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

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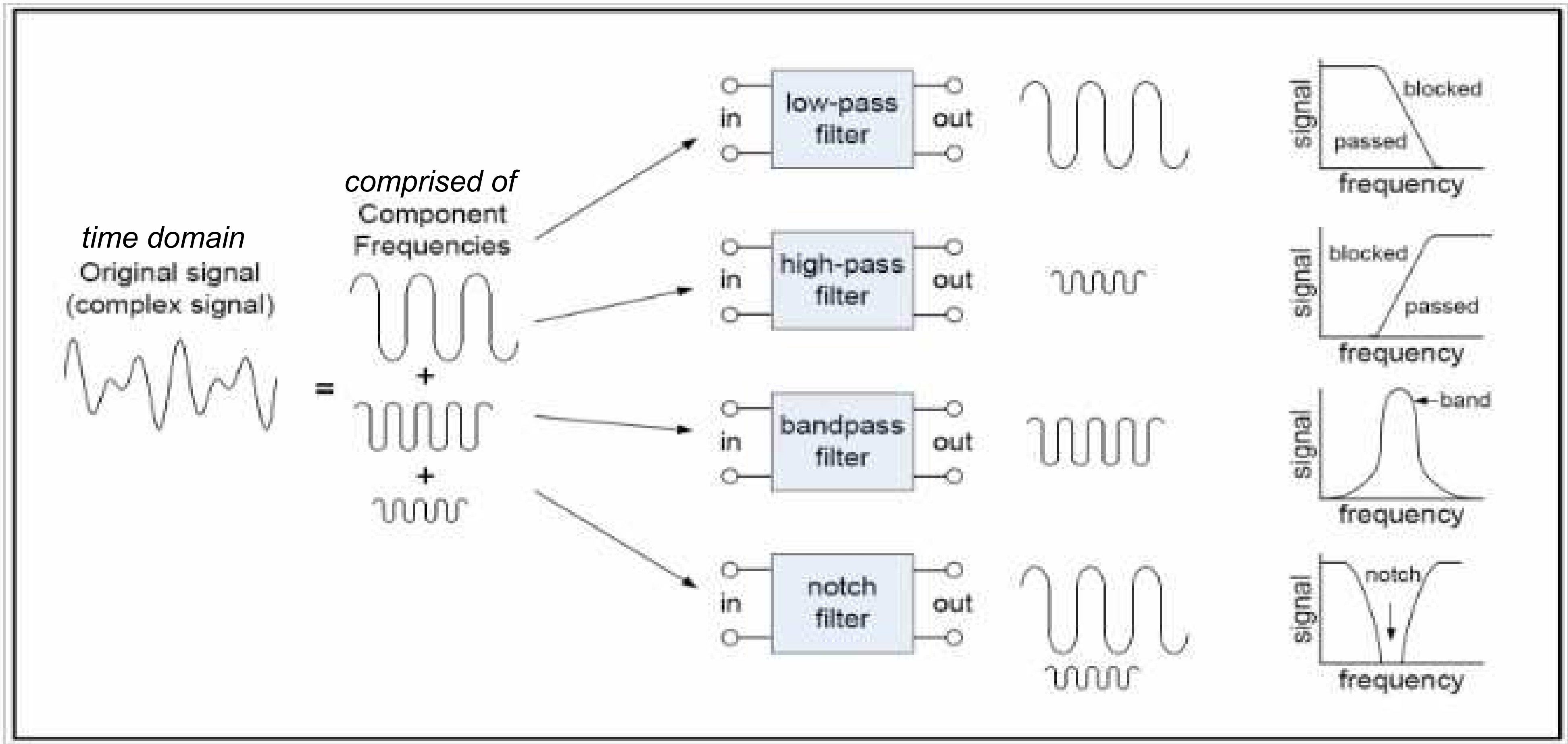
Application

- 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



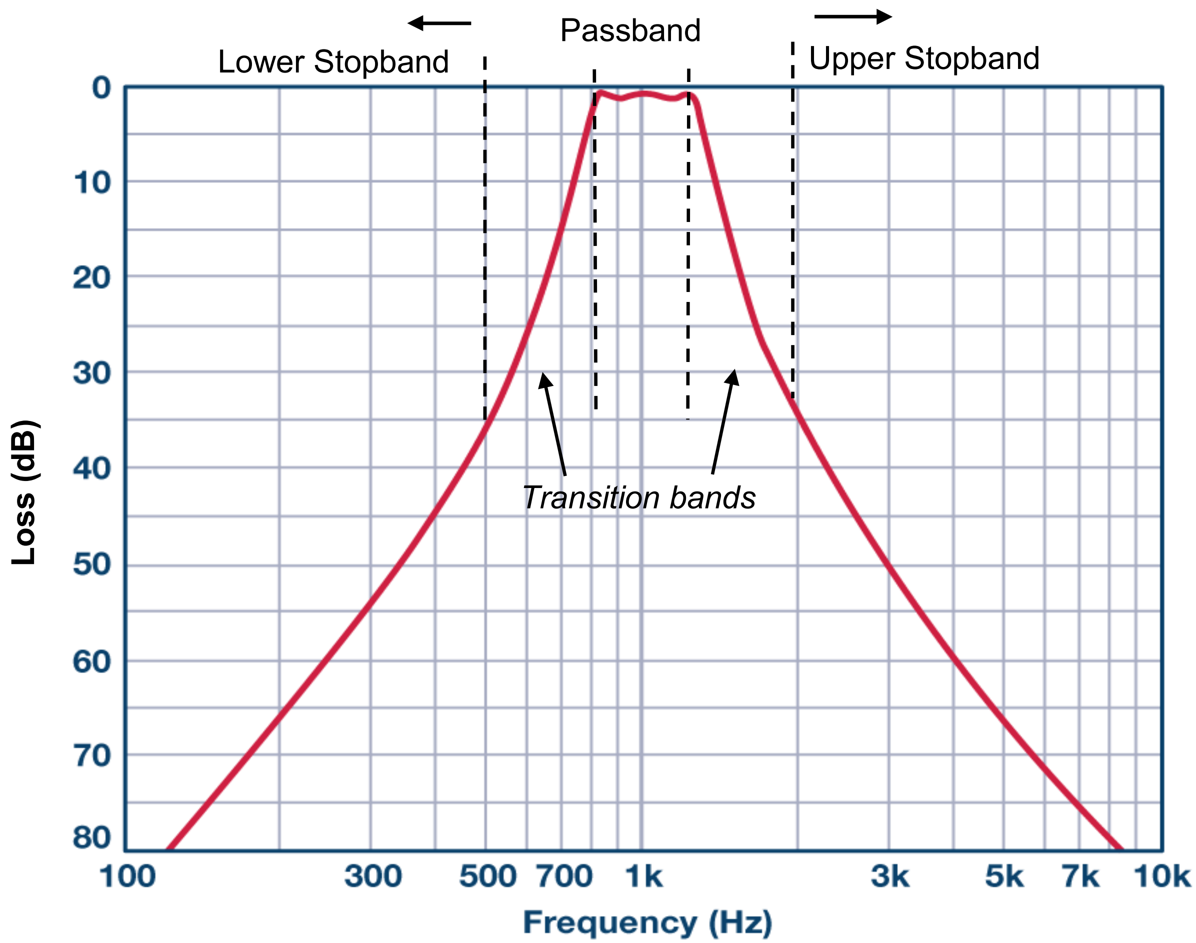
A basic depiction of the four major filter types.

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=jω***) gives a good *approximation* to the desired response shape.

Typical **bandpass filter** magnitude response shape:

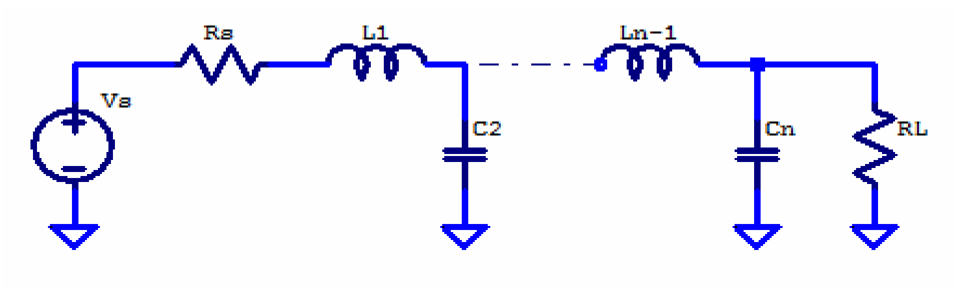
loss in dB as function of frequency



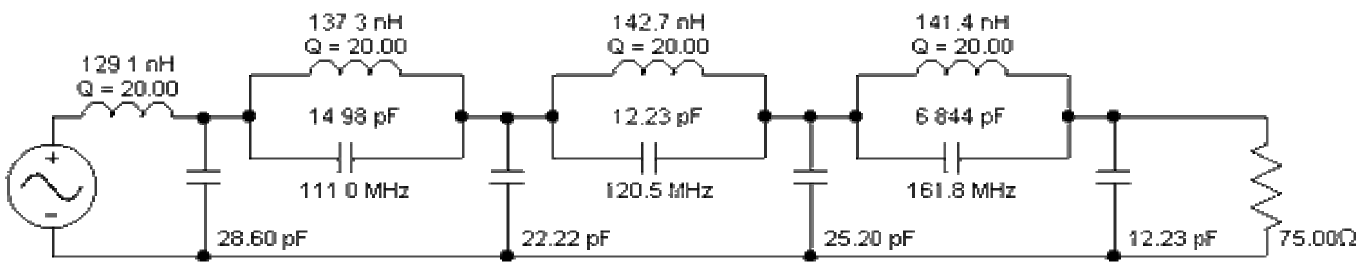
Filter Design: Network Synthesis

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

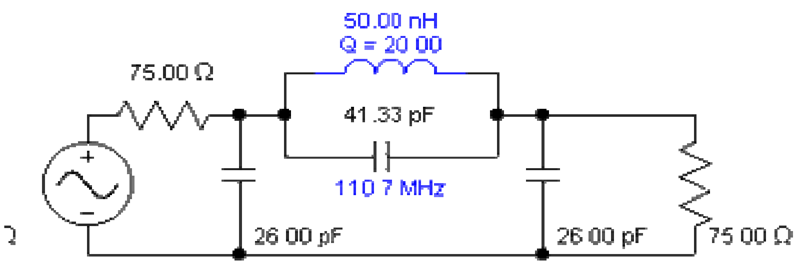
Examples (ladder filters):



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)

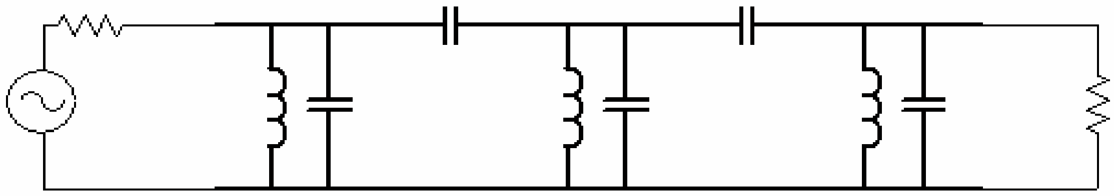


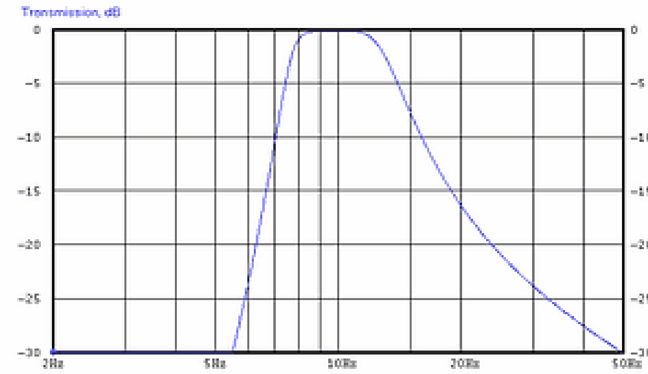
Filter Design Solutions

- 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: **http://www.tonnesoftware.com/downloads/FilterTutorial.pdf**

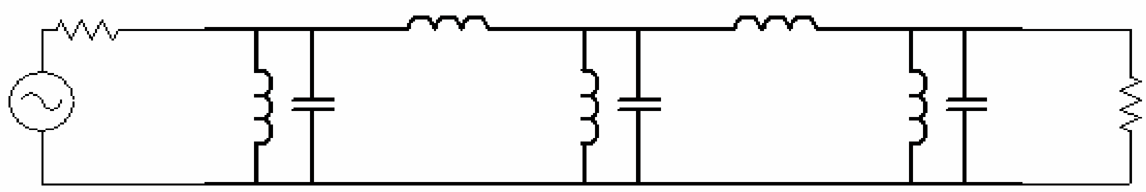
Bandpass Filter Structures *(selected from Elsie)*

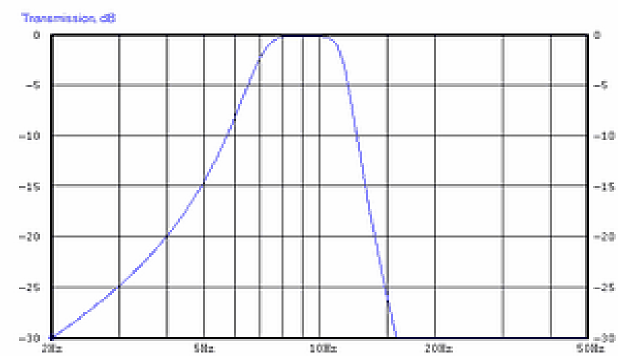
Nodal capacitor-coupled bandpass





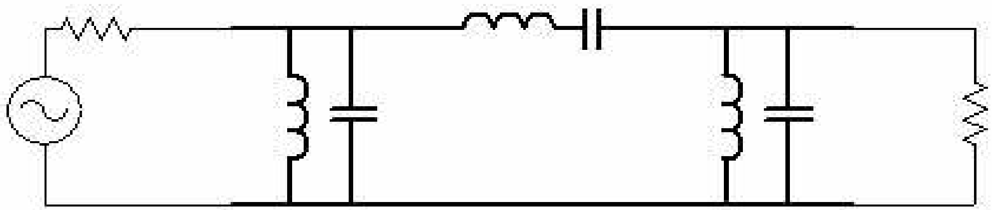
Nodal inductor-coupled bandpass

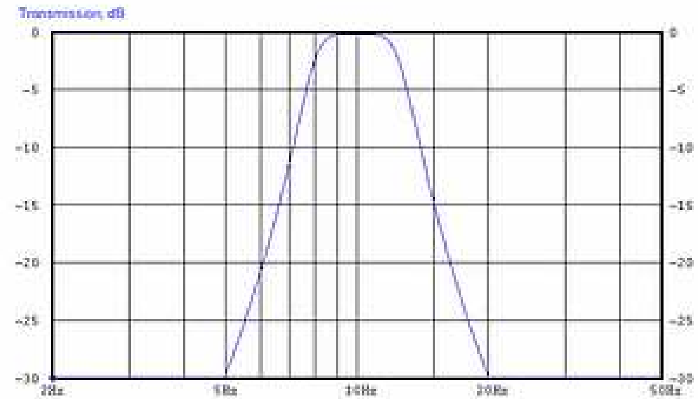




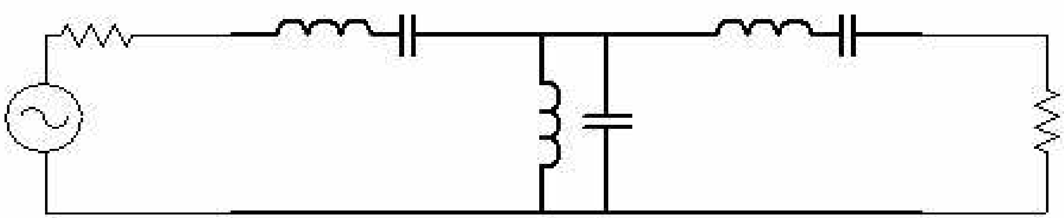
Filter Structures (cont'd)

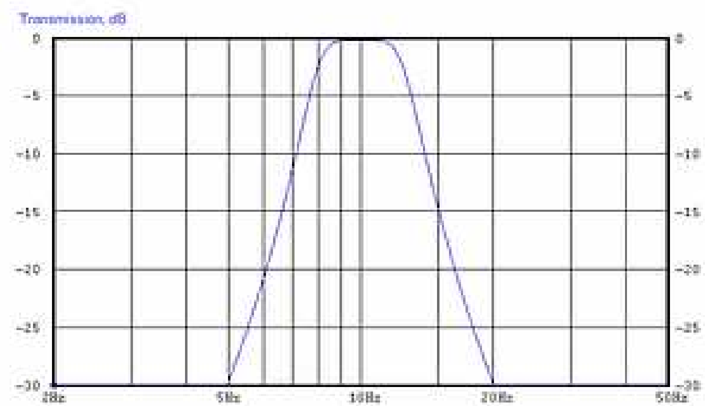
Shunt-input bandpass





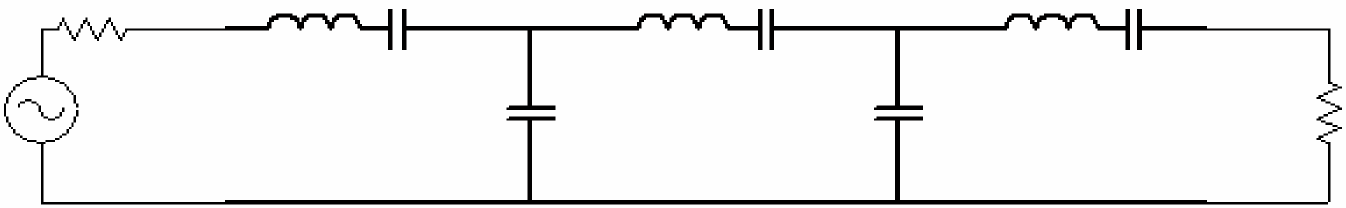
Series-input bandpass

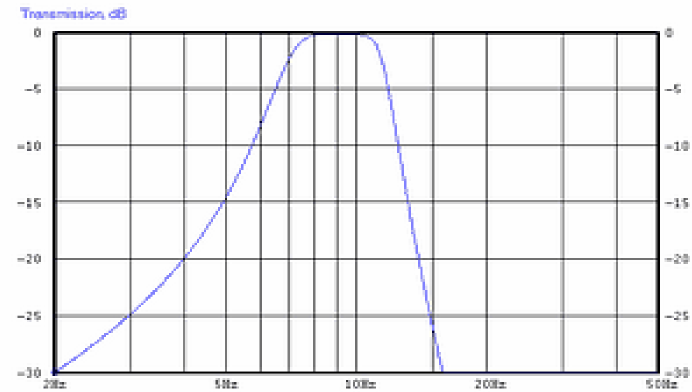




Bandpass Filter Structures

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

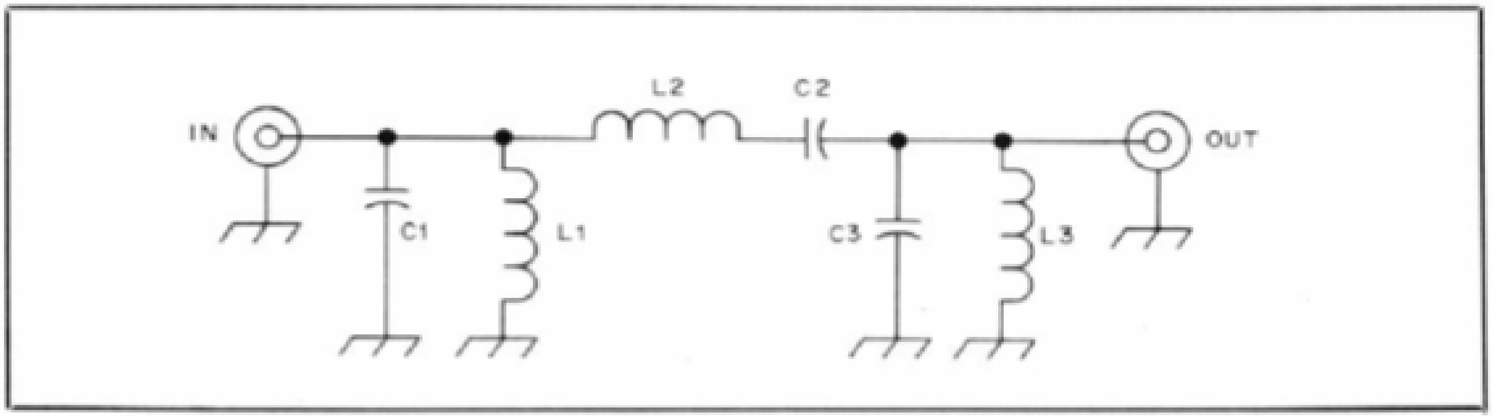


Fig 1—Schematic diagram of the three-pole Butterworth band-pass filters.

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

Filter	Loss (dB) in Band				
	40M	**30M**	**20M**	**17M**	**15M**
40M BPF	***0.5***	*15.7*	*32*	*42*	*47*
20M BPF	*32*	*7.9*	***0.5***	*8.5*	*16*

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.)

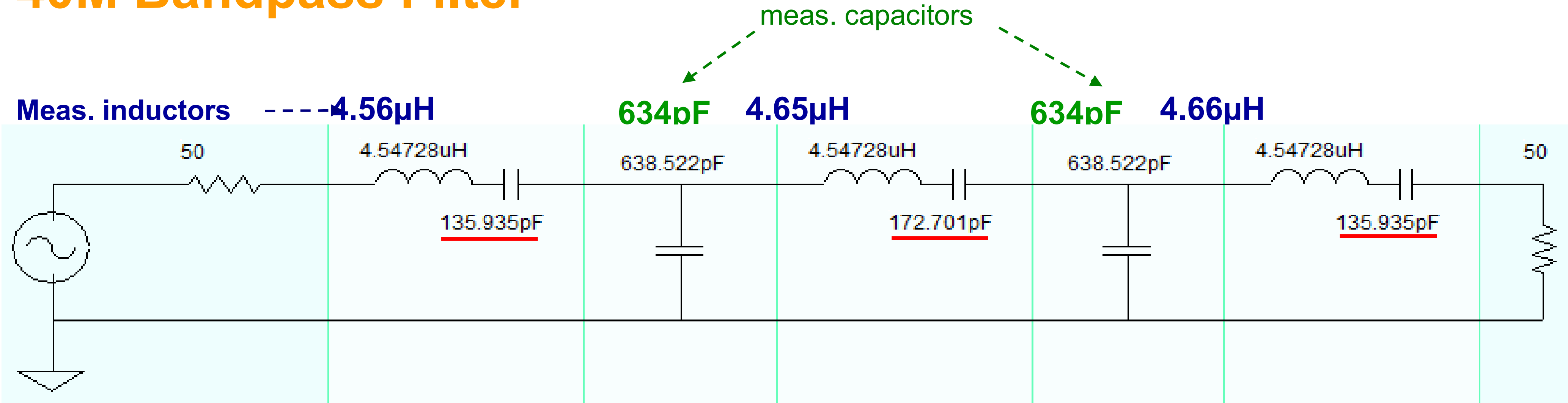
- For our filters optimization is *not* required to get good results

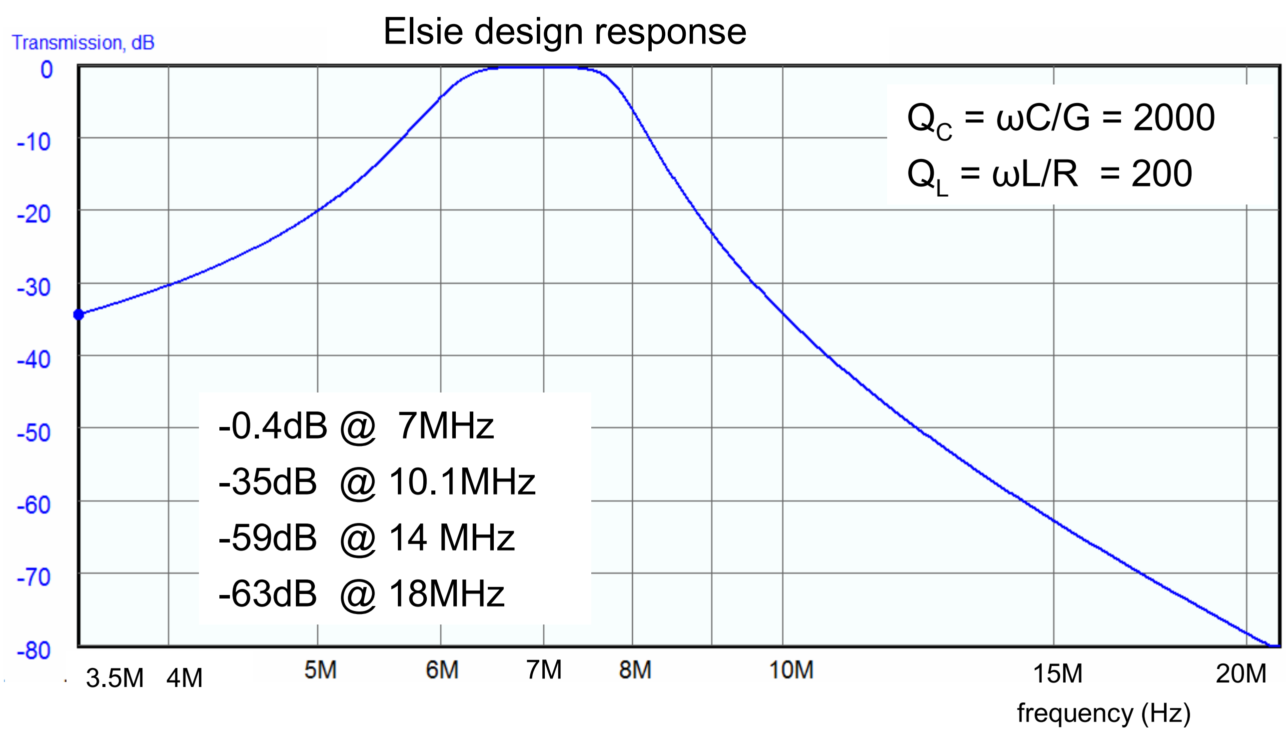
- No optimization in 40M filter; optimization used in 30M and 20M filters just to illustrate what can be done

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





Matching Elsie design values

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

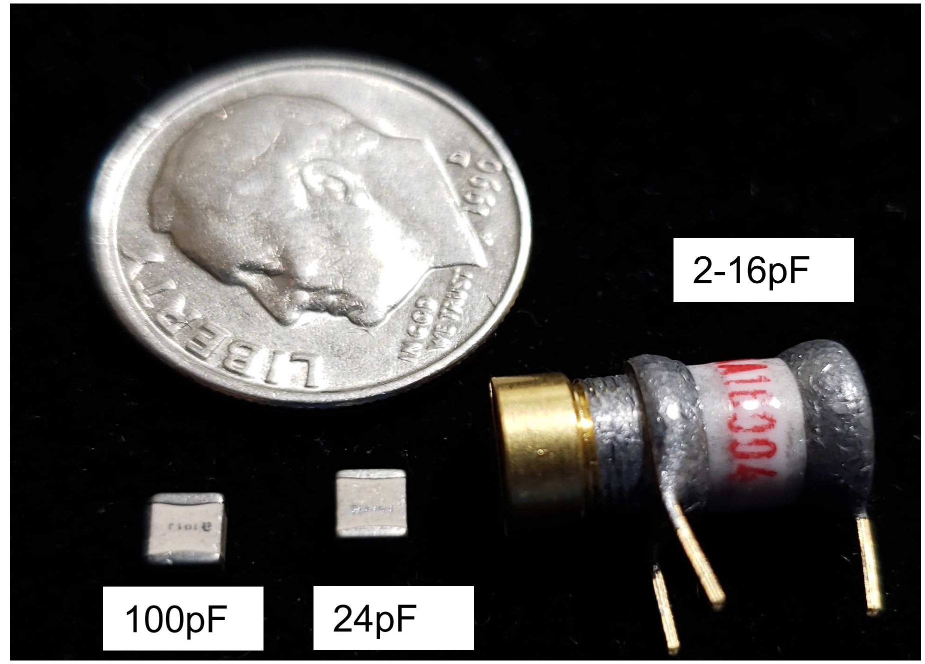
40M Bandpass Filter – match Elsie design values

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) trimmer

= **tunable (126 – 140)pF**

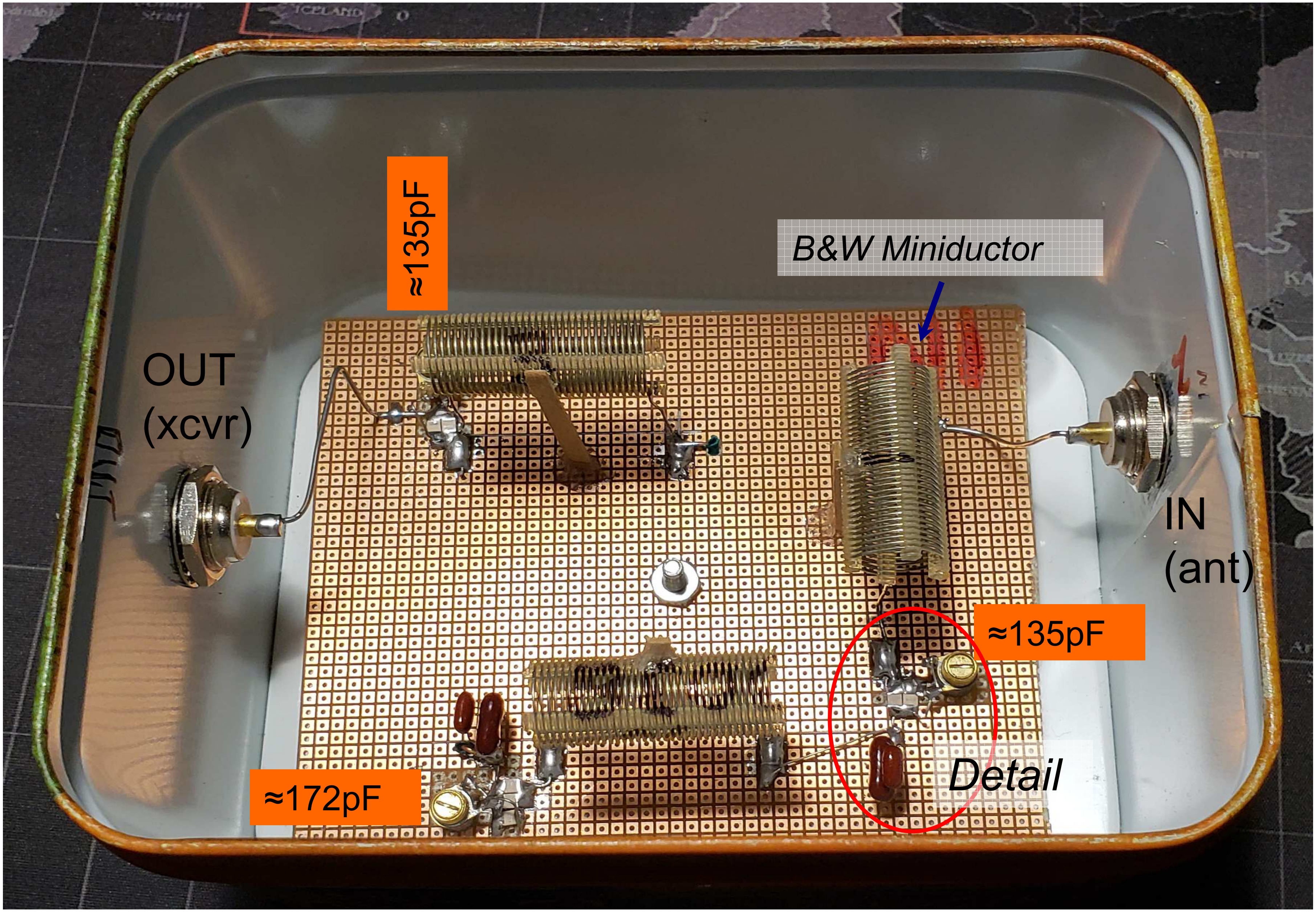


For ***172pF*** *capacitor value use:*

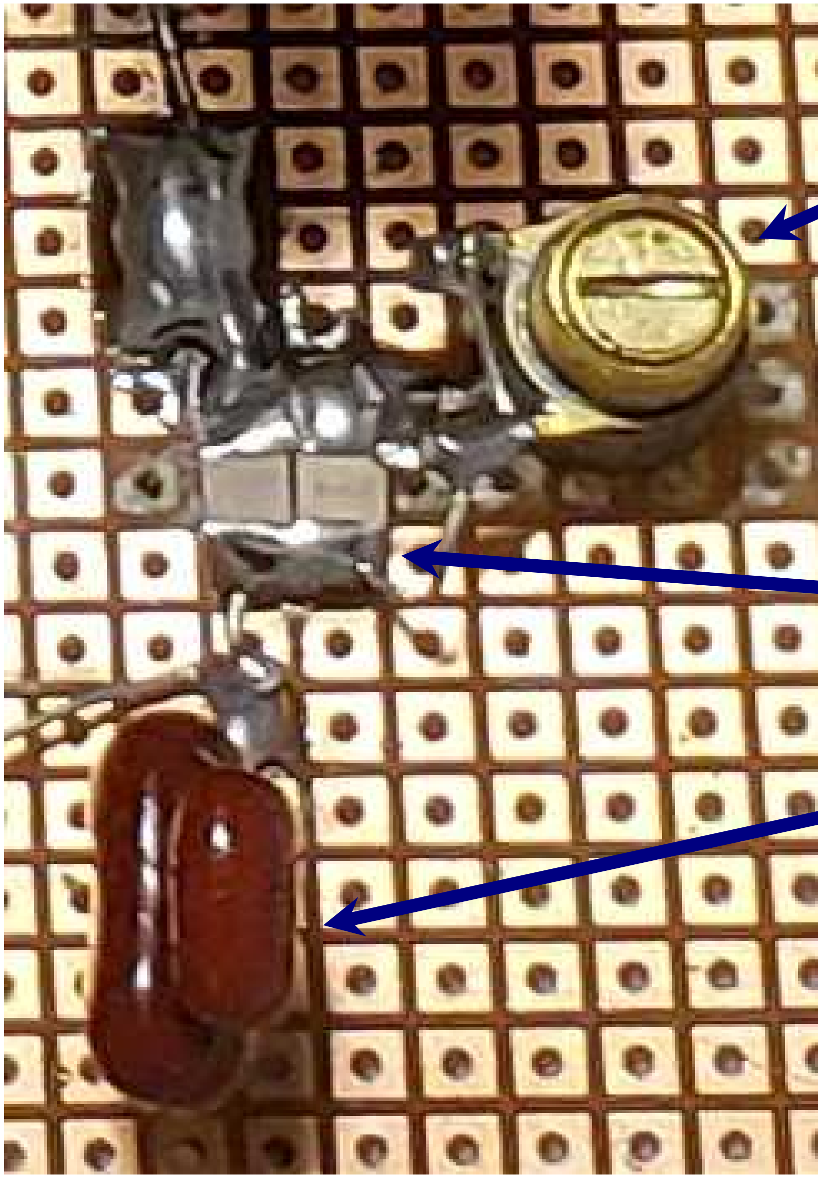
100 + 24 + 39 + (2-16) trimmer = **tunable (165 – 179)pF**

Filter tuning: **Adjust 3 trimmers for 1:1 SWR at 7.025MHZ**

40M BPF



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

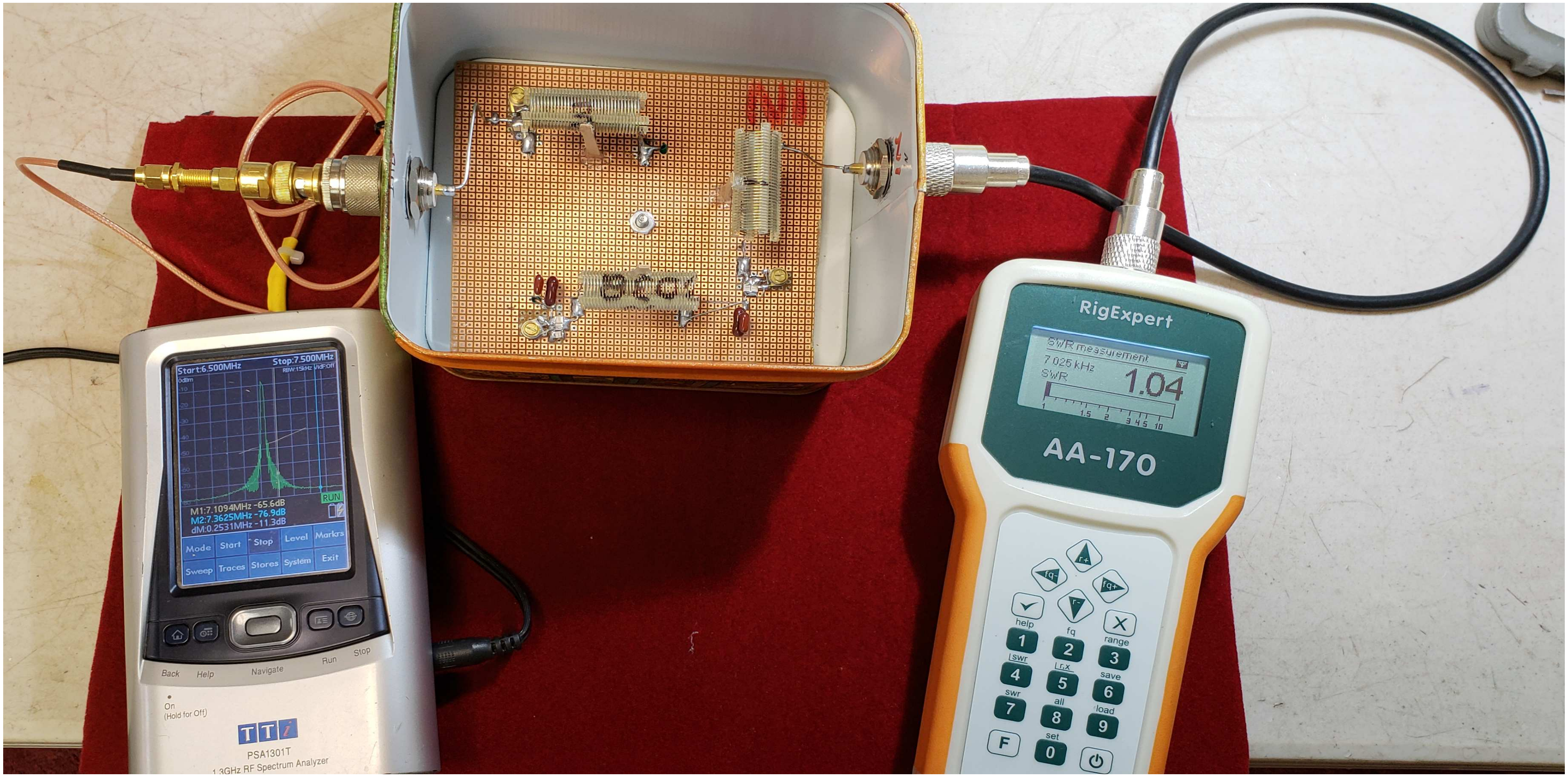
Straight-Through Measurement

Spectrum Analyzer

Antenna Analyzer

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

Filter	Loss (dB) in Band				
	80M	**40M**	**30M**	**20M**	**17M**
40M BPF	*32.1*	***0.5***	*28.4*	*46.8*	*54.0*

Elsie Design:		0.4	35	59	63

Measurement Frequencies

80M: 3.5 MHz

40M: 7.025 MHz

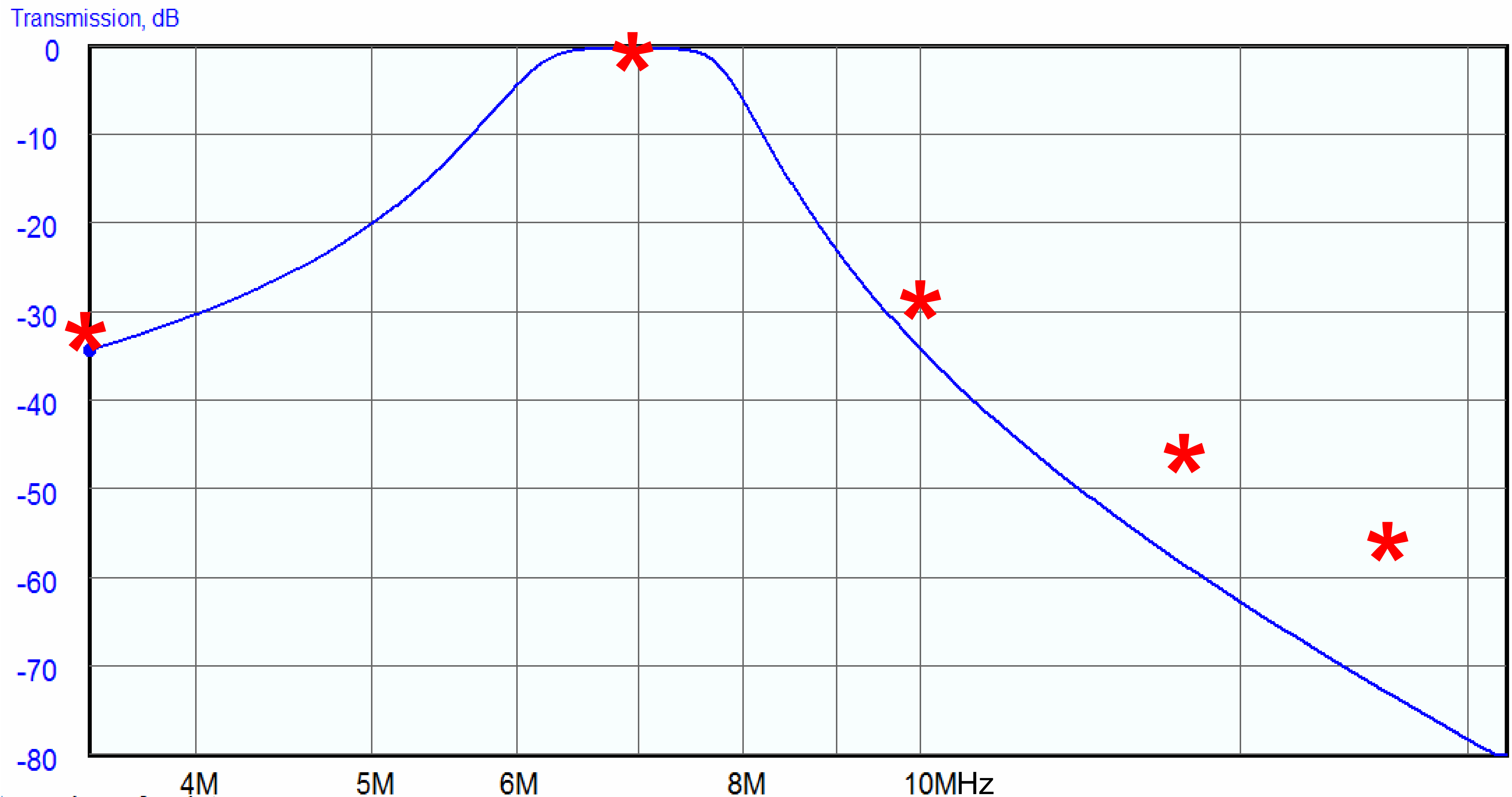
30M: 10.1 MHz

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

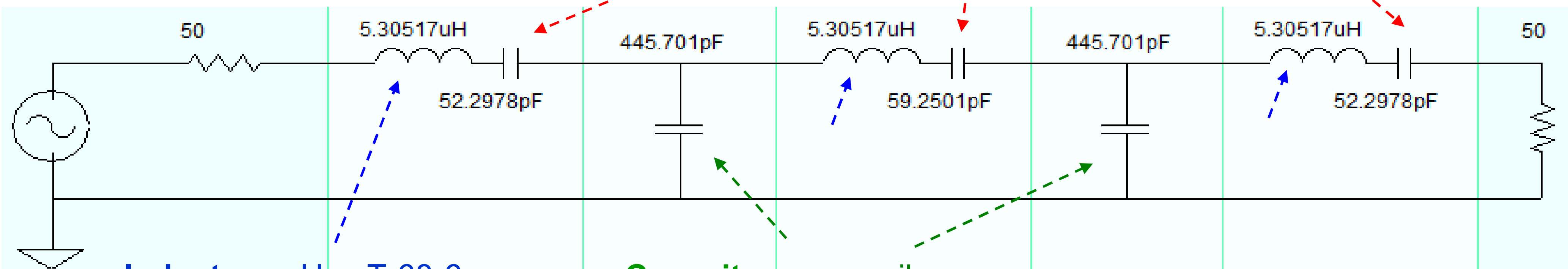
Ideal (Elsie) vs. Measured Response 40M BPF



30M Bandpass Filter

Component Selection

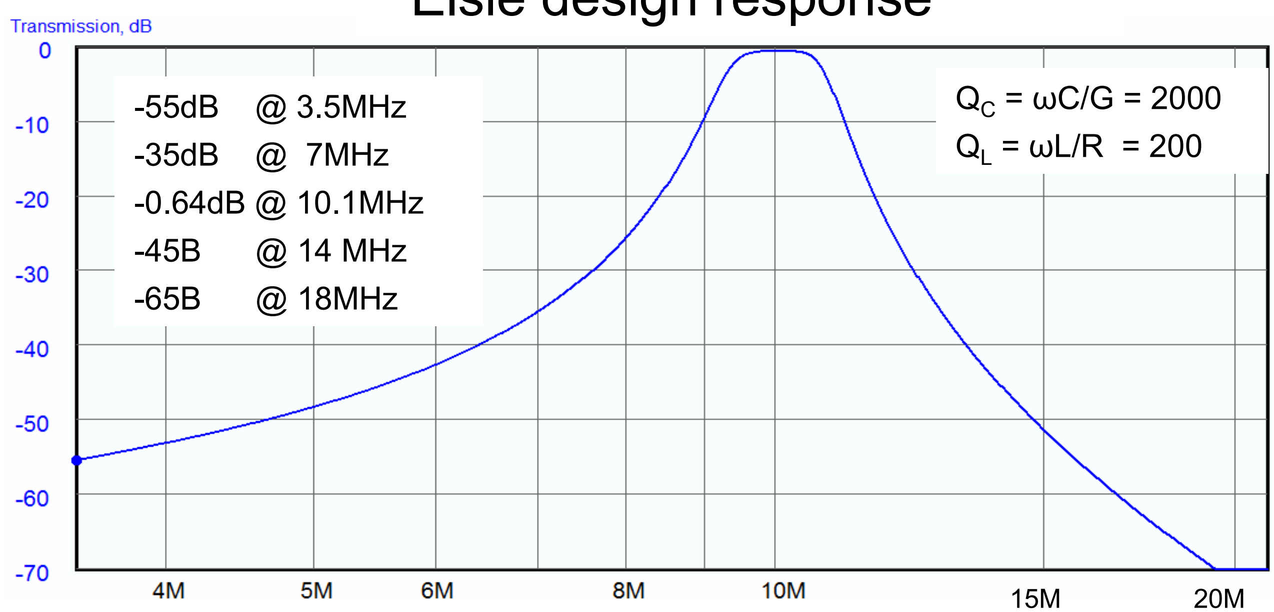
Capacitors: use ATC chips + trimmer



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

Capacitors: use silver mica meas. at 10.1MHz

Elsie design response

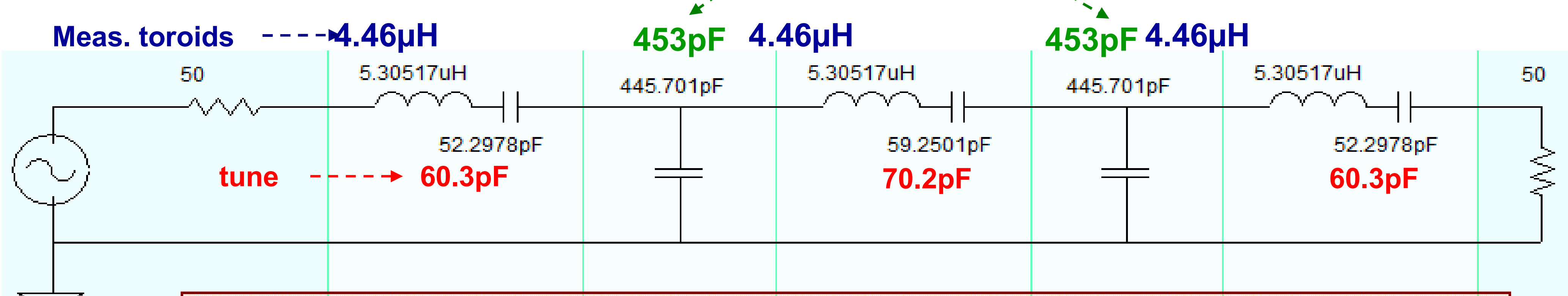


Capacitor Selection

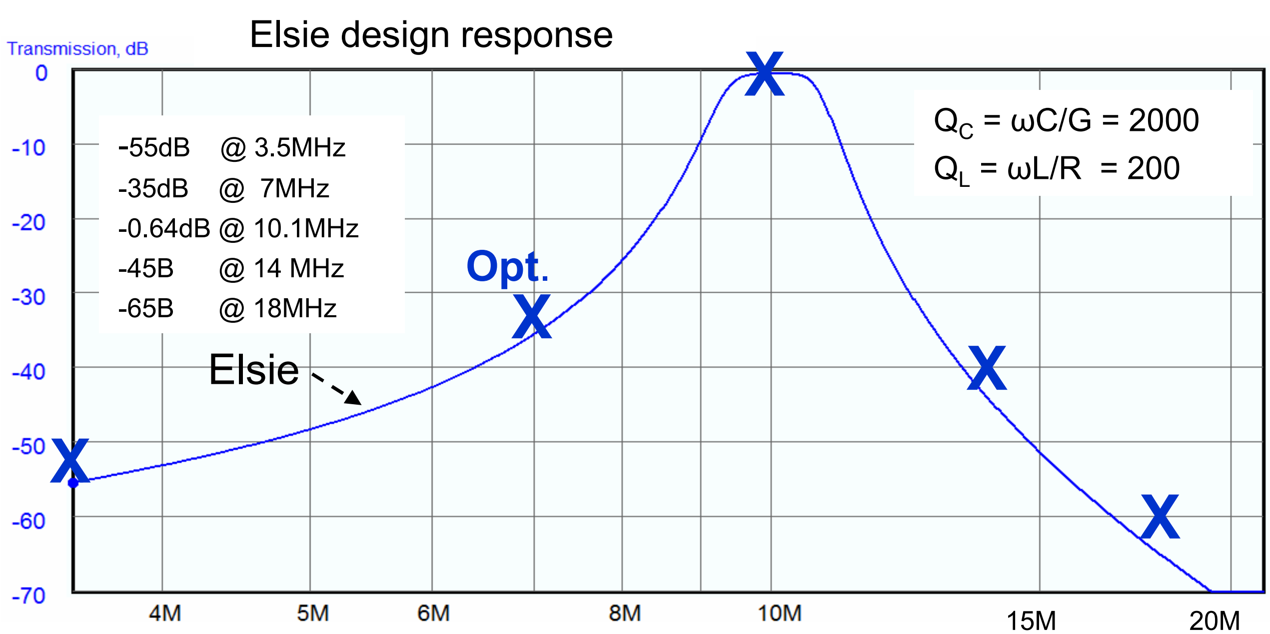
Silver Mica 390pF capacitor (+/- 5%. 500V)

Freq. (MHz)	*Measured Capacitance (pF)*
1	404
3.5	404
7	453
10.1	453
14	589
18.1	875
21	1520
25	self-resonance (becomes inductive past 25 MHz)

30M Bandpass Filter



- 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

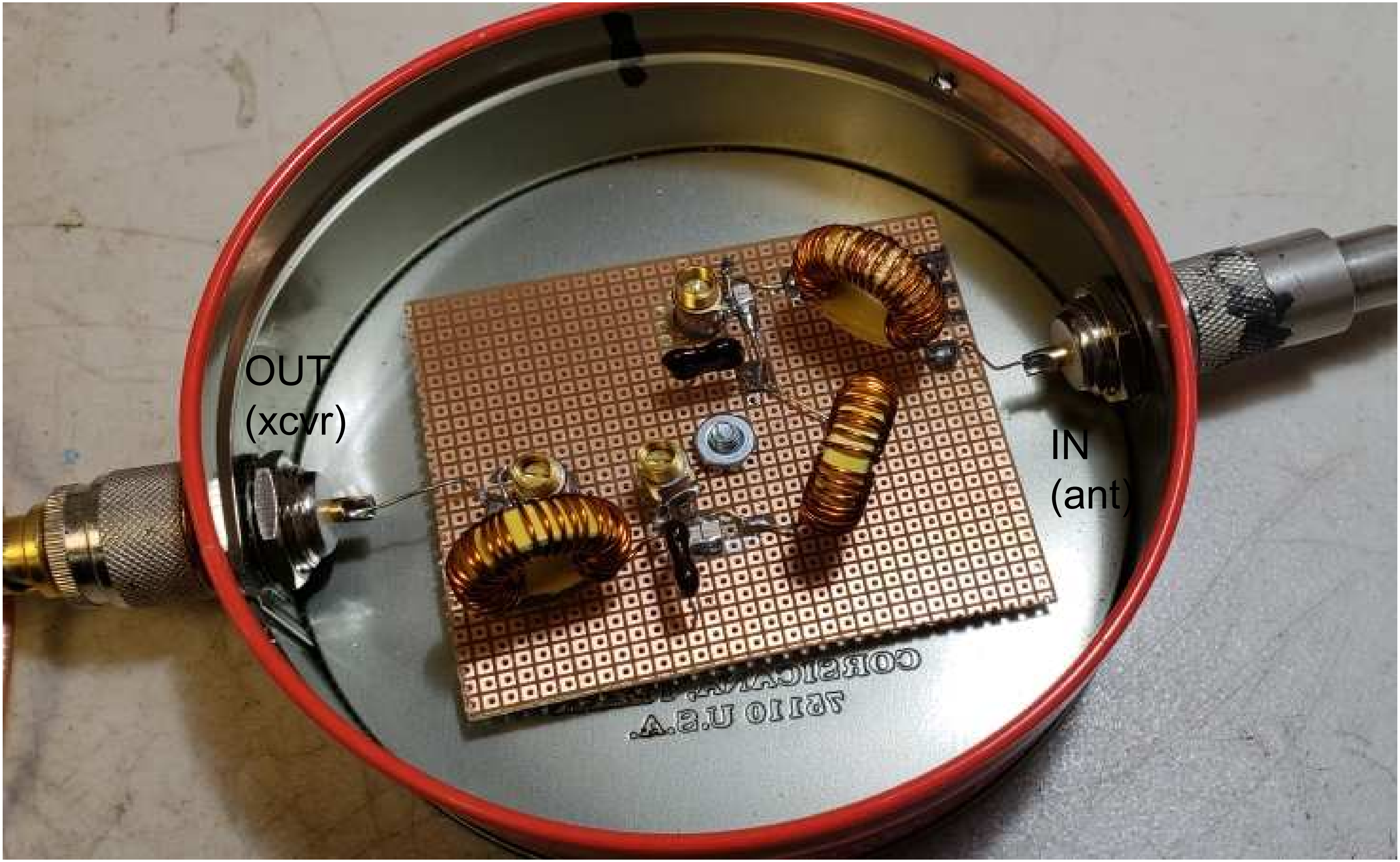


- **Capacitors: silver mica** 390pF meas. at 10.1MHz yields 453pF
- **Inductors:** Toroids T-68-6 meas. at 10.1MHz
- **Capacitors:** ATC chips + (trimmer)

  60.3 = 47 + (2-16) = 49-63pF

  70.2 = 47+12 + (2-16) = 61-75pF

30M BPF

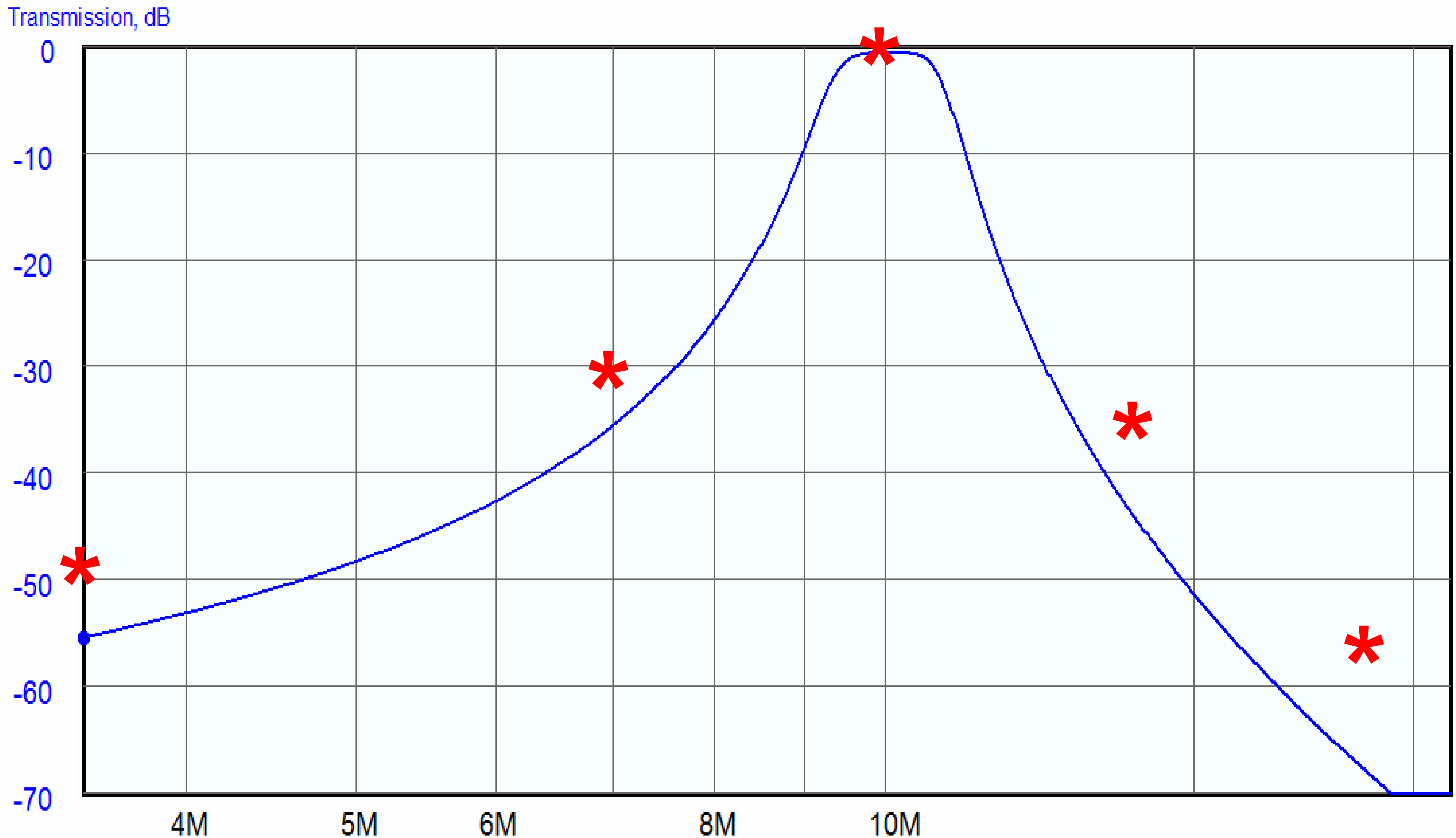


Measured Results, 30M BPF

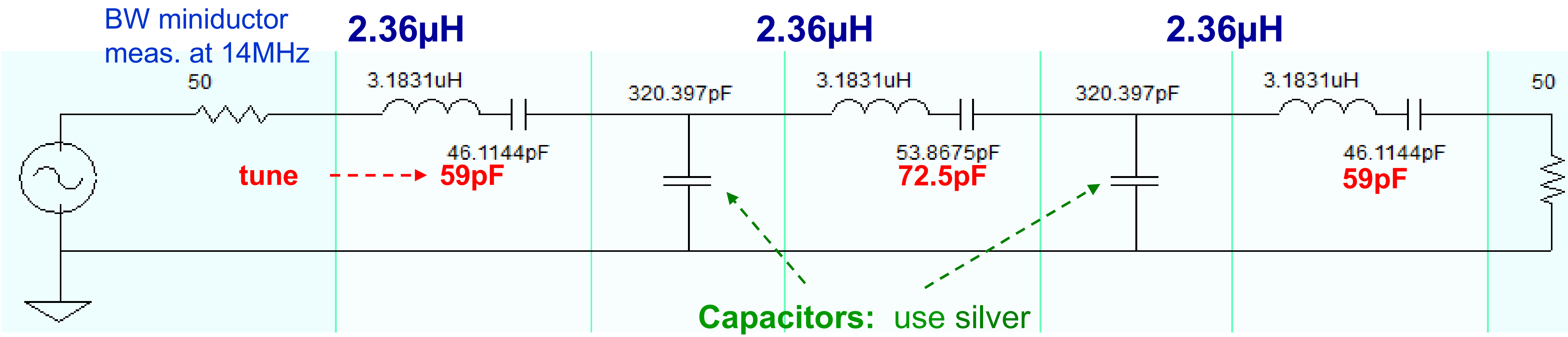
Filter	Loss (dB) in Band				
	80M	**40M**	**30M**	**20M**	**17M**
30M BPF	*49.0*	*30.6*	***0.4***	*34.2*	*55.4*
Elsie Design	55	35	0.6	45	65
Optimized	52	33	0.6	40	61

note

Ideal (Elsie) vs. Measured Response 30M BPF

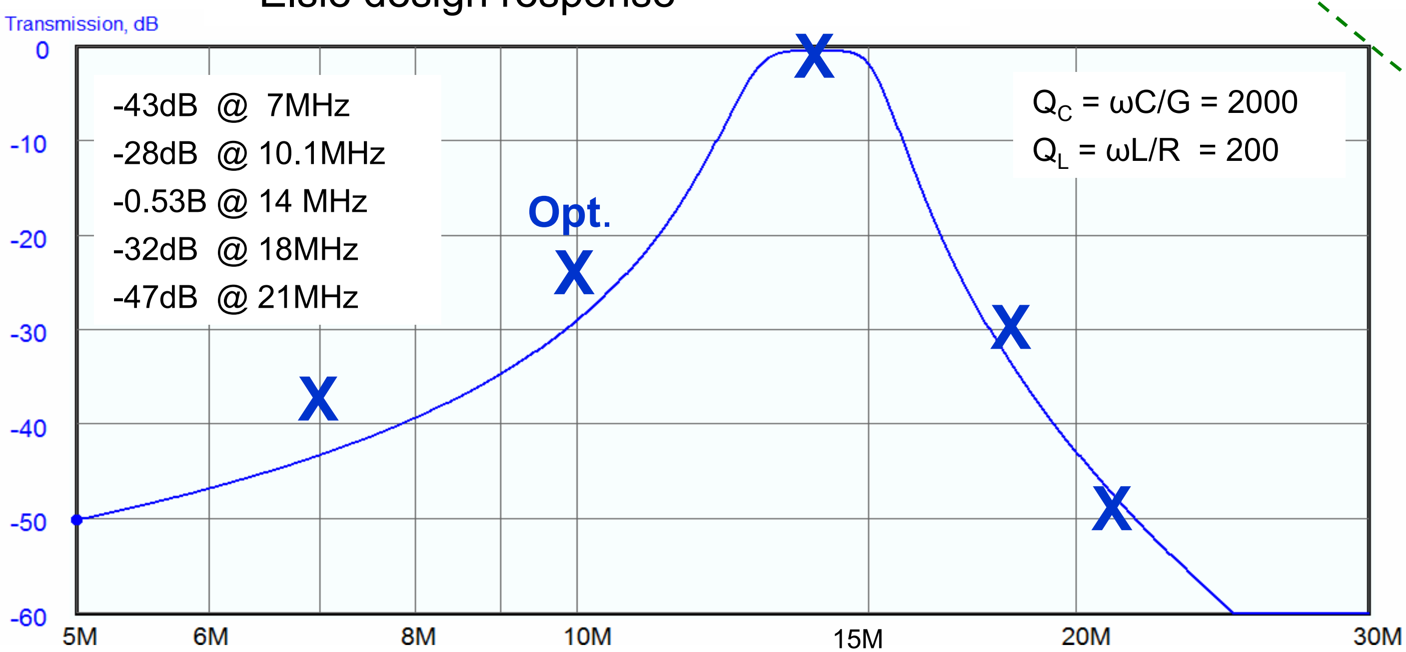


20M Bandpass Filter



Capacitors: use silver mica meas. at 14MHz

Elsie design response



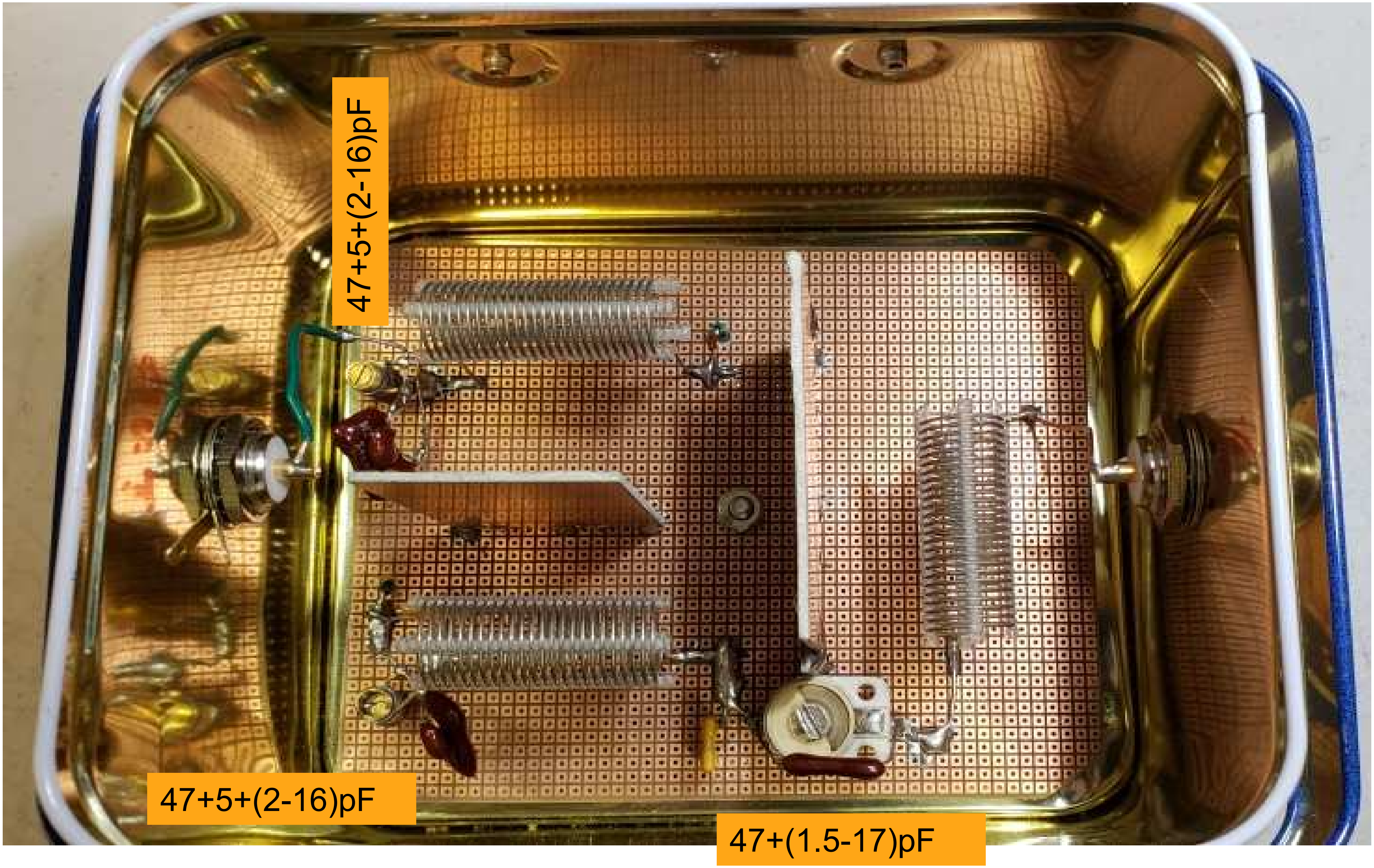
Model the frequency-dependent behavior of the silver mica capacitors

270pF Capacitor

7MHz	283pF
10.1	304
14	**352**
18	437
21	539

Optimize other component values for best match to the response requirements

20M BPF

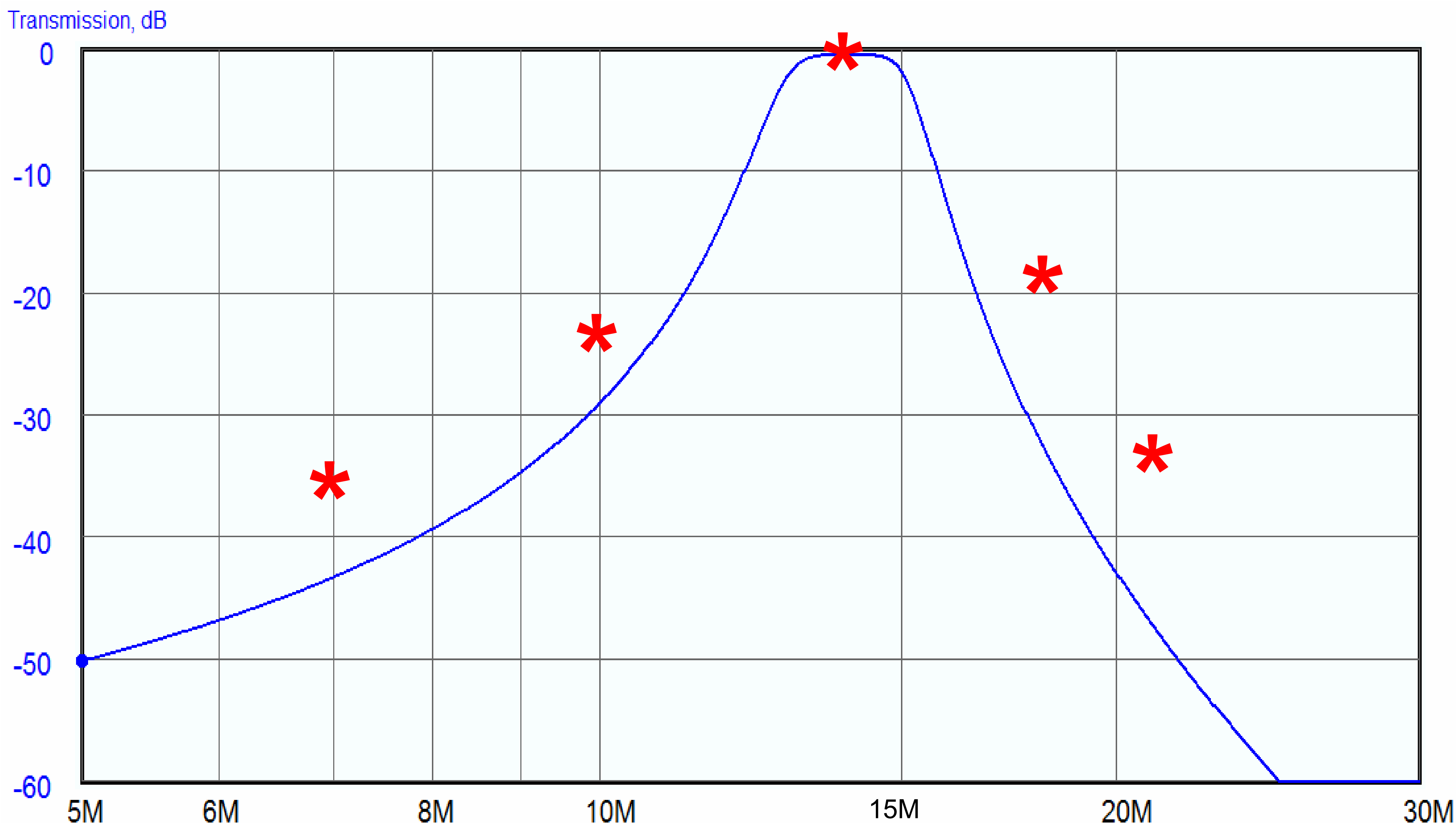


Measured Results, 20M BPF

Filter	Loss (dB) in Band				
	40M	**30M**	**20M**	**17M**	**15M**
20M BPF	*36*	*23*	***0.4***	*19*	*33*
Elsie Design	43	28	0.5	32	47
Optimized	37	24	0.5	30	49

- 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)

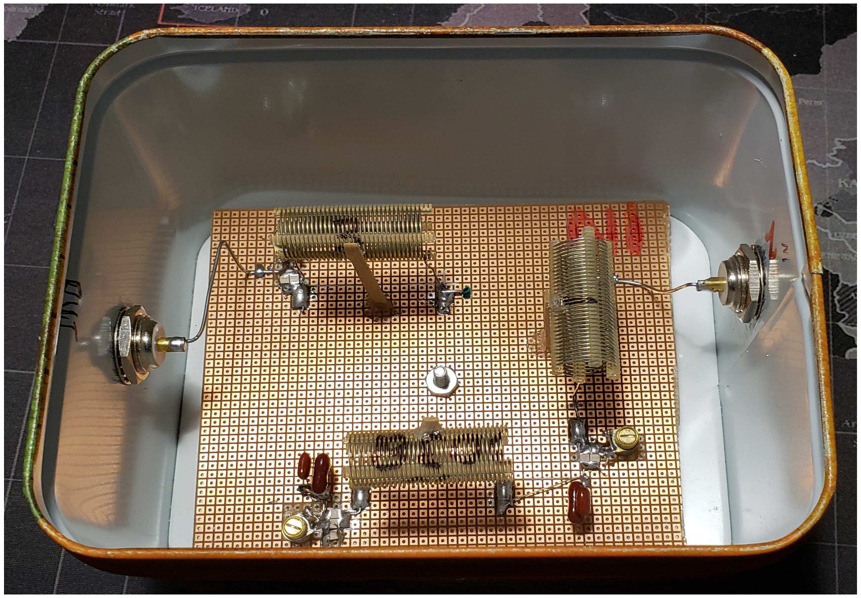
Ideal (Elsie) vs. Measured Response 20M BPF



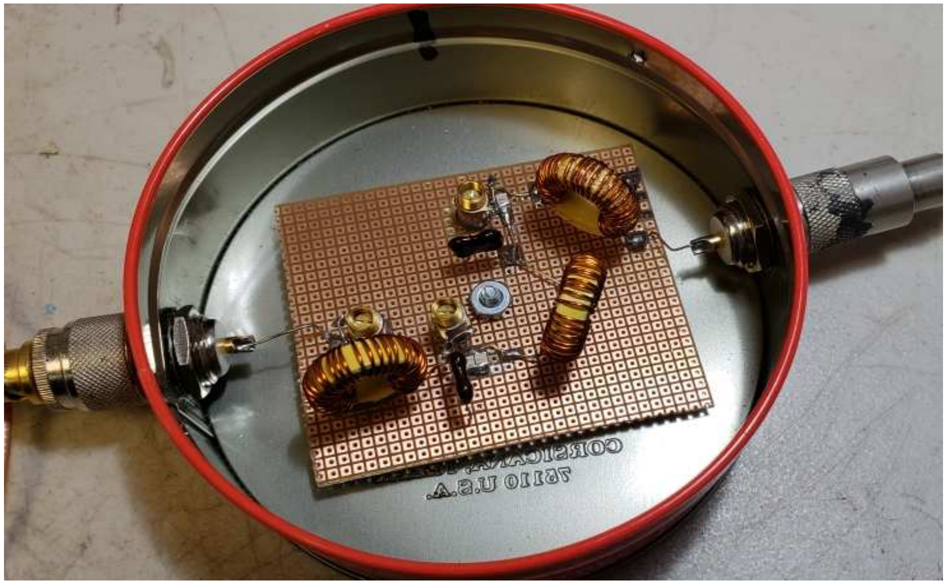
Summary


40M BANDPASS FILTER
20M BANDPASS FILTER
30M BANDPASS FILTER

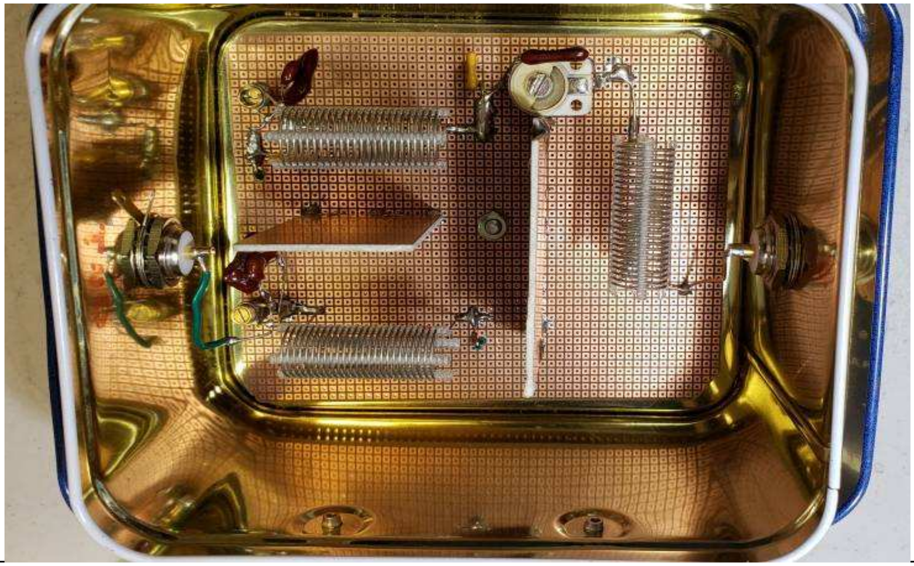
40M BPF



30M BPF

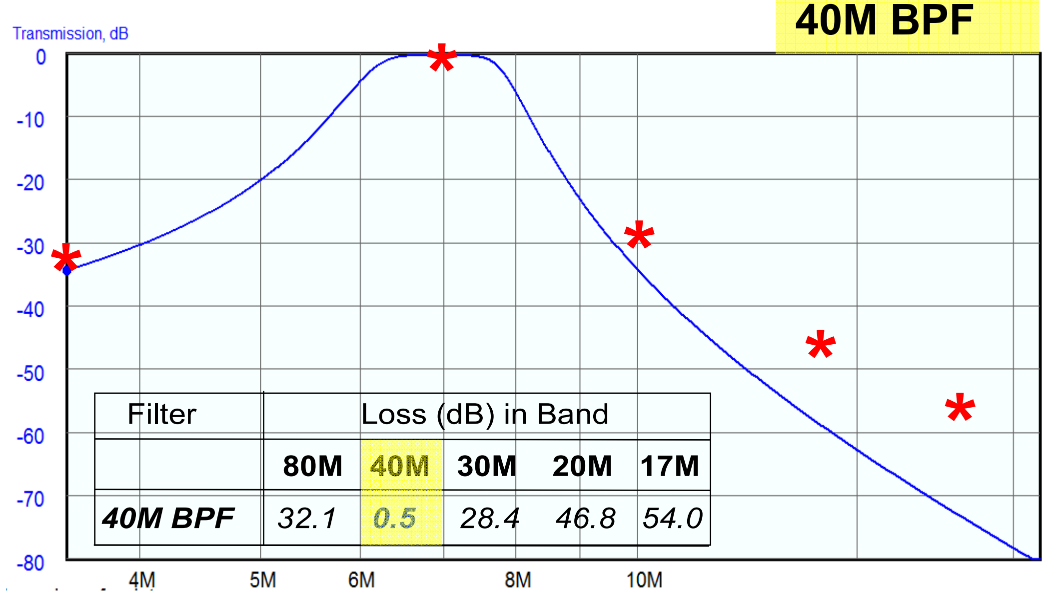


20M BPF



Summary

40M BPF



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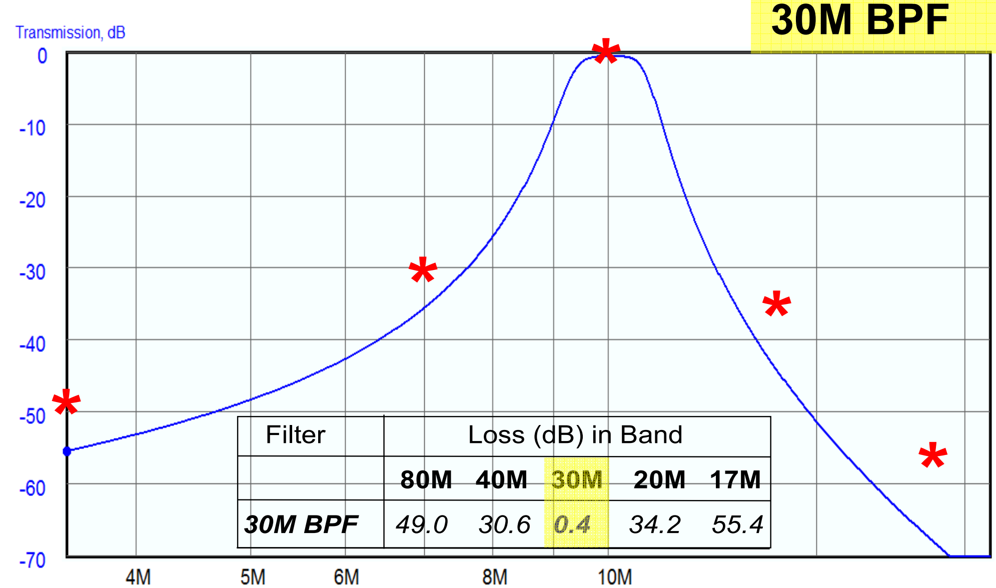
30M BPF



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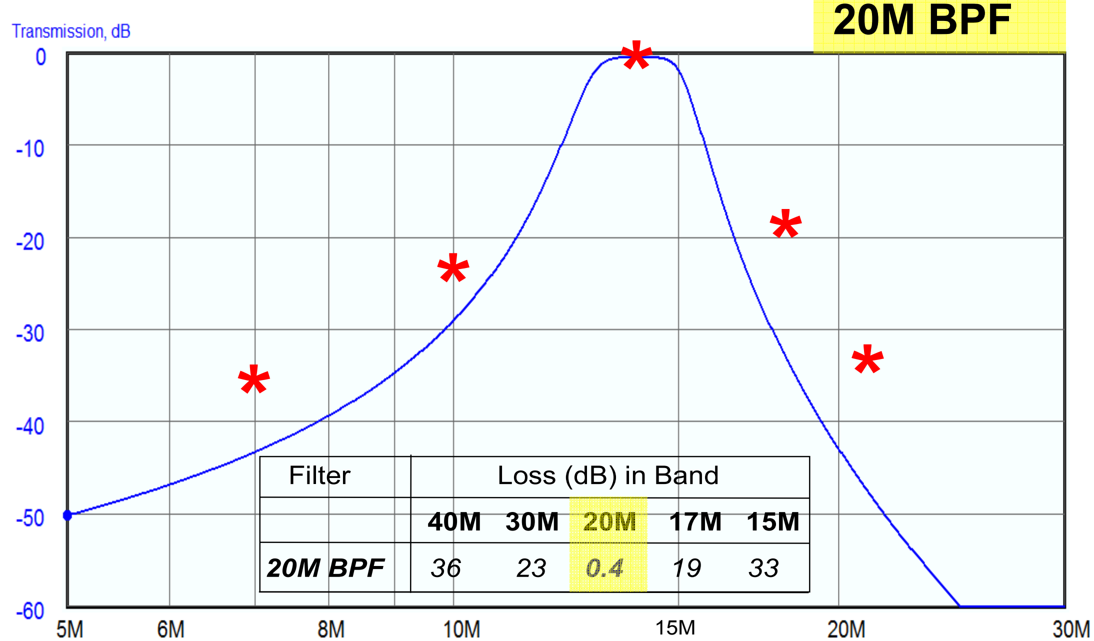
20M BPF



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	40M	**30M**	**20M**	**17M**	**15M**
20M BPF	*36*	*23*	*0.4*	*19*	*33*

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***