10.006 MHz Crystal Filter

Jack Hardcastle G3JIR

This material supplements my article in the summer 2011 issue of ‘Sprat’. For the benefit of members who have not made a crystal filter previously this is a good time to start because the crystal properties have already been measured by me, so you do not have to measure their fundamental parameters yourself. However, I must enter the caveat that I have only measured six crystals out of a large batch, so there is plenty of room for deviation from my small sample. For members who wish to verify my measurements, but have never tested crystals previously, there are references to suitable papers describing this procedure, at the end of these notes.
To get started call up the Dishal ladder crystal filter design program which is available on the Warrington Amateur Radio Club web site at www.warc.org.uk . You can also get a very useful ‘Help’ file from the same source. However since it is a very intuitive program to use you will probably only turn to the help pages when you want to explore more than its basic functions.

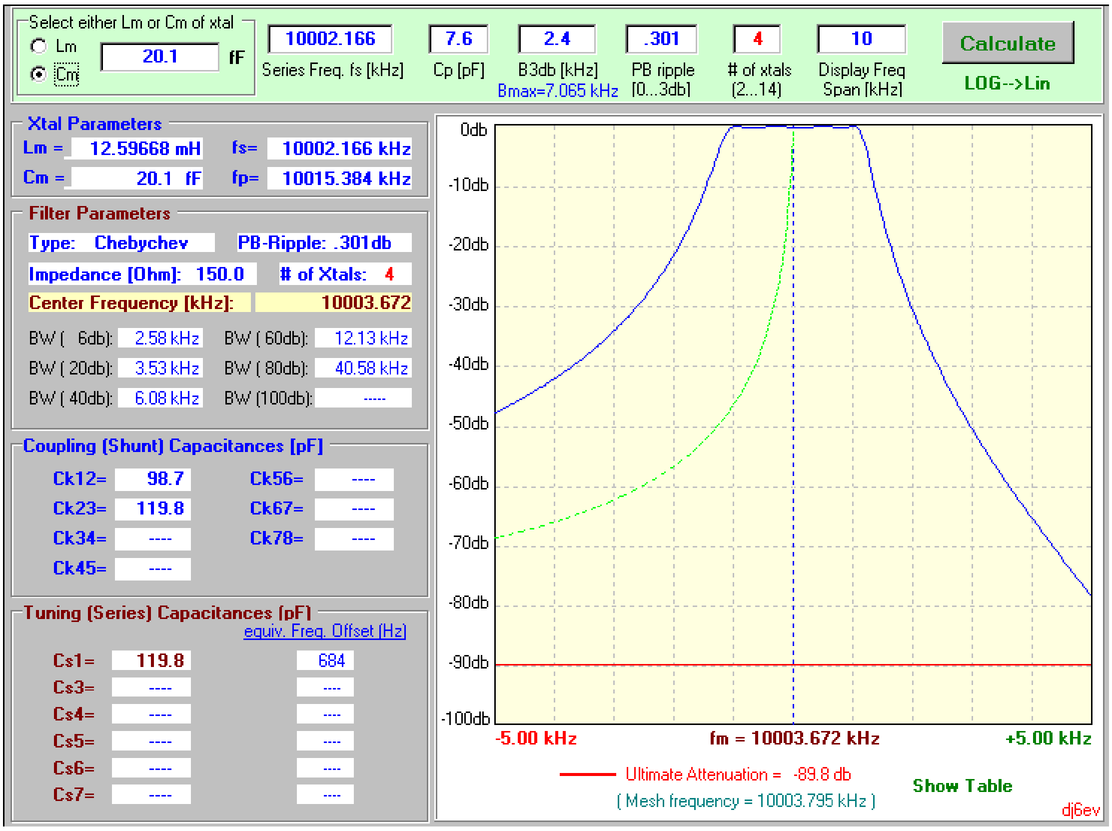

Fig 1a shows a screen shot of the Dishal program which was written by Horst Steder DJ6EV. The input parameters are entered in the seven boxes in the top panel. Pressing the 'Calculate' button displays the component values on the left-hand side of the display. A graphical display of the frequency response is shown on the right-hand side, also.

It is easy to modify a design by changing one input parameter at a time and clicking 'Calculate'. This feature is particularly useful for making small adjustments to help you to arrive at a design which uses standard value capacitors. For example you can change the ripple or the bandwidth by small amounts without radically altering the performance of the filter. Try doing this and see how the capacitor values are altered.

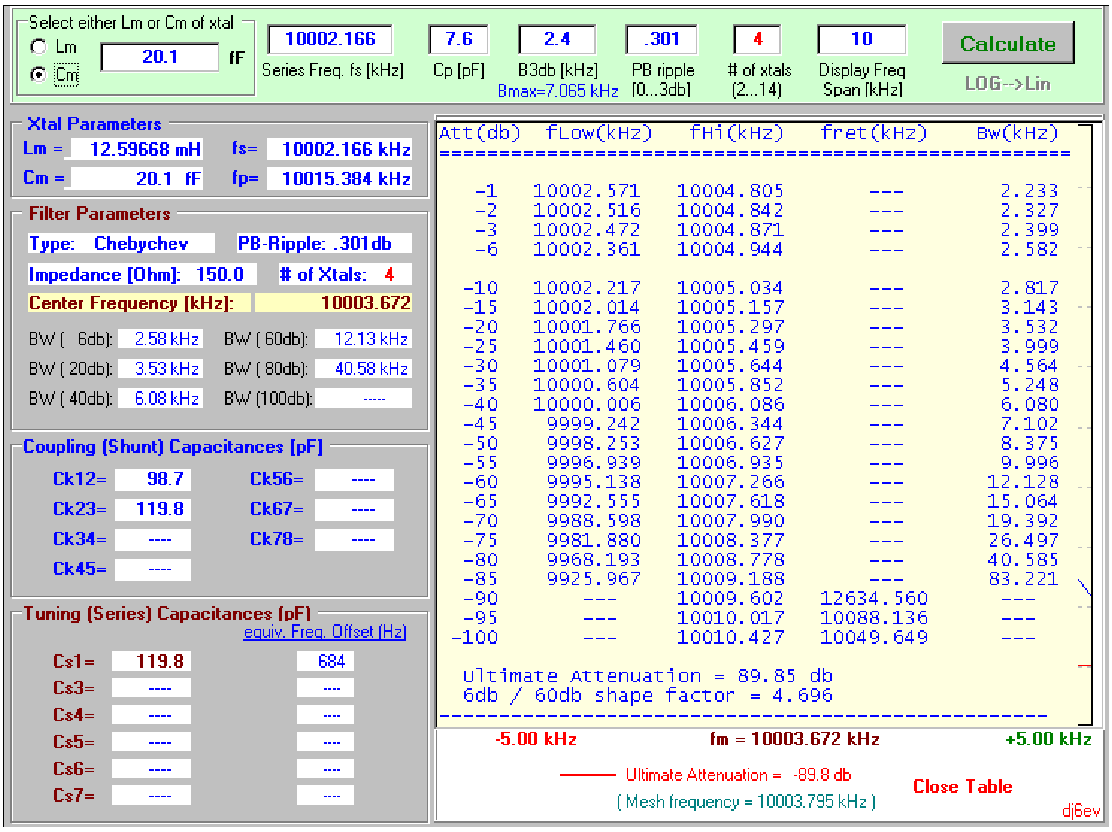

Fig 1b

The graphical display can be exchanged for a tabular display by clicking on ‘Show Table’ located in the bottom right-hand corner of the display.

Fig 2 This is the prototype 4-pole filter which was constructed on a piece of scrap PCB material. In your design you should trim the leads of the crystals much shorter than in my example. I only left them long so they would survive repeated soldering in my tests. The same applies to the capacitors. At 10 MHz the inductance of an inch of wire begins to have a significant effect on the performance so keep these leads short. I used this layout for two reasons. Firstly, because of its ease of access to the components and secondly, and more importantly, it locates the input and output connections as far apart as possible, so it does not need the careful screening which a more compact design requires. It is important to ground the case of each crystal because of the stray capacitance between the crystal and the case. When the case is earthed this capacitance adds to the shunt coupling capacitors and can be allowed for when selecting these components. It also provides extra screening between each section of the filter; for free !

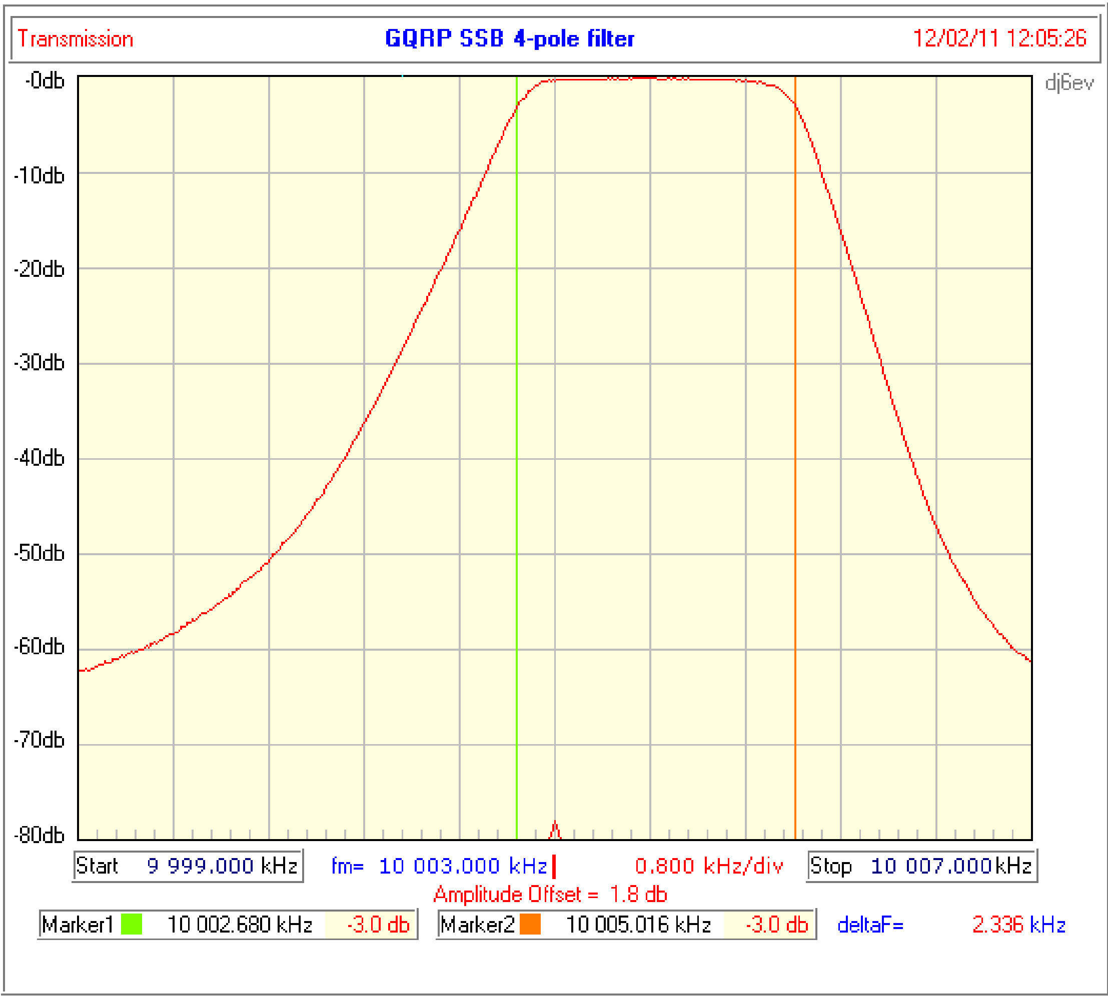

Fig 3 This is the frequency response of the 4-pole filter. I would regard this as the minimum performance for either a transmitter, or a receiver. For this reason the club is selling the crystals in batches of ten. This number will allow the selection of sufficiently well-matched crystals for at least a 6-pole filter.

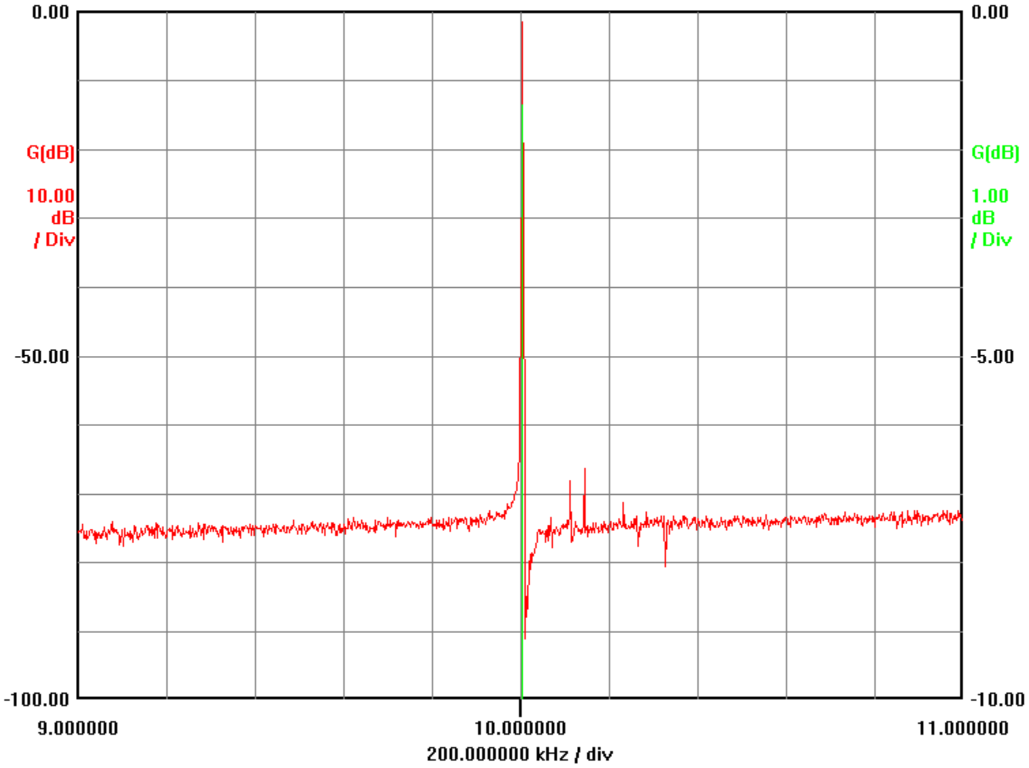

Fig 4 Here is a wide-band (warts and all !) frequency response of the same filter. Apart from a couple of very narrow 'spikes' the stop-band is better than 70dB below the pass-band. The 'spikes' are the result of spurious resonances which all crystals have to a greater, or lesser degree. They are usually of very narrow bandwidth and it is an advantage of the ladder circuit configuration that, except for the very rare case where they all congregate on the same frequency, they will cancel each other very effectively.

Higher-order filters have a steeper rate of cut-off at the edges of the pass-band and the stop-band attenuation is commensurately higher as well. However, there is a penalty to pay for adding extra stages to the filter. This is an unavoidable increase in insertion loss which is the result of the motional series resistance of each crystal. For instance, the insertion loss of the prototype 4-pole filter is 1.4 dB, so you can budget for a ball-park figure of an extra 0.4 dB for each additional stage using these crystals.

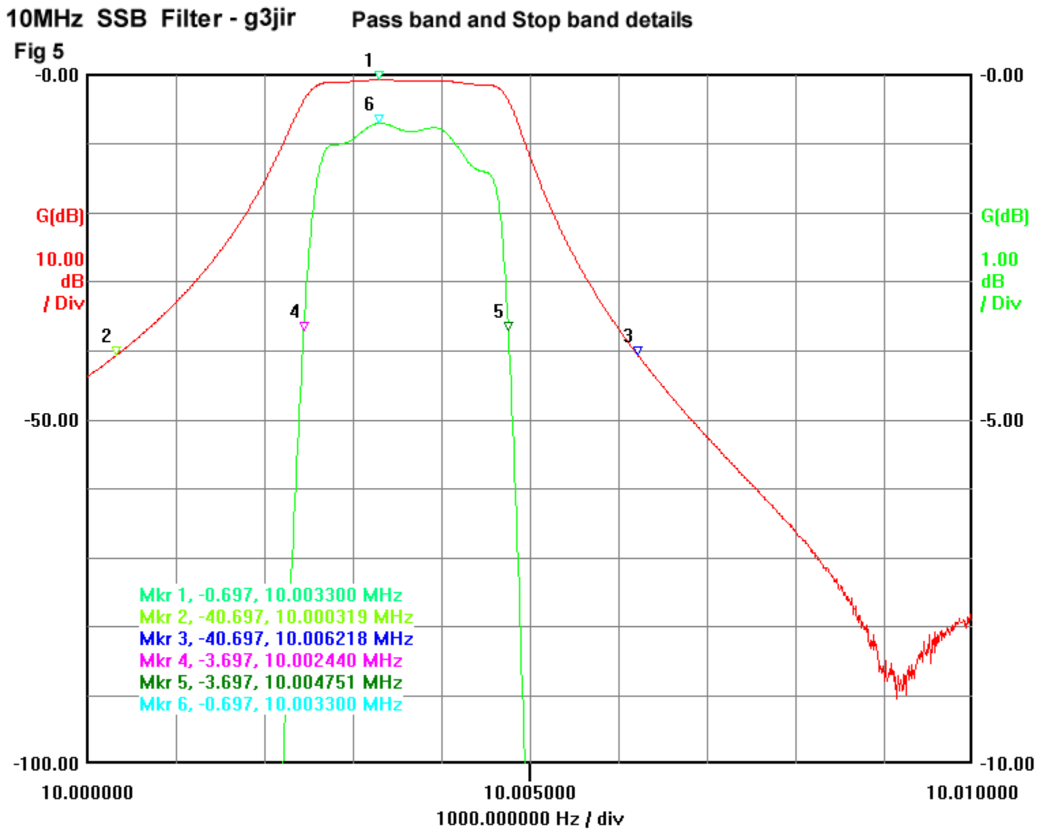

Fig 5 This is a detailed view of the pass-band and the stop-band. Here you can see the depth of the notch caused by the parallel resonance of the crystals. It will be even deeper in higher-order filters but will be hidden by the circuit noise.

In the magnified view of the pass-band you can see that the ripple is greater than the design specification. This is largely due to the finite 'Q' of the crystals. It is unlikely to detract from the overall audio performance of either the transmitted signal, or the received signal.

Additional Reading

1. There is a collection of my ladder crystal filter papers on the Warrington Amateur Radio Club web site at www.warc.org.uk . From the home page click on 'Projects' and then on Crystal Filter Design. Here you will find my interpretation of the original work on ladder crystal filters by M. Dishal, including all the formulas used by DJ6EV in his software. While you are visiting you will also see many other projects contributed by club members, including the ground-breaking CDG2000 transceiver.

2. B Carver High-performance crystal filter design.
Communications Quarterly Winter 1993.
This paper is included on the CDROM included in the ARRL publication 'Experimental methods in RF design' by Hayward, Campbell and Larkin.

3. W Hayward Refinements in crystal ladder filter design.
QEX June 1995 (ARRL)

4. J Makhinson Designing and building high performance crystal ladder filters.
QEX Jan 1995 (ARRL)

References 3 and 4 have are included in the ARRL book 'QRP Power' which many QRP enthusiasts will already have in their library.

5. W Hayward An oscillator scheme for quartz crystal characterisation.
This paper describes in detail how a crystal oscillator may be used to assess the parameters of a crystal. This method only needs the use of a frequency meter, a piece of test equipment which should be in every home-brew enthusiasts workshop; plus some capacitors of known value within 0.5 percent, or better. Wes Hayward credits Dr David Gordon-Smith with proposing this method. A copy of this paper is available from the W7ZOI web site at:
Www.w7zoi.net. From his home page click on the link near to the bottom of the page and go to the Technical notes/ 16 Nov 07 An oscillator scheme for quartz crystal characterization.