Chebyshev .01db Ripple 6 Crystal 3.0KHz Filter

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The crystals all come from the same batch of 8.388MHz crystals. Their parameters have already been measured and recorded with an N2PK VNA.

The filter design shape is chosen. In this case a .01db ripple Chebyshev approximation is selected. This filter has a shape close to the Butterworth, but has a bit steeper slope to the stopband. The target bandwidth is selected: 3KHz in this case. Experience has shown that actual bandwidth will be about 80% of design bandwidth. We shoot for a bandwidth of 2.4KHz which is good for SSB which means a design bandwidth of 3KHz.

Six crystals from the same batch are chosen. The lowest series frequency crystal should begin in position 2. If design capacitances come out negative, crystals should be swapped around until all capacitances are positive. The order selected for this filter is crystals: 31, 26, 5, 10, 21, 12.

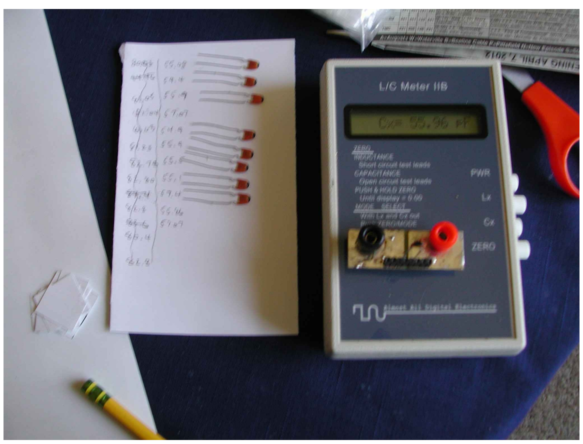
The crystals and parameters are run through the Design Program in the Maple script DesignAFilterV2.mws. The design parameters are entered in Params. Below is the design matrix. The second column gives the design capacitors in pF. The center frequency of the filter is the loop frequency: 3.3870986MHz. BW12_Hz comes closest to the 3db bandwitch of the filter.

"4/5/12"	*Chebyshevp01*	*BW_set*	3000
inL_uH	2.589	*BW_calc*	2711.7
inC_pF	122.6	*in_R*	422.3
[*X*, 31, *pF*]	82.07	*f_MHz*	8.3859642
C12_pF	59.36	*BW12_Hz*	2426.4
[*X*, 26, *pF*]	[*f_MHz*, 8.3850350]	*loop_MHz*	8.3870986
C23_pF	87.29	*BW23_Hz*	1650.0
[*X*, 5, *pF*]	165.8	*f_MHz*	8.3855265
C34_pF	92.74	*BW34_Hz*	1553.1
[*X*, 10, *pF*]	156.5	*f_MHz*	8.3855459
C45_pF	87.29	*BW45_Hz*	1650.0
[*X*, 21, *pF*]	661.0	*f_MHz*	8.3851538
C56_pF	59.36	*BW56_Hz*	2426.4
[*X*, 12, *pF*]	84.20	*f_MHz*	8.3859527
outC_pF	123.3	*out_R*	417.6
outL_uH	2.574	*Co_pF*	48.01

The table below gives the exact design capacitances and the closest standard values. About 10 capacitors of each standard value were measured. Values closest to the exact values were selected for use in the filter. One picture shows the selection process. Measured values were written on the paper and the capacitor placed beside the value. Another picture shows the capacitors in plastics bags with exact, standard, and actual values on a piece of paper included in the bag.

Capacitor Selection

Comp	Exact	Standard	Actual
Cry31	82.07pf	82pf	81.8pf
C12	59.36pf	56pf	57.1pf
Cry26	-	-	-
C23	87.29pf	82pf	84.4pf
Cry5	165.8pf	180pf	166pf
C34	92.74pf	82pf	84.5pf
Cry10	156.5pf	150pf	155.3pf
C45	87.29pf	82pf	83.6pf
Cry21	661pf	680pf	660pf
C56	59.36pf	56pf	57.1pf
Cry12	84.2pf	82pf	83.5pf

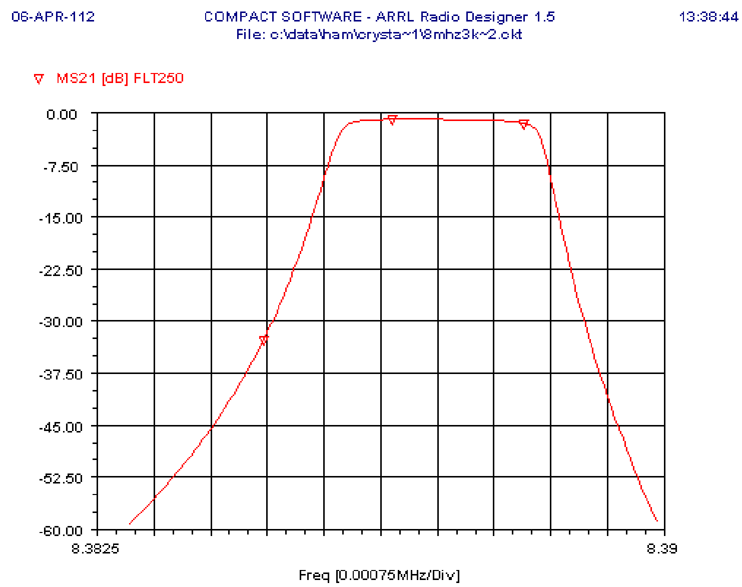


Finding a Capacitor Value

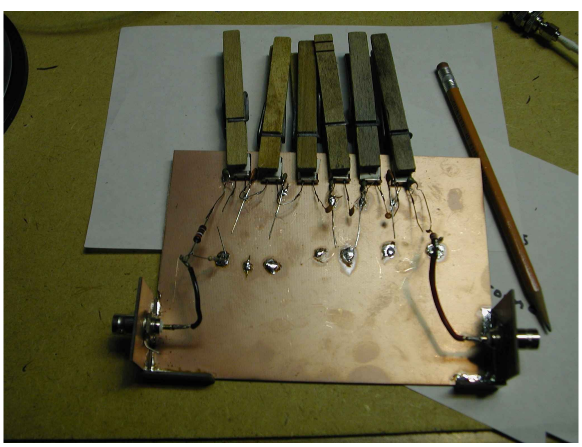

Bagged parts

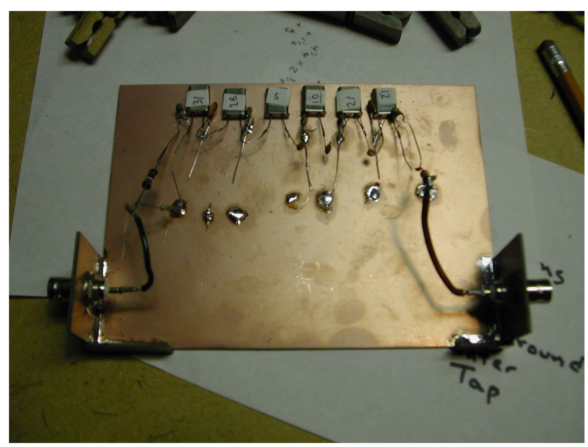
The filter was simulated first with exact values then with standard values. Design should be iterated until standard values give a decent design. Increasing the bandwidth is the most likely change. (Usually the first choice is too narrow.) The graph below shows the simulation with the actual values of selected capacitors.

The graph below is the simulation with Actual Values.
(8.384-8.389MHz = 5KHz 45db BW)

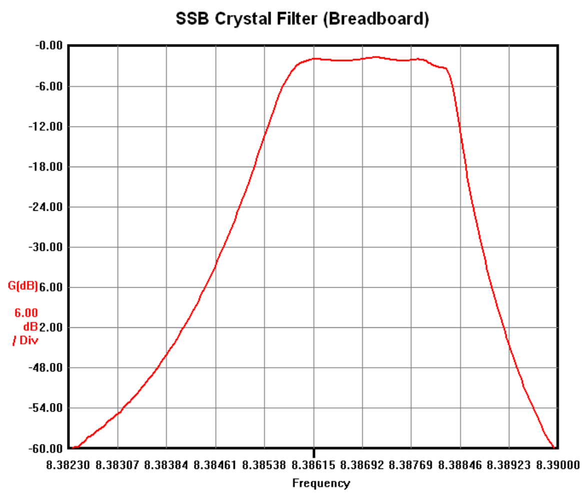


The filter is then built on a breadboard. Two pictures show the filter on the bread board with the clothespins removed and with the clothespins in place. The clothespins clamp the crystals to the ground plane, and hold the filter rigid for testing.

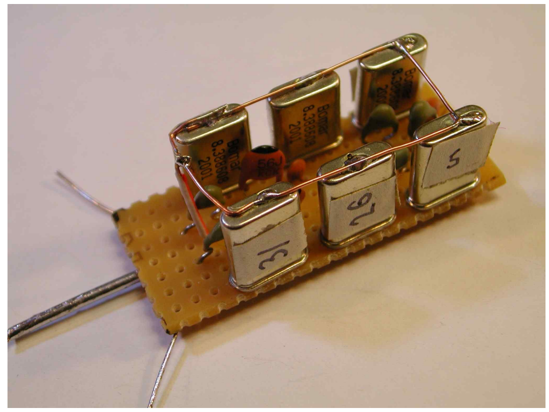

Breadboard Filter with Clips

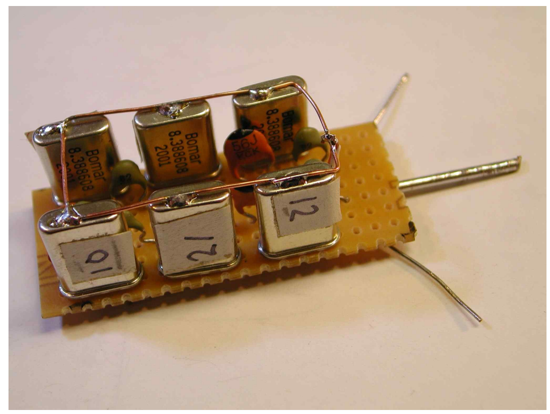

Breadboard without Clips

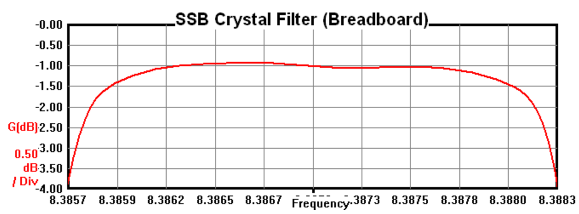
The end impedance of this filter is 420 ohms. For the graph below, transformers were wound to change 420 ohms to 50 ohms. The transformer match is imperfect so that the impedance match is approximate. Therefore, there is increased ripple in the filter passband which can just be seen at the top of the wideband response graph. This graph shows that the actual filter very closely matches the simulation. An N2PK VNA was used to measure the filter response. The response is asymmetrical because crystal parallel resonance is above the passband steepening the upper passband slope.



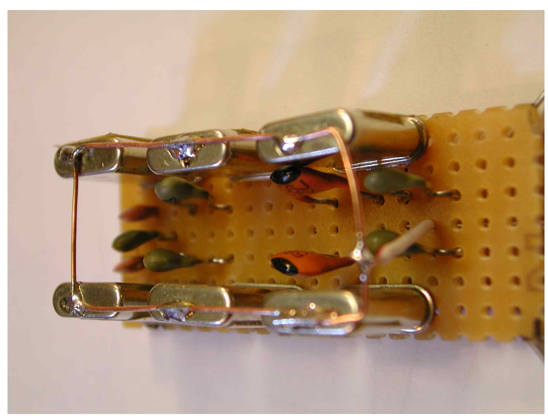
Graph of Breadboard Filter 60db Wideband
(8.3835-8.3898MHz = 6.3KHz 45db BW)

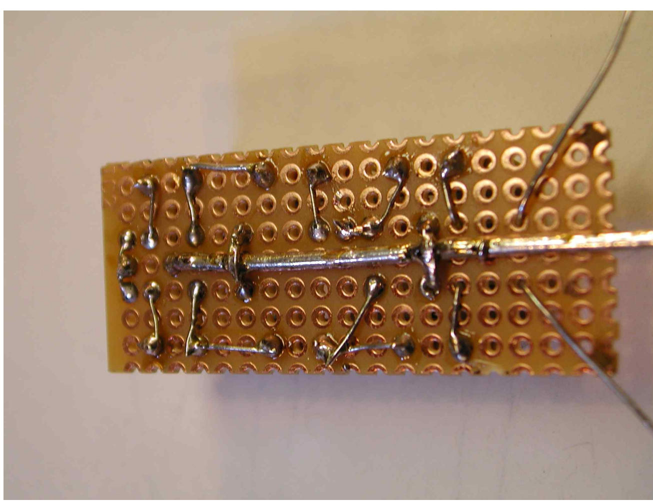






Graph of Breadboard Filter 3db Passband
(8.3857-8.3883MHz = 2.6KHz 3db BW)



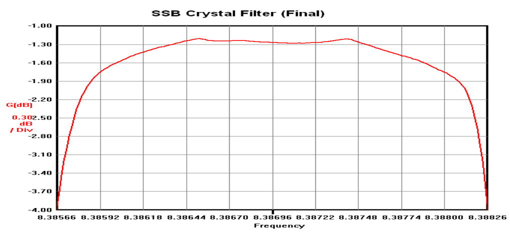


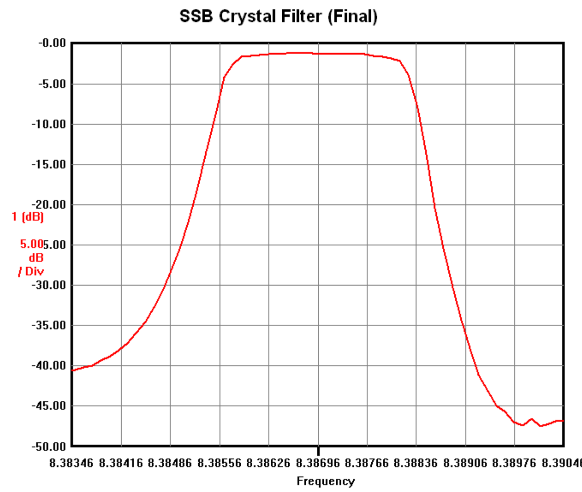
To get a better match, resistor L networks were used. These resistors introduced 23db of loss at each end of the filter limiting the dynamic range of measurements, but did give a good view of the top of the filter passband. The design assumes crystals of infinite Q. The finite Q tends to narrow and round the band edges.

The filter was finally assembled on perfboard. The pictures above show the final filter without end terminations.

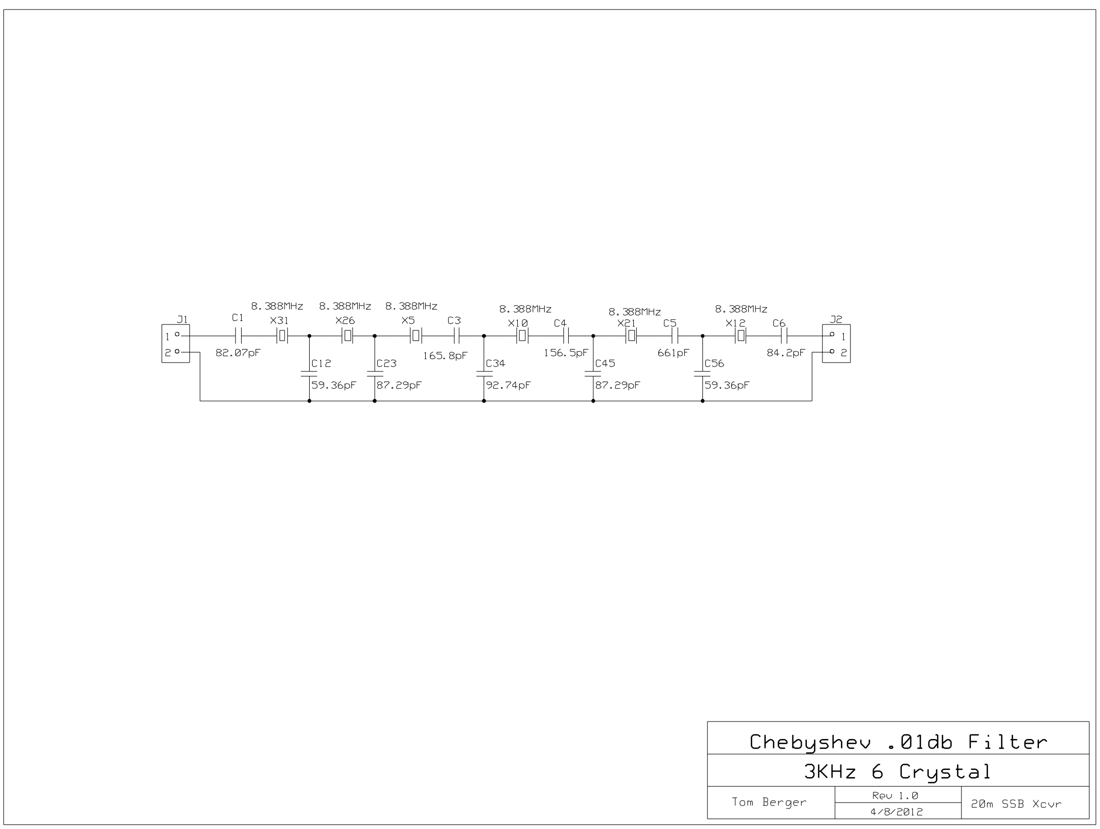
The center wire is ground. The small wires are input and output. The signal travels through the filter down one side and back on the other. The top view picture shows the placement of capacitors. The bottom view picture shows the wiring. The bottom view shows the hole count and thus the size of the perfboard.

The graphs below show the response of the filter with terminating L-match filters simulated to match the 50ohms of the VNA by myVNA software to the 420 ohm filter termination.





The schematic below shows the filter with the design values for the components. The end impedances are 420 ohms.



The following is the Radio Designer simulation script.

```
* Crystal Filter  8.386 465MHz
* With 6 Crystals 31,21,5,10,26,12

* Target 3KHz p. 346 Zverev
* Chebyshev .01db

* 2.6kHz BW @ 3.0db
* 2.8KHz BW @ 6.0db
* 6.3kHz BW @ 60db
* 6:60db shape factor: 2.25:1

* 0.8-2.3db ripple range in passband
* 420 ohm terminations

* The Crystals

BLK      ;Crystal 10
IND 1 2 L=19.11031mH ;Q=150372
 ;F=8385050Hz  ;motional inductance
CAP 2 3 C=.01885216pF
 ;motional capacitance
RES 3 4 R=6.69
 ;series resistance 6.69 (in the Q)
CAP 1 4 C=4.26pF
 ;parallel capacitance
CRY10: 1POR 1 4
END


BLK      ;Crystal 21
IND 1 2 L=19.84194mH ;Q=148770
 ;F=8385041Hz  ;motional inductance
CAP 2 3 C=.01815707pF
 ;motional capacitance
RES 3 4 R=6.69
 ;series resistance 6.69 (in the Q)
CAP 1 4 C=4.16pF
 ;parallel capicitance
CRY21: 1POR 1 4
END


BLK      ;Crystal 12
IND 1 2 L=19.02503mH ;Q=143434
 ;F=8385048Hz     ;motional inductance
CAP 2 3 C=.01893669pF
 ;motional capacitance
RES 3 4 R=6.99
 ;series resistance 6.69 (in the Q)
CAP 1 4 C=4.30pF
 ;parallel capacitance
CRY12: 1POR 1 4
END

BLK      ;Crystal 26
IND 1 2 L=18.77229mH ;Q=133686
 ;F=8385043Hz  ;motional inductance
CAP 2 3 C=.01919165pF
 ;motional capacitance
RES 3 4 R=7.40
 ;series resistance 7.40 (in the Q)
CAP 1 4 C=4.38pF
 ;parallel capacitance
CRY26: 1POR 1 4
END

BLK      ;Crystal 31
IND 1 2 L=18.96742mH ;Q=126597
 ;F=8385047Hz  ;motional inductance
CAP 2 3 C=.01899421pF
 ;motional capacitance
RES 3 4 R=7.90
 ;series resistance 7.90 (in the Q)
CAP 1 4 C=4.29pF
 ;parallel capacitance
CRY31: 1POR 1 4
END


BLK      ;Crystal 5
IND 1 2 L=19.20590mH ;Q=126557
 ;F=8385053Hz     ;motional inductance
CAP 2 3 C=.01875833pF
 ;motional capacitance
RES 3 4 R=7.99
 ;series resistance 7.99 (in the Q)
CAP 1 4 C=4.29pF
 ;parallel capacitance
CRY5: 1POR 1 4
END


;
; The Filter
;

BLK
CAP 1 11 C=81.8pf
 ;82pf ;82.07pf  C1 series

CRY31  11 3
 ; Section 1  cr31 8385047 8403589

CAP 3 0 C=57.1pf
 ;56pf ;59.36pf   C12

CRY26 3 4
 ; Section 5  cr26 8385043 8403393

CAP 4 0 C=84.4pf
 ;82pf ;87.29pf C23

CRY5  4 55
 ; Section 3  cr5 8385053 8403365

CAP 55 5 C=166pf
 ;150pf ;165.8pf C3 series

CAP 5 0 C=84.46pf
 ;82pf ;92.74pf C34

CRY10 5 66
 ; Section 4  cr10 8385050 8403583
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```
CAP 66 6 C=155.3pf
 ;150pf ;156.5pf C4 series

CAP 6 0 C=83.6pf
 ;82pf ;87.29pf C45

CRY21 6 77
 ; Section 5  cr21 8385041 8403320

CAP 77 7 C=660pf
 ;680pf ;661pf C5 series

CAP 7 0 C=57.1pf
 ;56pf ;59.36pf   C56

CRY12 7 88
 ; Section 6  cr12 8385048 8403491

CAP 88 8 C=83.5pf
 ;82pf ;84.2pf  C6 series

FLT250:2POR 1 8
END


FREQ
;STEP 8350000Hz 8425000Hz 500Hz
;Broadband
;STEP 8382900Hz 8389900Hz 50Hz ;Shape
Factor 7.0KHz 60db BW
STEP 8385710Hz 8388330Hz 10Hz ;Top
2.62KHz 3db BW
STEP 8385600Hz 8388430Hz 10Hz ;Top
2.83KHz 6db BW

END
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