Yaesu FT-847 70 MHz PA output and filter simulations

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The efficiency of the HF transmitter chain which is also used for 50 MHz and 70 MHz decreases with frequency. Because of this, the UK factory modification for 70 MHz limits the output power to 10 Watt. Also the current for maximum power at 50 MHz is high: 21 Ampere for my transceiver. This document describes my attempts to improve this behavior.

Low-pass filter LPF[6]

The low-pass filter for 50 MHz and 70 MHz is **Low-pass filter LPF[6]**. The filter circuits and the simulation results are shown below.

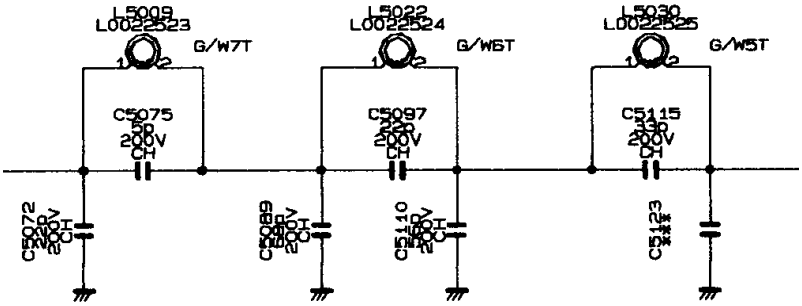

Figure 1: Low-pass filter LPF[6] circuit diagram

No inductor values are in the service manual. For the UK version I found the following values for L5009, L5022 and L5030 on the internet: 125 uH, 100 uH and 78 uH. **These values are incorrect and must read 125 nH, 100 nH and 78 nH.** With those values I found the following filter curve.

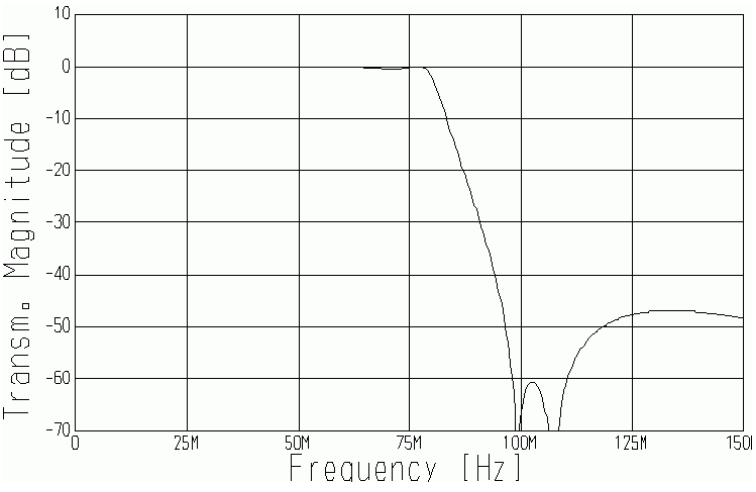

Figure 2: Low-pass filter LPF[6] simulated transfer

The stop-band suppression at 130 MHz is only 47 dB, so probably the inductor values for non-UK models are somewhat different. Anyway, with the UK inductor values, the attenuation at 50.0 MHz and 70.0 MHz is 0.03 dB and 0.51 dB respectively. Attenuation at 70.5 MHz is 0.52 dB, I will come back to this.

In the UK factory modification, C5123 is omitted. This leads to the nice filter response below.

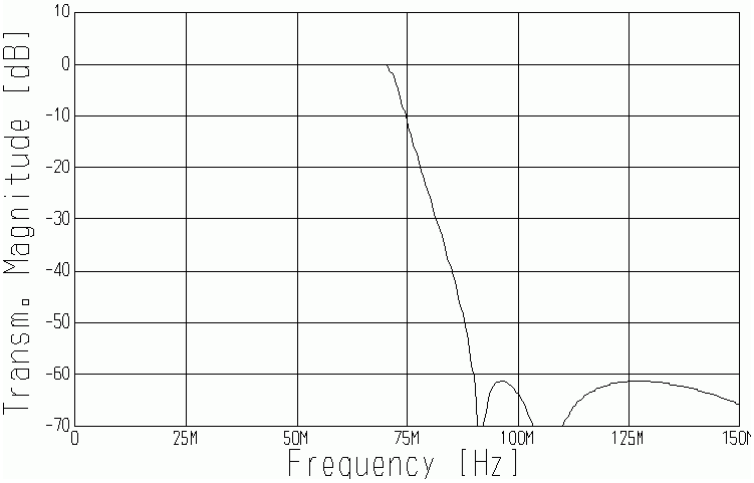

Figure 3: Low-pass filter LPF[6] without C5123 simulated transfer

Attenuation at 50.0 MHz and 70.0 MHz is 0.20 and 0.20 dB respectively. However, on 70.5 MHz the attenuation is 0.52 dB again. 70 MHz is really the top of the pass-band, component tolerances could easily increase attenuation with more then 1 dB! Combined with the higher loss at 50 MHz there is no reason for me to remove C5123…. if it wasn't for the regulations on harmonics suppression. Without C5123 the suppression on 140 MHz (second harmonic of 70 MHz) is nicely below 60 dB, with C5123 mounted this is only 47 dB. The choice is up to you. An external filter (or filtered amplifier) will also solve this.

PA output filter circuit

The above simulations indicate that the low pass filter cannot be held responsible for the low transmitter efficiency. As a next step I will investigate the PA output. Experience from UK amateurs is that the PA efficiency increases when ferrite material is inserted in inductor L5006 in the circuit below.

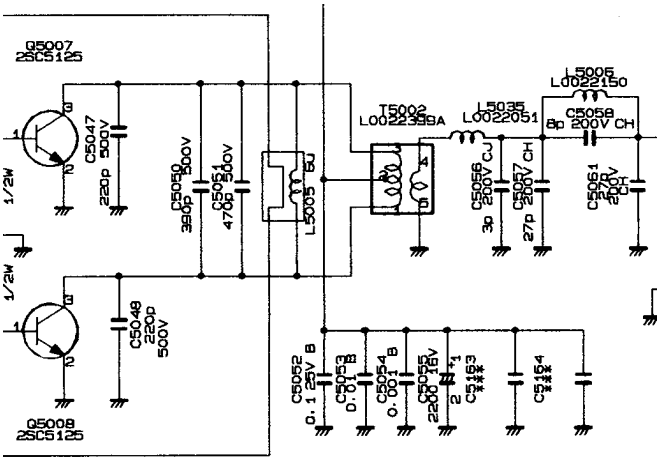

Figure 4: PA output filter circuit diagram

On the internet the increased efficiency was explained by lowering the resonance frequency of L5006 and C5058 which was suggested to be right at 70 MHz. Instead of shifting the resonance towards 50 MHz by inserting ferrite, I tried to shift it upwards by removing C5058. This improved efficiency at 50 MHz but didn't improve the 70 MHz efficiency significantly.

Next suspect is the PA output stage with its first filtering. Assume that the transistors provide a balanced output impedance of 3 Ohm that is transformed to 50 Ohm by T5002. For the capacitance we add half-of-a-single-collector-output-capacitance, C5050, C5051 and C5047-in-series-with-C5049. The 2SC5125 datasheet specifies the collector output capacitance at 250 pF for a single transistor. Adding the capacitances gives a total of 125 + 390 + 470 + 110 = 1085 pF.
The PA uses a 1:16 transformer (1 turn primary and 4 turns secondary). This would mean we can model the **impedance** at the secondary side of T5002 roughly as **50 Ohm** with 1085 / 16 = **68 pF in parallel**.

This input impedance was used to simulate the filter with L5035, C5056, C5057, L5006, C5058 and C5061 with the results in the next figure. Note: L5035 and L5006 were estimated to be 80 nH and 110 nH because the values are not given in the documentation.

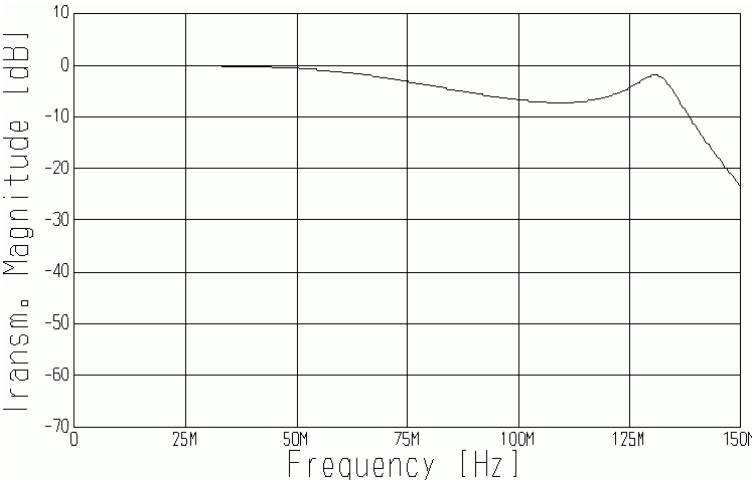

Figure 5: PA output filter simulated transfer

Losses at 50 and 70 MHz are 0.68 dB and 2.50 dB respectively. This means a significant mismatch for the PA transistors at 70 MHz. A nice resonance is present around 130 MHz, one could try to lower this resonance to 70 MHz, but a side-effect would be an increased attenuation at 50 MHz. This is the behavior described on the internet when inserting ferrite into L5006.

Now I wanted to verify my previous experiment of removing C5058 (trying to shift the resonance upwards). The results are in Figure 6.

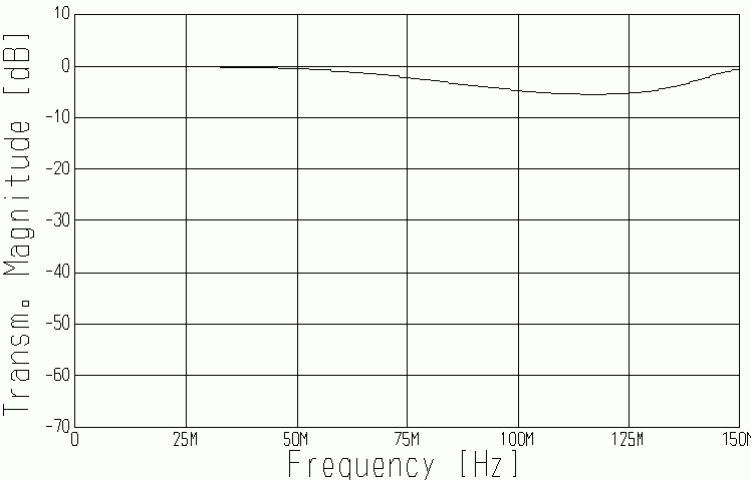

Figure 6: PA output filter without C5058 simulated transfer

Losses at 50 and 70 MHz are 0.58 dB and 1.78 dB respectively. Not the improvement we are looking for indeed.

So the problem can not be solved by shifting resonances around. Instead, the PA output circuit's bandwidth should be increased. I decided to leave C5047 and C5048 untouched, because they are probably required for stability and they are not significant anyway. The collector output capacitance of the transistors cannot be changed with given PA current, so the only values we can change are C5050 and C5051. If we remove C5050 and C5051, then the transformed capacitance at the output of T5002 would be circa 15 pF. Simulation results with this value are in Figure 7.

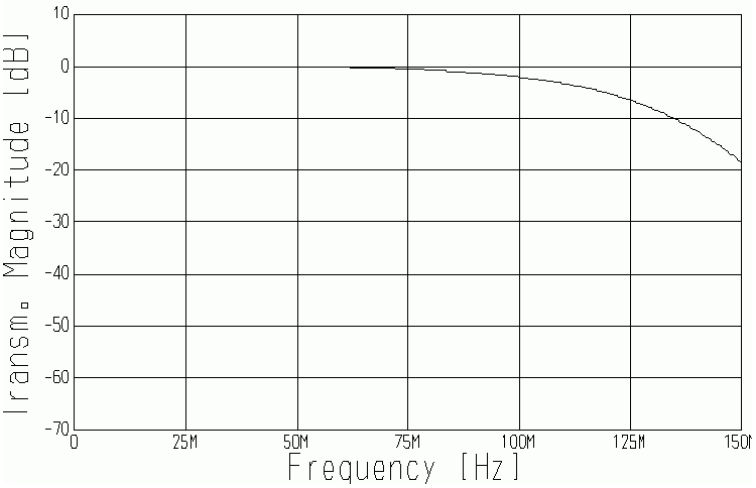

Figure 7: PA output filter without C5050 and C5051.

Losses at 50 and 70 MHz are 0.08 dB and 0.40 dB respectively. This would mean 100 W on the input would give 91 W on the output on 70.0 MHz and an increased efficiency (lower current) at 50 MHz.

Of course C5050 and C5051 were designed-in for a reason. They have a low impedance at harmonic frequencies, so they can be useful to increase efficiency of the PA (harmonic traps are often used for this purpose). Furthermore, they could be needed for a sufficient stability margin of this broadband PA! If we only remove C5051 (transformed capacitance 38 pF), the filter curve is like this:

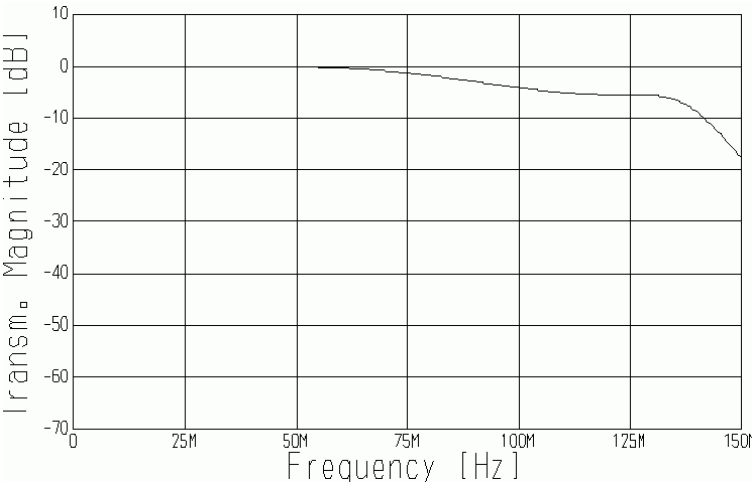

Figure 7: PA output filter without C5051

Losses at 50 and 70 MHz are 0.13 dB and 0.92 dB respectively. This would mean 100 W from the transistors would give 81 W on the output on 70.0 MHz. This is the modification I have implemented myself. Pictures are below.

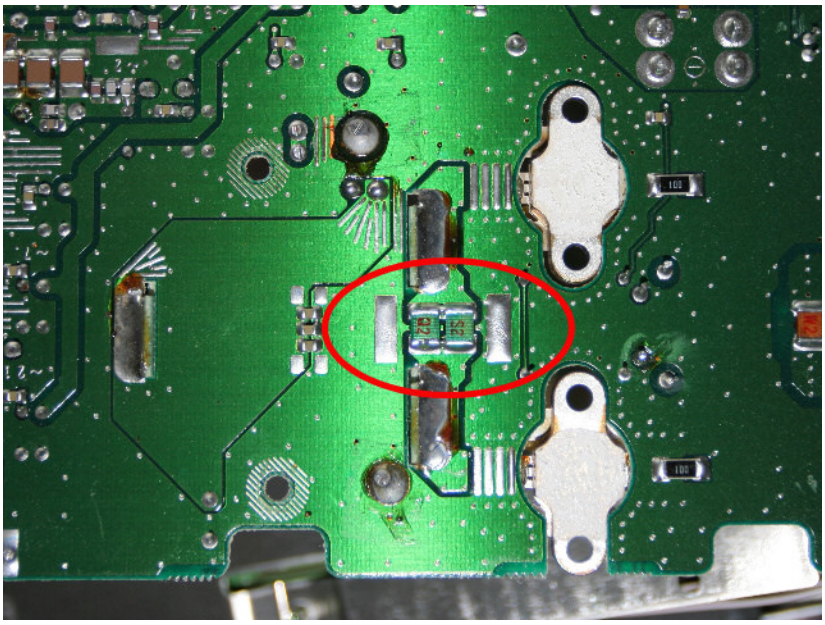

Figure 8: Unmodified PA output

After de-soldering the HF and 50 MHz outputs, the PA unit can be lifted, and at the solder side you can recognize C5050 and C5051. I removed the biggest one, with the result below.

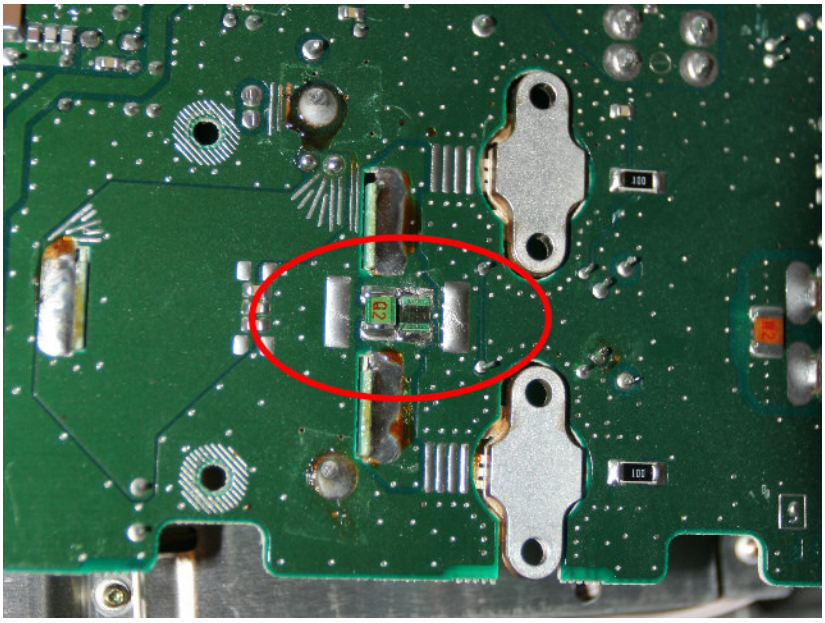

Figure 9: PA output without C5051

You can see in this picture that Yeasu used strong glue, the outer insulation of the SMD capacitor unfortunately remained on the PCB after de-soldering.

After re-assembling the transceiver I was happy to measure a positive result of this modification: Current of 16 A and 85 W output on 70 MHz. Also the current for 50 MHz dropped from 21 A down to 17 A for 100 W output. I experimented briefly with the value of L5006. Lowering the value decreases efficiency. Inserting ferrite might increase the output on 70 MHz even more but this wasn't tested.

So far I haven't noticed any negative side-effects of this PA modification. The PA is still stable for all bands.

Appendix: Simulated filter component values

Low-pass filter LPF[6]

C5072	22 pF
C5075 // L5009	5 pF // 125 nH
C5089	68 pF
C5097 // L5022	22 pF // 100 nH
C5110	56 pF
C5115 // L5030	33 pF // 78 nH
C5123	33 pF

Low-pass filter LPF[6] without C5123

C5072	22 pF
C5075 // L5009	5 pF // 125 nH
C5089	68 pF
C5097 // L5022	22 pF // 100 nH
C5110	56 pF
C5115 // L5030	33 pF // 78 nH
C5123	0 pF

PA output filter

Rin // Cin	50 Ohm // 68 pF
L5035	80 nH (estimated)
C5056	3 pF
C5057	27 pF
C5058 // L5006	8 pF // 110 nH (Estimated)
C5061	27 pF

PA output filter without C5058

Rin // Cin	50 Ohm // 68 pF
L5035	80 nH (estimated)
C5056	3 pF
C5057	27 pF
C5058 // L5006	0 pF // 110 nH (Estimated)
C5061	27 pF

PA output filter without C5050 and C5051

Rin // Cin	50 Ohm // 15 pF
L5035	80 nH (estimated)
C5056	3 pF
C5057	27 pF
C5058 // L5006	8 pF // 110 nH (Estimated)
C5061	27 pF

PA output filter without C5051

Rin // Cin	50 Ohm // 38 pF
L5035	80 nH (estimated)
C5056	3 pF
C5057	27 pF
C5058 // L5006	8 pF // 110 nH (Estimated)
C5061	27 pF