NØAX

Experiment #88 — *ELSIE* Filter Design — *Part 2*

HF operators who live near an AM broadcast transmitting facility often find the strong signals overload the input amplifiers and filters of a receiver, particularly on the lower HF amateur bands. Let's use *ELSIE* to design a *broadcast reject filter* to reduce the amplitude of those strong signals.

Specifying Filters

In order to use a filter design tool such as ELSIE, however, we need to speak the language of the filter designer. Figure 1 shows some of the terms used to describe a high-pass filter response. The graph is of *transmission* (the ratio of output to input signal strength in dB) versus frequency. For a passive filter, the maximum value of transmission is 0 dB. As less of the input signal is transmitted to the output, the value of transmission, in dB, becomes increasingly negative. Negative transmission is the same as attenuation.

On the frequency axis, F_C is the cutoff frequency at which the output signal power is ½ that of the input signal. F_S defines the *stopband width*. The passband for a high-pass filter consists of all frequencies above F_C. The stopband for a high-pass filter consists of all frequencies below FS. The *transition region* is the range of frequencies between the stopband and passband. (For a low-pass filter, FS and FC are reversed, along with the gray boxes they bound.)

The colored boxes leave a space between them through which the filter's amplitude response curve must pass. The borders of the colored boxes establish the required performance for the filter. The colored box defining the stopband is bounded on the bottom by the stopband depth. The filter's transmission in the stopband must be equal to or below the stopband depth. The colored box defining the passband is bounded on the top by the *passband ripple*. The filter's transmission in the passband must be equal to or greater than the passband ripple. (Why it's called ripple and not passband depth will be explained shortly.) Between FS and FC is the transition region in which the response curve passes between the stopband and passband. Any response curve that passes through the space between the colored boxes meets the performance requirements for the filter. (There are many other filter parameters beside amplitude response, but that's all we're going to consider now.)

What's passband ripple? Why is it called ripple? The filter response curve in Figure 1 is nice and smooth, typical of the common Butterworth family of filters often referred to as *maximally flat passband*. In the passband of other filter responses, such as the Chebyshev and Cauer, the response curve varies up and down before finally entering the transition region below F_C. This variation is referred to as ripple and it occurs in both the stopband and the passband. Allowing ripple results in a steeper response in the transition region. Speaking graphically, if we move the bottom of the stopband gray box up (reduce stopband depth or increase stopband ripple) and the top of the passband gray box down (increase passband ripple), the gray boxes can be moved closer together for steeper rolloff.

Broadcast Reject Filter

We need to attenuate all signals below the lowest amateur band, 160 meters with a low end of 1800 kHz, which will be our cut off frequency, F_C. The AM broadcast band covers from 550 kHz to 1700 kHz, so our stopband width, F_S, is 1700 kHz.

How much attenuation do we need? Generally speaking, the higher the change in response with frequency, the higher the required order of the filter and the more inductors and capacitors that are needed. In order to keep the filter simple, we should specify the smallest amount of stopband depth that allows our receiver to act properly. Unless you live very close to an AM antenna, a stopband depth of 20 dB should be sufficient.

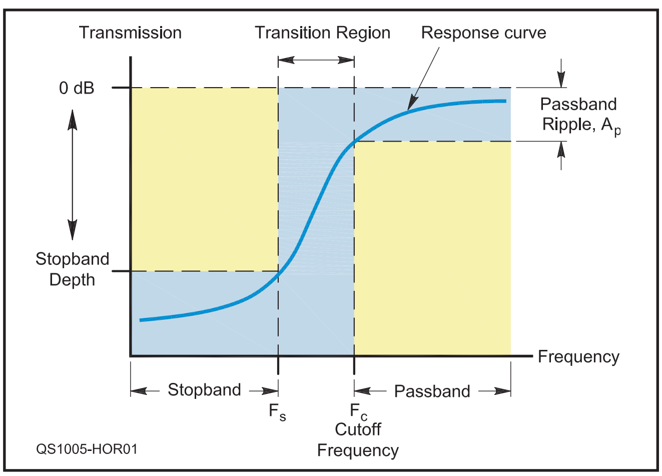

Figure 1 — The key specifications for a filter's amplitude response can be sketched on a transmission vs frequency graph. As long as the filter response curve stays between the boxes, it meets the design specifications.

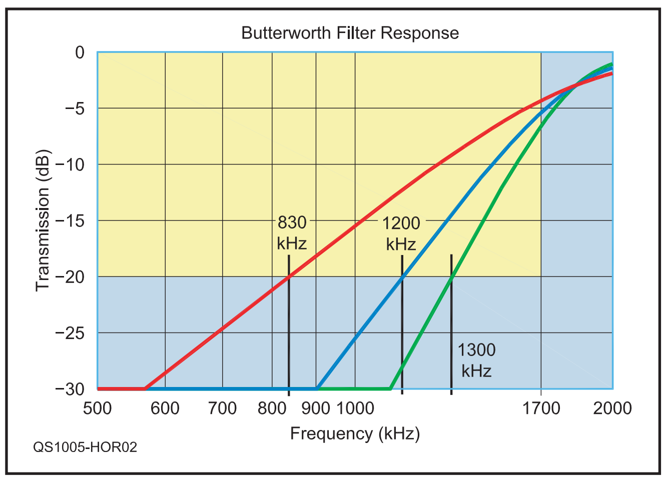

Figure 2 — Three Butterworth filter responses for third order (red curve), fifth order (blue curve) and seventh order (green curve). None provide the required 20 dB of attenuation across the AM broadcast band.

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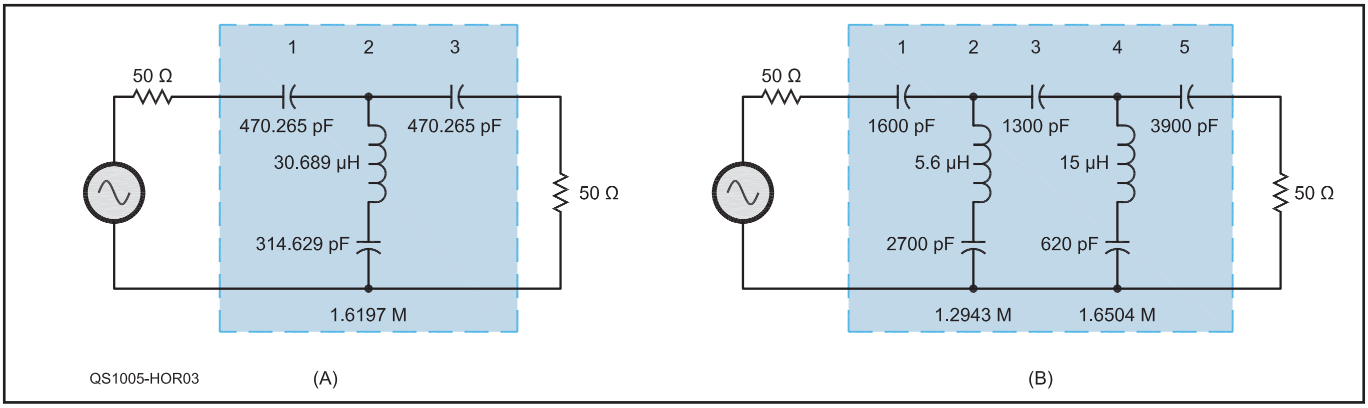

Figure 3 — At (A), the third order Cauer filter meets the specifications but not if the values are replaced with the nearest 5% series standard value. At (B), the fifth order filter using standard 5% series component values meets the performance requirements.

Run *ELSIE*, clicking NEW DESIGN on the opening screen. You're now in the DESIGN screen. Start on the left with TOPOLOGY, which refers to the arrangement of components. There are two choices for highpass filters, CAPACITOR INPUT and INDUCTOR INPUT. Select CAPACITOR INPUT, then click the H button to the right. A screen will pop up showing the filter's component arrangement or topology. Click RETURN, then select INDUCTOR INPUT and click H. Compare the two topologies. You'll note the difference in the blue response curves and also that the capacitor input topology uses fewer inductors. Since inductors are generally lossier and more expensive than capacitors, we'll use the capacitor input topology, so leave this selection checked.

Comparing Families

Next, select the BUTTERWORTH family and click H to compare the responses. You can see the ripple in the Chebyshev and Cauer families. Click RETURN TO DESIGN and enter values for FC (1800 kHz), ORDER (let's begin with 3), and INPUT TERMINATION RESISTANCE (R_S should be 50 Ω).

Select the ANALYSIS menu label at the top of the screen. These parameters control how the program displays the filter response. Keep all default values except for START FREQUENCY (enter 500 kHz) and STOP FREQUENCY (enter 2 MHz). Then click the PLOT menu label. A graph of the filter's response between 500 kHz and 2 MHz will appear. The response shows that our –20 dB transmission specification isn't met until frequency drops below about 830 kHz. We'll need more filter sections — a higher order filter.

ELSIE can save graphs for comparison. Click the SAVE OVERLAY button at the top of the screen and then SAVE AS 1. Now return to the DESIGN screen and increase the order to five. Click PLOT again — the filter response is still not good enough, but the –20 dB frequency has increased to about 1200 kHz. Save the graph as OVERLAY 2, then change the ORDER to 7 and plot again. Click GET OVERLAY and then GET 1 and GET 2 so that you see a graph similar to Figure 2. While all three filters have less than 3 dB of attenuation at 1.8 MHz, even though we've increased the order to seven (click SCHEMATIC to see the filter components) we're still not close to attenuating all of the AM broadcast band signals by 20 dB.

Return to the DESIGN screen and change the filter family to CHEBYSHEV. The passband ripple (AP) window will change to black as this is a design input for this family. With an order of three and a value of 1 dB for AP, plot the filter response and find FS for this filter (close to 900 kHz). It's an improvement, but we're not there yet! Increase the order to five and then to seven, saving the overlays for comparison as before. The seventh order Chebyshev comes pretty close, with an FS between 1.6 and 1.7 MHz, but is there a better filter?

The Cauer filter design increases filter complexity by substituting tuned circuits for some of the components. The tuned circuit creates a very steep response in the transition region. This comes at the expense of wider variations in attenuation in the stopband. Returning to the DESIGN screen, select the CAUER TOPOLOGY with an order of three, enter 1.7 MHz for FS and 20 dB for stopband depth. Plot the response — what a difference! Even a third order Cauer filter meets our design specification. (Verify this by reviewing the numeric data in the TABULATE window.)

Building the Filter

The schematic for the filter shown in Figure 3A has reasonable values for both capacitance and inductance. (The number 1.6197 M below the schematic is the resonant frequency of the tuned circuit.) To actually build the filter, we should try to use standard values.[1] Returning to the DESIGN screen, click NEAREST 5% and then TRANSFER ALL NEAREST-VALUE PARTS TO PARTS LIST. After clicking END NEAREST-VALUE ROUTINE, plot the response again. You'll see that the filter no longer meets the stopband depth requirement by a dB or so. Changing the filter component values deoptimized the design. Increase order to five in the DESIGN screen and repeat the process of changing components to the nearest 5% value as shown in Figure 3B. Plot the response and you'll see that it easily meets the filter specifications.

You can build this filter by tack soldering the components onto a scrap of printed circuit board as shown in Figure 2 of Experiment #44.[2] The 5.6 and 15 µH inductors can be wound as toroids (see Experiment #47) or purchased as axial inductors. Use plastic film or silvered mica capacitors. Connections into and out of the filter can be made with short pieces of RG-58 or RG-174 and a metal candy box will serve nicely as an enclosure. Test the performance of your filter by tuning in AM stations on your receiver and recording the signal level and frequency. Then insert the filter in the antenna feed line (don't transmit through it!) and remeasure the signal levels. The S-meter reading should be at least 3 S units lower with the filter in-line.

Parts List

Plastic film or silvered mica capacitors with values of 620, 1300, 1600, 2700 and 3900 pF.

Toroidal or axial inductors of 5.6 and 15 µH.

Next Month

Portable operation during the summer is a lot of fun, beginning with Field Day. In order to protect your sensitive gear, we'll take a look at a pair of over-voltage protection circuits for ac and dc power.

[1]A good discussion of component standard values is online at **www.ebyte.it/library/educards/ee/EE_StandardValues.html**.

[2]All previous Hands-On Radio experiments are available to ARRL members as downloadable PDF files at **www.arrl.org/hands-on-radio**.