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# HIGH-PERFORMANCE CRYSTAL FILTER DESIGN

## *Produce precisely shaped, very narrow CW filters that don't ring and SSB filters with incredible selectivity, without black magic*

Wes Hayward's ladder filter articles [1,2] described the design and construction of inexpensive crystal filters having good performance. In the years since these articles were published, ham literature has been full of homebrew rigs with ladder filters. Cohn filters, using identical crystal frequencies and capacitors throughout, are particularly attractive for simple cut-and-try filters.

But you don't need to stop at cut-and-try filters. With the same number of parts, just different component values, you can produce precisely shaped and very narrow CW filters that don't ring, and SSB filters with incredible selectivity. Making them requires neither luck nor black magic; this article explains the process, shares some practical ideas, and shows a few actual filter examples.

The schematic of, say, an 8-pole filter is always the same. The only difference between Chebychev, Butterworth, Gaussian, (or any response shape) lies in the component values. With perfect lossless coils, capacitors, and crystals, for a given impedance there is a set of component values that will produce a Butterworth frequency response. Another set of component values will make a 0.1-dB Chebychev frequency response, and so on.

Parts cost for filters is minimal. Once you're comfortable with the process, you can produce quite exotic filters inexpensively, essentially substituting time for money—a time-honored homebrew tradition.

## Equipment requirements

- **Counter.** A frequency counter with 1-Hz resolution.
- **Crystal tester.** Several adequate dedicated testers have already been described.[1,3] Some interesting variations are available from the author for an SASE.
- **Test oscillator.** The test oscillator needs to be more stable than a general-purpose signal generator. I threw together a VXO using a crystal from the batch being tested and tuned it with an ARC-5 tuning capacitor to get plenty of bandspread. In the tester, the

selectivity of the crystal being tested will filter out oscillator harmonics, but the substitution pot won't. This will cause an error in the crystal Q measurement. Use a simple five-pole low-pass filter to remove harmonics from the test oscillator signal.

• **Ohmmeter.** A bridge or DMM that's accurate to within 1 ohm is required and 0.1-ohm resolution is even better.

• **Computer and software.** This article assumes you'll use Wes Hayward's LADPAC software,* which runs on an IBM PC or clone. The software contains a group of interconnected general-purpose ladder network programs for designing of ordinary impedance-matching networks, and one program, **X**, used specifically for designing crystal filters.

LADPAC lets you see what selectivity you can obtain from 6 crystals, 8 crystals, or 15 crystals; you decide how much selectivity is "enough." You can change terminations, find out what the insertion loss will be, make matching networks to other impedances, and see how badly the filter shape will change if the capacitors are in error by 5 percent. I find the actual filters closely match the computer prediction.

Throughout the text, I list the actual keystrokes to run the program at certain points. Obviously, this will be meaningless without the program, so I apologize to the casual reader. However, for those who take the plunge and buy the program, this detail is useful to quickly see how the process is done.

## The design process

The steps of the design process are:

• Measure the parameters of your crystals. Crystal matching isn't too important, because crystals can be *tuned* during filter construction.**

• Choose a filter and bandwidth that you'll be able to make with the crystals you have.

• Perform the theoretical design using the LADPAC design program. It will estimate the performance you can obtain. Repeat steps 2 and 3 as many times as necessary to get the desired filter.

• Select the coupling capacitors specified by LADPAC.

• Match the series-resonant frequencies of your set of crystals to one *loop frequency*. If you can't obtain this with your crystals, *tune* a crystal with a series capacitor.

• Solder the parts together and make sure the design works as predicted.

## Measuring crystal parameters

To calculate a filter, you'll need to know crystal series-resonant frequency, series resistance, Q, and the parallel "holder" capacitance. Be as careful as possible because doing an accurate design hinges on knowing these parameters. I offer the following hints in addition to those mentioned in previous articles.

• The crystal case must be grounded in the finished filter and it's prudent to carefully solder the grounding wire to the case *before* you start testing. Use minimum heat; the heat of soldering might alter a crystal parameter.

• While crystals are stable, you'll be measuring in *cycles*. After inserting some crystals into the tester, I noticed that 20 to 30 seconds were required for the series-resonant frequency to stabilize fully. I finally traced this phenomenon to the warmth generated by my hands and eliminated the problem by handling the crystals with a sock during testing!

A crystal tester has resistors on each side of the crystal. With the tester off, measure the sum of those resistances by connecting the ohmmeter to the crystal leads. Call this resistance $r_t$.

Power up the tester, find the series-resonant frequency of a crystal, and record the relative amplitude. Tuning is relatively broad at the peak. Tune higher and lower and record the $-3$ dB frequencies, $f_H$, and $f_L$. Now substitute a pot for the crystal, and adjust it for the same maximum reading as the crystal. Measure and record the resistance of the pot, calling it $R_p$. You can now calculate the crystal parameters as follows:

| | | |
|---|---|---|
| series-resonant frequency | $f_o$ | $= (f_H + f_L)/2$ |
| 3-dB width | df | $= f_H - f_L$ |
| crystal Q | Q | $= (f_o/df)(r_t + r_p/r_p)$ |
| crystal equivalent inductance | L | $= (r_t + r_p)/(2\pi df)$ |

For example, if $f_H$ = 4,434,320 and $f_L$ = 4,434,120, then $f_o$ = 4,434,220 and df = 200. If the tester resistance, $r_t$, is 100 ohms and the substitution pot measured 20 ohms, then:

$$Q = (f_o/df)(r_t + r_p/r_p) = 133{,}026.6$$

$$L = 120/400\pi = 0.3/\pi = .0955 \text{ Hy}$$

*Unfortunately, as we went to press, we found out that LADPAC has been discontinued. However, an improved filter design program has evolved from LADPAC and is available at a *reduced price*. For more information contact Hayward Electronic Systems, Inc., 7700 S.W. Danielle Street, Beaverton, Oregon 97005. Ed.

**This will provoke the same philosophical argument as using the phrase "antenna tuner." Of course you aren't really tuning the crystal, you are adjusting the circuit to accept the crystal you have. From the circuit's standpoint, however, the crystal plus $C_t$ looks like a different crystal having the desired series-resonant frequency.

## Crystal capacitors

A crystal is usually modeled as a series-tuned circuit in parallel with a holder capacitance, $C_P$. A more complete model has three capacitors: the capacitance between the two crystal leads, $C_L$, and two capacitances, $C_C$, from each lead to the case (see **Figure 1**). I measured capacitance between the case and the two crystal leads *tied together*. I assigned half to each lead-case capacitance, $C_C$. Next, I measured and reduced the lead-lead capacitance by $C_C/2$. I measured the average capacitance of a wide variety of crystals. You can use the results shown in **Table 1**.

Wide filters operate at higher impedances and have smaller coupling capacitors. $C_C$ is in parallel with, and adds to the coupling capacitors, so you must subtract it from the physical capacitor you're soldering in. For example, if a theoretical filter design shows an 18-pF coupling capacitor between two HC-18 crystals, it should be reduced by 0.6 pF for each crystal (or 1.2 pF), to 16.8 pF. When only one crystal is connected to a capacitor (at the end of the filter) the calculated value should be reduced by only 0.6 pF. This correction isn't particularly important for narrow filters where coupling capacitors are hundreds of picofarads.

In most cases, the value used for $C_L$ isn't terribly critical. If you don't measure these capacitances for your actual crystals, you may use the LADPAC defaults and subtract the capacitance shown in **Table 1** from the coupling capacitor values, as I just described.

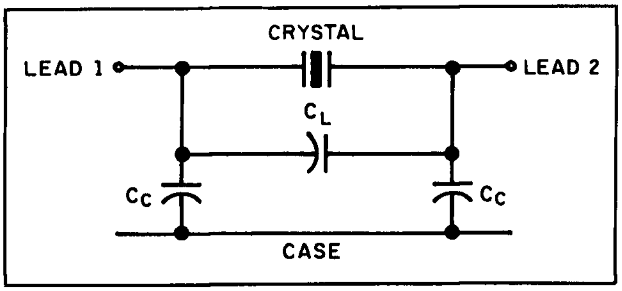


**Figure 1. A more complete crystal model with three capacitors; the capacitance between the two crystal leads, $C_L$, and two capacitances, $C_C$, from each lead to the case.**

| | |
|---|---|
| HC-6 | 1.4 pF |
| HC-18 | 1.0 pF |
| glass HC-6 | 0.5 pF |

**Table 1. Measured average $C_c$ for a variety of crystals.**

## Calculation of the average crystal

After you've tested all the crystals, look for groups of high Q crystals with similar values of inductance. Try to find a few more than you think you'll need. Once you get the hang of it, it's easy to add a few more poles to get better selectivity! After choosing your set, calculate the average Q and average inductance for LADPAC use.

## Filters that don't ring: Gaussian and linear phase

Neither Chebychev nor Butterworth filters are ideal for digital modes because they delay each part of the signal by a different amount of time. This is the origin of what we call "ringing" in a CW filter. RTTY and AMTOR also need to have reasonably constant delay to preserve proper timing in these signals. If you think a garden-variety filter is "only" irritating on CW, you should listen to the difference with a linear-phase filter!

Gaussian, Gaussian-to-6 dB, Gaussian-to-12 dB, and the equiripple phase families of filters approximate constant delay with slightly different compromises. They all give up some sharpness in frequency response to obtain the constant delay.

## Choosing a lossless prototype filter

LADPAC has built-in tables for lossless Butterworth or Chebychev filters. Lossless 6, 8, and 10-pole, 0.5-degree equiripple phase and Gaussian-to-6 dB prototype low-pass filters are tabulated in **Table 2**, but must be entered manually. For SSB, the Chebychev shape is common, while for CW, RTTY, or AMTOR modes the equiripple phase approximation filters have the least ringing, and Gaussian-to-6 dB has better selectivity and little ringing.

While we don't really have lossless crystals (that is, crystals with infinite Q), we can often assume so. The approximate minimum crystal Q required in a lossless design depends on the kind of filter being built. Compute the average crystal Q for the batch. If filter Q is defined as center frequency/bandwidth, then the approximate values desired for crystal Q for 6 and 8-pole filters are as shown in **Table 3**.

For instance, an SSB filter with bandwidth of 2 kHz at 4 MHz has a filter Q of 4000/2 = 2000. Crystal Q of about 2000 × 90 = 180,000 is fine for a 6-pole 0.1 Chebychev filter, while a crystal Q of 2000 × 230

| n | C1 | L2 | C3 | L4 | C5 | L6 | C7 | L8 | C9 | L10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 0.3313 | 0.5984 | 0.8390 | 0.7964 | 1.2734 | 2.0lll | | | | |
| 8 | 0.2718 | 0.4999 | 0.6800 | 0.6312 | 0.8498 | 0.7447 | 1.3174 | 1.9626 | | |
| 10 | 0.2359 | 0.4369 | 0.5887 | 0.5428 | 0.7034 | 0.5827 | 0.8720 | 0.6869 | 1.4317 | 1.8431 |

Gaussian response to 6dB. Load resistance is always 1 ohm and source is 1 ohm for n = 6, but source resistance for n = 8 is 1.0502 ohms and source resistance for n = 10 is 1.1372 ohms.

| n | C1 | L2 | C3 | L4 | C5 | L6 | C7 | L8 | C9 | L10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 0.5041 | 0.9032 | 1.2159 | 1.0433 | 1.4212 | 2.0917 | | | | |
| 8 | 0.5031 | 0.9699 | 1.2319 | 1.1324 | 1.4262 | 1.0449 | 1.6000 | 1.9285 | | |
| 10 | 0.4682 | 1.0839 | 1.1516 | 1.2991 | 1.3293 | 1.2748 | 1.4216 | 1.1730 | 1.5040 | 2.1225 |

L = henries
C = farads
All L and C are lossless (infinite Q).

**Table 2. Linear phase with equiripple error: Phase error = 0.5 degree. (Information taken from Zverev.[4])**

= 460,000 is required for an 8-pole 0.5 dB Chebychev filter.

"Linear phase" type filters will accept lower crystal Q as being nearly "lossless." A 400-Hz Gaussian-to-12 dB RTTY filter at 4 MHz will be happy with a crystal Q of 250,000 in a 6-pole filter.

These aren't hard-and-fast rules. Values down to half of these can be used without getting into too much trouble, but when you assume infinite Q and don't meet the multipliers indicated above, you should ask for a slight wider filter during design.

The 14-pole, 0.1 Chebychev filter described later uses crystals having filter Q × 72, about half of what could readily be considered "lossless." For that filter the −3 dB bandwidth came out fifteen percent narrower than the design, and the ripples of the ideal filer virtually disappear at the edges of the passband.

LADPAC can design these other types of crystal filters when the crystals meet (or nearly meet) these minimum Q values. **Table 2**, using information from **Reference 4** gives values for 6, 8, and 10-pole, *0.5-degree equiripple approximation to linear phase* and *Gaussian-to-6 dB* low-pass filters. There are additional low-pass tables in **Reference 4** for other filter shapes with 3 to 10 poles. LADPAC can convert these low-pass filters to bandpass crystal filters.

| Filter type | 8-pole | 6-pole |
|---|---|---|
| 0.5° error equiripple | filter Q × 25 | filter Q × 20 |
| Gaussian-to-6 dB | filter Q × 45 | filter Q × 35 |
| Butterworth | filter Q × 50 | filter Q × 32 |
| 0.01 dB Chebychev | filter Q × 120 | filter Q × 65 |
| 0.1 dB Chebychev | filter Q × 160 | filter Q × 90 |
| 0.5 dB Chebychev | filter Q × 230 | filter Q × 130 |

**Table 3. Approximate values desired for crystal Q for 6 and 8-pole filters.**

## From table low-pass values to crystal bandpass filter

To use the tables, start LADPAC's **L** (low-pass filter) program by typing **L ENTER** at the DOS prompt, then **3. Generate k and q values**. Enter **6, 8,** or **10** for order of filter, −1 to insert g[k] values from the table, then enter those values from left to right. After the last entry has been made, press **S** to save the computed values, and exit the **L** program by typing **99**.

Next start the crystal filter program by typing **X ENTER** at the DOS prompt. Press **K** to load the values previously computed by **L**. **X** will already know how many "meshes" are in the filter, so press **ENTER** in response to this question. The program will then prompt for the crystal frequency and average inductance. Type in the average values of the chosen crystals. Press **ENTER** to accept the first overtone default, then enter the value of holder capacitance and the average crystal Q. When the program prompts for each k value, the value will automatically be from the table-generated filter, so you can press **ENTER** for each k value prompt.

You then get to choose source and load resistances and see how the filter values look. If the capacitances are impractically small (say below 15 pF), you can change the resistance and the program will recompute the capacitors. When you are satisfied with a design, you exit with **D**, another **D**, and **escape** to exit the **X** program.

From the DOS prompt type **G ENTER** to start the general-purpose analysis program and load the crystal filter design by pressing **D**, then **B**. Press **D** to find insertion loss and bandwidth, **P** to draw pictures of the filter response, or **E** to edit the component values. At this point you can change capacitor values to see how critical each will be.

After you go through this process a few times, you can evaluate alternative filter designs very quickly, then pick up the soldering iron knowing exactly what to expect. Rest assured there's a good chance that your design will work the first time.

## Prototypes with losses

To use the lossless tables for a 100-Hz phase filter for Clover-I, **Table 3** says you'll need crystals having Qs on the order of at least one million at 4 MHz. Using crystals with a Q of 150,000 will *not* produce the desired filter! That doesn't mean that you can't make the filter with the crystals; it just means that you need to take the finite crystal Q into account. You can't use the lossless values of **Table 2**, or LADPAC's internal tables, which are also lossless. The solution is to use *predistorted* tables. Information included in **Table 4** is taken from such tables found on page 374 of Zvevrev.

Zverev's predistorted tables assume various amounts of loss in the crystals. These tables are tabulated for different values of $\mathbf{q_o}$ where:

$q_o$ = crystal Q × filter bandwidth/filter center frequency

If you want a 6-pole, 100-Hz width Gaussian-to-12 dB filter with the 4434 kHz crystals previously calculated to have Q = 133,026, then:

$q_o = 133{,}000 \times 100/4{,}434{,}220 = 2.99$

For this example, the nearest table value on page 374 of Zverev (included in **Table 4**) has $q_o = 2.791$, which gives the insertion loss of 9.77 dB for the filter. This signal loss is the price you must pay for the finite crystal Q. The table lists **input Q, output Q**, and the **coupling coefficients** required to produce the desired filter with those crystals. Instead of using **L** to first compute $k_{ij}$ values from low-pass filter components, those coupling coefficients are typed directly into the **X** program, then LADPAC will compute the coupling capacitors between each crystal.

A different set of tables is required for every type of filter and every number of poles, and every value of $q_o$. Pages 342 to 379 of Zverev (37 pages!) are necessary to list a reasonable range of possibilities from 3 to 8 poles. While it requires access to these tables, the job is no more difficult than designing a filter assuming lossless crystals. It's too bad the tables are too extensive to list here; but using Zverev in a library, you can design very narrow filters up to 8 poles with crystals that don't have enough Q for a lossless design.

For instance, a 15-meter receiver breadboard has eight DigiKey crystals in an 8-pole, 0.5-degree approximation filter with 120 cycle bandwidth. It matches the predicted response almost perfectly, has a wonderful "transparent" sound to it, doesn't ring at all, and can be operated for hours without fatigue. The insertion loss is 6 dB.

## Selecting coupling capacitors

Coupling capacitors can be as low as 10 to 20 pF for SSB width filters, to several hundred pF for a narrow filter. To obtain the desired filter, you must use the specified capacitor value. While using LADPAC's **G** program to simulate the filter, it is possible to edit each capacitor value and see how critical it'll be in obtaining the desired filter.

**Gaussian Response to 12-dB**

| $q_0$ | I.L. | $q_1$ | $q_n$ | $k_{12}$ | $k_{23}$ | $k_{34}$ | $k_{45}$ | $k_{56}$ |
|---|---|---|---|---|---|---|---|---|
| Inf. | 0.000 | 0.5427 | 0.5585 | 1.8394 | 1.4416 | 0.6857 | 0.7069 | 1.4676 |
| 22.327 | 1.125 | 0.5869 | 0.5714 | 1.7858 | 1.4334 | 0.6786 | 0.7196 | 1.4318 |
| 11.164 | 2.255 | 0.6464 | 0.5788 | 1.7399 | 1.4180 | 0.6682 | 0.7420 | 1.3982 |
| 7.442 | 3.390 | 0.7394 | 0.5737 | 1.7156 | 1.3776 | 0.6567 | 0.7796 | 1.3693 |
| 5.582 | 4.557 | 0.7896 | 0.6061 | 1.6631 | 1.3933 | 0.6787 | 0.7705 | 1.3232 |
| 4.465 | 5.768 | 0.8476 | 0.6420 | 1.6048 | 1.4148 | 0.7044 | 0.7631 | 1.2801 |
| 3.721 | 7.031 | 0.9157 | 0.6821 | 1.5384 | 1.4436 | 0.7363 | 0.7581 | 1.2406 |
| 3.190 | 8.359 | 0.9969 | 0.7268 | 1.4496 | 1.4818 | 0.7804 | 0.7570 | 1.2050 |
| 2.791 | 9.770 | 1.0962 | 0.7766 | 1.3247 | 1.5302 | 0.8525 | 0.7639 | 1.1748 |
| 2.481 | 11.290 | 1.2257 | 0.8300 | 1.0924 | 1.5633 | 1.0233 | 0.8024 | 1.1578 |

**Table 4. Values for 6-pole Gaussian-to-12 dB filters with different crystal Q. (Information taken from Zverev.[4])**

A large junkbox full of NPO or dipped mica capacitors is useful. Putting two capacitors in parallel reduces the number of capacitors you need in the junkbox, and gives considerably more flexibility. For example, a 92-pF coupling capacitor might be built from two 47-pF capacitors in parallel. Ten 47-pF capacitors can be paired up in 45 different ways, making it more likely you'll find two that produce 92 pF, or very close to it.

If you have access to an accurate capacitance bridge, select capacitors until you find one, or a pair in parallel, very close to the calculated value. You can build a capacitor tester and calibrate it to measure small capacitors within 1 to 2 percent.[5] Such a tester can also measure the lead-holder and lead-lead capacitance of your crystals.

## The tuning concept

Hayward stated that each crystal, when put in series with the coupling capacitors on each side of it, should resonate at the same *loop* frequency. LADPAC gives you a "head start" by computing the frequency offset of each crystal that will produce this result. If your coupling capacitors have the correct values and the relative series-resonant frequency of the crystals have the specified offsets from the "zero-frequency offset" crystal, no tuning is required and soldering these parts will produce exactly the filter you designed.

However, it's highly unlikely your crystals will have exactly the specified offset. Your capacitors will also display some deviation from the theoretical values. But you can compensate for minor deviations in components by tuning each loop of the crystal filter, using the actual parts.

## Tuning cookbook

Choose the lowest frequency crystal of the group as the zero-frequency offset crystal. Connect this zero offset crystal *in series* with the two coupling capacitors that will be on either side of the crystal in the filter. Measure the series-resonant frequency of this crystal-capacitor-capacitor combination. This is the *loop frequency*; the other loops need to be tuned to this same frequency.

For each other crystal of the filter, add the LADPAC-specified frequency offset to the series-resonant frequency of your zero-offset crystal. If you find a crystal from your set with this frequency, you should be able to use that crystal without any further tuning, although it should be checked, as I'll describe, to be absolutely sure. Otherwise, choose a crystal from your set with a series-resonant frequency slightly *below* that of your zero-offset crystal.

Put that crystal *in series* with the coupling capacitors that will be on either side of it, and add a third tuning capacitor ($C_t$) *in series*. Put this series combination of crystal and three capacitors into the crystal tester and change $C_t$ until it's resonant at the loop frequency. Smaller $C_t$ moves the frequency up, larger $C_t$ moves it down. If you don't need to move up very much $C_t$ might be as large as several hundred picofarad. If the crystal has the specified offset, $C_t$ becomes "infinite," just a piece of wire, so no $C_t$ is needed for this crystal.

Divide your desired filter bandwidth by 25. This is the maximum tuning error you should allow from the loop frequency. Less is better. For example, if you're making a 300-cycle CW filter, get the resonance of each loop within 12 cycles of loop frequency.

Permanently pair up each crystal with its $C_t$. Don't mix them up; they form a matched set that *tunes* the crystal to the proper frequency *for its position in the filter.*

Each coupling capacitor is used twice: once while tuning the crystal on its left, and again when tuning the crystal on its right. This procedure works for all crystals except the ones at the end. On one side, they don't have just a capacitor, they also have a load resistance. If the end capacitor happens to be zero, tune the crystal to the loop frequency with just two capacitors in series— $C_t$ and the coupling capacitor on the other side. Otherwise, calculate a temporary capacitor.

First calculate K:

$$K = (2\pi fr_{end} \times C_{end})^2$$

Then calculate the temporary capacitor:

$$C_{Temp} = C_{end}\,(1 + K/K)$$

Find $C_t$ with the end crystal in series with this temporary capacitor. The temporary capacitor isn't used in the filter; it's just for tuning. You haven't tuned with the actual parts that will be used in the filter. However, resonance at the ends of the filter are broadened by the source and load resistances and aren't as critical as the internal loops, so this causes no problem.

After you've "tuned" all the crystals, you can build the filter. Breadboard the filter on a piece of copperclad pc board material and check for the desired passband

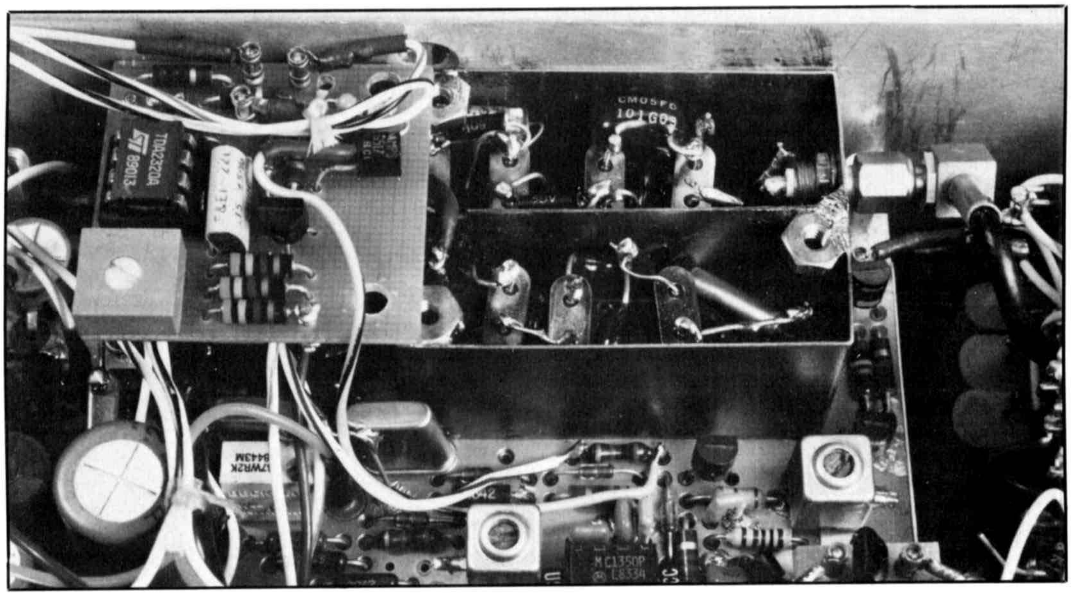

**Photo A. Eight-pole, 0.5-degree equiripple phase filter. This filter is 350-Hz wide, CF = 4434 kHz.**

shape. Use resistors initially to simulate the impedance level specified by the computer. After you've verified the filter shape, connect L-networks or transformers to match your circuit impedance. Check the shape again after connecting a matching network. Be very methodical, find any mistakes before you build the final filter, and you'll be rewarded with filters that match the computer prediction.

## Crystal sources

In three different orders from DigiKey, a total of almost 200 crystals with 3.579, 4.000, and 4.434-MHz frequencies, their *ECS* brand seemed to have the highest average Q and most consistent L for a little over $1 each.

I purchased about 300 4.000-MHz crystals at a swapmeet. Their Q was low; for filter purposes, half were junk and the remainder mediocre. However, their total cost was only $12.

I bought a group of interesting HC-6 style 3.006-MHz crystals in sealed glass cases from a swap table at an ARRL convention. They were excellent crystals with Q over 500,000.

## Construction hints

- Ground the crystal case wires.
- It's critical to isolate input and output ends of the filter. Put dividers between input and output leads of *each* crystal. There should not be a line-of-sight path from the shield of one crystal past the shield of the next crystal. The grounded crystal cases can be used as part of the internal shielding.
- Matching network inductors or transformers need to be well shielded or there can be inductive coupling around the filter. You can solder the case of the Amidon slug-tuned coil forms, or adjustable Toko coils, directly to the filter ground. Toroids can be placed inside soldered shield enclosures.
- I've used shields made from pc board material, tinned 0.02-inch sheet steel, and brass strips. All permit you to solder the shields in place, which makes it easy to build and modify. Brass strip can be obtained from almost any model shop. Its precision width makes construction of a rectangular box much easier.

## Examples of breadboard and finished filters

**Photo A** shows the 8-pole, 0.5-degree equiripple phase filter used in my 40-meter mobile rig. The box was built on a base of perforated copperclad Vectorboard, copper side out. Sides are 3/4-inch brass strips, soldered to 5/8-inch high, 1/4-inch diameter nickel-plated brass spacers at the corners, overhanging and soldered to the copperclad all around. Shields are soldered to the brass sides, and connected to the Vectorboard bottom with several heavy tinned wires. Crystal cases are soldered to the bottom with short wires, too.

Notice that the input comes through a miniature SMB coaxial connector on the side wall, and output goes through a hole in the bottom of the filter/IF amplifier board to an L network and MOSFET first IF

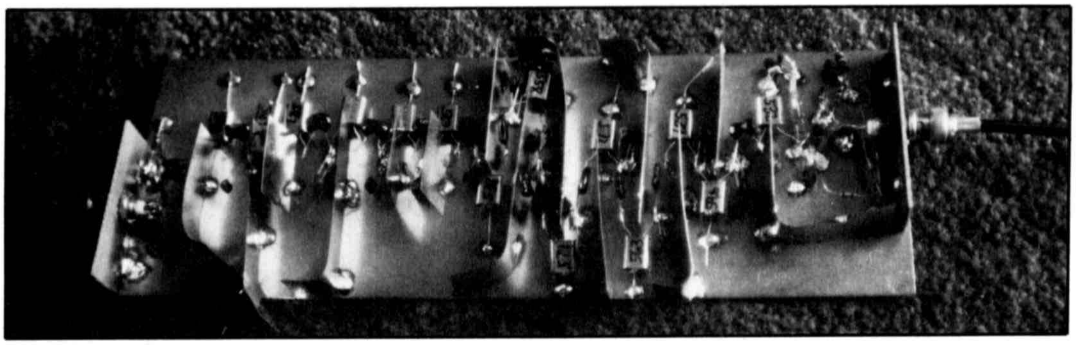

**Photo B. Fourteen-pole, 0.1 dB Chebychev breadboard filter, 1.95 kHz at −6 dB, CF = 4344 kHz.**

amplifier. Without the top cover in place the input-output isolation is about 70 dB. With it the opposite sideband is down over 120 dB.

Quarter-inch round spacers made of aluminum, brass, or steel are available. I recommend that you avoid aluminum spacers because it's impractical to solder to them. Brass or steel both take solder, and brass won't rust. The 120-degree angle of hex spacers doesn't permit neat 90-degree corners. I clamped the Vectorboard and the aluminum top cover together, then drilled holes through both for the spacers, assuring perfect alignment of the bottom and cover.

**Photo B** is a 14-pole, 0.1 dB Chebychev SSB-width filter, shown in a breadboard layout to give you a feel for the kind of layout and shielding that are appropriate for filters with this kind of performance. The passband of this filter is very flat, with just a slight 0.5 dB dip at the upper corner. SSB sounds very good through this filter. It is 4 kHz wide at −120 dB, with a 6:120 dB shape factor of just slightly over 2. Without shields, the breadboard had about 70-dB isolation between input and output. Adding a few shields quickly raised attenuation to 100 dB, but kept improving to more than 120 dB with the full complement of shields. To get the full ultimate attenuation from 8-pole filters, consider nothing less than complete shielding.

## Acknowledgement

Thanks to Wes Hayward, W7ZOI, for his patient mentoring.

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# PRODUCT INFORMATION

**The Major BBS® Version 6**

Galacticomm, Inc. has released Version 6 of The Major BBS—a product designed to provide a full-featured, easy-to-use bulletin board system (BBS) for both corporate and private use.

Dynamic Link Libraries (DLLS) automatically "link-in" services to the BBS. The system operator (Sysop) simply types "A:INSTALL" to include a service, such as a database module or text retrieval utility. The Sysop adds the service to a menu, answers a few configuration questions, and the new feature is available to users the next time the BBS is started.

The Major BBS now has the capability to exchange E-mail and Forum messages with MHS applications and gateways. Users can exchange messages with applications like DaVinci E-Mail and other mail networks such as cc:Mail, MCI Mail, CompuServe, X.400 networks, and Internet.

The system runs on an IBM-compatible 286, 386, or 486. It requires a minimum of 2 megabytes of extended memory, MS-DOS or PC-DOS version 3.3 or higher, and a hard disk. Hayes-compatible COM1/2/3/4 modems are supported from 300 to 38,400 bps (hardware performance permitting). For LAN users, a Novell network running NetWare® 2.1 or higher or NetWare Lite 1.0 or higher allows users to log on the BBS through the network. MHS message networking requires MHS version 1.5 or higher.

For additional information about The Major BBS contact Galacticomm, Inc., 4101 SW 47th Avenue, Suite 101, Fort Lauderdale, Florida 33314. BBS: (305) 583-7808. FAX: (305) 583-7846. Voice: (305) 583-5990.