QCX-20 Low Output Power Problem
Low-pass Filter Design Part 1

The Symptoms

After building and testing my QCX-20, I observed that the output power was significantly lower than indicated by the graph on page 138 of the Rev-4f manual. With 13 volts applied (voltage after D3), the QCX-20 output measured 2.5 watts vs 3.9 watts on the graph. My QCX-40 output measured 3.4 watts vs 3.7 watts on the graph, which is a reasonable difference.

Because low output power on the QCX-20 seems to be a common problem, I decided to do some further investigation. The measured output power of the QCX-40 at different frequencies across the 40 meter band was nearly constant. However, the measured output power of the QCX-20, varied inversely with frequency.

Plotting the peak output voltage (instead of power) from the QCX-20 across a 50 ohm load versus frequency gave a straight line. This suggested that the operating frequency was too close to the knee of the low-pass filter. The slope of the plotted line was 11 volts / MHz. With this information, I calculated how much the low-pass filter cutoff frequency would need to be increased to get 4 watts out across the entire band, as follows.

Peak voltage required for 4 watts across 50 ohms = 20 volts
Peak voltage measured at 14.350 MHz (the top of the 20 meter band) = 12.2 volts
Required increase in filter frequency (20 V – 12.2 V) / (11 V / MHz) = 0.709 MHz

Although only 5% of the operating frequency, this required frequency change seems too large to be simply a symptom of component tolerances, particularly when considering the number of users experiencing the problem. Therefore, I decided to do further analysis of the low-pass filter.

Analysis of Filter Sources

My first stop was "A short guide to harmonic filter for QRP transmitter output" by G3RJV (http://www.gqrp.com/harmonic_filters.pdf), which is the source for the low-pass filter component values used in the QCX transceivers.

The spread sheet (below) shows the filter data from TABLE 1 of this article. Columns highlighted in purple are added to assist with the analysis.

Low Pass Filters (all frequencies in MHz)

Band	Bottom	Top	F – co	F-co – Top	F – 3dB	F-3dB / F-co	F – 30dB	2nd Harmonic
160	1.800	2.000	2.160	0.160	2.760	1.278	4.000	3.600
80	3.500	4.000	4.130	0.130	5.110	1.237	7.300	7.000
40	7.000	7.300	7.360	0.060	9.040	1.228	12.900	14.000
30	10.100	10.150	10.370	0.220	11.620	1.121	15.800	20.200
20	14.000	14.350	14.400	0.050	16.410	1.140	22.500	28.000
17	18.068	18.168	18.930	0.762	22.890	1.209	32.300	36.136
15	21.000	21.450	21.550	0.100	27.620	1.282	39.900	42.000
12	24.890	24.990	25.240	0.250	28.940	1.147	39.800	49.780
10	28.000	29.700	31.660	1.960	40.520	1.280	58.500	56.000
Avg				0.410		1.213		

The first added column is the difference between the top of each band and the corresponding F-co (ripple cutoff frequency). Apparently, F-co is not necessarily the frequency of no attenuation (see graph below). Highlighted in yellow are differences that seem low (less than 0.1 MHz), one of which is 20 meters. Highlighted in orange are differences that seem high.

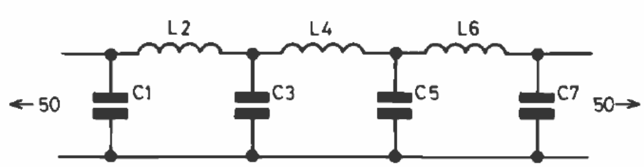
The second added column is the ratio of F-3dB (frequency of 3dB attenuation) for each band and the corresponding F-co. Highlighted in yellow are the lower ratios, including 20 meters. The lower ratio indicates the 3dB point is closer to F-co, suggesting that part of the pass-band is more likely to be attenuated. The average ratio is in blue. Ratios less than 1.2 were of concern.

The third added column is the 2nd harmonic of the bottom frequency of each band, which is what needs to be attenuated. The corresponding F-30dB frequencies that are higher than the 2nd harmonic are highlighted.

With these concerns, I decide to go to the source of this information which is a 2-part article by W3NQN. This article, “Low-pass Filters for Attenuating RF Amplifier Harmonics,” can be found split between the December 1983 and January 1984 issues of The Short Wave Magazine (https://www.americanradiohistory.com/Short_Wave_UK.htm).

In his article, W3NQN describes several 5-element low-pass filters and argues for the use of a 7-element Chebyshev low-pass filter for solid state amplifiers. The article is worth reading, but the most relevant part is a list of 30 pre-designed filters using standard-value capacitors, which is where G3RJV obtained the filter data for TABLE 1.

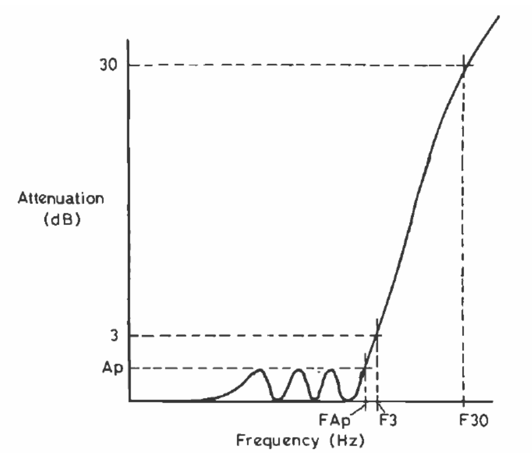
Figure 2 (below) of the W3NQN article shows the schematic of the 7-element filter and graph of attenuation vs frequency. The component designators in this schematic are used for most of the following discussion.



C1 = C7, C3 = C5, L2 = L6

(a) Schematic diagram

NOTE: F-Ap, F-3dB, and F-30dB are indicated on the graph, but it is not clear if F-Ap is what the author refers to as F-co.



(b) Typical attenuation response. The passband attenuation ripple amplitude (Ap) is exaggerated for clarity.

Fig. 2 7 ELEMENT CHEBYSHEV LOW-PASS FILTER

Looking at the list of 30 filters, I did my own selection of a filter for each Ham band. The following criteria were used to make the selections, prioritizing in the order listed, but in a few cases compromises were made.

1) F-3dB / F-co should be 1.2 or greater to reduce the possibility of attenuation in the pass band.
2) F-30dB should be less than the 2nd harmonic to ensure more than 30dB attenuation of the 2nd harmonic.
3) F-co – Top (of the band) should be a minimum

Low Pass Filters (all frequencies in MHz)								
Band	Bottom	Top	F – co	F-co – Top	F – 3dB	F-3dB / F-co	F – 30dB	2nd Harmonic
160	1.800	2.000	2.170	0.170	2.590	1.194	3.600	3.600
80	3.500	4.000	4.100	0.100	4.820	1.176	6.700	7.000
40	7.000	7.300	7.360	0.060	9.040	1.228	12.900	14.000
30	10.100	10.150	10.330	0.180	12.990	1.258	18.600	20.200
20	14.000	14.350	14.450	0.100	17.260	1.194	24.300	28.000
17	18.068	18.168	18.930	0.762	22.890	1.209	32.300	36.136
15	21.000	21.450	21.550	0.100	27.620	1.282	39.900	42.000
12	24.890	24.990	25.680	0.690	30.950	1.205	43.700	49.780
10	28.000	29.700	30.660	0.960	38.240	1.247	54.700	56.000
Avg				0.347		1.221		

The rows highlighted in green are changed from the original table. The following are a few items to note.

1) For 20, 80, and 160 meters, F-3dB / F-co is less than 1.2, but only 80 meters is significantly less and needs testing.
2) For 160 meters, F-30dB is not less than the 2nd harmonic frequency because no better option is available.
3) For 10, 12, and 17 meters, the differences between F-co and the top frequency are relatively large because no better options are available.

Note that F-3dB for 20 meters increased from 16.410 MHz to 17.260 MHz, a difference of 0.850 MHz. Previously, an increase of the filter frequency to obtain an output of 4 watts across the entire band was calculated to be 0.709 MHz. Therefore, these new component values for 20 meters should work.

Below is a list of the capacitor and inductor values for the selected filters. The component designators refer to the schematic in figure 2 from the W3NQN article, not the QCX schematic.

Band	C1,7	C3,5	L2,6	L4
160	1000	2400	4.863	5.880
80	560	1300	2.624	3.135
40	270	680	1.380	1.698
30	180	470	0.952	1.188
20	150	360	0.729	0.882
17	110	270	0.548	0.668
15	82	220	0.444	0.561
12	82	200	0.406	0.493
10	62	160	0.324	0.403

For the QCX-20, the number of turns for L2, L4, and L6 remain the same as the current QCX design. However, the capacitors are reduced.

The list of 30 filters in the W3NQN article also provided VSWR data. The filters on the list were selected from a larger list because they have a VSWR of about 1.1:1 or less. From the W3NQN data, my selected Ham band filters all have a VSWR of 1.07:1 or less.

<u>Conclusion and Test</u>

The table below shows the component values for 20 and 40 meter W3NQN low-pass filters. The values currently used in the QCX design are on the left, and the revised filters are on the right. The component designators are from the W3NQN schematic.

	QCX-20	Turns	Selected	Turns
C1, 7	180 pF		150 pF	
C3, 5	390 pF		360 pF	
L2, 6	0.77 uH	16	0.73 uH	16
L4	0.90 uH	17	0.88 uH	17
	QCX-40	**Turns**	**Selected**	**Turns**
C1, 7	270 pF		270 pF	
C3, 5	680 pF		680 pF	
L2, 6	1.4 uH	21	1.4 uH	21
L4	1.7 uH	24	1.7 uH	24

Using the revised filter for 20 meters requires reducing the capacitor values as highlighted in green. The turns for L2 and L6 in the QCX-40 are highlighted in yellow because, by calculation, these toroids require 21.6 turns, which would normally be rounded up to 22 turns. However, as specified in the QCX manual, I used 21 turns when I built the QCX-40, and it works great.

Before completing this analysis, I modified the QCX-20 by removing one turn from L1 and L3 (QCX schematic designators), as recommended on the QRP Labs web site. The resulting performance provided a constant appropriate output power across all but the top of the 20 meter band. As the CW / lower half of the band was operating normally and 150 pF capacitors were not readily available at that time, I stayed with this modification.

After completing this analysis, I purchased some 150 pF NP0 capacitors, and modified the QCX-20 by rewinding L1 and L3 with the original 16 turns and changing C25 – C28 (QCX schematic designators) per the values highlighted in green. The resulting performance provided a nearly constant 3.5 watts across the entire 20 meter band. Although slightly less than the 3.9 watts on the graph in the manual, this output seems appropriate.

To be continued

In part 2, the revised list of W3NQN low-pass filters will be further analyzed. Also, a number of parameters will be considered to develop a worst-case design for low-pass filters.