# 8-pole 10MHz SSB Ladder Crystal Filter

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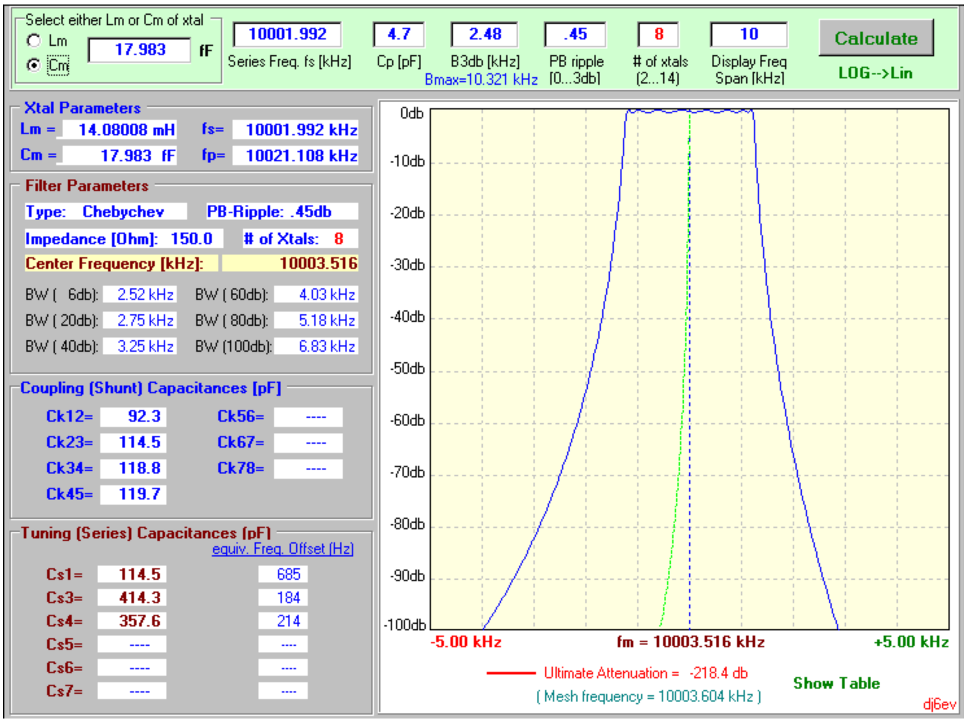
Since completing the 4-pole filter published in the Summer 2011 edition of Sprat I have purchased a batch of 20 crystals from Club Sales and my measurements of the properties of this much larger sample have caused me to revise my figure for their motional capacitance. For this filter I have used a figure of 17.983fF , this being the average for those crystals which were actually used in its assembly. If you are unable to measure crystal parameters yourself I would suggest the adoption of 18fF as a good ball-park figure for these crystals. Even if your own crystals are a little removed from this figure be reassured that ladder crystal filters are very tolerant of departures from the theoretical ideal. The worst that can happen is that the bandwidth and centre frequency will depart a little from their design value. In any case because of the finite Q of all crystals you will need to allow for some ‘shrinkage’ of the pass bandwidth. For example, in my own filter the measured 3db bandwidth was 2317hz rather than the specified 2480hz. This is typical of what you may expect. Similarly, the ripple may also depart from the number you were aiming for.

My input to the ‘Dishal’ design program was as follows:
Cm=17.983fF Fs=10001.992kHz Cp=4.7pF BW=2.48kHz Ripple=0.45dB
as you can see in the illustration below.



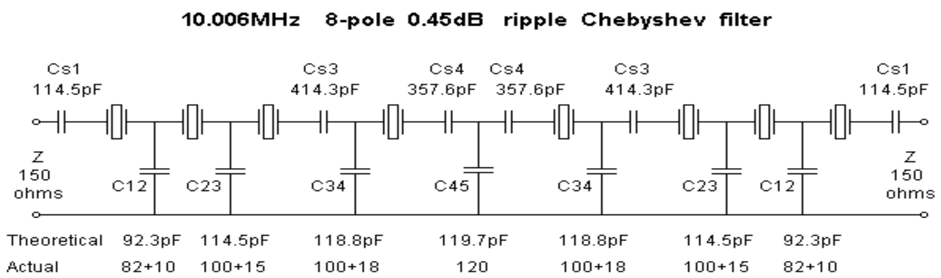

For clarity the calculated component values are repeated below.

Coupling capacitors C12=92.3pF C23=114.5pF C34=118.8pF C45=119.7pF
Series capacitors Cs1=114.5pF no Cs2 Cs3=414.3pF Cs4=357.6pF
Impedance Z=150 ohms.

It was not that I actually ‘wanted’ a ripple of 0.45dB; it was simply the result of interacting with the program while progressively increasing the ripple value and the bandwidth, until the calculated values for impedance and coupling capacitors were all readily achievable using only standard value components.

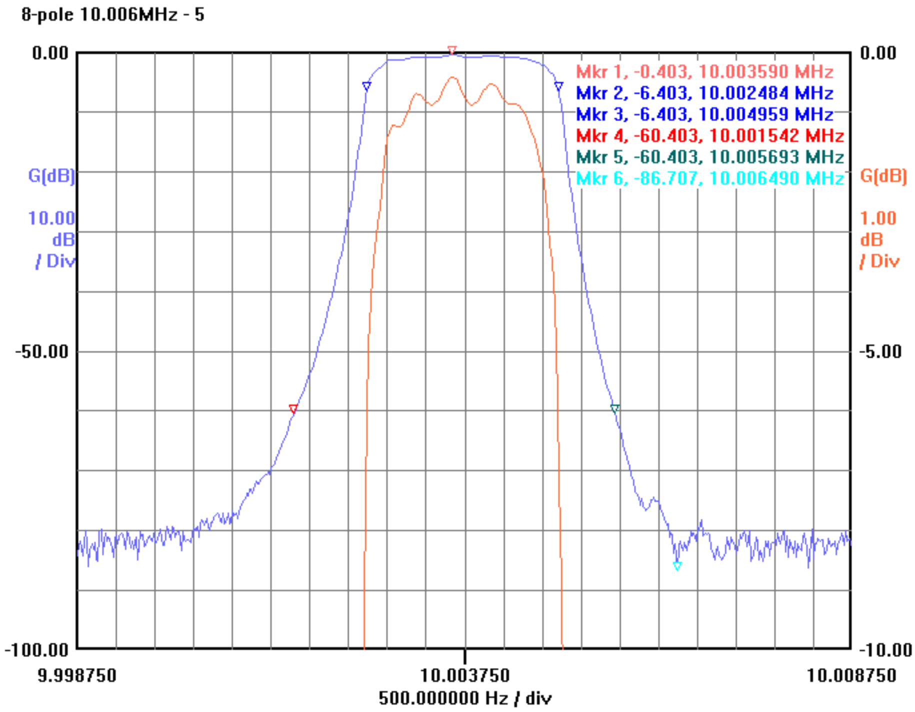
The calculated values for the series capacitors are of rather less importance because they will all need to be selected during the tuning process. This allows crystals to be used which are higher, or lower in frequency than the average Fs used in the calculation. For instance, the calculated value for Cs4 was 357.6pF but the final value required was just over 1000pF (actually 330 and 680pF in parallel). This is due to the series resonance of the crystal being so much higher than the others in this group. Indeed, if it had been much higher I could have omitted this capacitor altogether. By careful selection of capacitors and crystals I was able to tune each mesh of the filter so that all were within a spread of 24hz.

However, if you are making your first filter and are in a hurry to see some results, you can forget this individual tuning stage. So long as you have selected the 8 crystals which are nearest to each other in frequency, just fit capacitors made-up from standard values and check the frequency response. With any luck it will be adequate; at least for your first project. As I said earlier, ladder filters are very tolerant of deviations from the ideal: much more so than lattice filter designs. Later-on you will very likely feel as I did and go back to do some fine tuning.




This is the circuit of the 8-pole filter showing calculated values for the capacitors. Also shown are the nearest standard values which were actually used for the coupling capacitors. These were selected from stock using a capacitance bridge. It was found to be easy to select pairs of capacitors within 1-2pF of the desired value.

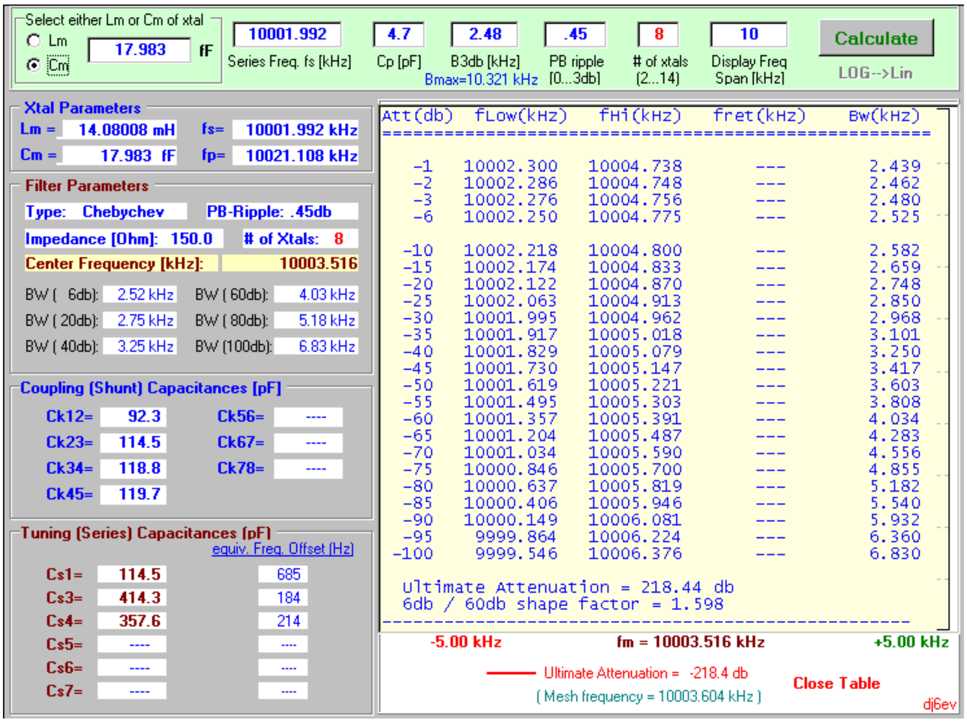
Here is the measured frequency response of the 8-pole filter.




The markers show that the bandwidth is 2475hz at -6dB, and 4151hz at -60dB; thus the 6:60 dB ratio is 1.7:1 . The stop band rejection is better than 80dB, but see later how I improved this figure to more than 90dB. Also included here is an expanded trace of the pass band. This shows that while the ripple is very close to the design specification of 0.45dB there is an unavoidable droop at each side of the pass band which is due to the finite Q of the crystals.

When the above figures are compared with the specification you can see that the pass-band is smaller than required and the stop-band is wider. Experience will show you how much to allow for the pass bandwidth reduction when you put this figure into the program; but in the case of the stop band you must add more crystals at the design stage if you want to improve the rate of cut-off. The ultimate stop band attenuation is a function of layout and screening as well as the number of crystals. This latter factor showed-up in my own prototype measurements because of the total lack of any screening in my breadboard layout. Quite simple screening increased the rejection by 10dB and I proved this was possible by inserting baking foil as a temporary screen. Radiation from your test leads cannot be neglected either. Mine needed the baking foil treatment to prevent them acting as antennas. More permanent arrangements will have to wait until time is available and I have fewer pressing domestic needs !

The Dishal program provides a tabular output of the frequency response as an alternative to the graph shown previously. I find this to be a valuable additional facility because it allows a ready comparison between the measured results and the theoretical response.

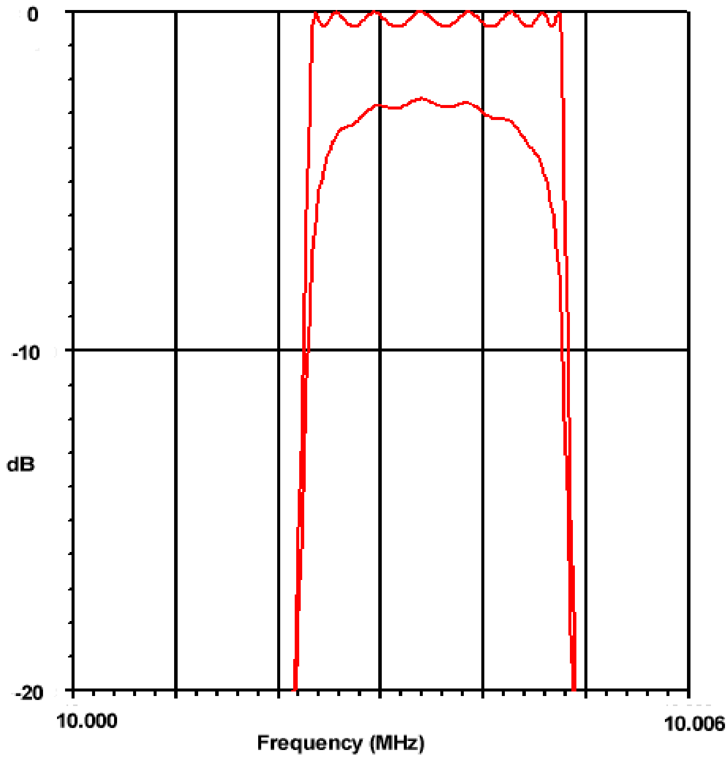



| Att(db) | fLow(kHz) | fHi(kHz) | fret(kHz) | Bw(kHz) |
|---|---|---|---|---|
| -1 | 10002.300 | 10004.738 | --- | 2.439 |
| -2 | 10002.286 | 10004.748 | --- | 2.462 |
| -3 | 10002.276 | 10004.756 | --- | 2.480 |
| -6 | 10002.250 | 10004.775 | --- | 2.525 |
| -10 | 10002.218 | 10004.800 | --- | 2.582 |
| -15 | 10002.174 | 10004.833 | --- | 2.659 |
| -20 | 10002.122 | 10004.870 | --- | 2.748 |
| -25 | 10002.063 | 10004.913 | --- | 2.850 |
| -30 | 10001.995 | 10004.962 | --- | 2.968 |
| -35 | 10001.917 | 10005.018 | --- | 3.101 |
| -40 | 10001.829 | 10005.079 | --- | 3.250 |
| -45 | 10001.730 | 10005.147 | --- | 3.417 |
| -50 | 10001.619 | 10005.221 | --- | 3.603 |
| -55 | 10001.495 | 10005.303 | --- | 3.808 |
| -60 | 10001.357 | 10005.391 | --- | 4.034 |
| -65 | 10001.204 | 10005.487 | --- | 4.283 |
| -70 | 10001.034 | 10005.590 | --- | 4.556 |
| -75 | 10000.846 | 10005.700 | --- | 4.855 |
| -80 | 10000.637 | 10005.819 | --- | 5.182 |
| -85 | 10000.406 | 10005.946 | --- | 5.540 |
| -90 | 10000.149 | 10006.081 | --- | 5.932 |
| -95 | 9999.864 | 10006.224 | --- | 6.360 |
| -100 | 9999.546 | 10006.376 | --- | 6.830 |

Ultimate Attenuation = 218.44 db
6db / 60db shape factor = 1.598

## Computer Circuit Simulation

It is interesting to see how computers can use software to produce an accurate forecast of the frequency response by building into the model circuit losses to be expected in practical components. This  simulation of my design was made by DJ6EV using the ARRL ‘Amateur Radio Designer’ package which was marketed some years ago. Unfortunately, this is no longer available, but many alternatives can be found in an Internet search. Free trial versions are also out there.




The top graph shows the frequency response of a filter made of perfect, loss-free, crystals while the lower response shows the result of incorporating typical real-world crystals having a Q of 100,000. Even such high quality crystals have sufficient loss to cause the rounding of the edges of the pass band in the prototype filter shown in the previous diagram.

### Filter design software

The ‘Dishal’ ladder crystal filter design program written by Horst Steder DJ6EV  is available from the Warrington Radio Club web-site at www.warc.org.uk. You will find this, and our crystal filters articles, in the ‘Projects’ section of the site.