LC Bandpass Filters for
20M, 30M, 40M

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Application

- In multi-station environments: special events, field day, portable operating, we need to protect receivers from excessively strong signals

- We place **bandpass filters** between the transceiver and the antenna

- Out of band signals greatly attenuated on receive, preventing receiver desensitization and overload

- On transmit, the filters should be transparent to the transmitter

- (No help for two stations on the same band)
Definition of a Filter

Filters are electrical networks that pass radio-frequency (RF) energy in certain bands and attenuate RF energy in other bands.
Filter Design: The Approximation Problem

First Step: **Construct the transducer loss function** $H(s)$, in the Laplace-transformed frequency variable $s$, that, when evaluated in the frequency domain ($s=j\omega$) gives a good *approximation* to the desired response shape.

**Typical bandpass filter** magnitude response shape:
loss in dB as function of frequency

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**Graph:**
- **Passband**
- **Lower Stopband**
- **Upper Stopband**
- **Transition bands**
Filter Design: Network Synthesis

Second Step: Perform network synthesis by expanding the function $H(s)$ in such a way as to identify a network structure comprised of inductors and capacitors.

Examples (ladder filters):

Note: Filters are designed to transfer power between a source resistance and load resistance (e.g. transmitter output circuit and an antenna)

Singly-terminated network (between a high impedance source and finite load)
Filter Design Solutions

• Filter design is a complex mathematical process

• Evolved from the first filters designed in the 1920s for the telephone network

• Many different types of both analog and digital filters used today throughout all communications circuits

• Computer programs exist for the automated design of various types of filters

• **Elsie** is very good for inductor-capacitor (LC) filters for ham applications  (*free version*: tonnesoftware.com)

• Excellent tutorial on filter design:
Bandpass Filter Structures

(Nelected from Elsie)

Nodal capacitor-coupled bandpass

Nodal inductor-coupled bandpass
Filter Structures (cont’d)

**Shunt-input bandpass**

**Series-input bandpass**
Bandpass Filter Structures

Mesh capacitor-coupled bandpass
Selecting a Circuit Topology (Structure)

- We want a network that has a minimum number of inductors (which are inherently lossier than capacitors)

- We want circuit element values that are neither too large nor too small so that the components are commercially available or, for inductors, can be wound easily

- To meet the filter requirements, can experiment with circuit degree (number of inductors plus number of capacitors)

- Can try all the circuit structures

- Experienced filter designers know that narrowband bandpass filters often best realized with mesh capacitor- coupled structure (also called coupled-resonator filter)
A Previous Design from QST (Lew Gordon, K4VX, Sept. 1988)

Shunt-input bandpass filter

Values given for 160, 80, 40, 20, 15, 10M (toroidal inductors and silver-mica capacitors)

No designs for WARC bands 30, 17, 12M probably because of contest emphasis

Results for 40M, 20M BPF

<table>
<thead>
<tr>
<th>Filter</th>
<th>Loss (dB) in Band</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40M   30M   20M   17M   15M</td>
</tr>
<tr>
<td>40M BPF</td>
<td>0.5    15.7   32     42     47</td>
</tr>
<tr>
<td>20M BPF</td>
<td>32     7.9    0.5    8.5    16</td>
</tr>
</tbody>
</table>

Results inadequate for WARC band rejection
Filter Design

- Using Elsie, **design** three bandpass filters: for 20, 30, & 40M

- Sometimes we **modify** the design obtained by Elsie (circuit optimization):
  1. Fix certain component values and vary the others to get the best response
  2. Model nonideal behavior of L’s and C’s and obtain new design values for best response
  3. Combination of (1.) and (2.)

- For our filters optimization is *not* required to get good results

- No optimization in 40M filter; optimization used in 30M and 20M filters just to illustrate what can be done
Filter Construction and Tuning

- Select and measure the inductors and capacitors at the passband frequency (e.g. via AA-170 antenna analyzer)

- Build the filters, including capacitive trimmers for adjustment of series capacitors (i.e. the resonator capacitors)

- Measure and adjust the filter for best passband response (1:1 SWR).

- Accept the resulting stopband attenuation.
40M Bandpass Filter

Meas. inductors: 4.56µH, 4.65µH, 4.66µH
634pF, 634pF

Bandwidth (BW) miniductor measured at 7MHz

Capacitors: silver mica 470 + 100pF (500V) measured at 7MHz (=634pF)
ATC chips + adjustable piston trimmer

Matching Elsie design values

- Inductors: BW miniductor measured at 7MHz
- Capacitors: silver mica 470 + 100pF (500V) measured at 7MHz (=634pF)
- Capacitors: ATC chips + adjustable piston trimmer

\[ Q_C = \frac{\omega C}{G} = 2000 \]
\[ Q_L = \frac{\omega L}{R} = 200 \]

Elsie design response:
- 0.4dB @ 7MHz
- -35dB @ 10.1MHz
- -59dB @ 14 MHz
- -63dB @ 18MHz

Bandpass Filters

October 13, 2018
40M Bandpass Filter – match Elsie design values

Chip capacitors true to their stated values up to microwave frequencies
500V rating; can handle 100W (2A into 50Ω)

For **135pF** capacitors value use:

\[
100 + 24 + (2-16) \text{ trimmer} = \text{tunable } (126 - 140)\text{pF}
\]

For **172pF** capacitor value use:

\[
100 + 24 + 39 + (2-16) \text{ trimmer} = \text{tunable } (165 - 179)\text{pF}
\]

**Filter tuning:** Adjust 3 trimmers for 1:1 SWR at 7.025MHz
40M BPF

Bandpass Filters
Detail

100 + 24 + (2-16) trimmer

chip capacitors

470pF + 100pF
Measuring Components at the Passband Frequency

2064nH = 2.064µH at 7.025MHz

2805nH = 2.805µH at 28.025MHz

Measured values a function of frequency
Straight-Through Measurement

Establish reference signal level, verify 1:1 SWR in 50Ω system
Tuning Setup and Transmission Measurement

Adjust trimmer capacitors for minimum SWR at 7.025 MHz  (was quite good to begin with)
Measure transmission at  20, 30, 40M
# Measured Results, 40M BPF

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<thead>
<tr>
<th>Filter</th>
<th>Loss (dB) in Band</th>
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<tbody>
<tr>
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<td>80M</td>
</tr>
<tr>
<td><strong>40M BPF</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>32.1</td>
</tr>
</tbody>
</table>

Elsie Design:

- 0.4  35  59  63

**Measurement Frequencies**

- 80M: 3.5 MHz
- 40M: 7.025 MHz
- 30M: 10.1 MHz
- 20M: 14.0 MHz
- 17M: 18.068 MHz

- Not quite as much out-of-band rejection as Elsie design; still quite adequate
- Errors due to: non-exact values, high-frequency coupling between the air-wound inductors, frequency dependence of silver-mica capacitor
Ideal (Elsie) vs. Measured Response  40M BPF
30M Bandpass Filter

Component Selection

**Capacitors:** use ATC chips + trimmer

**Inductors:** Use T-68-6 toroids meas. at 10.1MHz

**Capacitors:** use silver mica meas. at 10.1MHz

Elsie design response

```
-55dB  @ 3.5MHz
-35dB  @ 7MHz
-0.64dB @ 10.1MHz
-45B   @ 14 MHz
-65B   @ 18MHz
```

\[ Q_C = \frac{\omega C}{G} = 2000 \]

\[ Q_L = \frac{\omega L}{R} = 200 \]
## Capacitor Selection

**Silver Mica 390pF capacitor**  (+/- 5%. 500V)

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Measured Capacitance (pF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>404</td>
</tr>
<tr>
<td>3.5</td>
<td>404</td>
</tr>
<tr>
<td>7</td>
<td>453</td>
</tr>
<tr>
<td>10.1</td>
<td>453</td>
</tr>
<tr>
<td>14</td>
<td>589</td>
</tr>
<tr>
<td>18.1</td>
<td>875</td>
</tr>
<tr>
<td>21</td>
<td>1520</td>
</tr>
<tr>
<td>25</td>
<td>self-resonance</td>
</tr>
<tr>
<td></td>
<td>(becomes inductive past 25 MHz)</td>
</tr>
</tbody>
</table>
30M Bandpass Filter

- **Meas. toroids** --- 4.46µH
- **453pF 4.46µH**
- **453pF 4.46µH**

**Elsie design response**

- **Capacitors:** silver mica 390pF meas. at 10.1MHz yields 453pF
- **Inductors:** Toroids T-68-6 meas. at 10.1MHz
- **Capacitors:** ATC chips + (trimmer)
  - $60.3 = 47 + (2-16) = 49-63pF$
  - $70.2 = 47+12 + (2-16) = 61-75pF$

- Fix C value at 453pF (ignore variation of C with frequency)
- Relax loss req’t at 14MHz to 40dB (will yield to lower values for inductances)
- Optimize other components for best match to response requirements
30M BPF

OUT (xvpr)

IN (ant)
# Measured Results, 30M BPF

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<tr>
<td><strong>30M BPF</strong></td>
<td>49.0</td>
</tr>
<tr>
<td>Elsie Design</td>
<td>55</td>
</tr>
<tr>
<td>Optimized</td>
<td>52</td>
</tr>
</tbody>
</table>

*note*
Ideal (Elsie) vs. Measured Response  30M BPF

Transmit, dB

4M 5M 6M 8M 10M

Bandpass Filters
20M Bandpass Filter

BW miniductor meas. at 14MHz

Capacitors: use silver mica meas. at 14MHz

Elsie design response

Model the frequency-dependent behavior of the silver mica capacitors

Optimize other component values for best match to the response requirements
20M BPF

Bandpass Filters

October 13, 2018  30
## Measured Results, 20M BPF

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<tr>
<td><strong>20M BPF</strong></td>
<td>36</td>
</tr>
<tr>
<td>Elsie Design</td>
<td>43</td>
</tr>
<tr>
<td>Optimized</td>
<td>37</td>
</tr>
</tbody>
</table>

- Not as much out-of-band rejection as Elsie or optimized design
- Errors due to: high-frequency coupling between the air-wound inductors (shielding probably inadequate)
Ideal (Elsie) vs. Measured Response  20M BPF
Summary
40M BPF

30M BPF

20M BPF
Summary

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Conclusions

• Elsie program can design bandpass filters for transceivers

• Optimization of the design is possible but not necessary

• Have choice of air-core or toroidal inductors; leaded or chip capacitors

• Must be aware of component value variation with frequency

• Match component values as closely as possible; allow tuning of series capacitances by using trimmers; we avoid inductance adjustment

• Design approach here is to get best passband result and accept stopband attenuation

• If more stopband attenuation is required, can design a more complex filter

• Filters like these are also commercially available