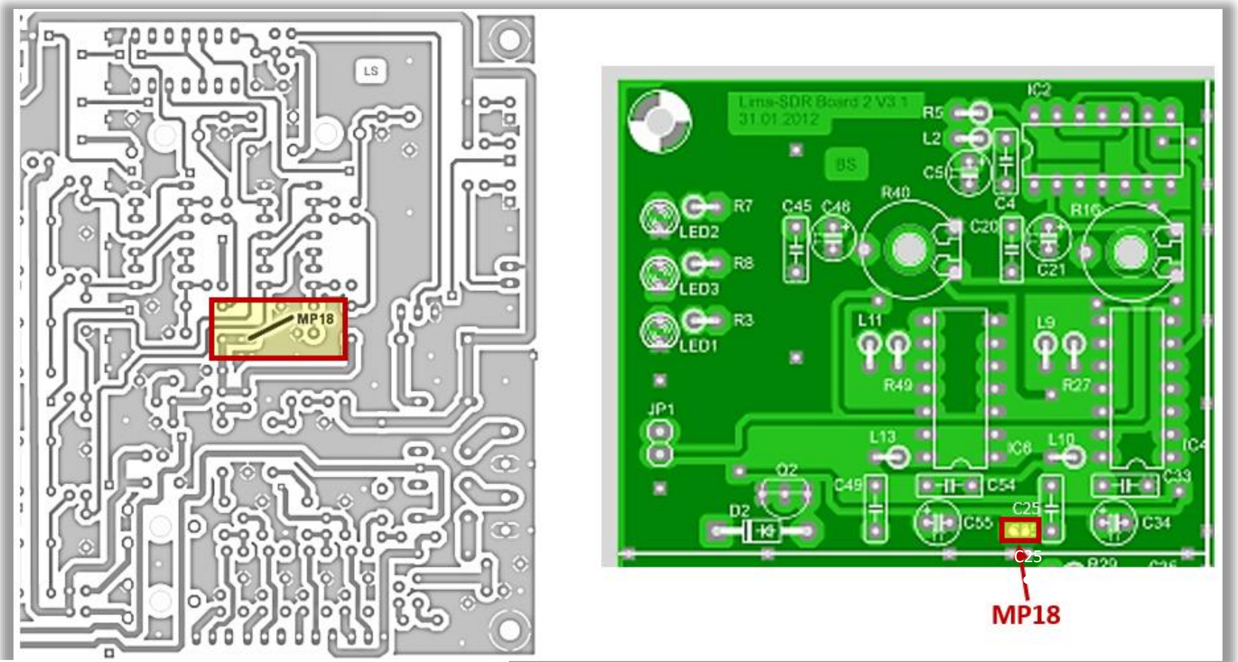


Fig. 11, MP18 as measuring and or tapping point.

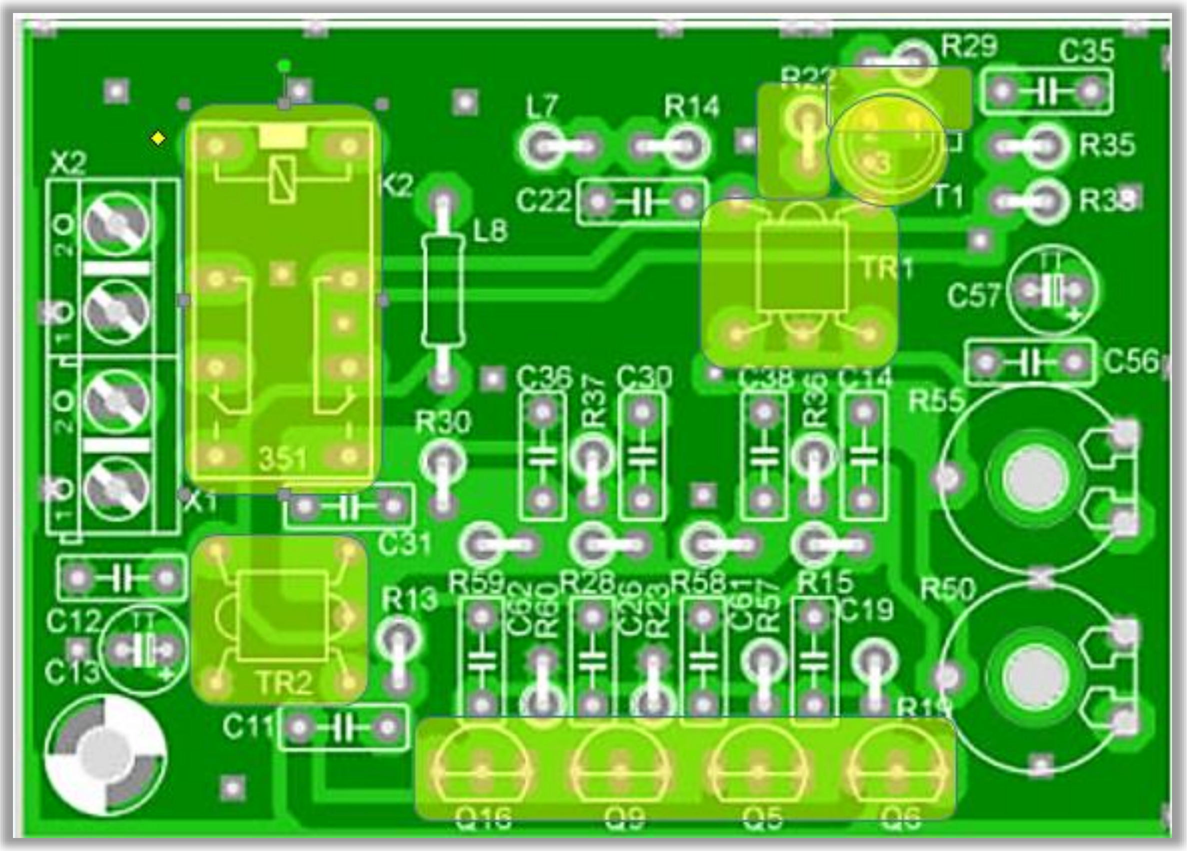


fig. 12, Removing peripheral components and the 1W PA transistors, component side.

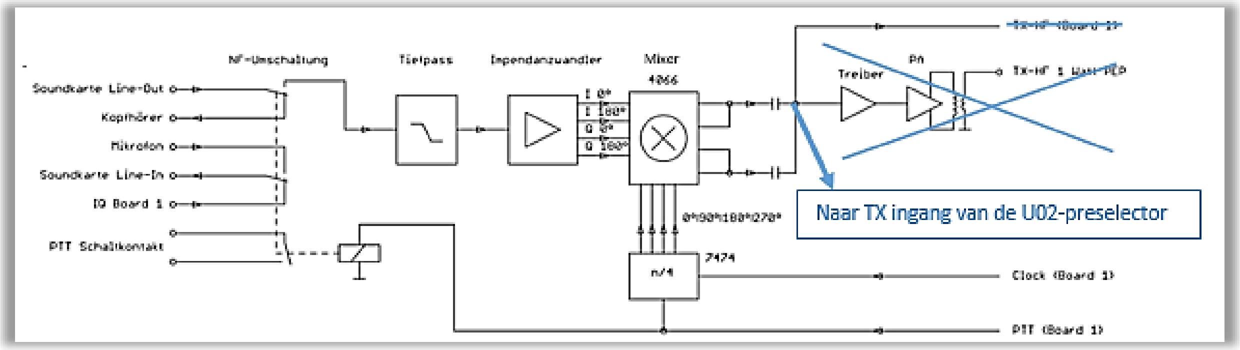


Fig. 13, Block diagram, branch point, TX print.

2.2. TX Clock.

If you have the Lima-RX and TX boards in a housing, this signal is already connected and you don't have to do anything else.
However, if you have housed the PCBs in a separate tin housing, the TX-Clk line must be connected to the RX PCB via a coaxial cable. It is best to take the signal from the 11-pin plug JP2, with a coaxial cable (eg RG-316).

2.3. PTT.

You also branch off the PTT line from the JP2 plug and connect it to the RX print. Shielding is not necessary here. The potentiometer R12 "PTT delay" must not be against the stop, a very small delay is necessary, so that the PTT line can have sufficient level.

3. Microphone amplifier of DJ0ABR

3.1. Microfoon versterker.

Since the line-in input of the sound card is already in use, a microphone cannot be connected directly. This small expansion card amplifies the microphone level sufficiently for the Line-IN input of the sound card. It also includes a speaker amplifier that is loud enough for most applications. The PCB is so small that you can place it directly in the Lima-SDR TX housing, fig.14a. Here is the schematic, fig.14.

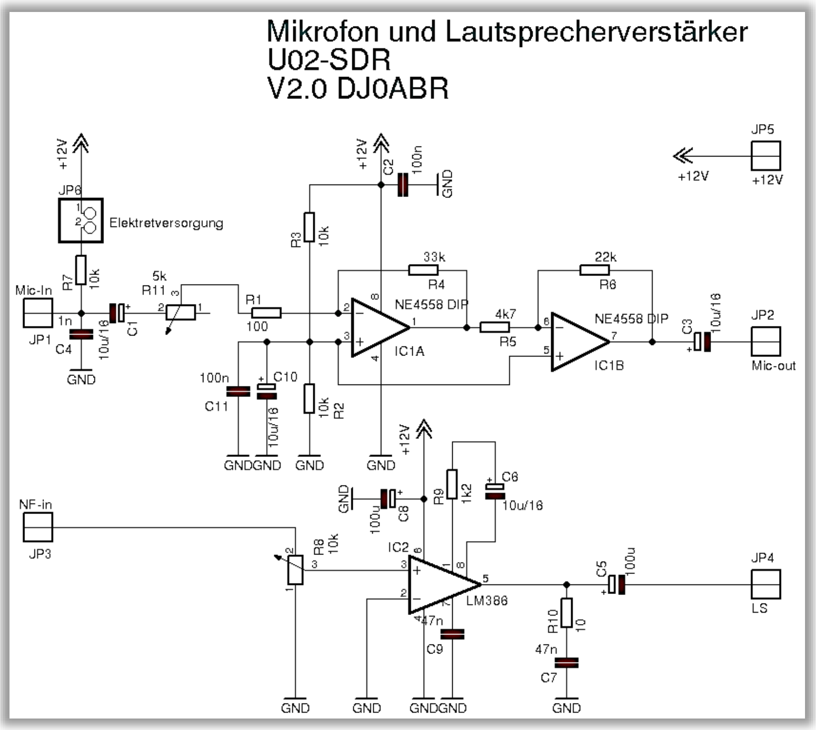


Fig. 14, Amplifier circuit

1. The microphone is connected to connector Mic-in, JP1, via X6.
2. MIC-out, JP2, of the amplifier board, via X5 to MIC-in of the PC.
3. Line-out, PC , is connected to LF-in, JP3, of the amplifier board
4. With JP4, Speaker, you connect a normal loudspeaker, use the free X8 relay.
5. And at +12V you connect the normal power supply..

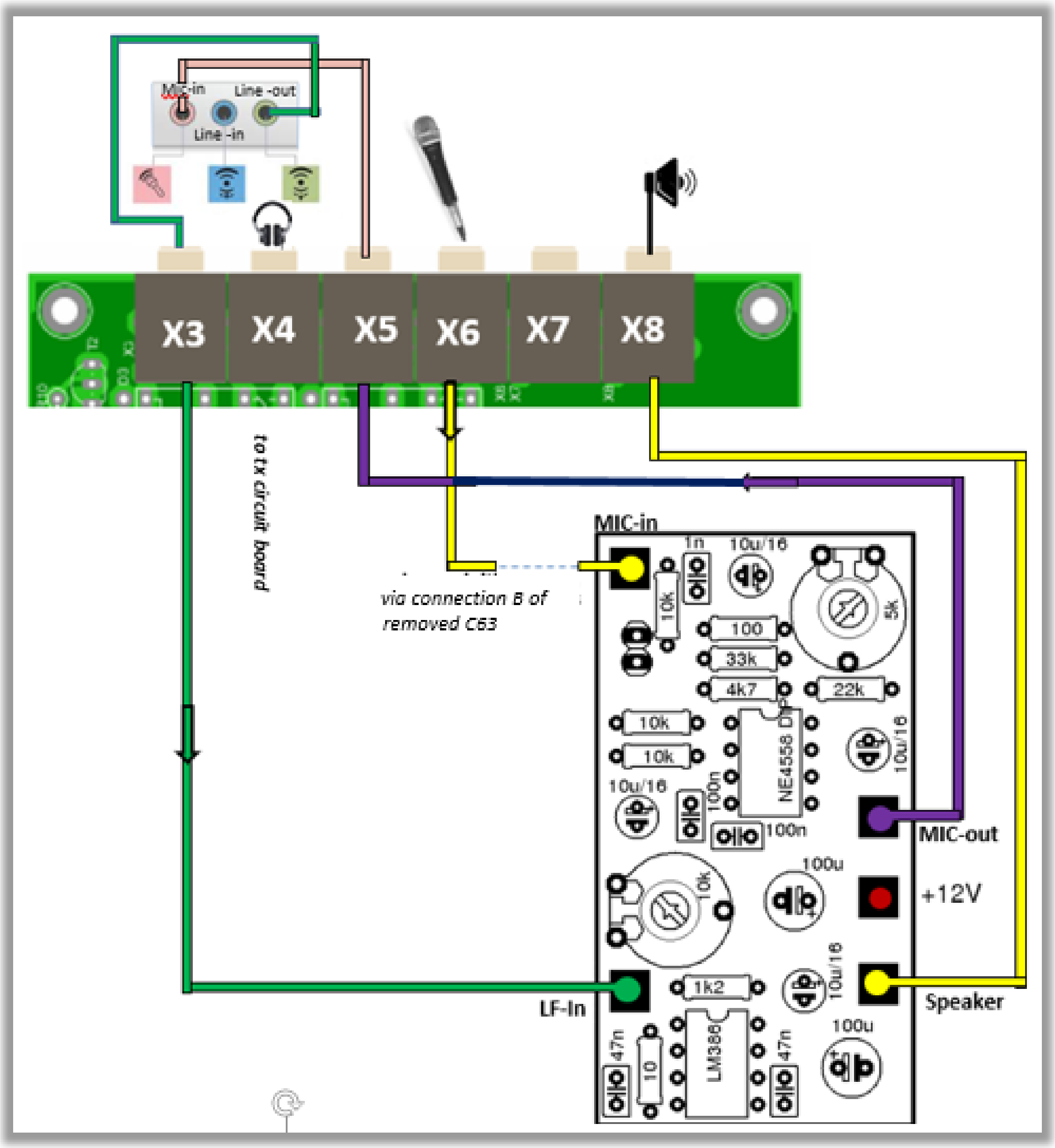


fig. 14a, overview connection to the amplifier board.

The gain of the microphone amplifier can be adjusted with R11 and thus optimally adapted to the microphone used. Use R8 to adjust the speaker volume. To do this, fully adjust the volume control (AF) in Power SDR and then set R8 so that the language remains very loud but still not distorted. Then set the volume to the desired level in Power SDR.

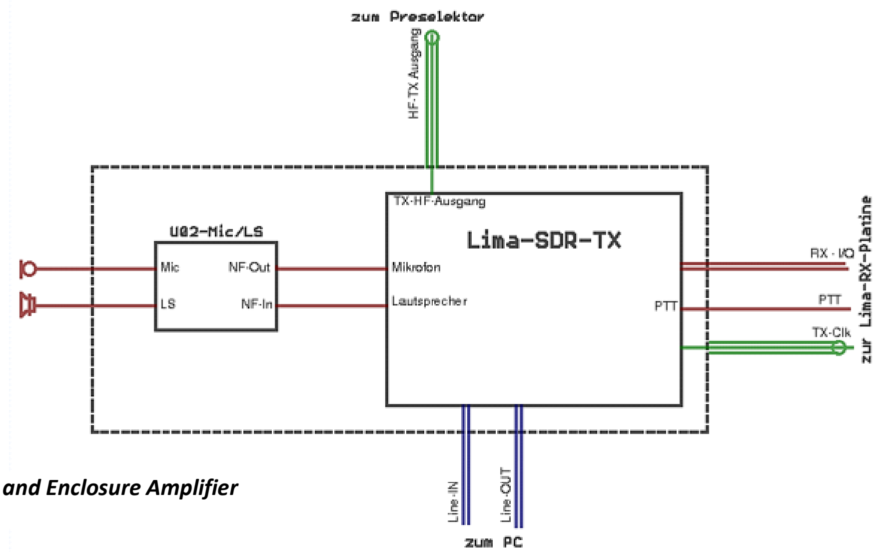


fig. 14b, Lima-RX and Enclosure Amplifier

The Lima microphone amplifier is disconnected, in its place the DJ0ABR amplifier. By removing C63 and R67 you can solder the branches for the diversion from there, fig.15.

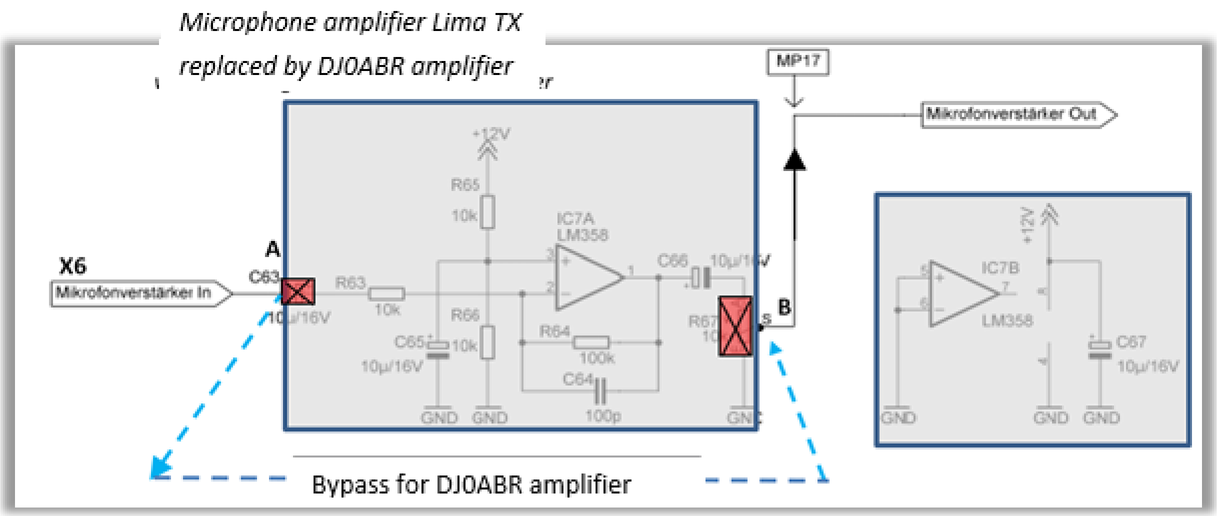


Fig. 15, noodzakelijke aftakkingen en omleiding voor de DJ0ABR versterker.

The picture below shows the solder side of the amplifier, fig. 16.

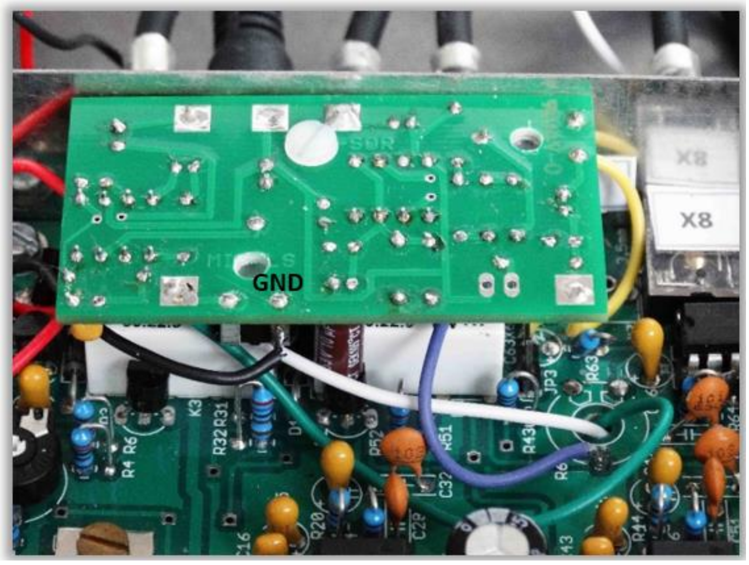


Fig. 16, versterker print.

4. Adjust microphone PTT switching.

When using the 100 watt PA, there may (depending on the design of the device) RF radiation in the microphone amplifier, which is noticeable by loud pulsating gurgling in the pauses. As a remedy, connect a 22nF capacitor in parallel with R4. Thus, these disturbances are eliminated.

4.1. Connect microphone switch.

To use your microphone's PTT switch, it must be connected to the PC. For this you must have a Serial interface, this is easy to make, without any electronics knowledge. For this you need a 9-pin Sub plug suitable for the Serial port of the PC, or a USB-to-Serial adapter cable. The two lines of the PTT switches are connected to pins 4 and 6 of the D-sub connector, fig. 17 and 18. At Connections Primary, in PowerSDR, set the desired port.

4.2. Expansion.

The above-mentioned very simple connection has the disadvantage that the PTT is not connected to ground. Therefore, DJ0ABR has expanded the circuit somewhat with a ground-based PTT that works well in practice. So you have to bring both wires from the PTT switches without ground connection to the PC. To ground the PTT correctly, the PTT button must lead the connection to the PC ground, that's what this circuit is intended for. The transistor is a P-channel MOSFET, the BS250, or the like. As long as the PTT is not pressed, the MOSFET is blocked via R1. When the PTT is pressed, the gate of the MOSFET is pulled to ground. Since my COM interface is +6V on pin 4, the MOSFET conducts and switches +6V from pin 4 to pin 6. This recognizes PowerSDR and goes on transmit.
Note: I have removed the Zener from the DJ0ABR scheme because it does not pull the Gate sufficiently to zero.

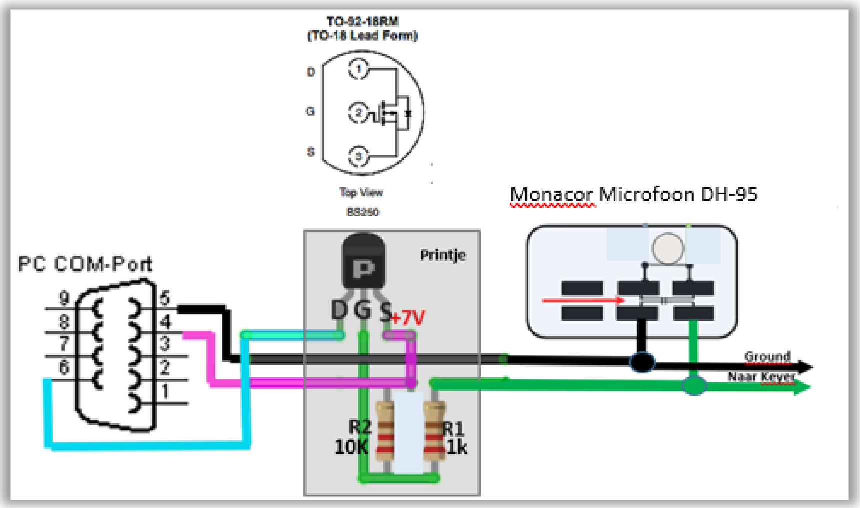


Fig. 17, bedrading, mijn microfoon.

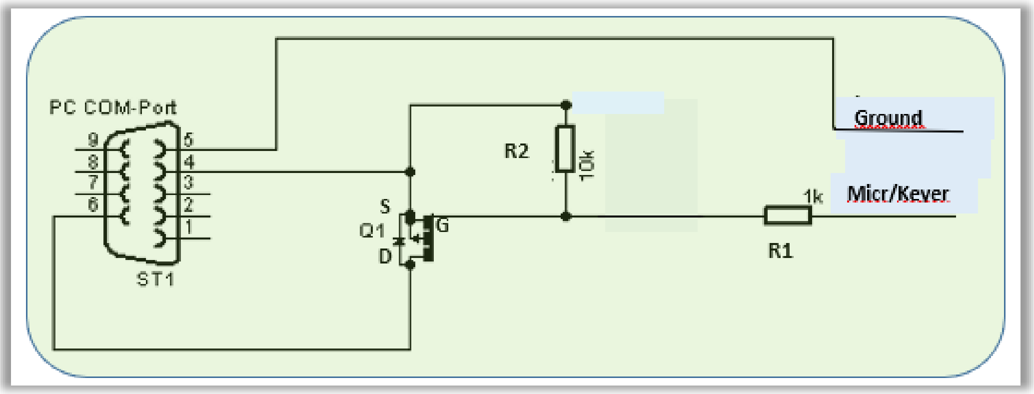


Fig. 18, schakelschema.

DJ0ABR: “The few components are built directly into the housing of the 9-pin Sub-D connector”.
Many PCs nowadays no longer have an RS232 port, a USB-RS232 converter offers the solution, fig.19.

I soldered the components on a piece of experimental PCB because the space in the 9-pin Sub-D is very small, fig. 19a.

Fig.19, USB-RS232 converter.

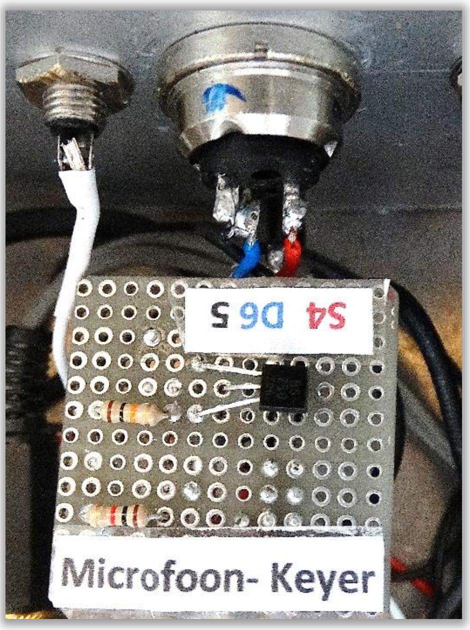


Fig.19a, Circuit on an experimental PCB.

5. Preselector.

5.1. Explanation.

De Lima is now prepared to proceed to the construction of the Preselector. The main goal is to achieve optimum low-pass damping and good flank steepness.
According to DJ0ABR, this goal was achieved, see table 1. The transmission attenuation is smaller than 1.2dB on all bands. I have not been able to check that myself, because I lack the necessary measuring equipment. Three measures are required to achieve the above:

-1. Relays are used instead of diode switches. This measure saves approx
3dB attenuation
-2. As filter capacitors connected to GND, Styroflex capacitors are used.
suits. This measure saves 3 to 6 dB of damping per band.
-3. Iron powder toroids or air coils are used as coils. Although this is a
small attenuation makes the filter very comfortable in the passage (better than 0.2 dB
ripple), which cannot be achieved with SMCC coils.

An MMIC (SGA 5289) is used as the RX preamplifier and the ERA-5 as the TX amplifier. The separation of the RX and TX preamplifier has brought great benefits to the step-by-step explanation. An initial test with WSPR, compared to the Lima-SDR Preselector, showed a significantly higher yield from the received stations. 6 to 10 dB extra gain can already be put to good use. Together with the very good RX mixer of the Lima-SDR, one thus has a very sensitive receiver that even outperforms an IC756 ProII. Subjectively, the noise part is a bit smaller and the modulation with an ICOM a bit more pure. But when it comes to taking very weak signals, this SDR has an edge.

5.2. Measured values from the Preselector.

Band	Frequenz [MHz]	Durchlass-Dämpfung [dB]	1.Ober-welle [dB]	2.Ober-welle [dB]	Verstärkung RX-Vorverstärker [dB]	Verstärkung TX-Vortreiber [dB]
<1MHz	0,1 - 1	-0,3	-15	-23	+11,3	-
160m	1,4 - 2,3	-0,5	-22	-36	+11,5	+14,6
80m	2,0 - 4,6	-0,9	-14	-27	+12,0	+14,5
40m	6,6 - 7,4	-1,2	-46	-64	+11,7	+14,5
30m	9,5 bis	-1,0	-8	-24	+11,6	+15,0
20m	15	-1,0	-21	-39	+11,8	+14,9
17m	17,7 bis	-0,6	-24	-51	+11,5	+14,6
15m	23	-0,5	-34	-60	+11,8	+15,1
12m	23 bis	-0,6	-25	-45	+11,7	+14,8
10m	31	-0,6	-36	-60	+11,6	+14,9

Table 1

5.3. Solder relay with band switching.

First you solder all components, with the exception of all filter branches (between the relays), furthermore you omit the two MMIC amplifier ICs. So you have soldered all the components required for the relay circuit.

5.4. Test nutrition.

Now connect an adjustable power supply to the PCB, but still at 0 volts and a current limit of about 0.5A. Now measure the voltage on the 74HC04 between pins 7 and 14 while slowly increasing the supply voltage. The measured voltage should then rise slowly. When the supply voltage is between 6 and 7V, you should measure about 5V. If you increase the supply voltage further, the measured voltage should remain 5V. If the measuring voltage exceeds 5.5V, the voltage regulation does not function and you must abort the test. Then check the soldered components. Also abort the test if the current exceeds 0.5 A, in which case there is a short circuit. Finally, you measure the output voltage of the 7808, which should be approximately 8 Volts at a supply voltage of 12 Volts.

5.5 Testing the band switching relays, fig.20.

If the tests at 5V are OK, you can put the full 12V (or the usual 13.8V) on the PCB. The voltage across the inputs of the 74HC04 (measured across the 100k resistors) is stabilized at +5 V. As a result, the outputs of the 74HC04 are at 0 V and the relays are not switched over the ULN2803 and the belt relay is therefore de-energized. You check that with a “beeper” by measuring between pin 1 (GND) and pin 7 of the belt relay. 0 Ohm must be measured. This kind of reed relay switches inaudibly and only switches to ground, as long as they are de-energized. If you now connect one of the band inputs to ground (Meder Dips on pins 1 to pin 7), the two relays connected to it must also activate. Check this by measuring between pins 1 and 14 of the corresponding relay.

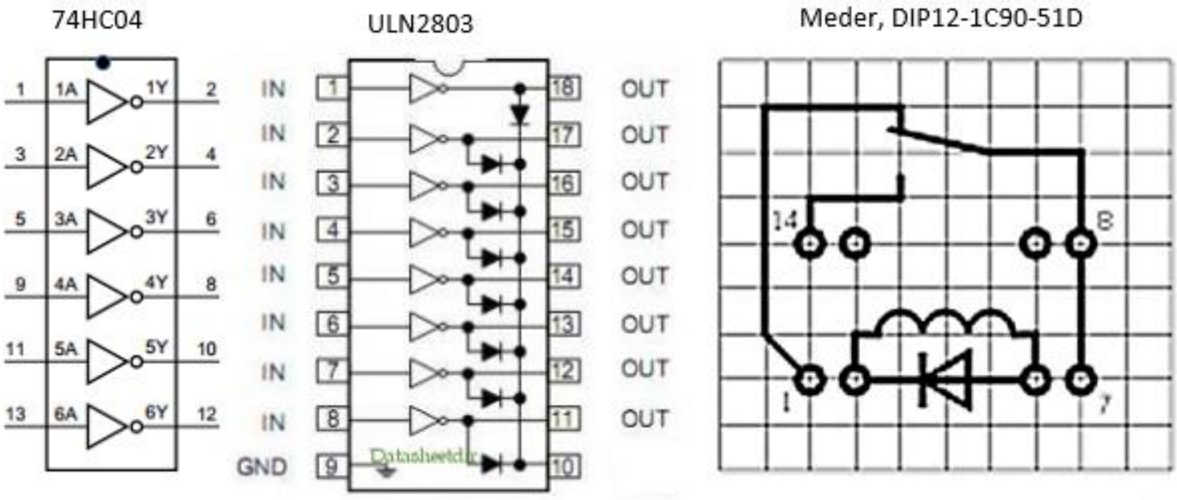


Fig. 20, Applied Relays. ***Bandschakelaars***

5.6. Detail of the Bandpass filters, fig.21.

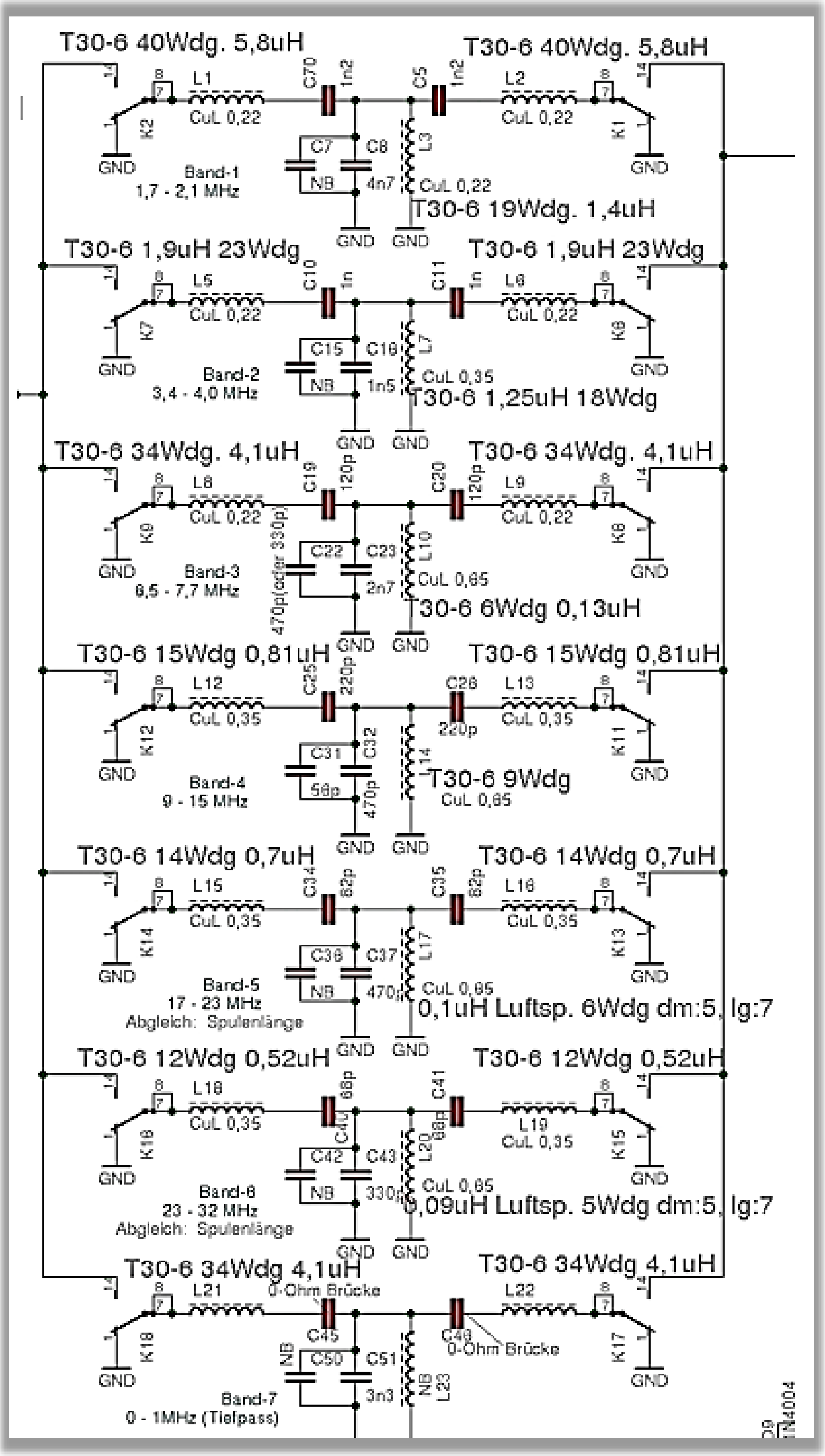
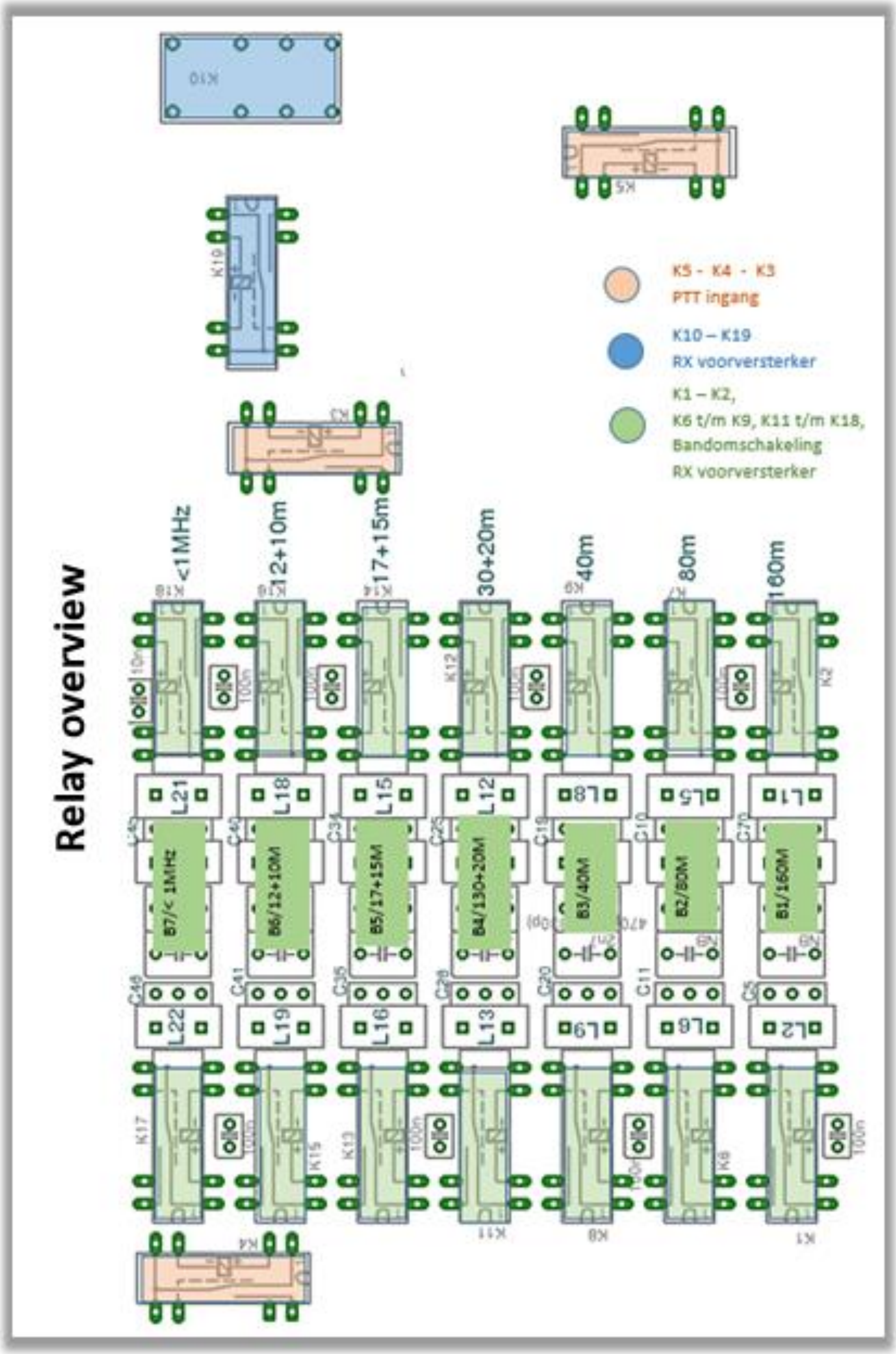


Fig. 21, Bandfilters.

5.7. Relay positions.

I have made the image below for myself, so that control measurements can be made faster and more accurately, fig.22.



5.8. Relay circuit, detail, fig. 23.

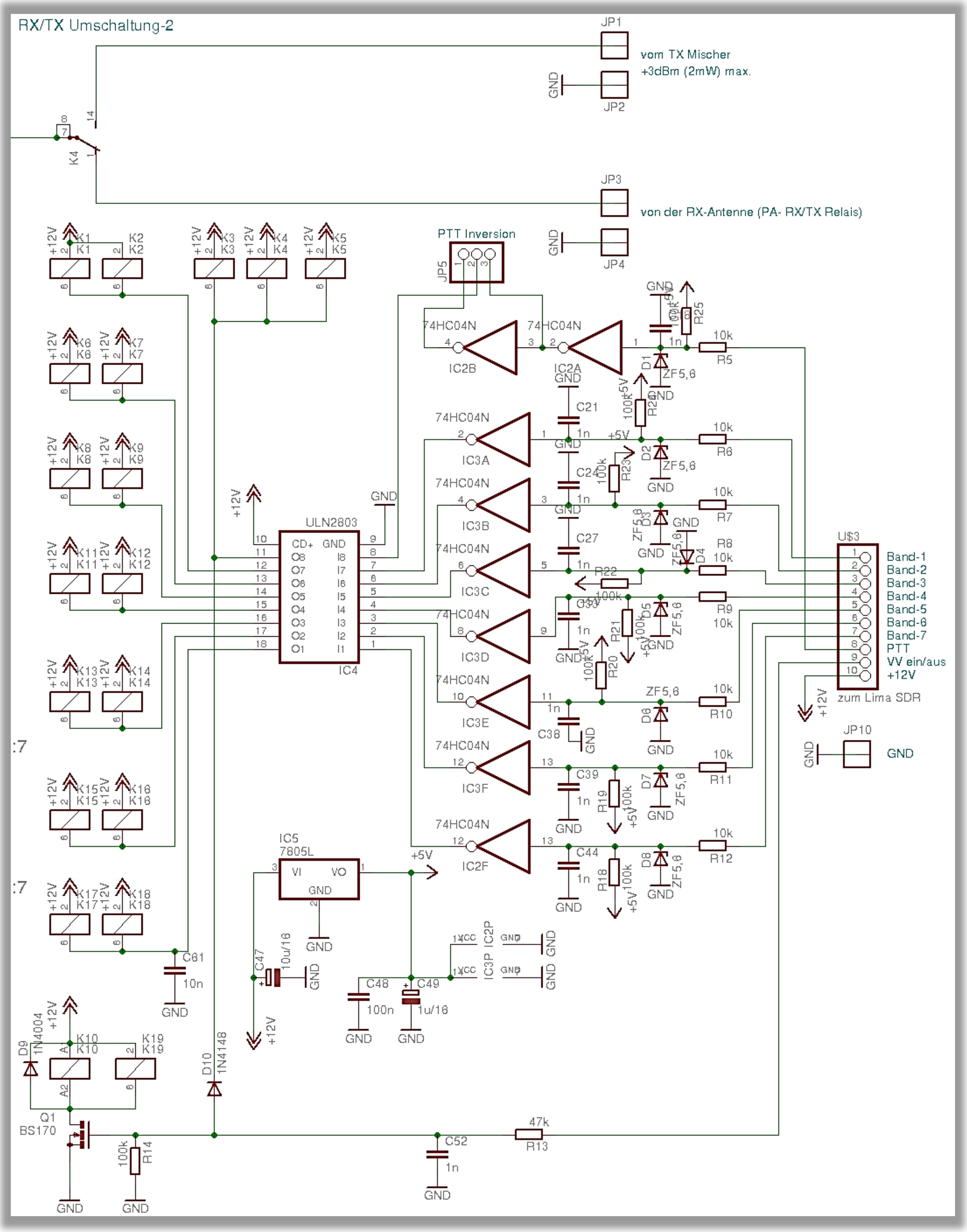


Fig. 23, Relay circuit diagram.

5.9. Testing the two RX preamp relays.

Now the relay of the RX preamplifier has to be tested. You put the connection U$ 3 pin9 (Amp) to ground. Relays K10 and K19 (bottom left of the diagram) are now de-energized because the Fet BS170 is not closed. You can check that again with the “beeper” between points 1 and 7 of the two relays. Then you apply this port to +12 V and the two relays should then attract. You can also check that again with the “beeper” between points 7 and 14 of the two relays. For this test, the PCB must be in RX mode. In TX mode, the preamplifier is always turned off. You can do this, for example, by placing JP5 between 2 and 3 and nothing is connected to the PTT input. This means that the entire relay control has been checked.

5.10. Testing the three PTT relays.

Now you are looking at the PTT relay. This one needs another jumper on JP5. Here you can set whether the PCB will send when the PTT input should go to +. In Lima-SDR, PTT goes on + when transmitting. Therefore, the jumper must be set so that relays K3, K4 and K5 energize as long as no PTT line is connected. The resistor R25 (100K) holds the PTT input to +, which means "Send". So you put the jumper JP25 in such a way that the relays pull, (1-2). If you connect the PTT input (plug U $ 3 Pin 8) to ground, the relays should drop out, fig. 24 and 25.

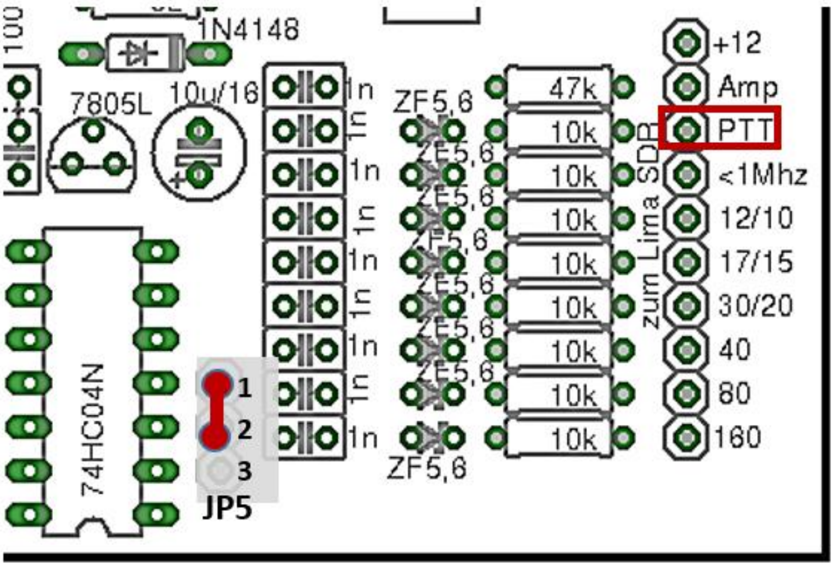


Fig. 24, PTT

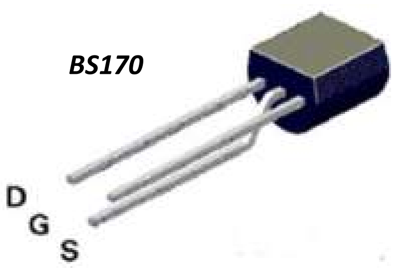


Fig.25, Connect pins BS170

Why should the jumper be set to 1-2, see the explanation below, fig.25.

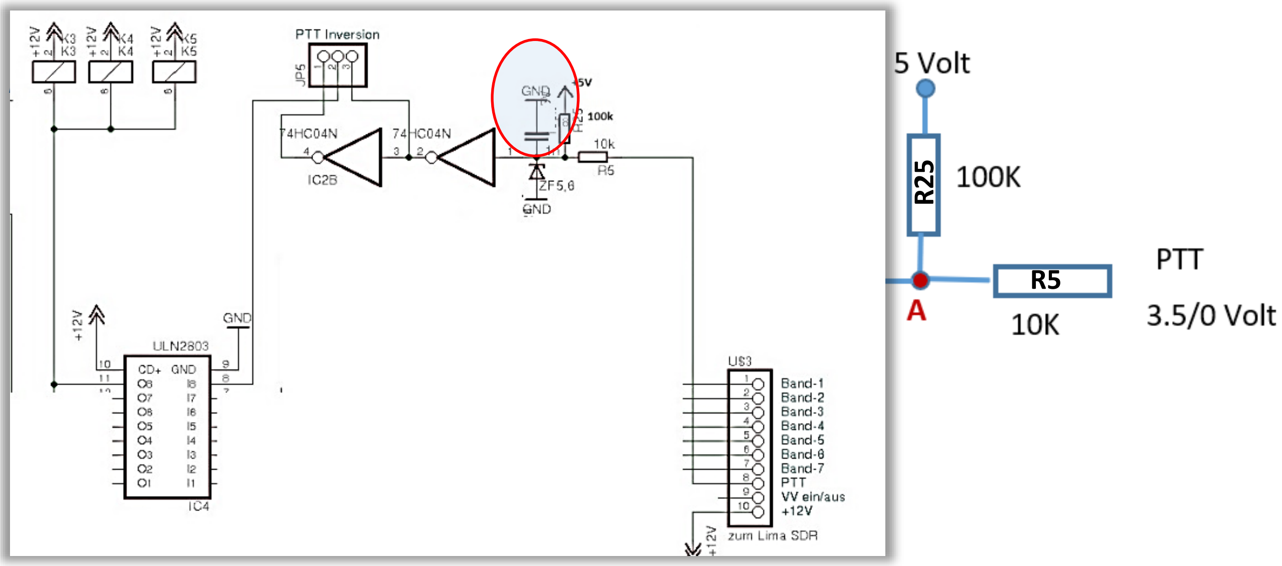


Fig. 25, PTT.

The resistors and R5 and R25 form a voltage distribution. With 3.5V on the PTT input, the voltage at point A is: 10/110 x 5V + 10/110 x 3.5V = 3.6V. That is 'high' for the inverter, so the output goes to low, so 0V.

The same goes for 0V: 10/110 x 5V + 100/110 x 0V = 0.45V. That is 'low' for the inverter, so the output goes high, so 5V. JP5 should therefore be set to 1-2.

5.11. Schematic of the full Preselector, fig.26.

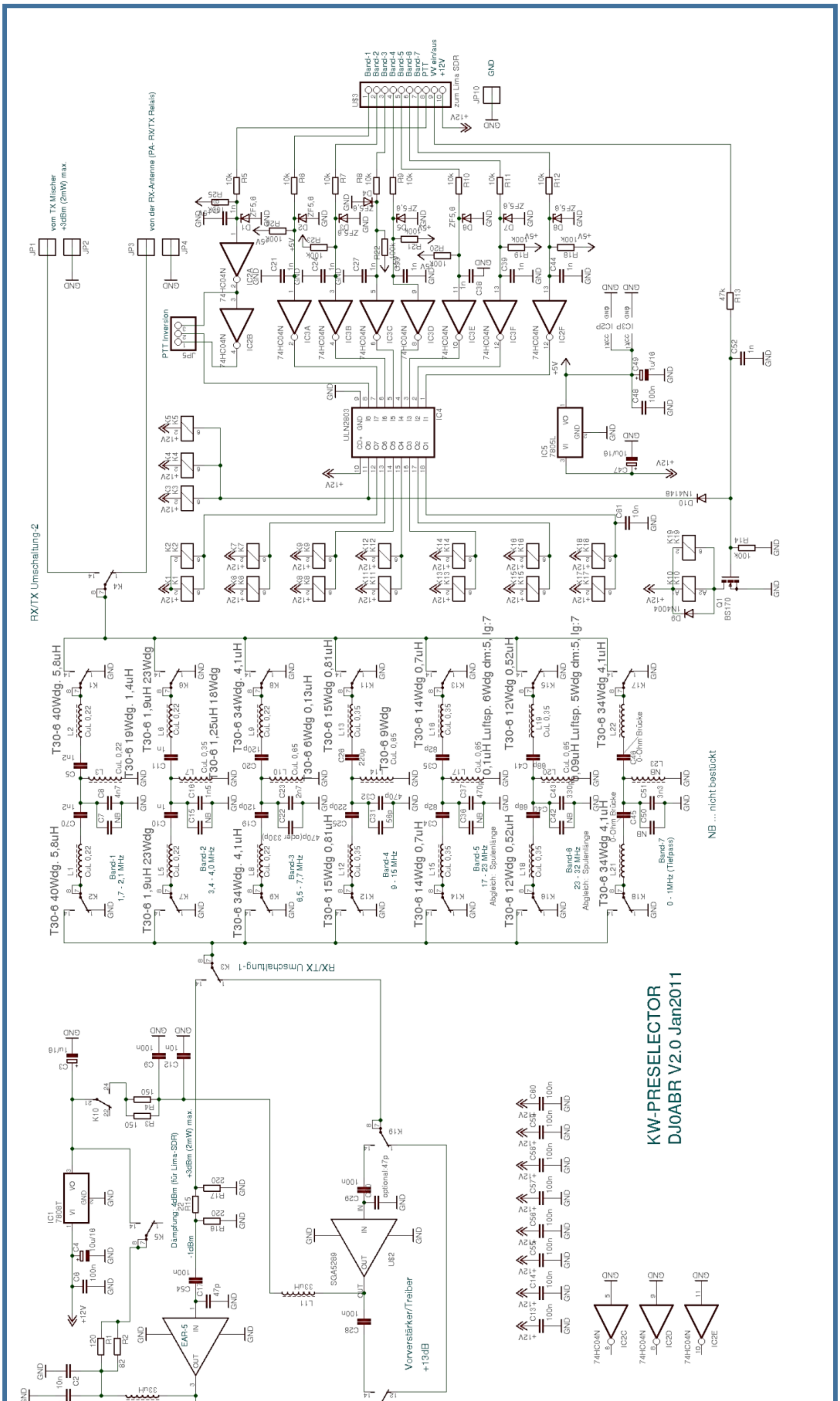


Fig. 26, Schema Preselector

5.12. Install the Band filter.

Now you can solder all seven bandpass filters. The core material, number of turns and wire thickness can be found in the circuit diagram, table 2. The turns must be wound evenly next to each other over the core, do not wrap turns over each other. When placing the capacitors, it should be noted that all capacitors that are grounded (in the filter center) must necessarily be of the Styroflex version. Good transmission damping is not achieved with ceramic Cs!
The number of turns around the core corresponds to the number of wires on the inside of the core.

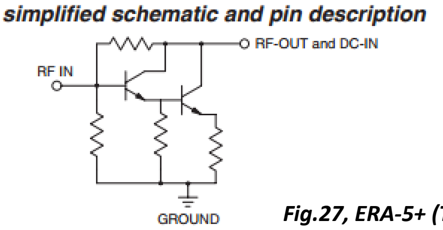
Help table for winding coils

Coil [L]	[uH]	Wdg	Wire diam.[mm]	Band [MHz]	Air coil	
					Diam. [mm]	Length [mm]
1	5.8	40	0.22			
2	5.8	40	0.22	Band-1 1.7-2.1		
3	1.4	19	0.22			
5	1.9	23	0.22			
6	1.9	23	0.22	Band-2 3.4-4.0		
7	1.25	18	0.35			
8	4.1	34	0.22			
9	4.1	34	0.22	Band-3 6.5-7.7		
10	0.13	6	0.65			
12	0.81	15	0.35			
13	0.81	15	0.35	Band-4 9-15		
14		9	0.65			
15	0.7	14	0.35			
16	0.7	14	0.35	Band-5 17-23		
17	*0.1*	*6*	*0.6-0.7*		*5*	*7*
18	0.52	12	0.35			
19	0.52	12	0.35	Band-6 23-32		
20	*0.09*	*5*	*0.6-0.7*		*5*	*7*
21	4.1	34	0.22 ?	Band-7 0-1		
22	4.1	34	0.22 ?			
23						

Tabel 2

5.13. Solder the Amplifier IC.

Finally, solder the two MMICs for the RX and TX preamp, fig. 27 through 30. Watch out for static charge from your hand and soldering iron, which must be discharged to ground, as you can statically destroy this IC! The printout is now ready and when you have an analyzer you can check the transmission curves.



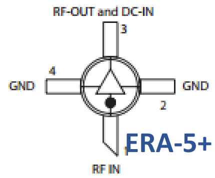


Fig.27, ERA-5+ (TX amplifier) terminals.

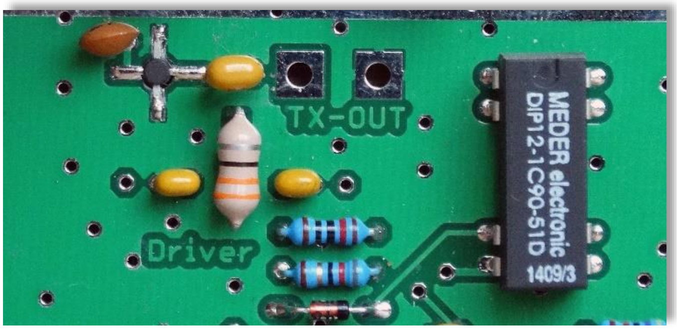


Fig. 28, Component side ERA-5+.

1	RF IN	RF input pin. This pin requires the use of an external DC blocking capacitor chosen for the frequency of operation.
2, 4	GND	Connection to ground. Use via holes for best performance to reduce lead inductance as close to ground leads as possible.
3	RF OUT/ BIAS	RF output and bias pin. DC voltage is present on this pin, therefore a DC blocking capacitor is necessary for proper operation.

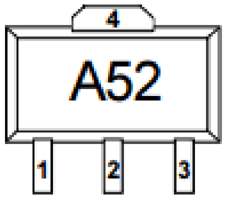


Fig. 29, Terminal pins A52.

Fig. 30, Component side (RX preamp, SGA5289).

5.14. The completed Preselector, fig.31.

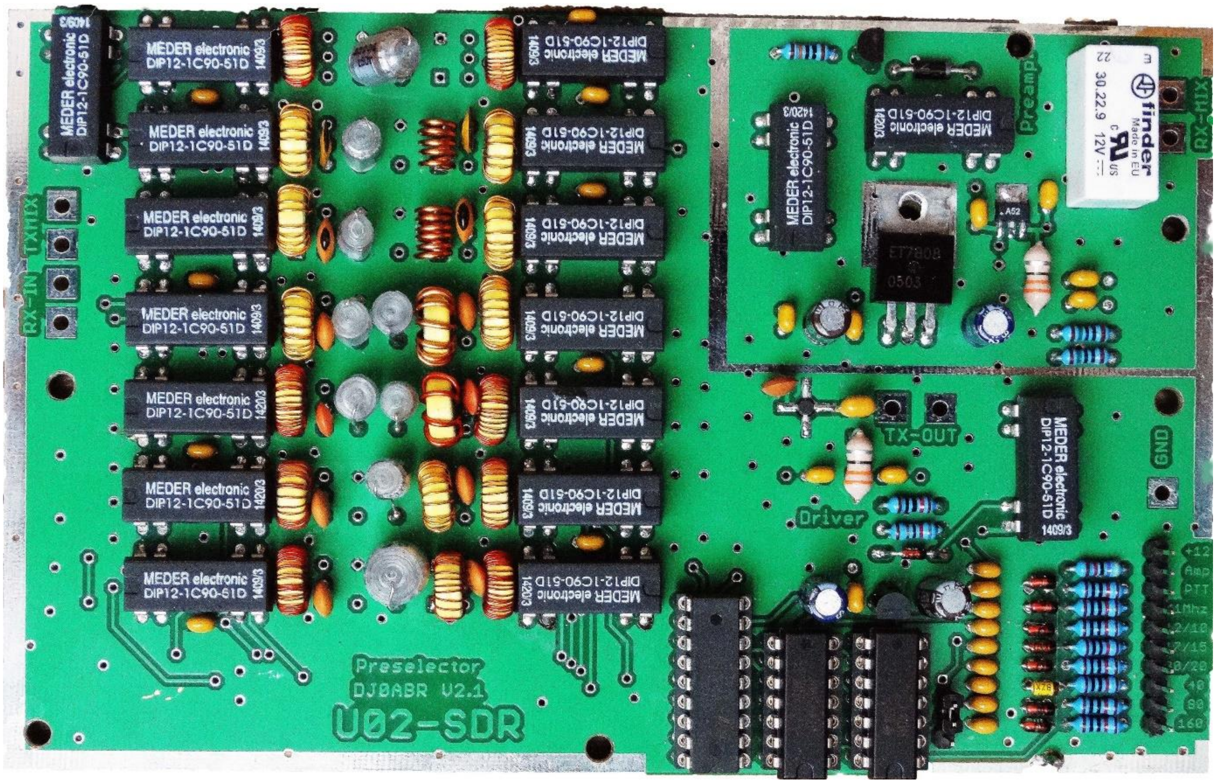


Fig. 31, Component side, Preselector.

Feed-through capacitors with draught-free tin housing:
For DC or LF lines, 1nF feedthrough capacitors are used, Fig. 32, and for HF lines, the 1pF glass feedthroughs, Fig. 33.

Fig. 32, Feed-through capacitor for LF (1nF).

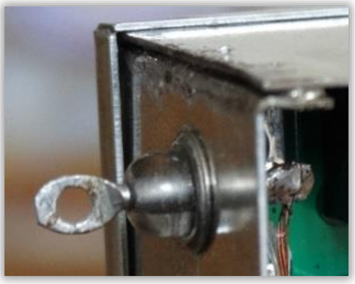


Fig. 33, Feed-through capacitor for HF (1 pF).

5.15. Band switching.

For automatic band switching of the U02 SDR TX Low Pass filter, which may be built later, and the U02 SDR Preselector, the tape control lines are tapped as follows:
From the IC13 (74HC138) the following pins are tapped and brought out,fig. 34, to 37.

Pen 13…. 160m
Pin 12….. 80m
Pen 11…..40m
Pen 10 ...30 +20 m
Pin 9 ......17+ 15 m
Pin 7 ......12+ 10 m

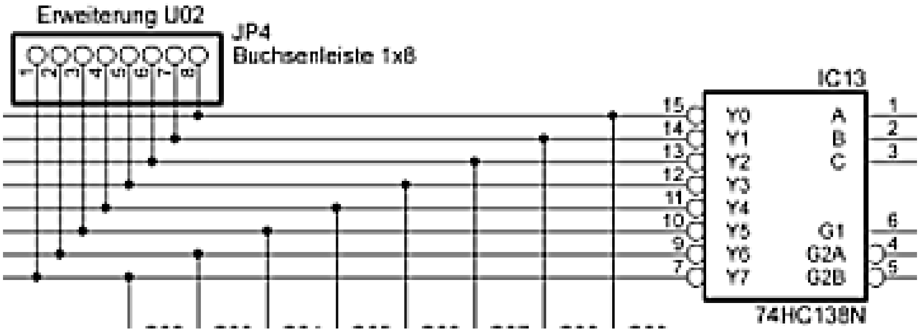


Fig. 34, Lima-SDR band tap diagram.

Fig. 35, Bandfilter Branch points.

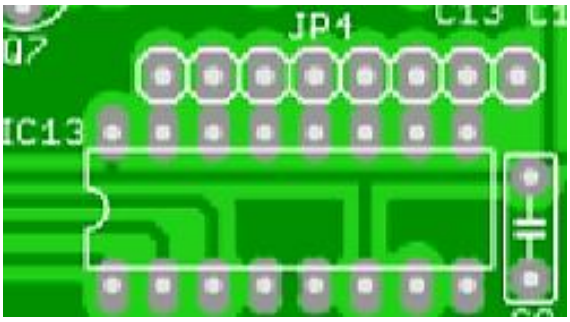


Fig.36, Branch points from the component side.

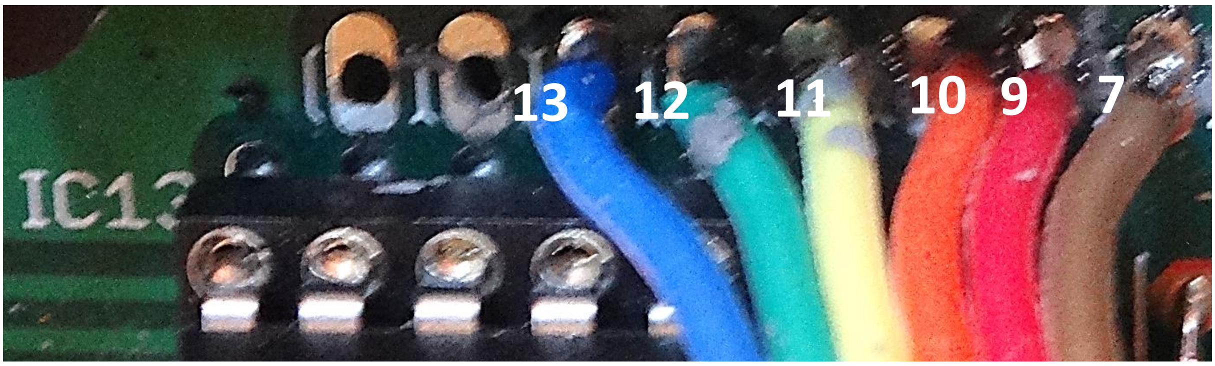


Fig.37, solder points.

5.16. Switchover for medium and long wave.

For medium and long wave interested parties, additional cabling is required, which is discussed separately, because it is not interesting for everyone.
This requires 5 pieces of 1N4148 diodes, fig.38.

5.17. Wiring for the U02-SDR-TX low-pass filter.

At the IC13 (74HC138), the following pins are wired with diodes:

Pin 15 on a 1N4148 diode (cathode - dash)
Pin 14 on a 1N4148 diode (cathode - dash)
Pin 13 on a 1N4148 diode (cathode - dash)

The anodes of these 3 diodes must be connected to each other and run this line. This is connected to the terminal of the 160m U02 SDR TX low pass filter.

5.18. Wiring for the U02-SDR Preselector, Fig. 38.

Pin 15 on a 1N4148 diode (cathode - dash)
Pin 14 on a 1N4148 diode (cathode - dash)

The anodes of these 3 diodes must be connected to each other and run this line. This is connected to the <1 MHz band connection of the U02 SDR Preselector board.

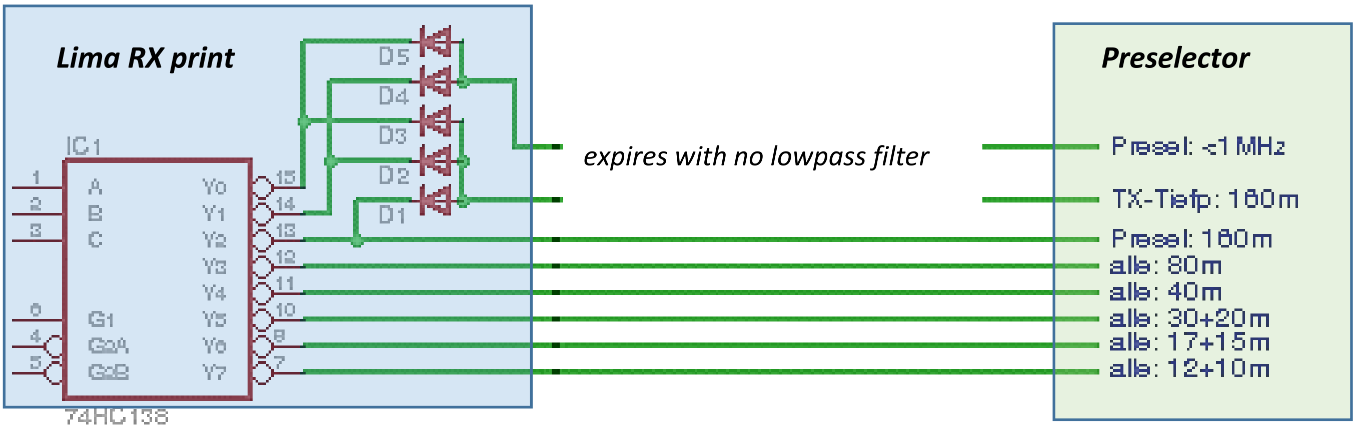


Fig. 38, Optional circuit.

Of course, all additional boards must be connected to +12 V (up to max. 15 V) and grounded. The ground connection is the shielding of the coaxial cable.

6. Power Amplifier, 10 Watt.

After the Preselector it is the turn of the 10Watt HF Power Amplifier. The PA scheme is shown below, fig. 39

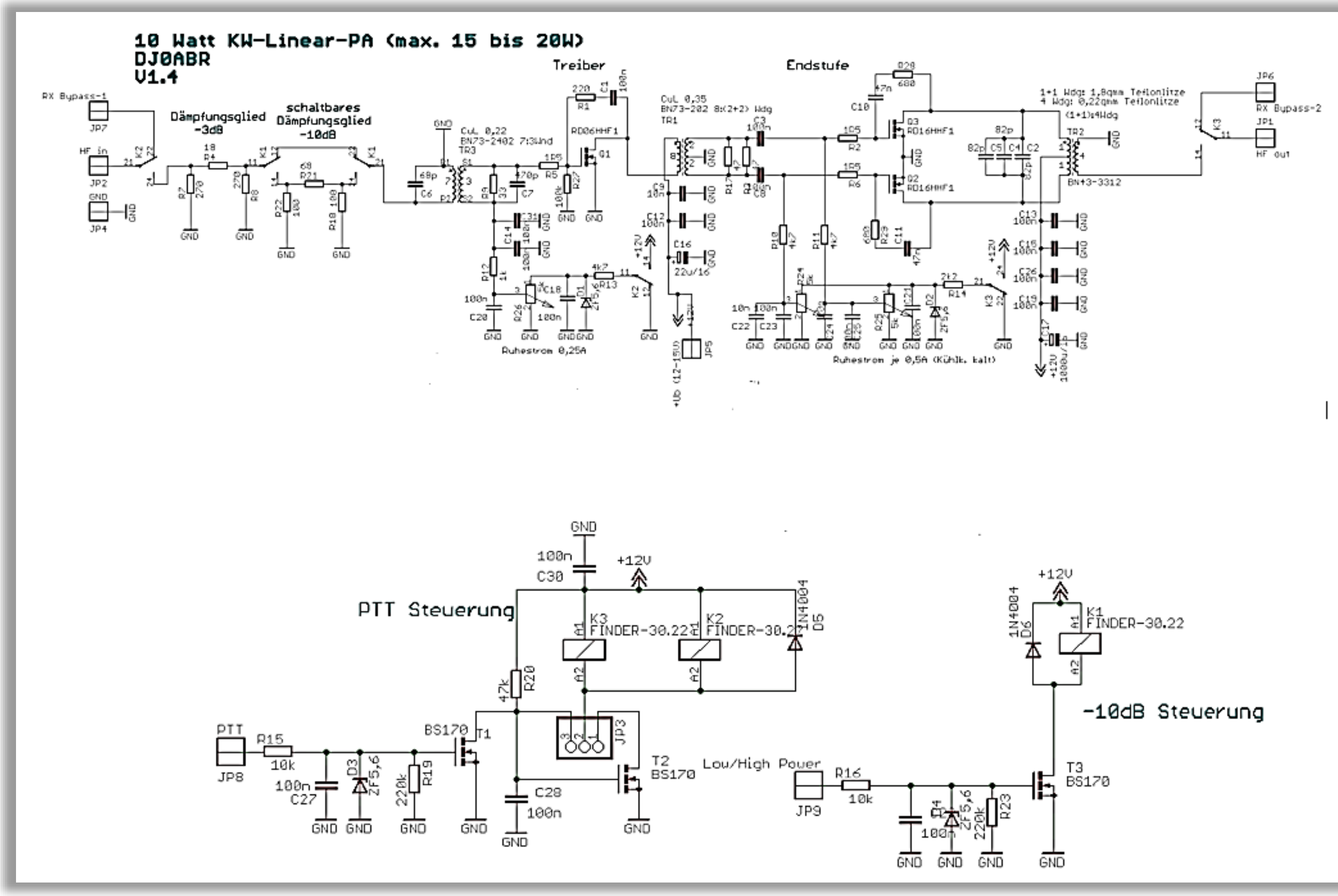


Fig. 39, PA- scheme.

The PA cannot be connected directly to the Lima-SDR transceiver, it has too much output power to drive this PA.
The Lima is connected to the PA via a Preselector, see "Building description Preselector and modifications to the Lima RX and TX".

Description of the circuit.

6.1. input attenuator.
This freely configurable attenuator R4, R7, R8 is used to adapt it to the control transmitter. With the provided -3dB attenuation attenuator, the PA is ideally suited for the U02 Preselector. If you want to use them for other transceiver, you can also change the attenuator.

6.2. switchable attenuator.
For QRP applications you have to take the sound card output far back. This may reduce the signal, but unfortunately not the interfering carrier. For QRP, it is better to switch on these attenuators and only fine-tune the sound card with the sound card.

6.3. input to the driver.
TR3, R9 and C7 link the control power in the driver stage with the RD06HF1 Mosfet.
The input is connected to an HP Analyzer with an SWR measuring bridge and these components are optimized for the best SWR. From 160m to 10m that is approximately 1:1.3 to 1:1.7. Using another attenuator will still improve. C6 and C7 compensate for the double-hole core and provide a smooth frequency response.

6.4. output transformer.
TR2 adjusts the output to 50 ohms. In order to keep the harmonics tolerable over the entire frequency range, a compensation has to take place. This is what C2, C4 and C5 do. It takes about 250pF. Since these capacitors get relatively warm (especially at 10m), 3 82PF capacitors are used to distribute the power.

6.5. transformer winding.
TR3: a small BN73-2402 double-hole core. Easy to wrap: 3 Wdg on one side and 7 Wdg on the other. Just wrap one after the other, don't twist anything. Wire: copper wire 0.22.

TR1: a BN73-202 double hole core. Wrap 2 Wdg first, then leave a longer piece of wire in front of the center branch and immediately wrap the second 2 Wdg. Then wrap the other side 8 Wdg. Wire: copper wire 0.35mm2. Just wrap in order, don't twist anything.

TR2: primary side (Mosfets side): here 2 turns with silver-plated Teflonlitze (1.8 mm2). After a turn you make a tap for the middle branch by slightly removing the insulation and soldering a piece of wire to it. The secondary is wound with 4 turns with silver-plated Teflonlitze (0.22 mm^2).

6.6. Mosfets confirmation.
The PCB is mounted with 5mm spacers:

* You put the transistors in the holes from below. To do this, the pins of the transistors are bent upwards at a right angle.

* With the loosely inserted transistors, you can easily mount the PCB on the heatsink.

* Now mark the three holes for the transistors on the heat sink. Now remove the PCB, drill the 3 holes and tap them with M3 thread.

* Now you apply thermal paste to the transistors and mount the PCB, transistors only loosely connected (not soldered).

* The following photos show how using 3mm solder tab creates an additional ground.

***** Once the Transistors are properly adjusted and screwed hand tight, solder the Transistor pins to the PCB. Then tighten the transistors firmly with the screws.

Setting and modifications.

6.7. quiescent currents.
The Driver step boosts the 40mW at the input to approximately 1 watt at the TR1. The optimum linearity I (DJ0ABR), measured at a quiescent current of 250mA.

The push-pull output stage is set to 0.5 A per transistor, with a cold heat sink. With a warm heat sink, this current rises to about 0.7 A.

At full load (15 Watts) the entire output stage takes about 2.5-3.0 A. This is about 50% efficiency. With not optimally tuned antennas, the power consumption can sometimes reach 3.5A.

6.8. regulation of quiescent currents.
The quiescent currents are set using the the 3 potentiometers, which are shown in the printout of the printed circuit board, track side, with the components soldered on.
Note: the initial setting of the potentiometers must be such that the resistance in the Gate line is 0 Ohm.
The adjusting screws of all three potentiometers must be turned clockwise until this value is reached.

Now first put the TX connection on an adjustable power supply and turn it up to approx. 2.7V. Connect the Mosfet power supply to approximately 14 Volt.

1. potentiometer 1: (turn counterclockwise): setting value 0.25A
2. potentiometer 2: (turn counterclockwise) total supply current 0.75A (0.5A for Q2)
3. potentiometer 3: (turn counterclockwise) total supply current 1.25A (0.5A for Q3)

6.9. PTT.

With the solder bridge jumper SJ1, you can choose whether the PTT when sending to ground or + is switched. At the Lima SDR the PTT goes to +3 V, at most other stations to ground.
PS: For the Lima, seen from the top of the PCB, the left two pins of the jumper must be connected.

6.10. PTT connection to the Lima.

The PTT output of the Lima-RX board has a fairly high impedance. Therefore, the voltage on the Lima PTT output (normally about 3V) can under certain circumstances be pulled down so far that the voltage level is no longer sufficient to switch the PA to the TX. The PTT line must have a level of at least 2.8V when transmitting. On reception, this level is 0V.
If this level is not reached, then the resistor R23 (4.7 K) on the printed circuit board of the RX-Lima must be replaced by a 1K resistor, fig.40. This means that the level of the PTT line is certainly 3V.

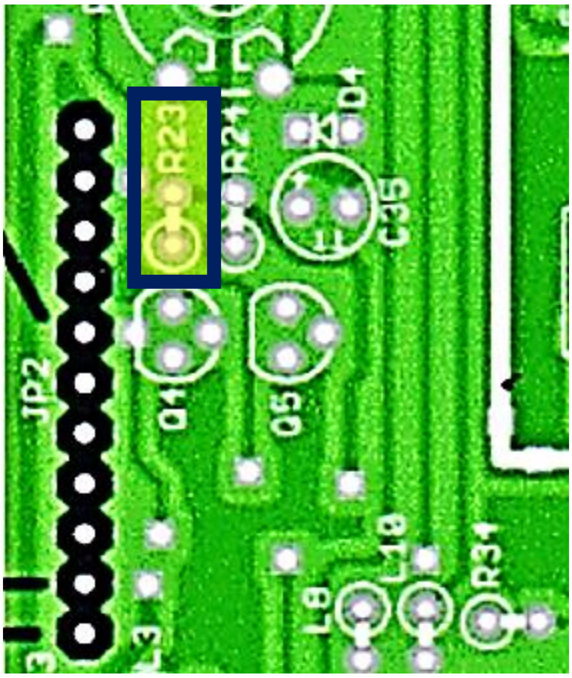


Fig. 40, R23, board.

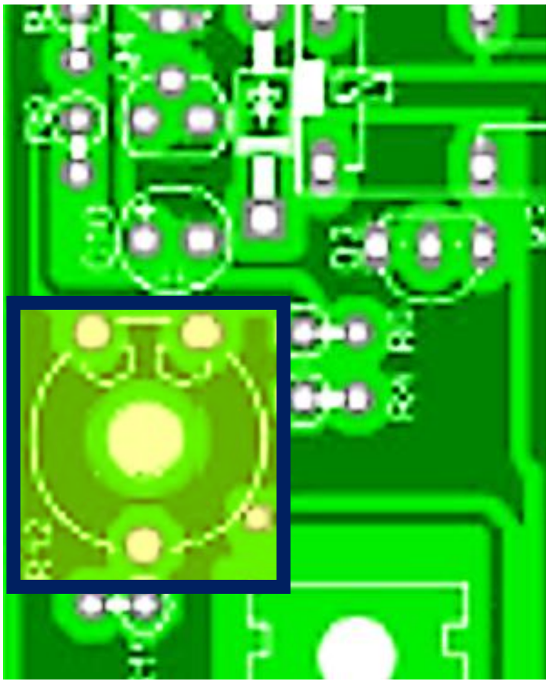


Fig. 41, R12, TX board.

Bovendien is het echter noodzakelijk dat de op de Lima-TX print aanwezige potentiometer R12, fig.41, niet tegen de aanslag staat, zoals in de Lima documentatie wordt beschreven, maar een klein stukje er vandaan wordt gedraaid, omdat anders de PTT-lijn nog meer zal worden belast. Met deze potentiometer stel je dus een kleine vertraging van de PTT in. Dit is een goede zaak, een vertraging van ongeveer 1/4 seconde heeft bewezen in de praktijk goed te functioneren.

6.11. PA component side.

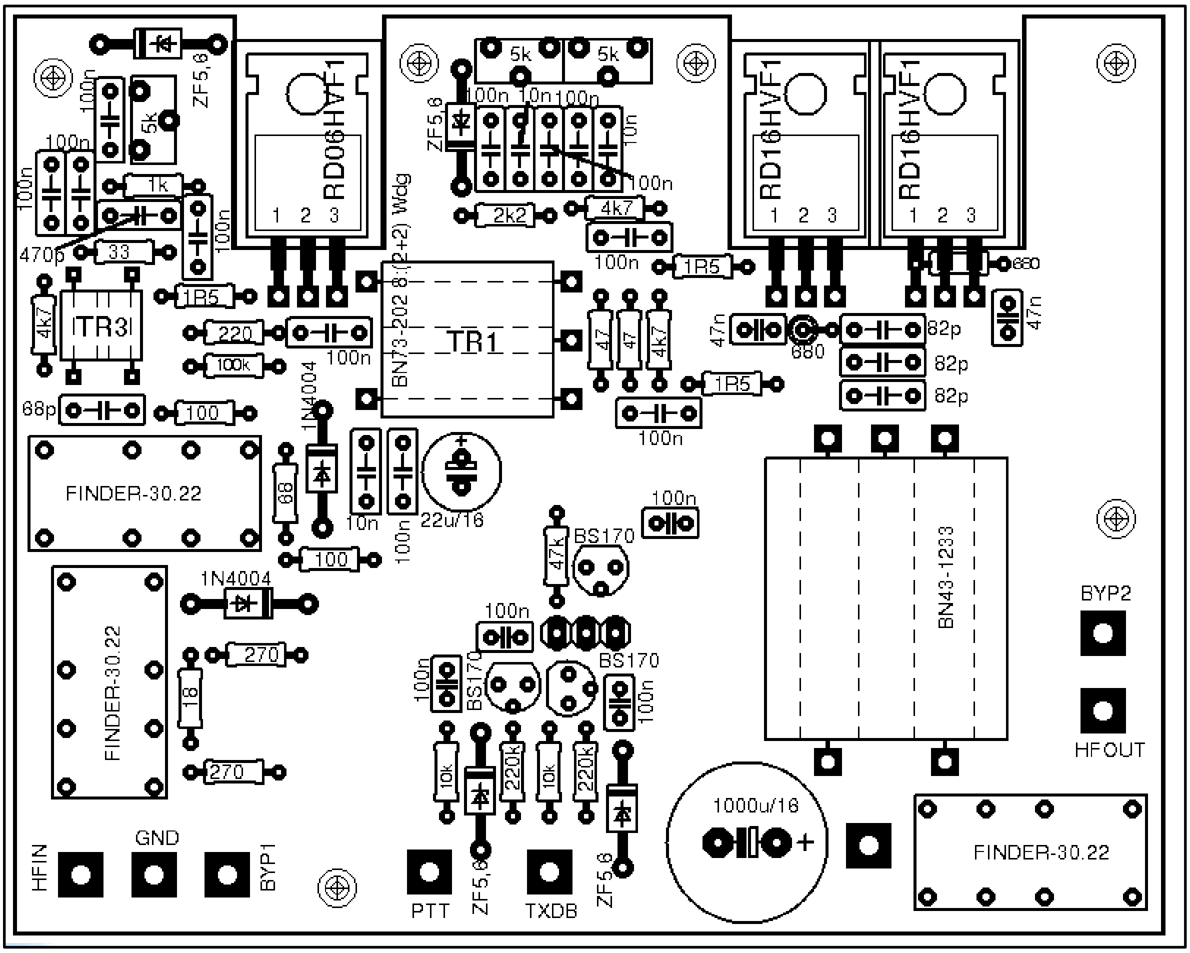


Fig. 42, Parts arrangement.

6.12. Bottom of PA circuit board.

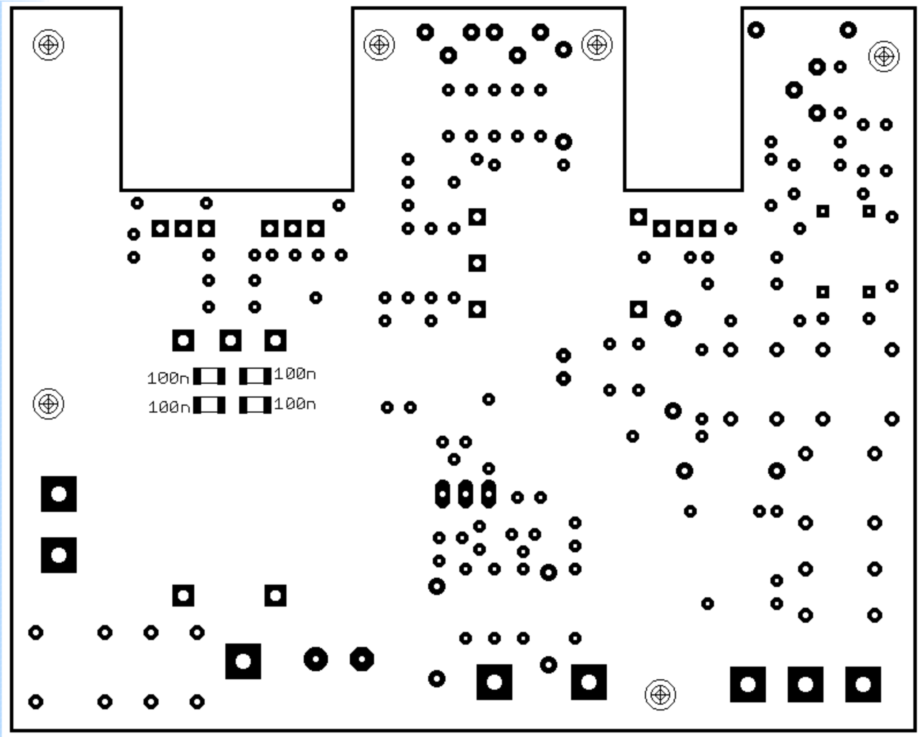


Fig. 43, PA board.

6.12. PA board, solderside.

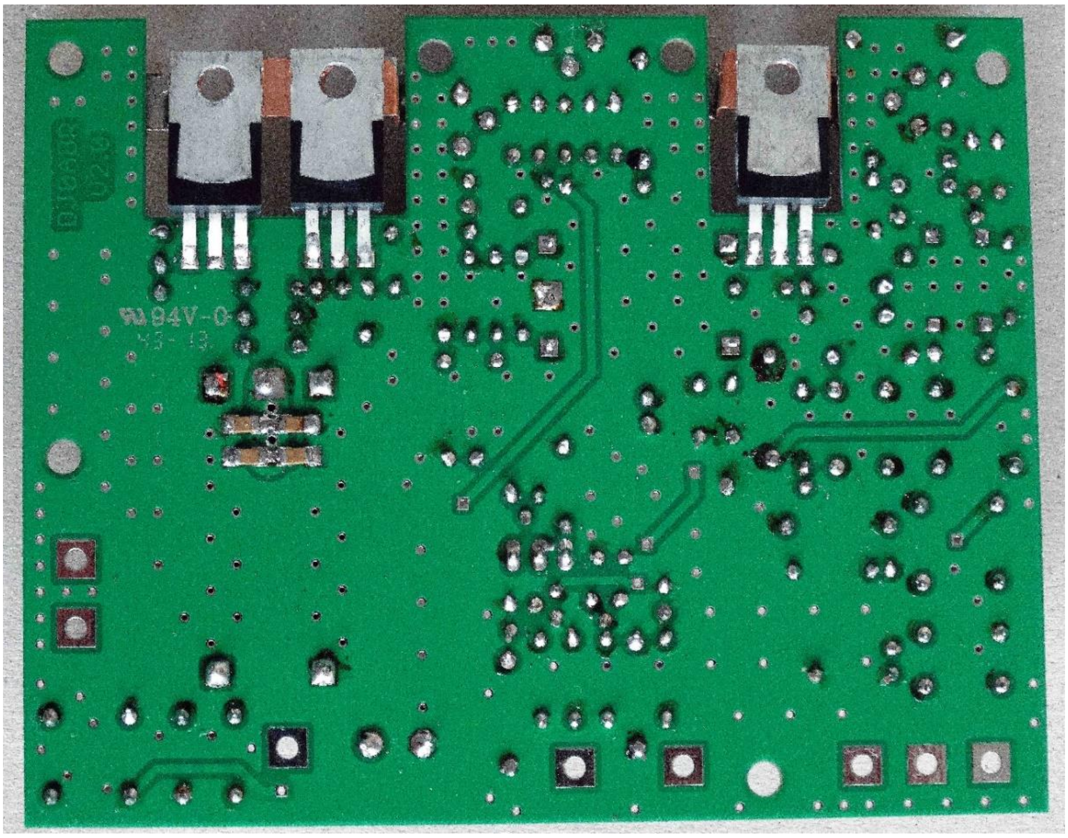


Fig. 44, Solder side PA PCB, Mosfets visible.

6.13 Dimensions HF bottom, fig. 45 and 46.

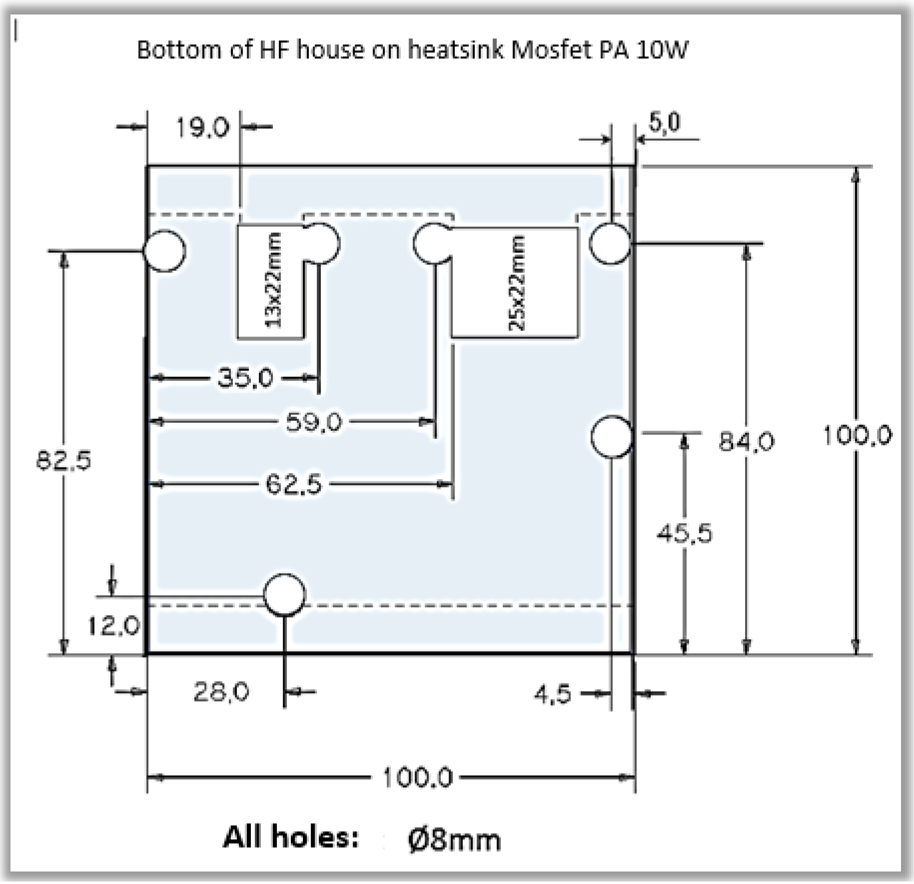


Fig. 45. PA housing.

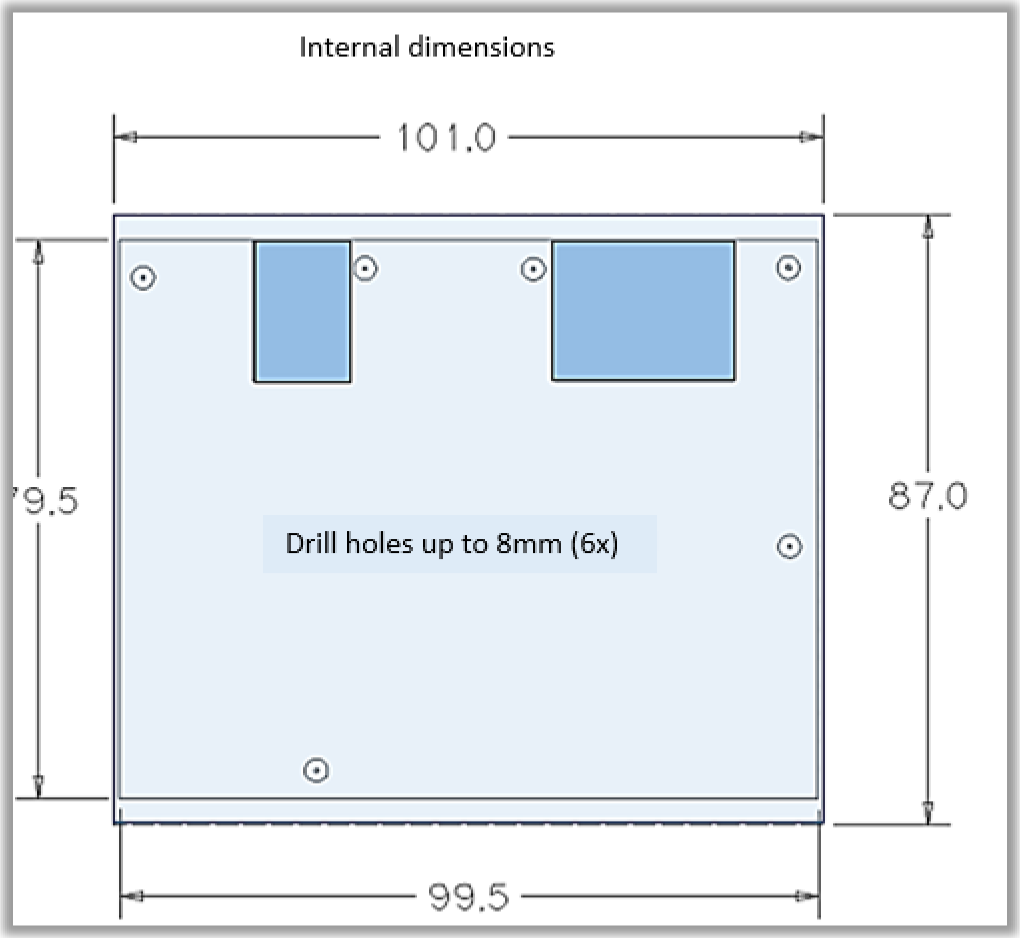

Internal dimensions
101.0
79.5
87.0
Drill holes up to 8mm (6x)
99.5

Fig. 46.

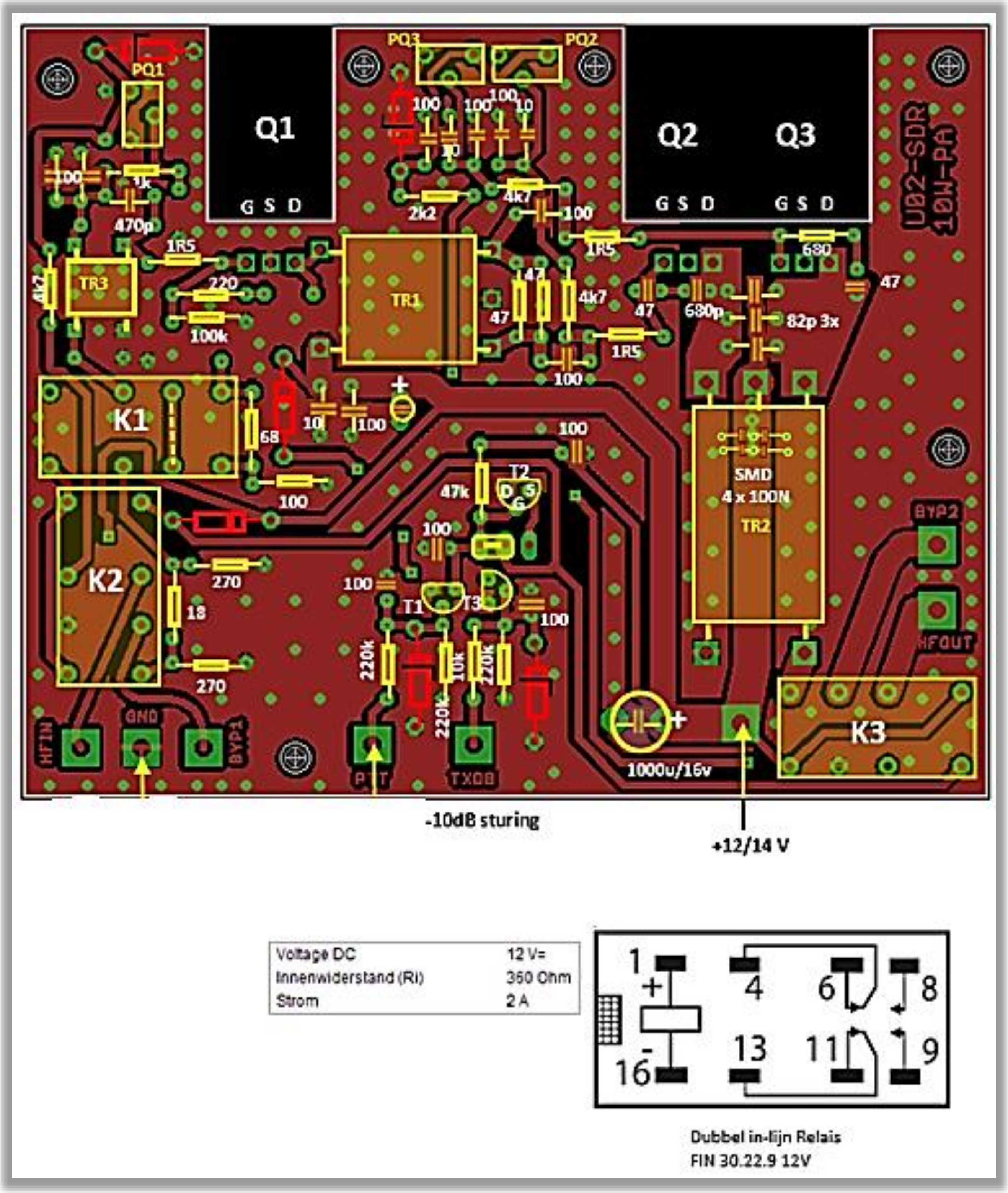
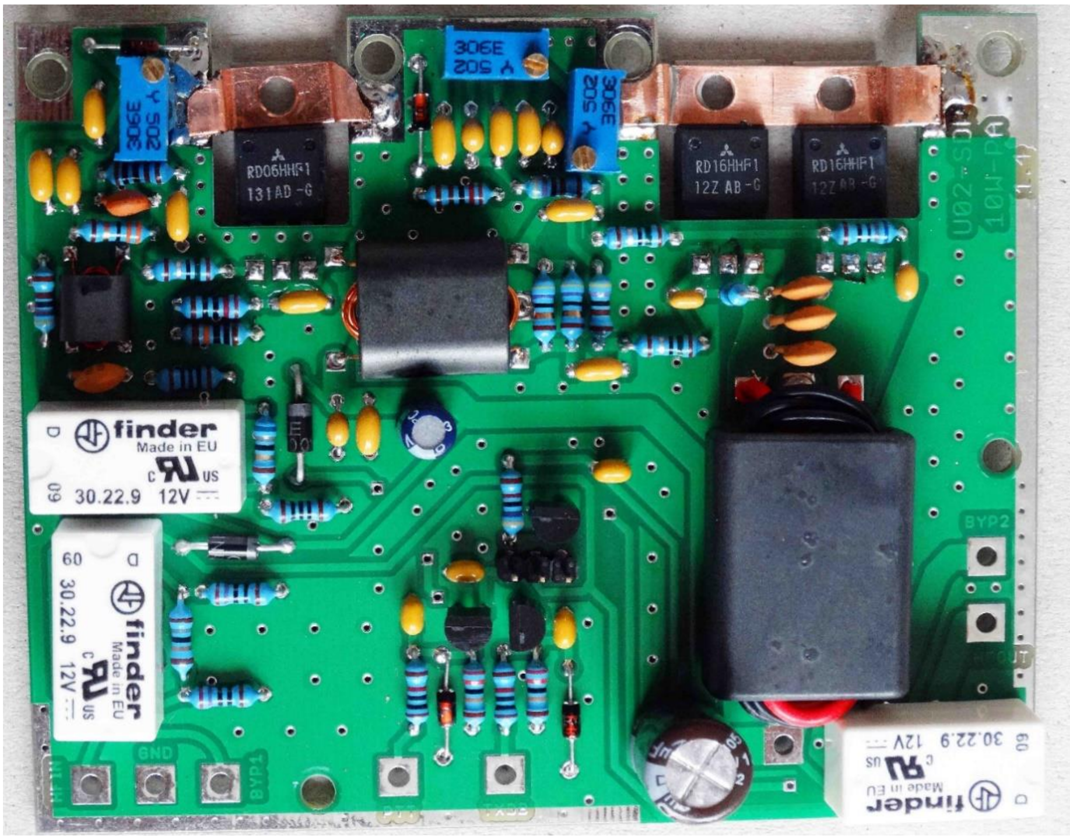
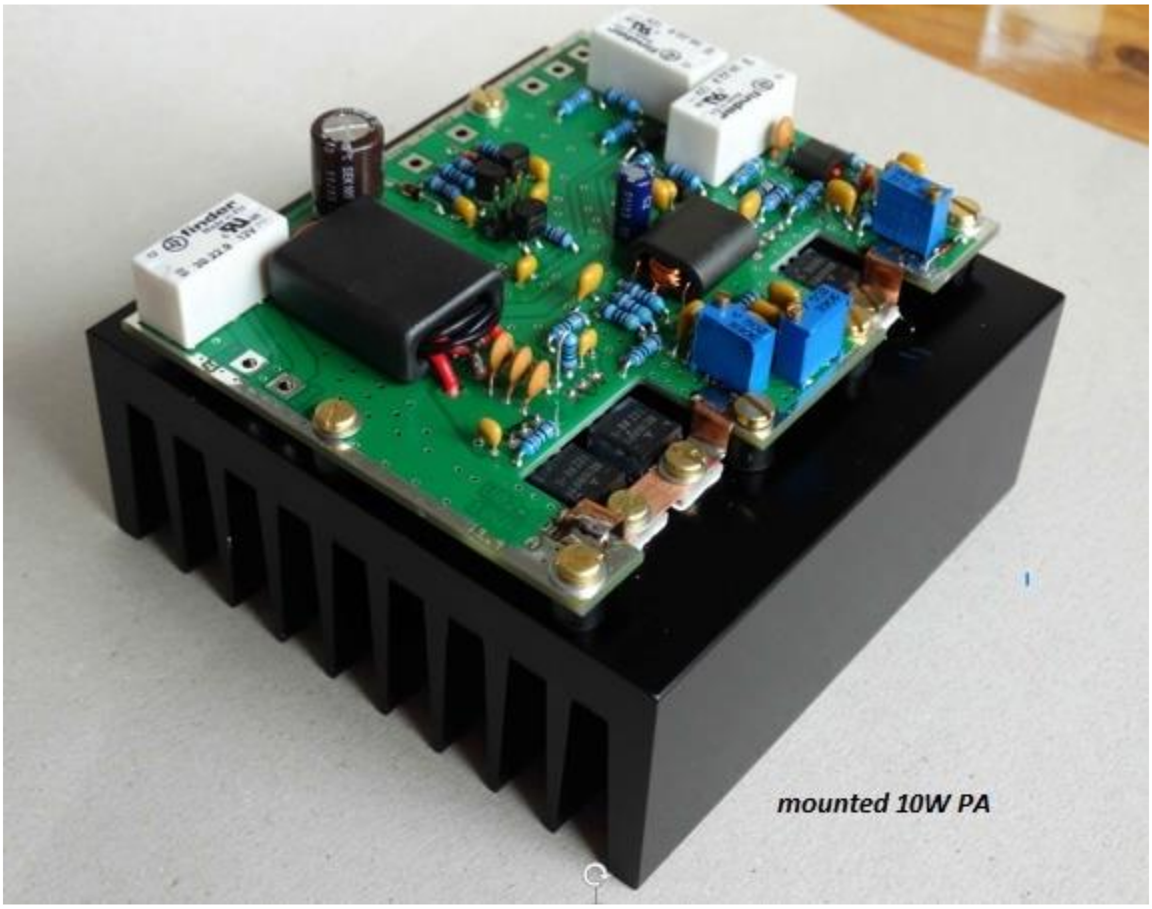


Fig. 47, solder side with components.

6.15 Various clarifying photos.



Detail of the MosFet mounting.


mounted 10W PA
finder


finder
Made in EU
12V

6.16. Connecting to the Lima-SDR.

As shown in the block diagram, fig.48, the following connections are necessary.

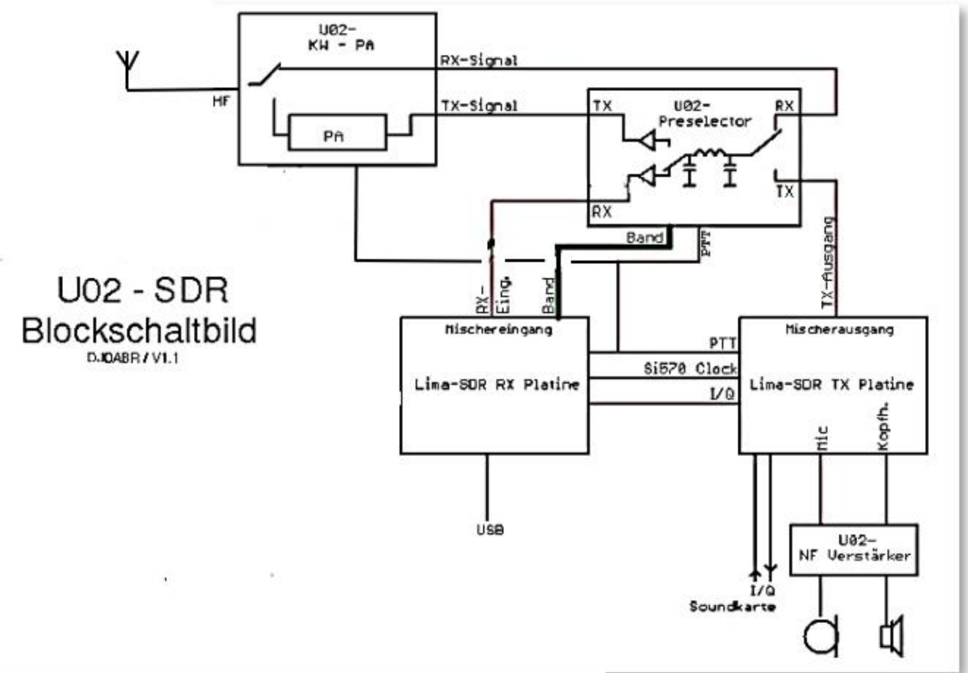
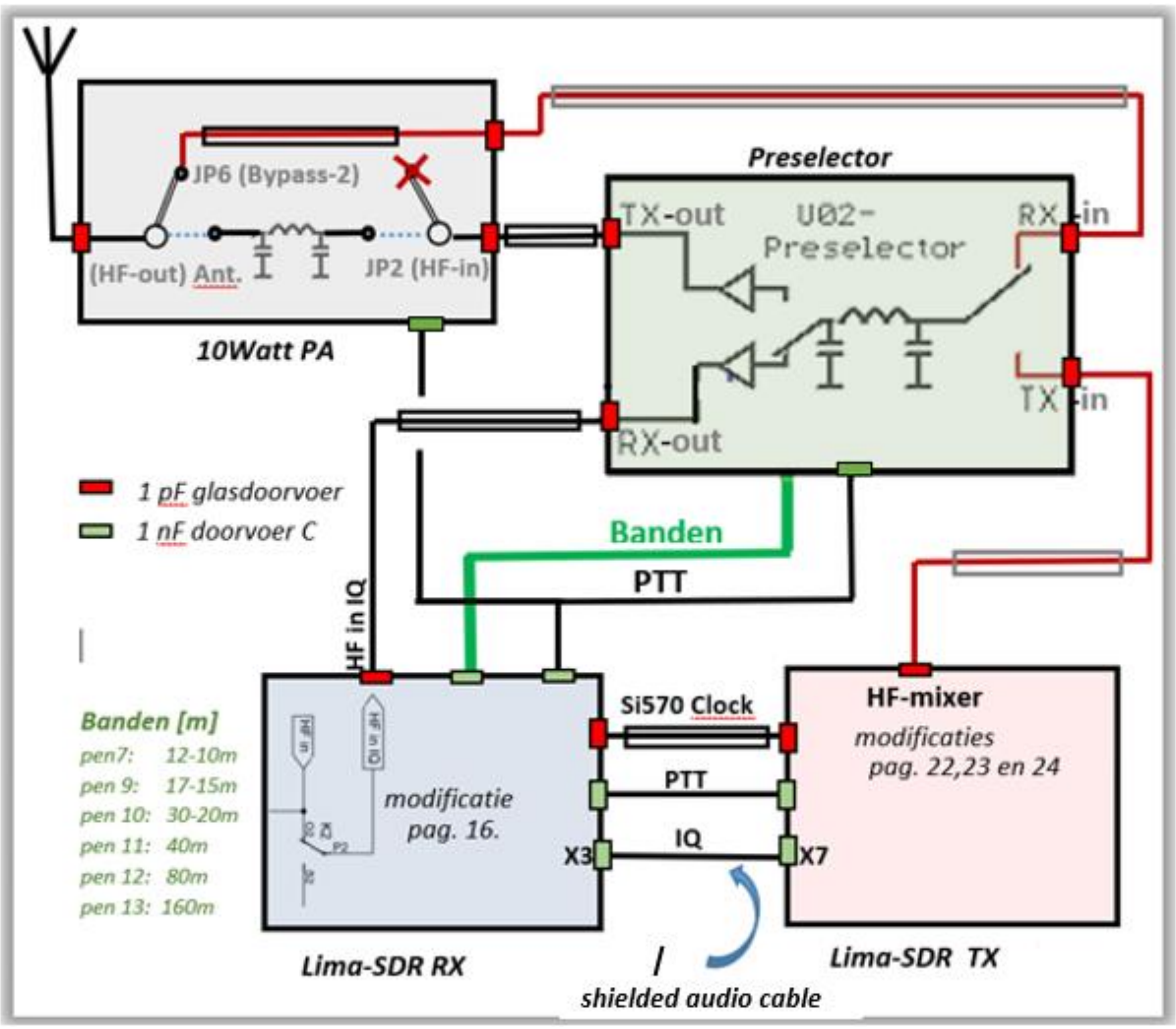


Figure 48 and 49, block diagram of the Lima SDR transceiver.



Figuur 49

a) As mentioned before, the LIMA-SDR RX board has a 74HC138 that handles the band switching. The outputs of this IC go to the RX-Preselector board and on to the TX low-pass filter board. Band filter 7 is for reception below 1MHz. Those who use it still have to install different diodes in Lima-RX, will be described later.

b) branch the PTT line from the 11-pin contact strip between the Lima-RX and Lima-TX board and connect it to the PTT input of the RX/TX Preselector board and on to the TX low-pass filter and 10Watt PA.

Important:
The PTT line of the Lima-RX board has a high impedance, so that there must be sufficient voltage for a sufficient PTT switch at the Lima-TX (transmitter board) the potentiometer R12 must be opened slightly and must not under any circumstances against the stop, otherwise the PTT will not work. This gives you an extra light PTT delay, which is also very beneficial.

c) I switch the control line for the RX preamp (AM) with a rocker switch between ground and +12V to switch the preamp on and off.

d) connect the HF cables with thin Teflon 50 ohm coaxial cable (eg RG316) as shown in the block diagram.

Remark:
Preselector board outputs RX input and TX output separately. This makes it a perfect match for the power stages, where you can connect these coaxial cables directly (the power stages have the RX/TX relay for the antenna). If you want to make a connection with QQRP (with 40 mW) to the antenna, the Preselector can connect directly to an antenna. However, to do this you need an external RX/TX relay.

7. Possible Problems and Solutions.

7.1. Faults on the PC via USB connection.
Solution:

Interference can occur in both directions, from the SDR to the PC (especially at high power) and from the PC to the SDR (radiation):
Especially on the higher bands (15, 12, 10 m ...) you quickly get throughput disturbances and noticeable due to many vertical lines in the waterfall graph. When the USB plug is removed from the SDR board, these faults disappear. This is a sure sign of radiation interference from the PC to the RX board. Suppression of disturbances propagating through the entire cable, even visible on the display, that are not canceled by the shield. For example, ferrite rods are mounted as close as possible to the USB cable with the SDR housing. It is even better to use a toroid core where the USB cable is wound a few times. The toroidal solution is only effective if the SDR is installed in an HF draft-free housing and the cable from the housing to the RX PCB is kept short.

7.2. When transmitting at higher powers (> 5W), USB interface suddenly crashes.
This is particularly unpleasant because the PTT then hangs and the SDR is set to continuous transmission.
Solution:
Suppression of asymmetrical disturbances, are carried by the inner conductors of the USB cable and have the sheath as ground, so they are shielded. However, once the USB cable terminates and is routed into the RX board, it can radiate interference and easily bridge the few cm to the nearby mixer. A solution is only possible if you do not use the USB plug to the RX board, but run it with separate wires to the external USB plug of the RX board. In this case, the USB D+ and D- lines run through ferrite cores, the longer the distance the better. The Ferrite tubes from Reichelt (Order No.: DFP 7.5) are very suitable. In addition, you solder a 1nF ceramic C from D + and D- to ground. All this as close and as close as possible to the RX print. The +5V lead of the USB cable is omitted, it is not necessary and also transports interference. At 20 to 12m, I almost completely got rid of the disturbances. Residual disturbances are still present at 10 meters, but are not a nuisance.

7.3. PTT does not work on the TX PAs.
Solution:

The PTT output of the Lima-RX board has a fairly high impedance. Therefore, the voltage on TX (about 3V) can drop to the point where it can no longer switch the PA. The PTT line must have a minimum level of at least 3V (has 0V when receiving).
If this level is not reached, the resistor R23 (4.7K) on the Lima-RX board must be replaced by a 1K resistor. The level of the PTT line is then definitely too 3V. In addition, however, it is necessary that the potentiometer R12 on the Lima-TX is not set to stop, but that it is turned slightly away from it. removed, otherwise the PTT line will be further loaded. Set this potentiometer so that a slight delay occurs in the PTT line. That's a good thing, a delay of about 1/4 second has proven itself to be good in practice.

7.4. Windows 7 (64-bit) issues.
Solution:
In Windows7, especially for the 64-bit version of Microsoft, Microsoft has once again pushed the meddling for the apparently incompetent user too much.

To control the SDR, the SI570 driver must be installed. This is supplied with the Lima PCBs. If you try to install it, Windows7 (64bit) will refuse, because a signature is required. Fortunately, there is a back door to install the driver.

You start Windows, and immediately press F8 at the start. Now a black screen will appear, with a selection of recovery and diagnostic options. The bottom line is called, Disable Driver Signature Enforcement.
Select this option and press the Enter key. Now Windows will boot and accept the installation.
This trick is only required for the 64 bit version. In the 32-bit version of Windows, it still complains about the lack of a signature but the installation starts anyway.

Warning: This trick with the F8 key must be done when you start Windows, otherwise the installation option will be disabled again!

After this experience, I (DJ0ABR) have to advise against using Win7-64bit for SDR, it is cumbersome. This is much easier with the 32-bit version.

8. Settings.

8.1. RX level control with Power SDR.
Power SDR can indicate the level of the received signal with a high precision in dB. I (DJ0ABR) didn't expect that, but it's really possible. The precondition for this is a clean calibration over the entire level. The steps are as follows:

8.2. Input Level (Microphone or Line-in Level) Setting:
The volume of the sound card input has little influence on the signal strength of the received signal. The reason for this is probably that the Power SDR does not include the reception level in relation to the noise? I don't know exactly, but that can be measured.
The level of the received signal is therefore only of limited importance for the correct setting of the sound card input. It is important that the sound card is not overloaded. You have to turn up the level until the sound card can process the signals cleanly.

A level of approximately -30dBm (1uW, equivalent to 20mVss at 50 Ohms) is applied,
(mVss = millivolt peak to peak) at the receiver input. Preferably with a generator or alternatively with a transmitter with suitable attenuators. Here you have to look for a solution. With this level on the receiver you set the recording level of the sound card so that it remains well below the maximum of overload (factor 3-4 times). It is easy for anyone who owns a 202 EMU sound card, because this card has two green LEDs that light up shortly before overloading. The recording level is set in such a way that the two LEDs barely light up.
With other sound cards you have to measure the input voltage of the sound card with an oscilloscope and set it (according to the manual of the sound card) so that the maximum level is not reached. If you don't have measuring options, set it to about 2/3 of the maximum level, which is not ideal but better than no setting.

8.3. Receive level setting in PowerSDR.

After the sound card is set up, we need to tell the Power-SDR where the reference levels are, only then can the SDR power be displayed correctly.

We add to the receiver an input signal of exactly -60dBm. (1NW 0.625mVss corresponds to 50 ohms).

In Power SDR we tune in to this signal, which can be heard clearly. Now we come to the Settings menu: General – Calibration, fig.50.

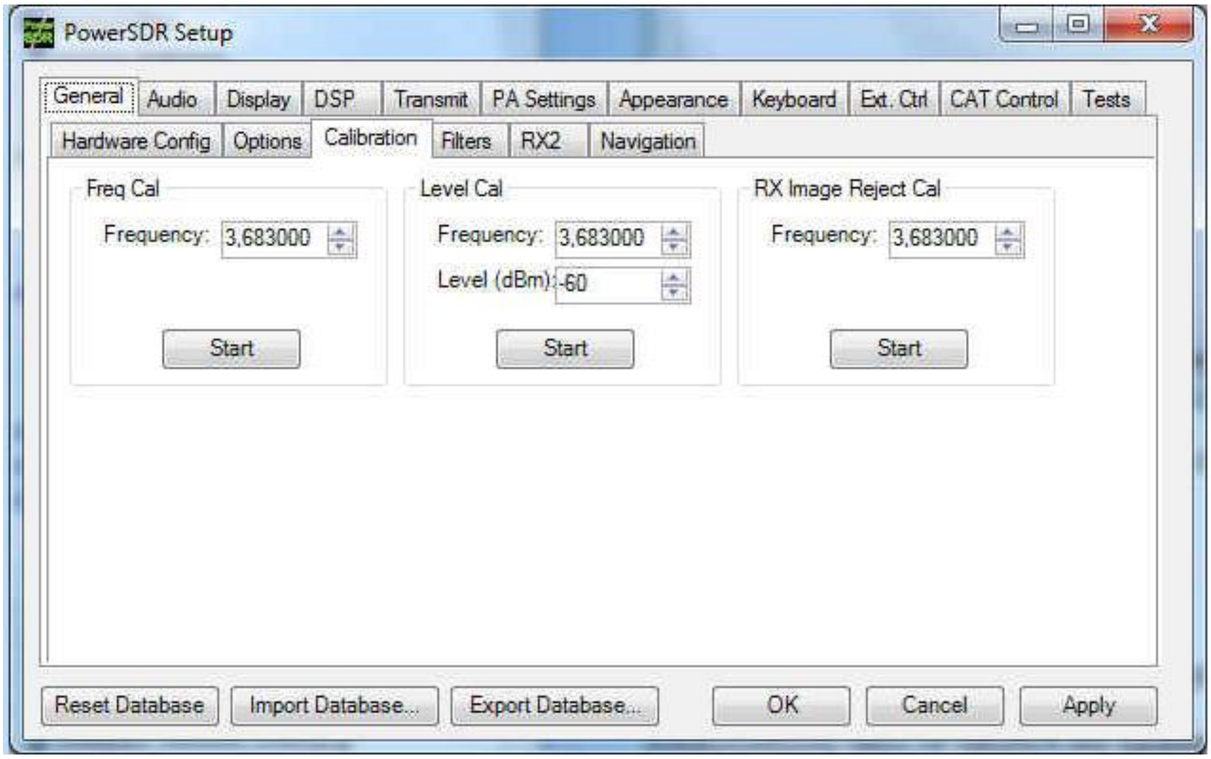


Fig. 50, PowerSDR calibration window.

In Level Cal we set the frequency of the test signal and as Level -60dBm. Now we press "Start" and Power SDR will calibrate to this level.

From now on, Power SDR can accurately display any level from nearly -120 dBm to -40 dBm to dB. The exact range depends on the quality of the sound card.

Only after this setting is the SDR really sensitive and making QSOs even more fun!

8.4. TX transmit power and the RX volume:

These two settings in Windows we use the same controller (the Power-SDR controller, see photo above). That is why we first only set the power with this controller. For the volume of the speaker, we have other options.

a. TX Transmit power.

The precondition for the procedure described below is that the entire level from the sound card to the antenna is correct. These conditions are described in Part 6. Sound card.

b. U02 mic preamp.
This is a potentiometer. With this potentiometer you can set the preamplifier in such a way that the sound card is good but not overdriven. So, for example, if you whistle loudly into the microphone, then with the potentiometer on the PCB you set an LF level on the sound card input of 1 Vpp (that must be tolerated on every sound card Line-in). This LF whistle then goes to the sound card and further into the PowerSDR.

Power SDR generates the modulated I/Q signal and passes it on to the line-out of the sound card and on to the SDR transmitter.
In PowerSDR you now go to transmit and turn the "Drive" control clockwise, so full power. The Mixer Regulator PowerSDR can be set in such a way that the transmitter SDR (see photo above) supplies exactly the full output power (ie 10 watts or 100 watts, depending on the power amplifier) to the antenna.
From now on, you only set the transmit power with the Drive controller in PowerSDR. The Windows sound card settings can no longer be changed!

c. RX volume.
To adjust the volume of the reception, you should NEVER try to adjust controls in Windows, as this will destroy one of the hard-to-find settings.
First, in Power SDR, turn the "AF" control to the right to maximum volume. On the PCB U02 mic / LS amplifier, turn the volume potentiometer so that a received station comes out of the speaker loud, but not distorted.
Now in PowerSDR you can adjust the sound with the AF button in such a way that the gel sound is pleasant to the ears.

8.5 High current switching, PA 100Watt.
Switching low currents of the power supply on and off is no problem. If we apply the 10Watt PA, a commercial switch that can switch a maximum current of 4 Amps is needed. This is no longer possible with a 100Watt PA 100W PA. Currents up to 30A can occur, too much for any switch or relay (or you build a switch that can handle this high current). After much consultation and the most adventurous ideas, the inspiration suddenly came, how this can be done in an elegant way.

You leave the PAs connected to +12V and only switch off all other components with a 3A switch. This works well because the Lima-SDR, which on the PTT line goes to “+” at TX and is at Massa at RX. When the PTT is set to RX, the Mosfets of the PAs are blocked by the quiescent current control. In this case no current flows (not even a fraction of a mA). It is therefore possible to keep the PA permanently connected to + 12V and only switch the rest of the components on and off. As soon as you switch off, the PTT line is de-energised and the tansceiver is definitely switched off. The PTT line as soon as you switch off is all dead and the transceiver is enabled safe removal.

8.6. Power supply and connection cable.
The power supply must have the usual voltage of +13.8V. The unit also runs on +12V, but the PAs (especially the 100W PA) can only produce full power at 13.8V.
The power supply must provide at least 5A at the 10Watt PA, for the 100 Watt PA 100W operation a 30A power supply must be used.

A 2.5 qmm cable is used for the 10 Watt PA as the power cable between the power supply and the TRX. For 100W PA you need for optimal use, I recommend a 6 qmm cable. By the time the display's illumination flickers during modulation, a thicker cable should be used. If you manage to supply 13.8V to the PA without significant losses then you have enough power, you can even expect 150 Watts or more with good modulation.
Als voedingskabel tussen de voeding en de TRX wordt voor de 10Watt PA een 2,5 qmm kabel gebruikt. Voor 100W PA die je nodig hebt voor optimaal gebruik, adviseer ik een 6 qmm kabel. Tegen de tijd dat de verlichting van de display flikkert bij modulatie, moet men een dikkere kabel nemen. Als het je lukt om 13.8V zonder aanzienlijke verliezen aan de PA toe te voeren dan heb je voldoende vermogen, je kunt zelfs een vermogen van 150 Watt of meer verwachten bij een goede modulatie.

8. Sound card.

A balanced adjustment of the transmission levels is particularly important with SDR transmitters.
The first rule for low-interference reception is:

The volume of the sound card should be set as high as possible!
The reason for this is actually understandable. Imagine, the sensitivity and gain of the transmitter would be so great that you can only work with the transmitter with minimal sound card level. In this case, the small useful signal will be greatly amplified, and with them all unwanted adjacent broadcasts, residual carriers, mirror frequencies etc. The result is a very distorted transmit signal.

Otherwise, if the sound card outputs is set very high, then the total gain of the transmitter should be low. As a result, hardly any noise is amplified and the signal-to-noise ratio is then very good.

In order to optimize things, DJ0ABR has created a level plan in which all unwanted disturbances remain below the required 40dB. The following information is matched to the maximum output power of U02, 10 Watts of output stage, but is a similar analogy to other amplifiers. The measurements are best performed in a 30m or 20m band. If you do not have an oscilloscope that can measure at least 60 MHz, the 40m band is chosen.

9.1. Sound card output level: 1.7 Vpp (volts peak to peak).
this level is reached when my (DJ0ABR) EMU-202 sound card is tuned to about 2/3 full scale. The limit to the top results from the following level value:

9.2. I/Q signal at the input pins of the 4066 TX Mixer: 3 Vpp (volt peak to peak).
This voltage is checked with an oscilloscope (all 4 inputs of 4066). At sound card voltage of 1.7Vss I measured 3Vpp here and the signal was still a clean sine wave. Increasing the output level of the sound card shows when the signals enter the boundary. For me, the limit was 3Vpp, which is the maximum voltage.
If you don't reach 3Vpp, that means that the signal goes into the limit earlier, and we have to revise the impedance converter, (see TX adjustments).

9.3. Mixer output: 3 dBm.
At the output of the mixer, at the intersection of C25 / C49, an HF level should be +3 dBm

(2 mW). With an oscilloscope (if it is fast enough) one can measure a voltage of about 0.9Vss, which corresponds to 2 mW at 50 ohms. The output must of course be terminated at 50 Ohms. The signal on the oscilloscope, however, looks very "fragmented", because here all nearby disturbances are still present at full power and the voltage can only be estimated.

9.4. Output level of the U02 preset switches.

The U02 Preselector has a TX Driver step and boosts the signal to +17 dBm (50mW).
At 12m and 10m, the level is lower, which is normal and is compensated by the output stage. In At 50mW one can measure an HF voltage of about 4.4 Vpp. Here one already measures a clean Sinus, since the signal was purified by the Preselector.
If this level is not reached or exceeded (limit), the attenuator on the U02-Preselector board can be adjusted (resistors: R15, R16 and R17). In my device, the values are optimal.

9.5. Output level of 10W – PA.

The +17dBm of the Preselectors are the input signal of the 10W-PA. There is an attenuator at the entrance of the PA. With the specified mounting, I can achieve the following clean signal output levels:

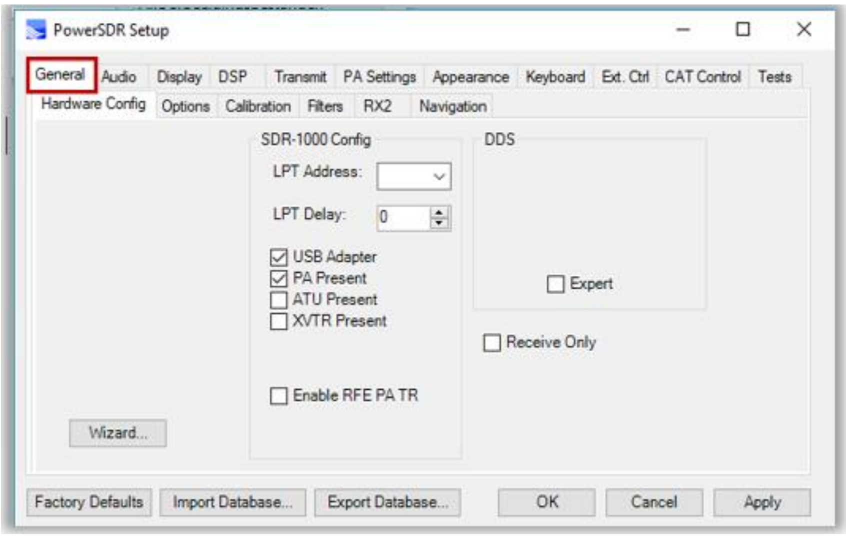
160m	80m	40m	30m	20m	17m	15m	12m	10m
+38 dBm	+40 dBm	+40 dBm	+40 dBm	+41 dBm	+40 dBm	+39 dBm	+40 dBm	+40 dBm

(+40 DBm related to 10 watts, and a voltage at 50 ohms of about 65Vss)

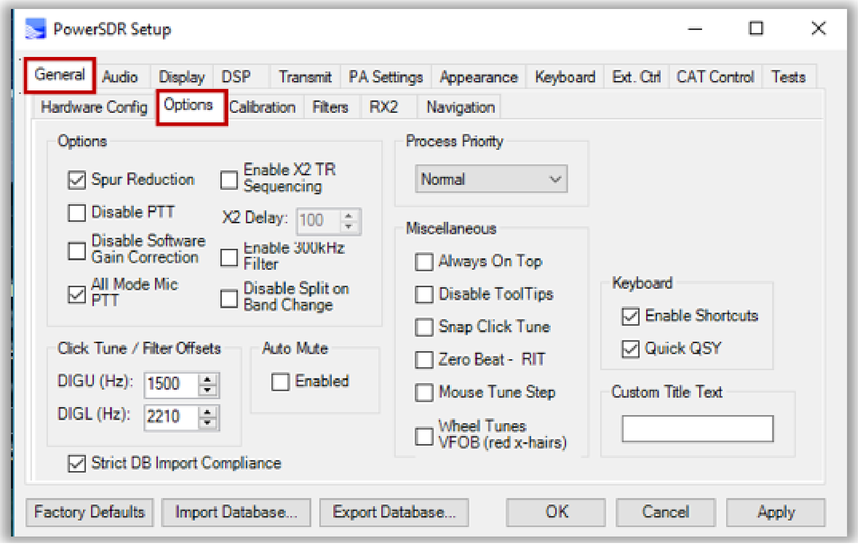
It is possible to gain a few Watts with a higher input level, but that comes at the cost of line
Better a clean signal with 10 watts and a garbled output of 13 watts.
If these values are not reached, this can be adjusted with the attenuator of the 10W-PA (resistors: R7, R7 and R8).

8. My PowerSDR Settings.

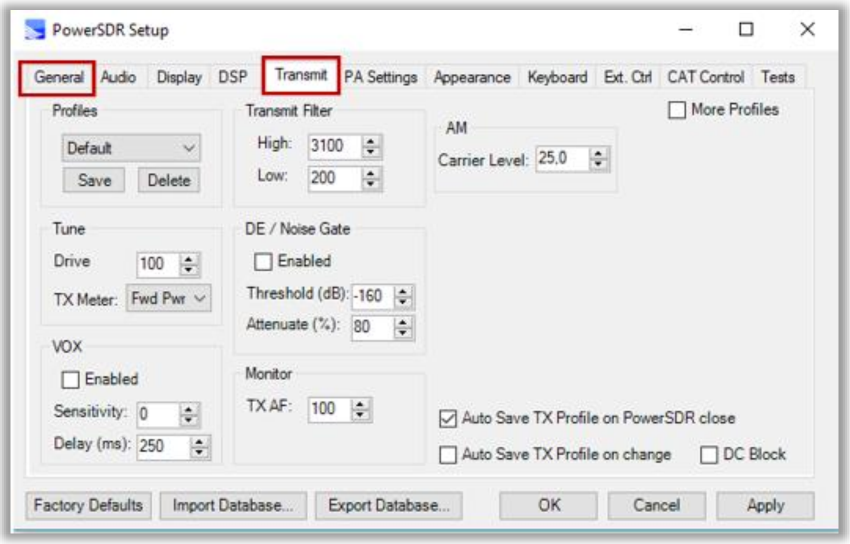
General.



General-Hardware Config



General-Options

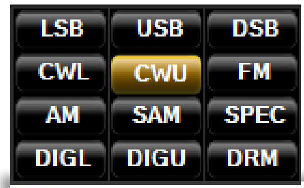


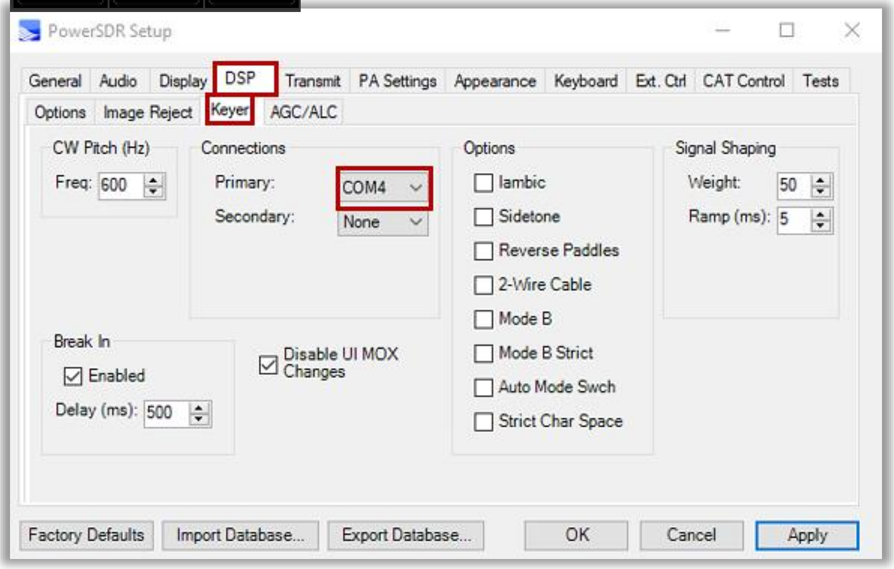
General-Transmit

CW.

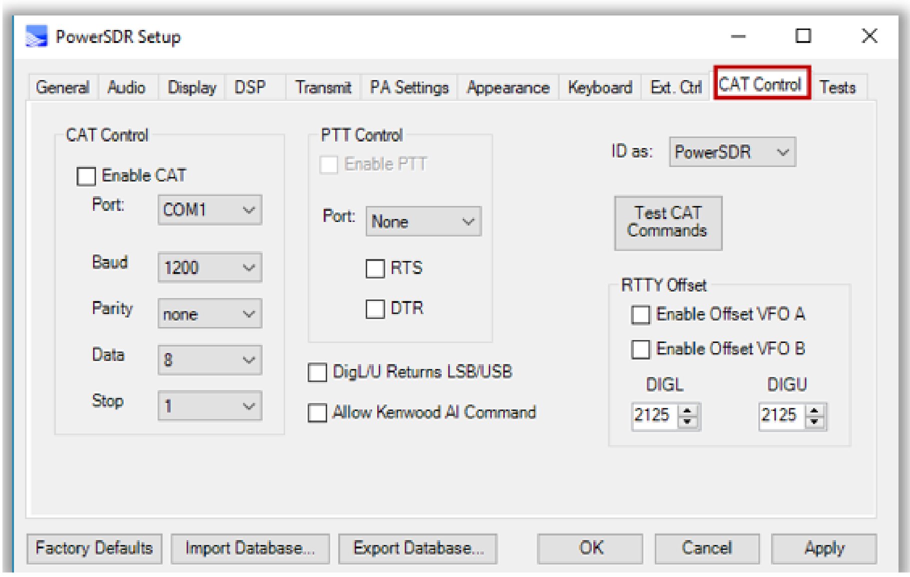
Weight: Determines the ratio between the dot and stripe width.

Ramp: Sets the length of the leading and trailing edges of the tones in milliseconds.



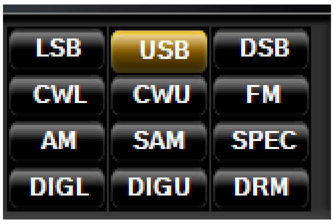


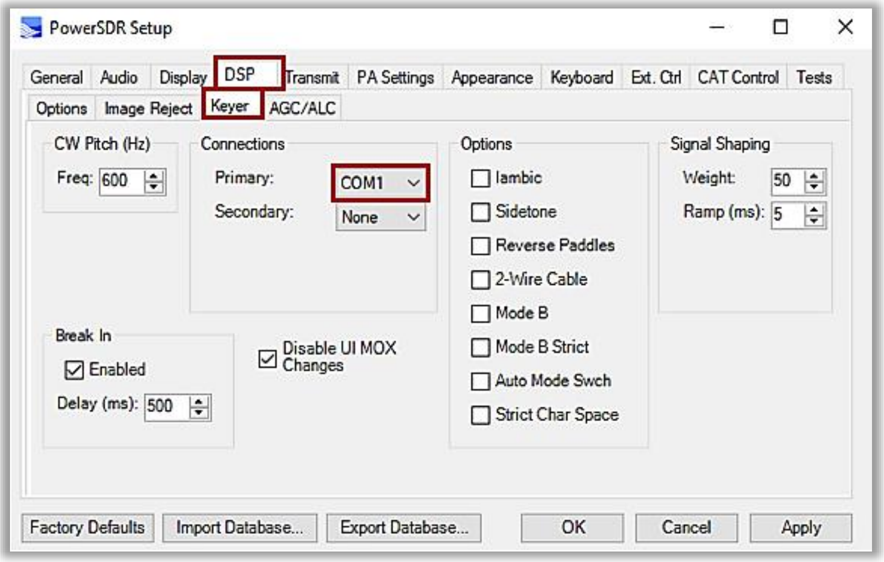
DSP-Keyer



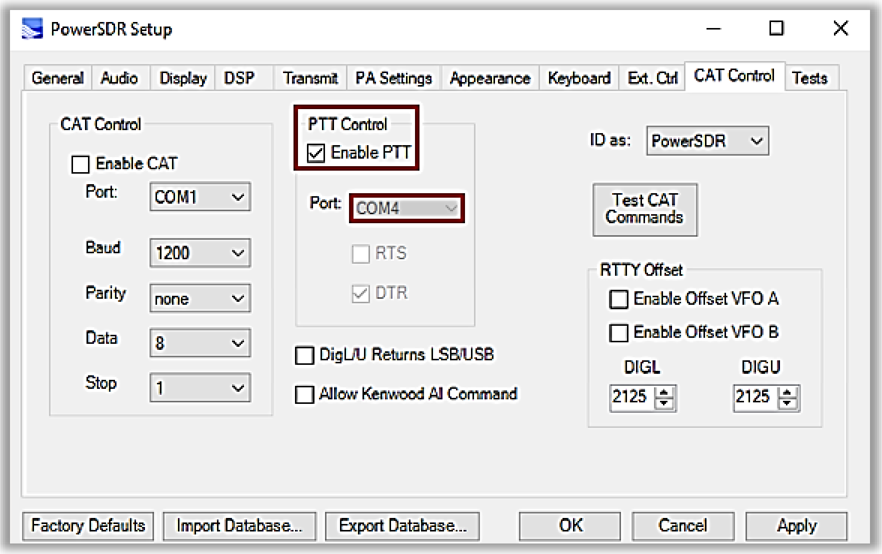
CAT Control

Phone





DSP-Keyer



CAT Control

8. Low Pass Filter.

Version: 1.1
Author and developer: DJ0ABR
OVV-U02 and prototype tester: DH5RAE

General information:
SDR transmitters have highly conditioned system conformal harmonics. The power amplifiers also generate harmonics. So it makes sense to put an effective low-pass filter between transmitter and antenna. This project represents a multi-band (160 m - 10 m) low pass filter and shows all the steps to the successful replica.
The band switching is compatible with the Lima SDR and is done automatically there. Measured values of the pattern of the first series:

Band	Durchlaß-dämpfung KERKO-500 Cs	Durchlaß-dämpfung Glimmer Cs	1.Oberwelle	2.Oberwelle
160 m	0,6 dB	0,15 dB	-41 bis -60 dB	< -55 dB
80m	0,4 dB	0,18 dB	-40 bis -50 dB	< -60 dB
40m	0,5 dB	0,25 dB	-45 dB	< -60 dB
30m	0,7 dB	0,34 dB	-13 dB	< -60 dB
20m	0,5 dB	0,5 dB	-60 dB	< -60 dB
17m	0,5 dB	0,4 dB	-29 dB	< -60 dB
15m	0,5 dB	0,5 dB	-40 dB	< -60 dB
12m	0,5 dB	0,2 dB	-54 dB	< -60 dB
10m	0,4 dB	0,4 dB	-50 dB	< -60 dB

8. Low Pass Filter.

Versie: 1.1
Auteur en ontwikkelaar: DJ0ABR
OVV-U02 en prototypetester: DH5RAE

General information:
The following components are soldered:
* all Finder relays
*ULN2003
* holder for the 74HC04
* Voltage regulator 78L05
* 10uF Elco
* 1uF Elco
* 100nF capacitor

* six 47k SMD resistors
* six 1nF SMD capacitors

The 74HC04 is NOT connected!

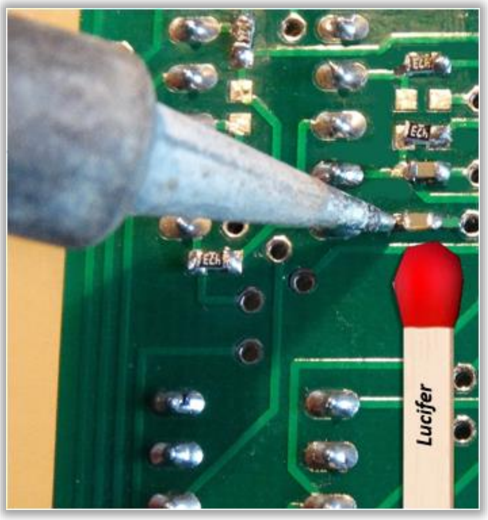


fig. 51, use a thin soldering tip.

Step 2: Check the relay circuit.

For the power supply, you use a power supply of approximately 12 volts output voltage. It makes sense to use a power supply with current limitation, so that no extreme currents can take place. After careful optical inspection of the solder joints and the components (are the ICs installed correctly?) connect the PCB to the power supply and measure the voltage between pin-7 and pin-14 of the socket for the 74HC04. There should be a voltage of about 5V (4.8V to 5.2V is good). The power consumption is still minimal and below 30 mA.

Then disconnect the circuit board from the power supply again. Now place the 74HC04 in the socket and switch the power on again. If the board is properly equipped, none of the relays will switch on. Now connect the band inputs 1 to 6, one after the other, to ground (GND = Minus the power supply).

ATTENTION: never set the band inputs to +12V! Doing so destroys the 74HC04 and you must replace it! So you connect the port for Band-1 to GND. You can clearly hear the band-1 relay click and the power consumption increases.

With a buzzer you can now easily check whether the relays are closing. You can find the measuring points in table 3 and figures, 52 and 54.

11.4. Measuring points of the relay, see table 3.

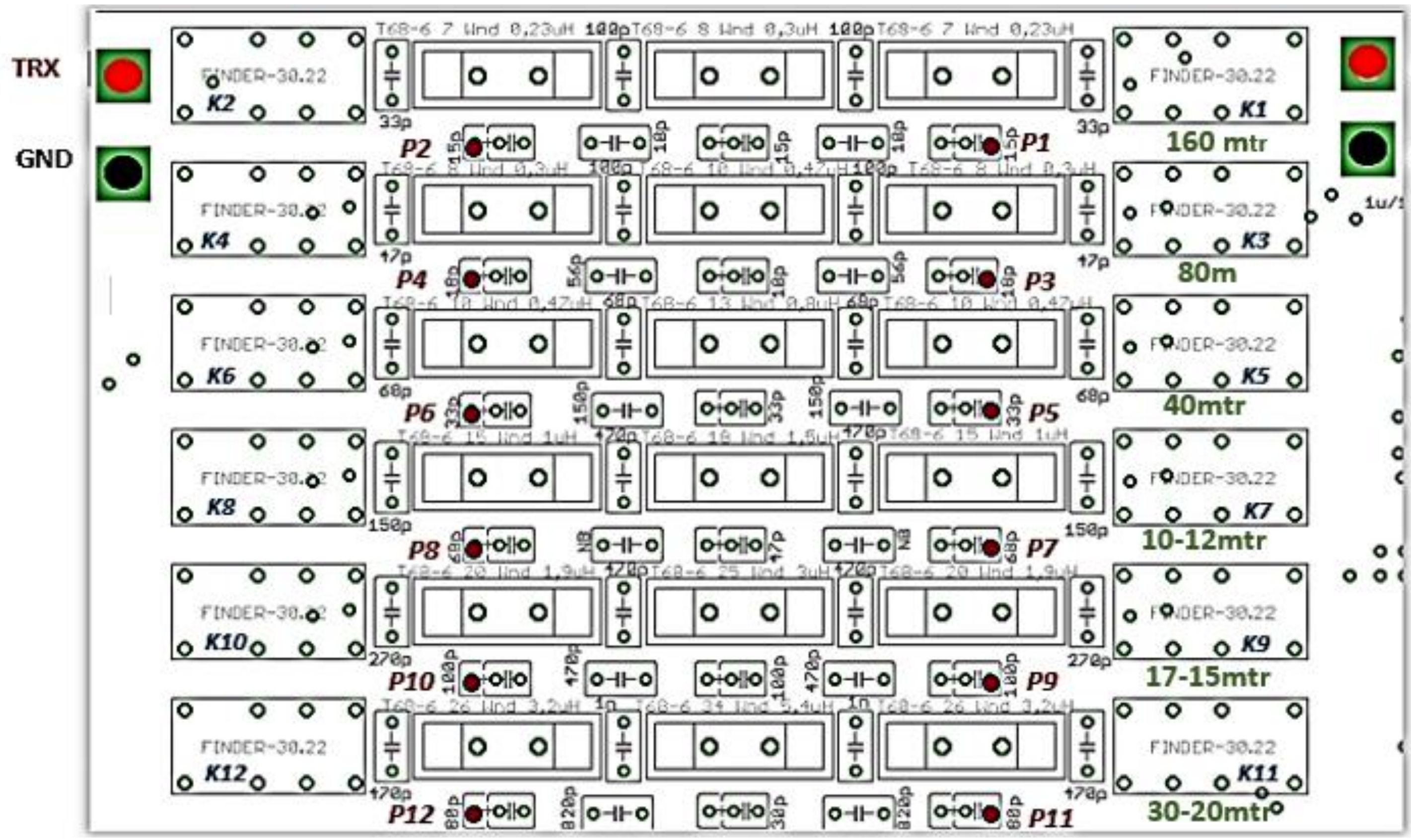


Fig. 52, test points component side

TRX			Band	ANT		
Relais	Measuring P	Exit		Relais	Measuring P	Exit
K1	P1	PA	12-10	K2	P2	Antenna
K3	P3		17-15	K4	P4	
K5	P5		30-20	K6	P6	
K7	P7		40	K8	P8	

K9	P9		80	K10	P10	
K11	P11		160	K12	P12	

Table 3, test points, relay circuit.

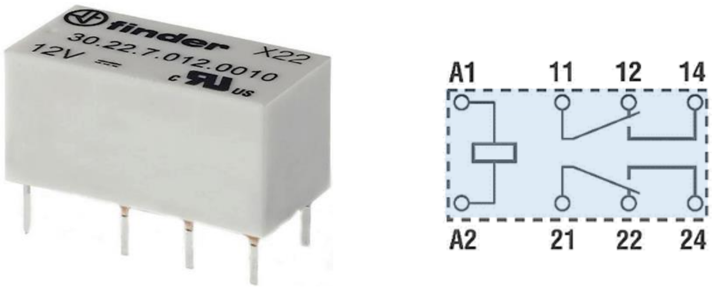


Fig. 52a, Finder relais.

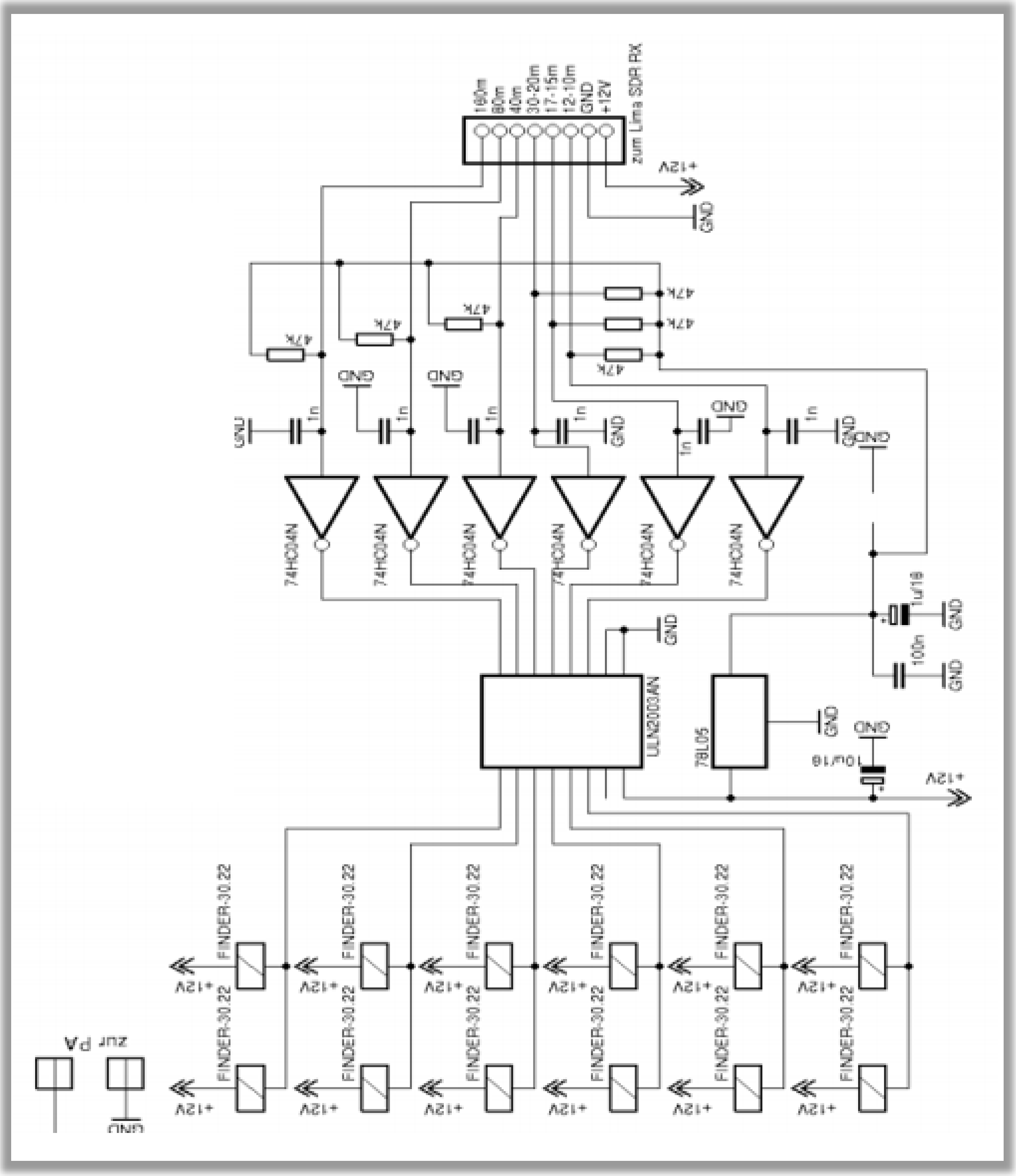


Fig. 53, TX LowPass Filter, DJ0ABR

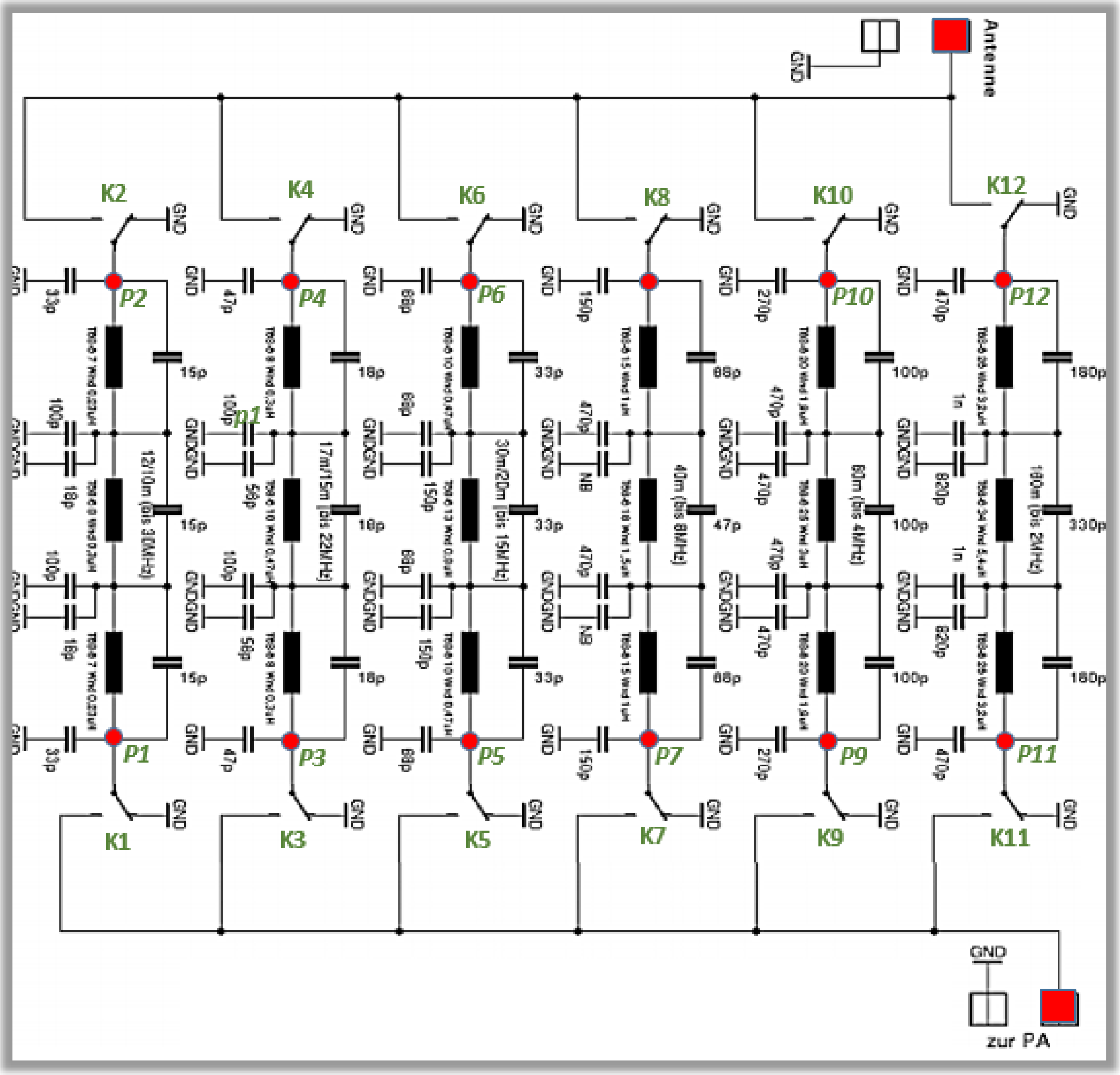


Fig. 54, measuring points, TX LowPass Filter scheme.

Step 3: Assembly and testing of the low-pass filter.

First you wrap the toroids.

The number of turns is shown in the circuit diagram. Wrap the wire evenly over the entire core, without overlapping. For the tapes 10-20m use with 0.85 mm CuL wire, for the tapes 40 to 160 meters you must use the 0.65 CuL wire, all turns overlap around the core.

First solder the capacitors because otherwise it is a bit difficult to insert the C's between the cores in the PCB. Mount only those capacitors, which are marked with a value. The other free C's labeled NB are not applied.
The capacitors in the middle of the filter, going to ground, were in the
most filters split with 2 capacitors. This measure proposed by DH5RAE could reduce, improve the transmission loss by up to 0.5 dB.
The number of winds must be exactly right for the filter to function! Now you can solder in all toroids.

Note:
By counting the wires on the inside of the core you have determined the correct number of turns.

If you do not have a measuring instrument to determine the filter curves, you can now also solder in all capacitors, as shown in the diagram.
If you have an analyzer (e.g. the cheap FA-NWT, which is a very good piece of equipment), you can probably take the filter banks individually in turn, measure the filter curve and adjust the capacitor values if necessary. We built the PCB several times and it also handled the given values very well.

11.5. Connection to the Lima SDR, inputs for automatic band selection.
The LIMA-SDR RX card has a 74HC138 that handles the band switching signals. The outputs of this IC go to the preselector of the RX board. These lines are picked up and fed to the band selection inputs of the TX Lowpass-Filter board.

11.6. Nutrition.
The TX Low-Pass filter board is powered with 12V.

11.7. RF input/output.
Here you connect both the antenna and the transmitter output, see the block diagram, fig.55.

Note about the 5 diodes in the description of the Lima RX changes:
These are only necessary if you are interested in receiving long and medium waves. If you only want to work normally on the Amateur bands 160 to 10 meters, you don't need them. Do not install diodes. Then the 160m tape input goes directly to pin 13 of the 74HC138.

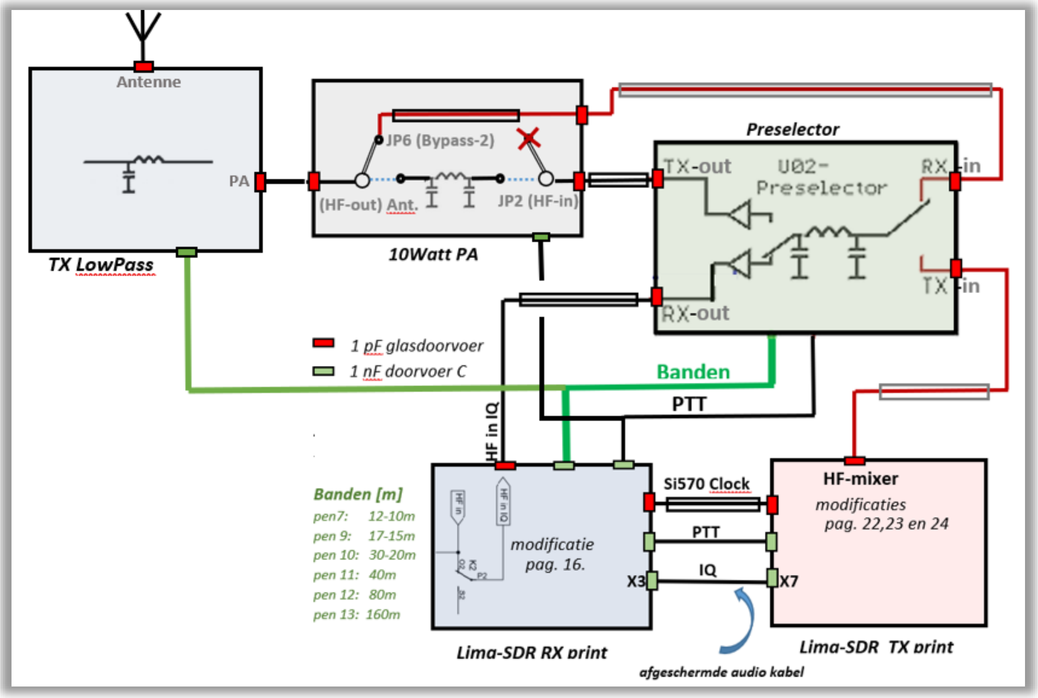


Fig. 55, Schedule supplement with TX LowPass Filter.

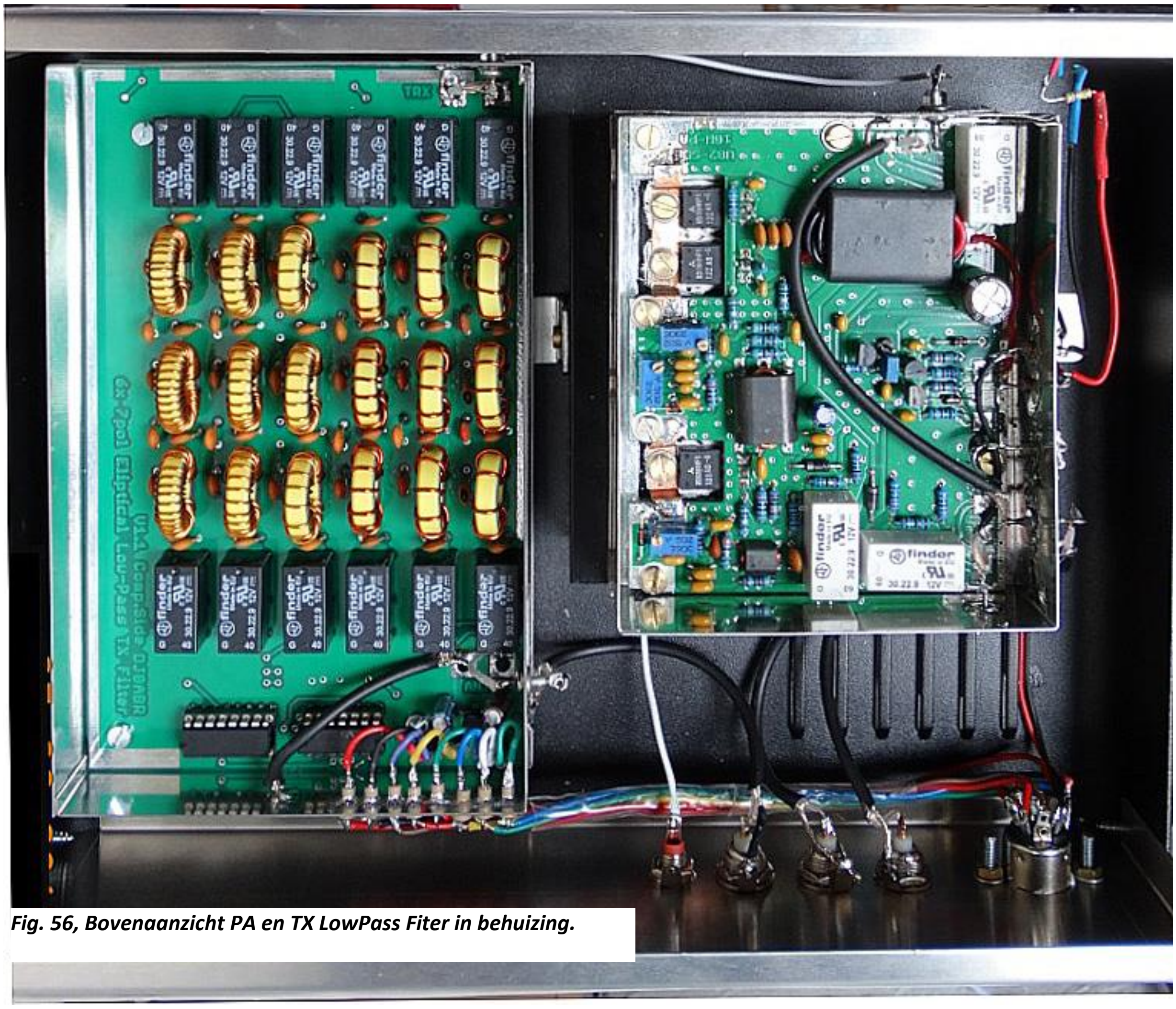


Fig. 56, Bovenaanzicht PA en TX LowPass Fiter in behuizing.

12. Cover inscriptions.

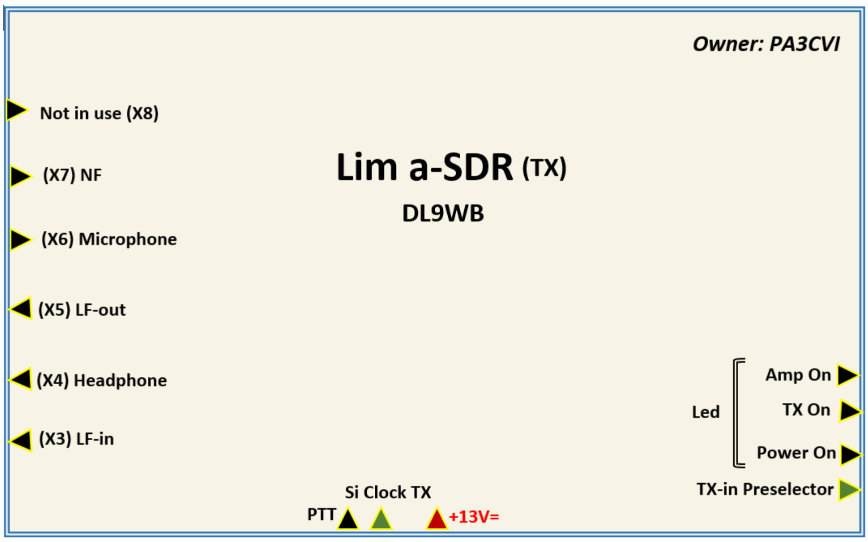


Fig. 57, cover Lima-TX.

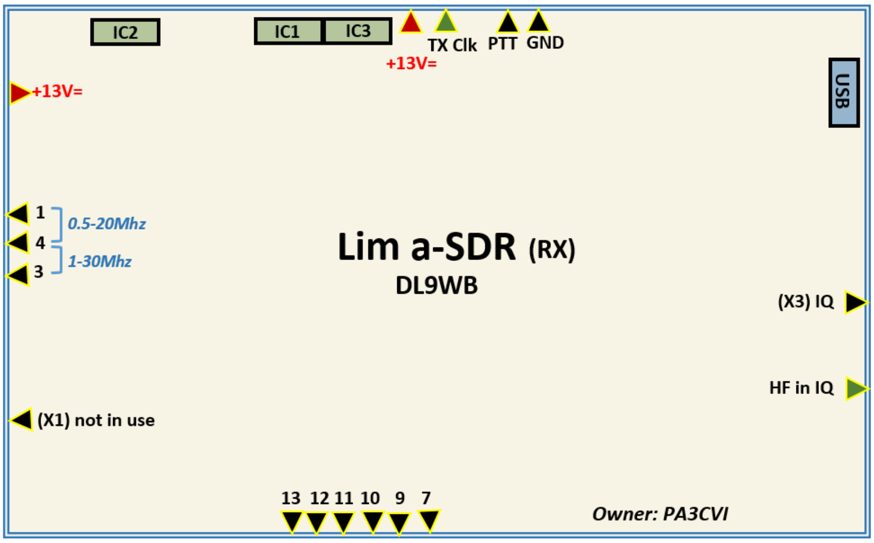


Fig. 58, coverLima-RX.

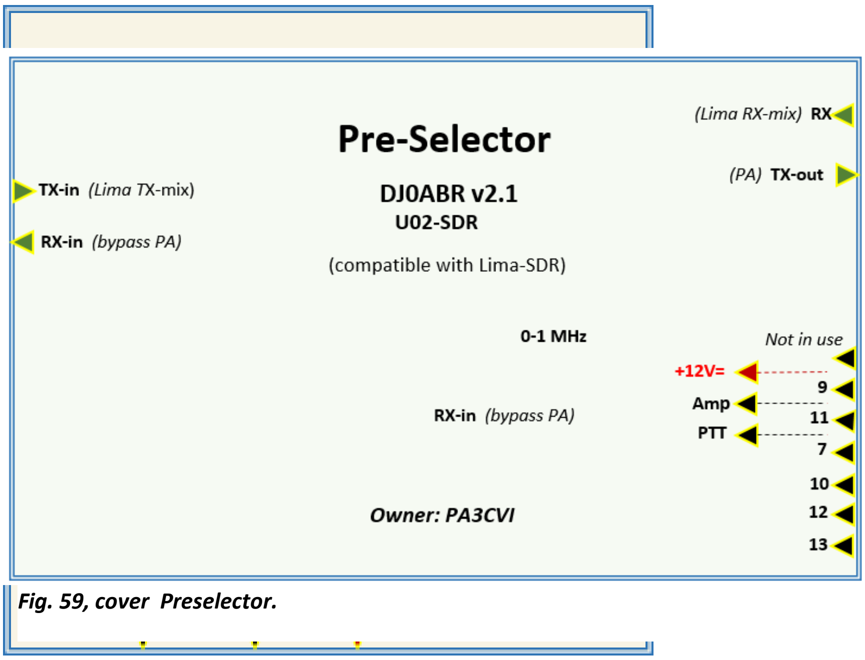


Fig. 59, cover Preselector.

Fig. 60, cover Preselector.

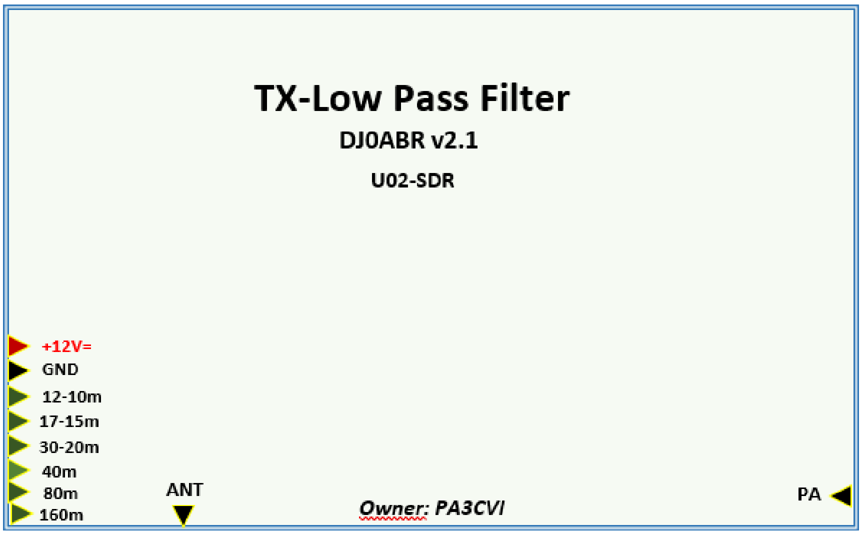


Fig. 61, cover Preselector.

Fig. 62, Front Enclosure, PA and LowPass Filter.

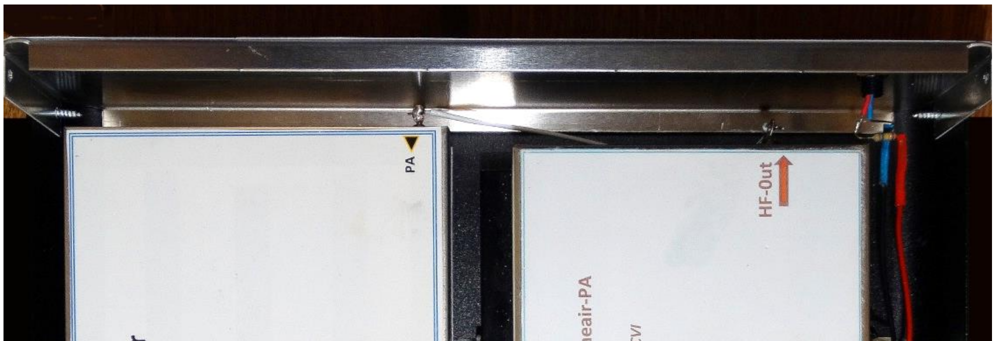
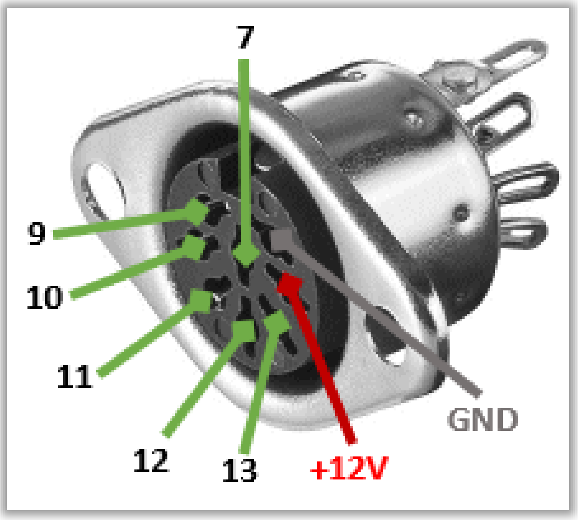


Fig. 63, Top view LowPass Filter and PA, canned.

Fig. 64, Rear LowPass Filter and PA housing.

My band selection pin arrangement is pictured below, fig.65.



Chassis part 8-pin-bandselection

Fig. 65, Chassis pin assignment, band selection, +12V and GND.

Nr	Band [Mtr]	Kleur
7	12+10	Bruin
9	15+17	Blauw
10	20+30	Roze
11	40	Geel
12	80	Groen
13	160	Blauw
+12V	Nvt	Rood
GND	Nvt	Zwart

Number and color assignment

13. Component Wiring Overview