Introduction

I am investigating building my own set of bandpass filters with a goal of satisfying my station needs for a possible future SO2R operation, as well as to use on Field Day. My club's FD operation has consistently put five different HF transmitters on the air, not counting a GOTA station, so the RF environment warrants additional protection for the receiver front ends.

In actuality it may turn out to be the case it would be less expensive, and certainly far less time consuming, to just go purchase a commercially available set of filters. Dunestar and those available through Array Solutions are attractive, however there is little satisfaction in this route compared to "building your own". Toward that end, I have put this assemblage of simulations and circuit details together to ensure I have a) proper lumped element values, and b) more importantly, understood the expected peak voltages and currents under ~ 150 watts of RF drive power.

The designs herein are from W3NQN's second-generation[i] bandpass filters utilizing the Cauer family of filters.

The following pages are in frequency progression, beginning with 160m and working up through 10m. The details for each filter are the following:

1) Design values derived from the main reference[ii] and shown schemtically
2) Predicted performance from ELSIE[iii]
3) Schematic with element values for TOPSPICE[iv] simulation
4) TOPSPICE bandpass simulations results
5) Maximum voltages and currents for 150 W into 50Ω
6) Some example current/voltage figures from TOPSPICE
7) Inductor currents when implemented with quadrifilar or quintifilar toroids
8) Actual realization schematically with quadrifilar or quintifilar turns on input and output

K∅ZR Note:
After considerable research into various capacitor vendors it became obvious that finding sufficiently high voltage rated capacitors which are also relatively stable as required for filters, was difficult at best. Combined with minimum purchase quantities and of course the price of each, this design seems somewhat unattainable. After discussions with NC4S, wherein he expressed concern about the power ratings of the toroids, I spent some time looking into the maximum flux density incurred in the more stressing cases and found additional problems. In those cases where I thought I would just go to a larger core size to address flux density, staying within the same core material family, I found that those core sizes were not easily available. Therefore, this design is not going to be pursued further, falling back to the original Chebyshev-based N3NQN designs.

In the meantime, the analysis which follows had already been completed so is included here for the person that has a deeper "junk drawer" or is more adept at finding hard-to-find parts.

The Filters

160M Bandpass Filter

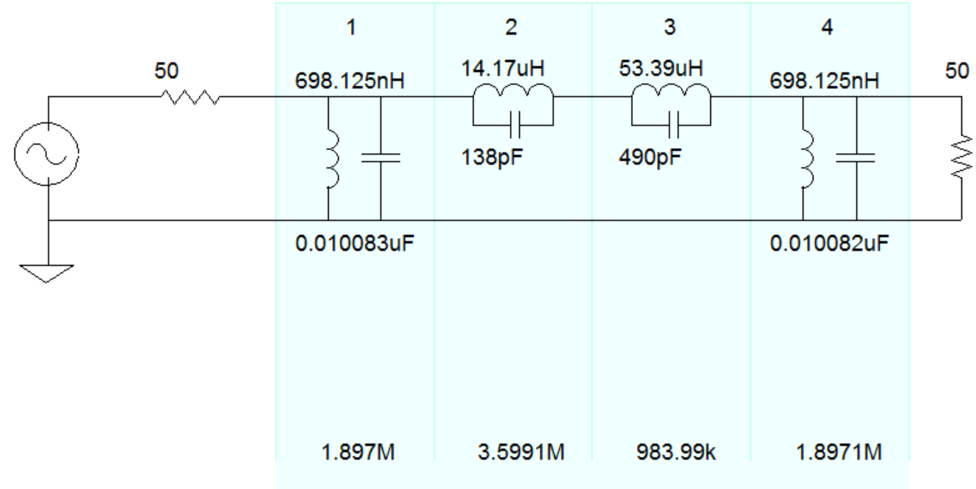


Figure 1-1 These are the Resonant Frequencies of Each Combination

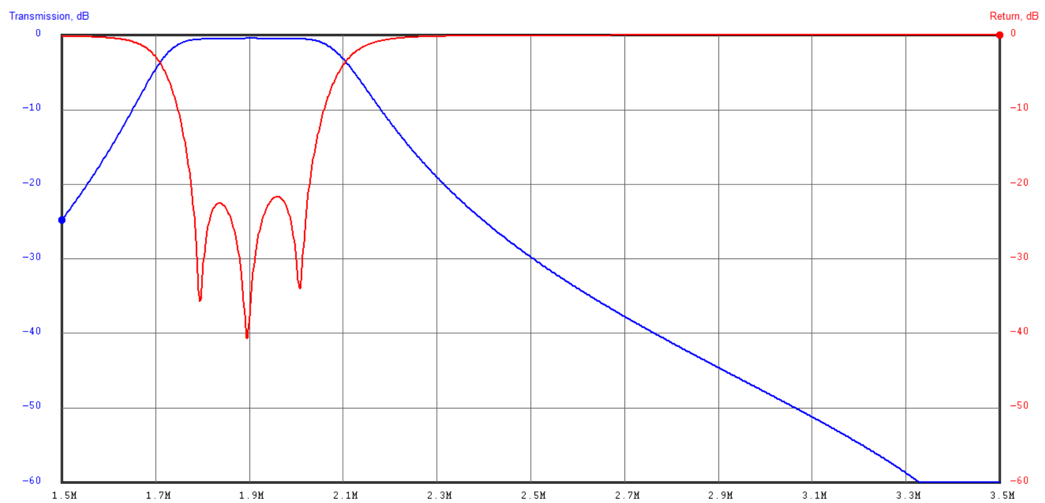


Figure 1-2 ELSIE Predicted Performance

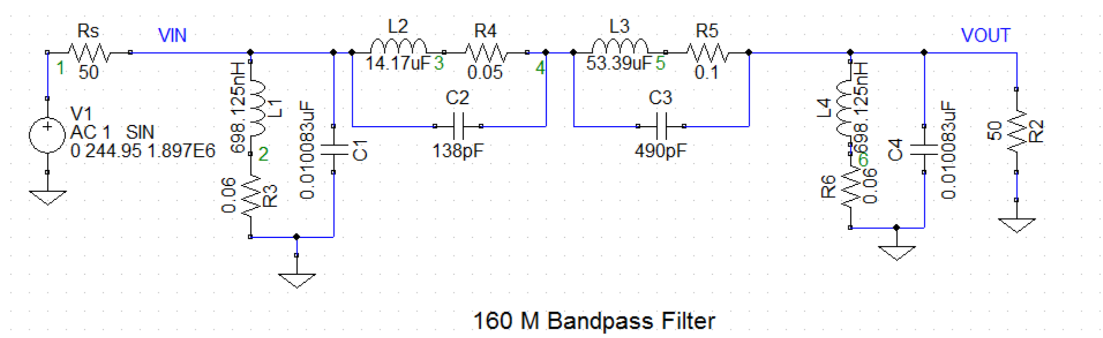


Figure 1-3 Schematic as Viewed in TOPSPICE (single windings format)

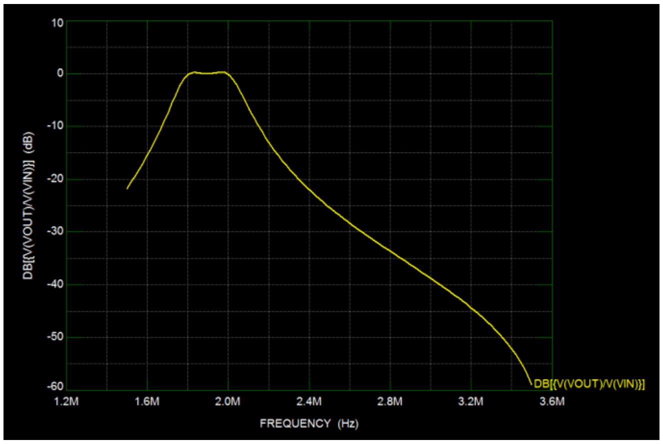


Figure 1-4 Passband Response of 160m BPF in TOPSPICE

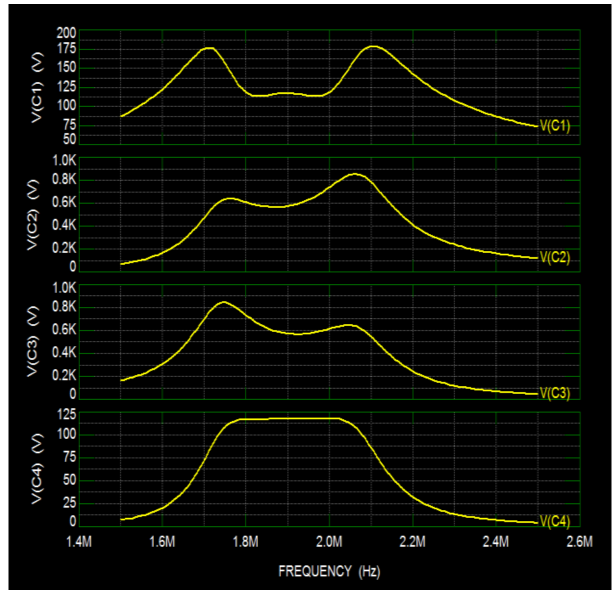


Figure 1-5 Capacitor Voltages in 160m BPF from TOPSPICE

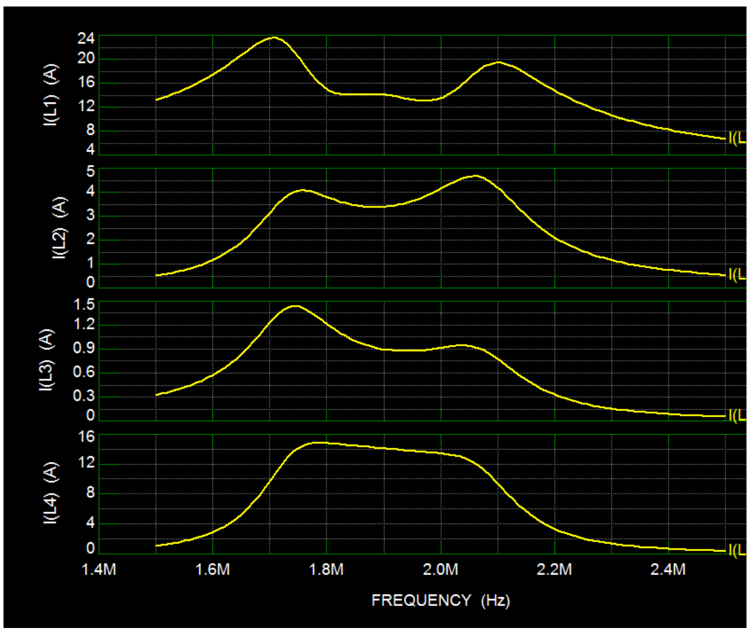


Figure 1-6 Inductor Currents in Single Inductor Version { Schematic in Figure 1-3 }

The currents to the left in Figure 1-6 are for the BPF of Figure 1-3, wherein Quadrifilar windings have not yet been implemented. Use of quadrifilar windings changes the current levels significantly, as we will see shortly.

Notice that summing the first four currents in Figure 7 equals the total current in L1 in Figure 1.6. { L1 in Figure 1.6 is the equivalent of L1 - L4 in Figure 1.7 }

Figure 1.9 is the schematic for the simulations in Figure 1.7.

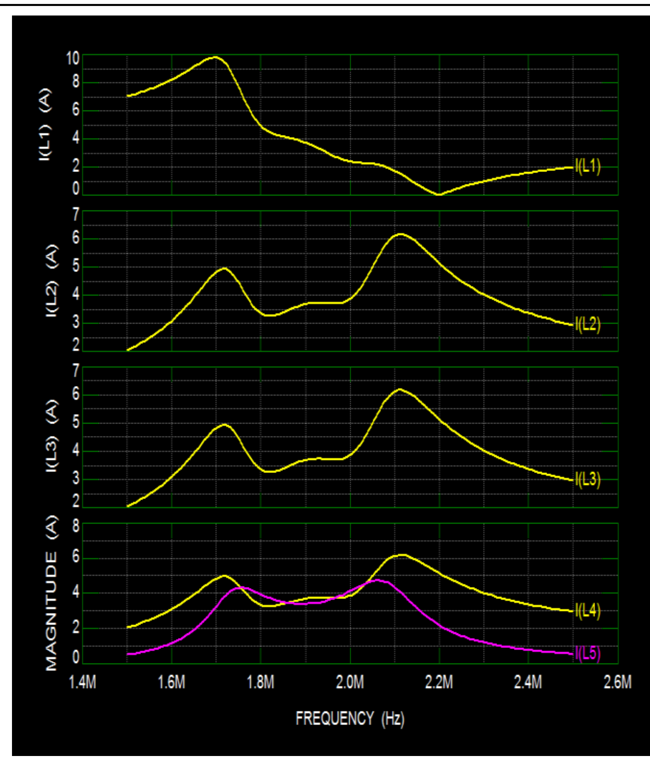


Figure 1-7 Currents in the Quadrifilar Version of the 160m BPF

Note the following observations. Below the designed passband frequency the current magnitude in winding L_1 can be considerably greater than in the other quadrifilar windings $L_2 - L_4$. The converse is true above the passband frequency where at one point $I(L_1)$ is actually zero while $I(L_2) - I(L_4)$ are approximately 6 amps.

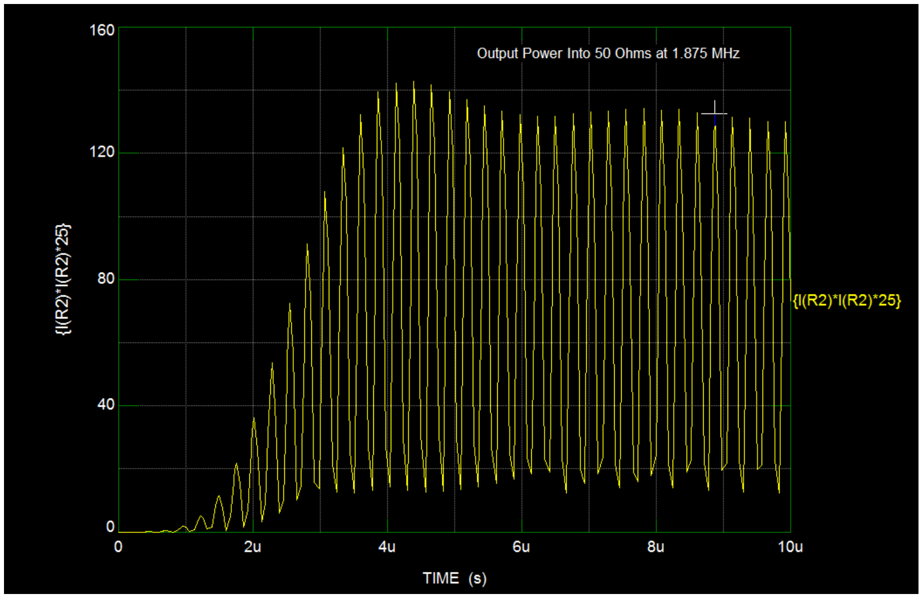


Figure 1.8
150 Watts Input Power / ~ 135 Watts Ouput Power (~ 0.45 dB Loss)
Results Taken from Transient Analysis

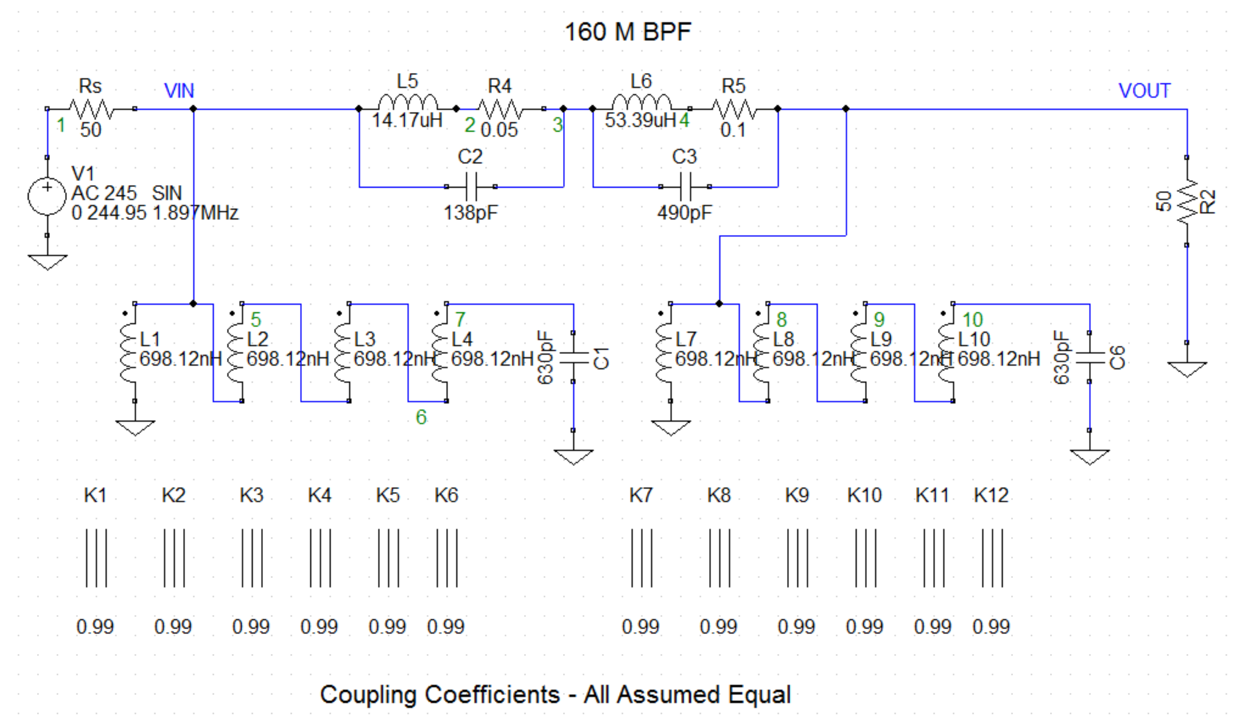


Figure 1.9

80 M Bandpass Filter

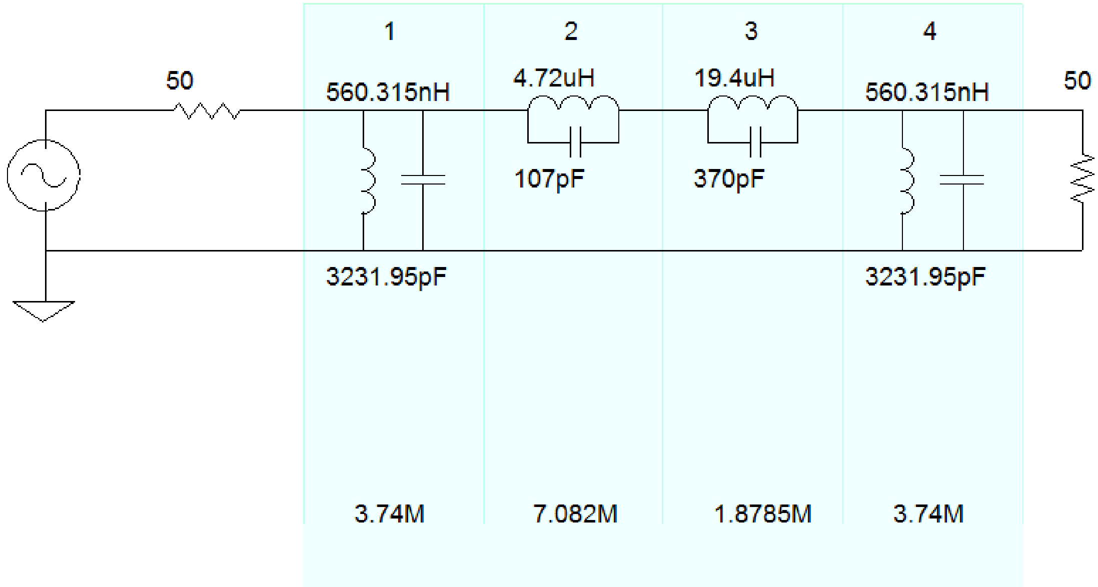


Figure 2.1 These are the resonant frequencies of each combination

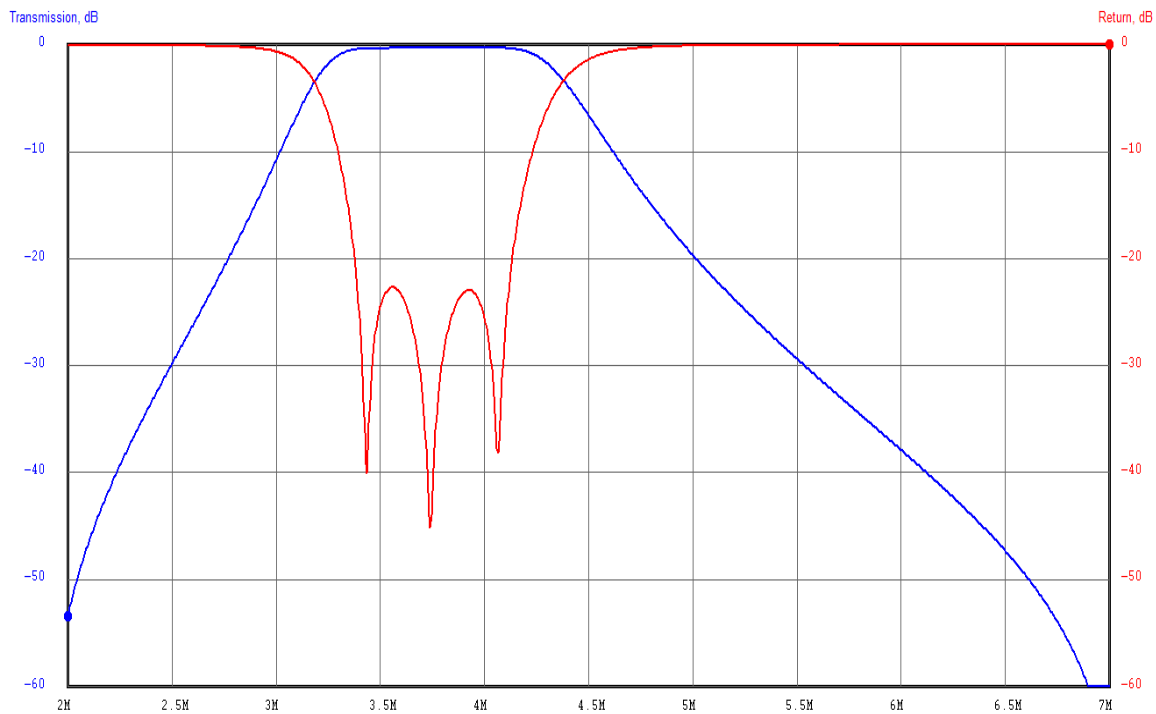


Figure 2.2 ELSIE Predicted Performance

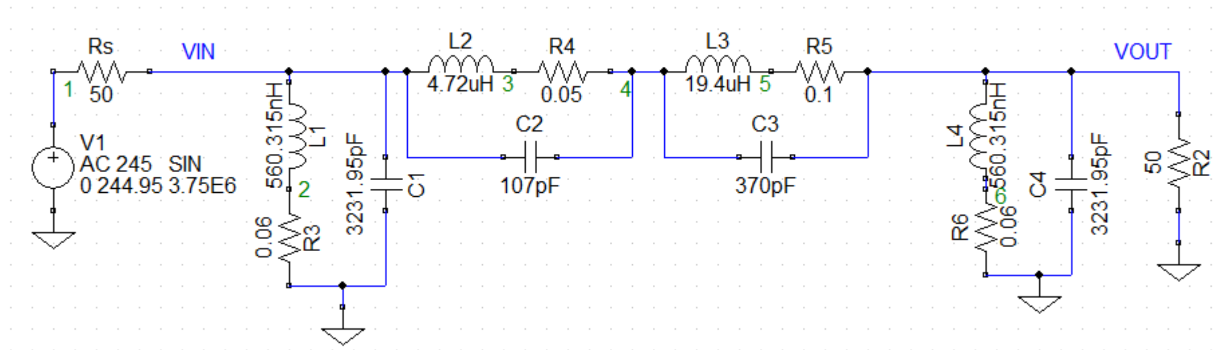


Figure 2.3 80 M Schematic as Viewed in TOPSPICE (Single Windings)

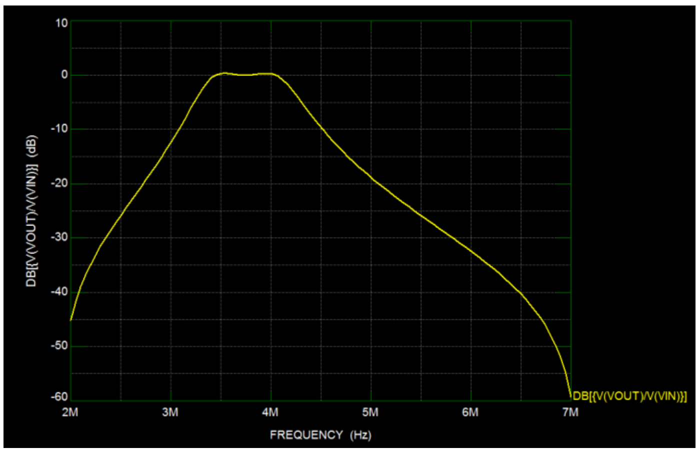


Figure 2.4 Passband Response of 80 M BPF in TOPSPICE

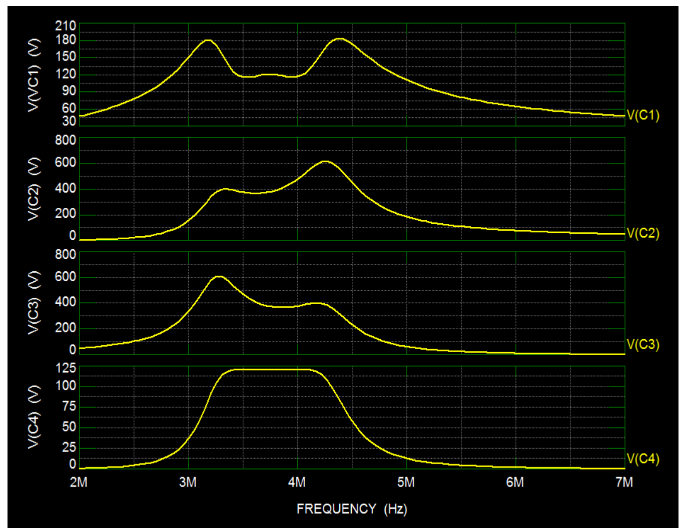


Figure 2.5 Capacitor High Voltages for Schematic in Figure 2.3 ↑

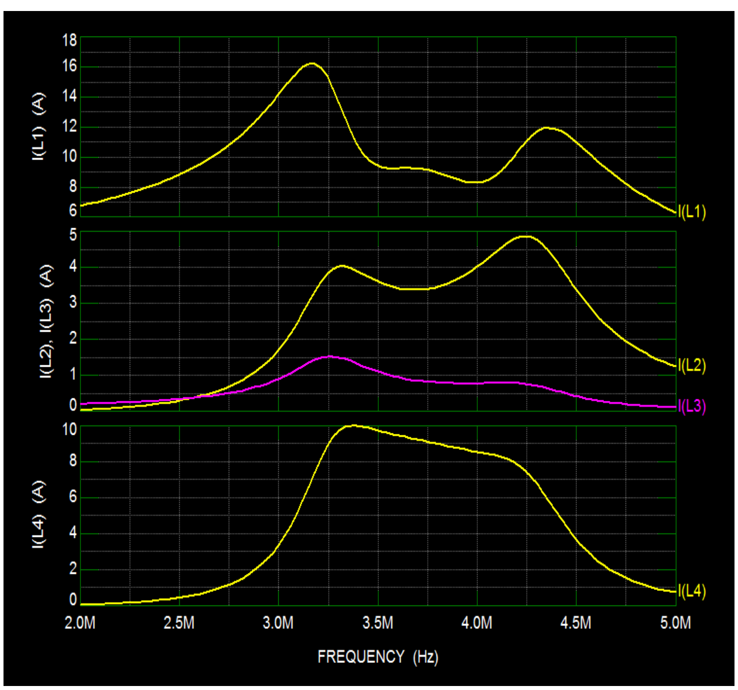


Figure 2.6

Current Through Inductors L1 – L4

These currents are for the schematic above, Figure 2.3, not the case wherein Quadrifilar windings are in use. Quadrifilar windings change the current levels; see following Figure 2.7.

Figure 2.7

Current Through the Four Windings of the Quadrifilar Toroid Comprising L_1

Notice that summing the first four currents in Figure 2.7 equals the total current in L_1 in Figure 2.6. { L_1 in Figure 2.6 is the equivalent of L_1 – L_4 in Figure 2.7 }

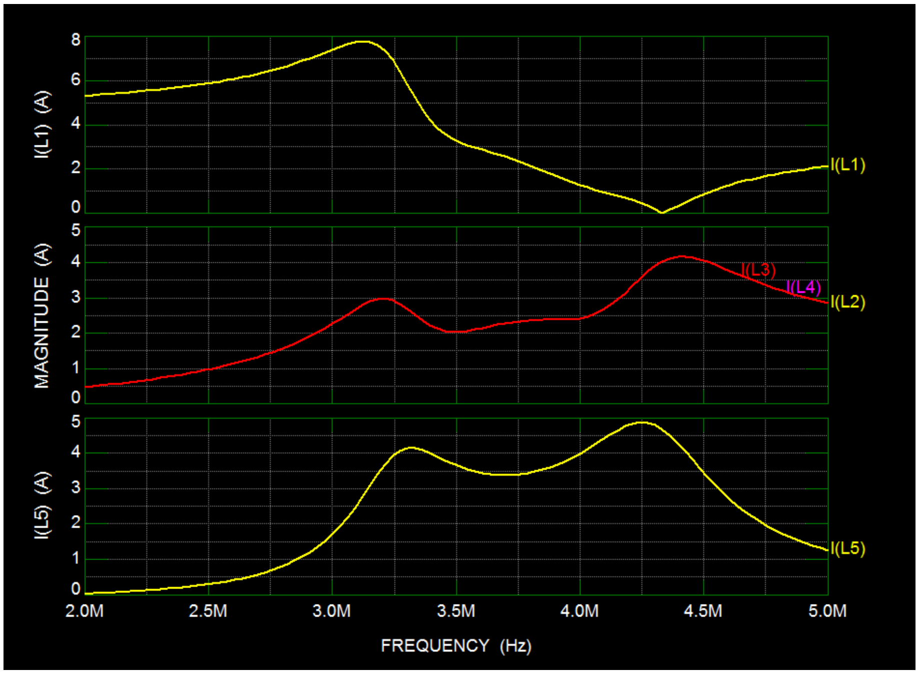


Figure 2.8 is the schematic for the simulations in Figure 2.7.

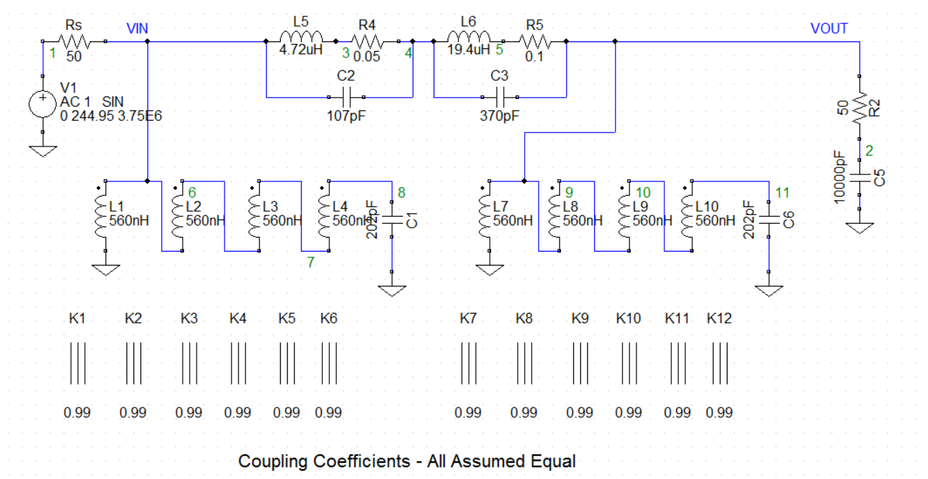


Figure 2.8 TOPSPICE Simulation with Quadrifilar Turns on L1 and L4

Table 1 Ampacity for Various Wire Gauges

AWG	Dia Inch	Cir Mil	Dia mm	Area $Inch^2$	lb/kft	ohms /kft	Ohms /km	CU Max free-air Amps	CU Max enclosed Amps
32	0.008	63.2	0.20	4.964E-05	0.19	164.1	538.4	.53	0.32
30	0.010	100.5	0.25	7.894E-05	0.30	103.2	338.6	.86	0.52
28	0.013	159.8	0.32	1.255E-04	0.48	64.9	212.9	1.4	0.83
26	0.016	254.1	0.40	1.996E-04	0.77	40.81	133.9	2.2	1.3
24	0.020	404.0	0.51	3.173E-04	1.22	25.67	84.22	3.5	2.1
22	0.025	642.4	0.64	5.046E-04	1.94	16.14	52.95	7.0	5.0
20	0.032	1,021.5	0.81	8.023E-04	3.09	10.15	33.30	11.0	7.5
18	0.040	1,624.3	1.02	1.276E-03	4.92	6.385	20.95	16	10
16	0.051	2,582.7	1.29	2.028E-03	7.82	4.016	13.18	22	13

40 M Bandpass Filter

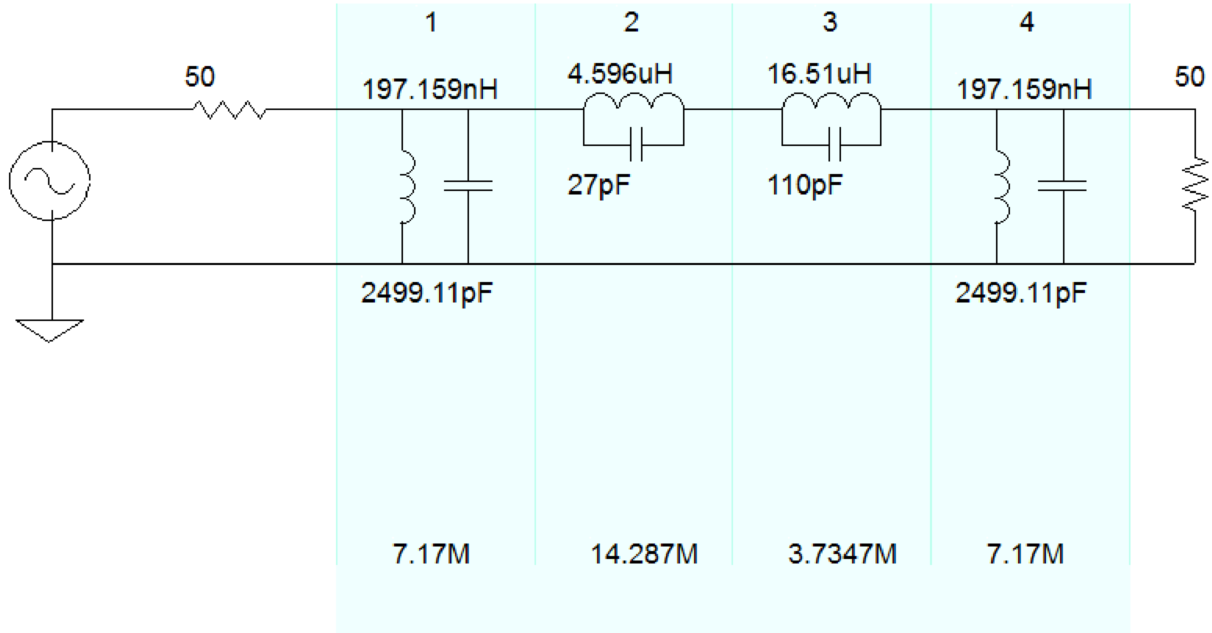


Figure 3.1 These are the resonant frequencies for each combination

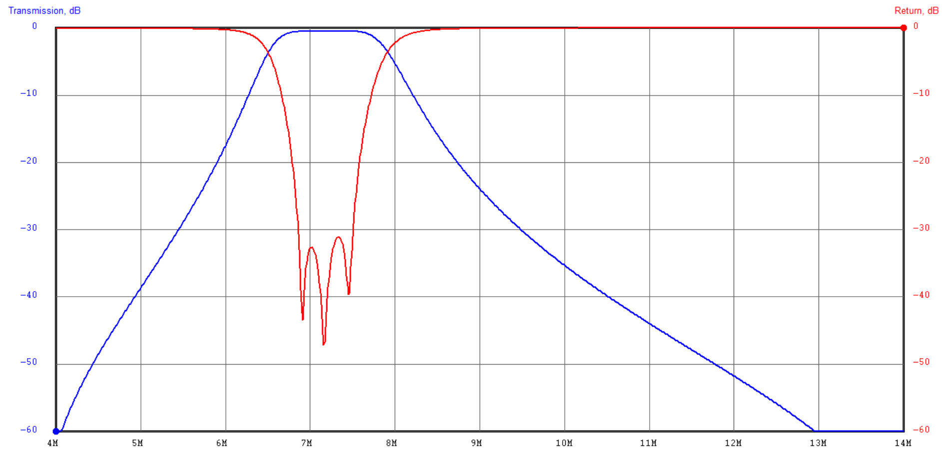


Figure 3.2 ELSIE Predicted Performance

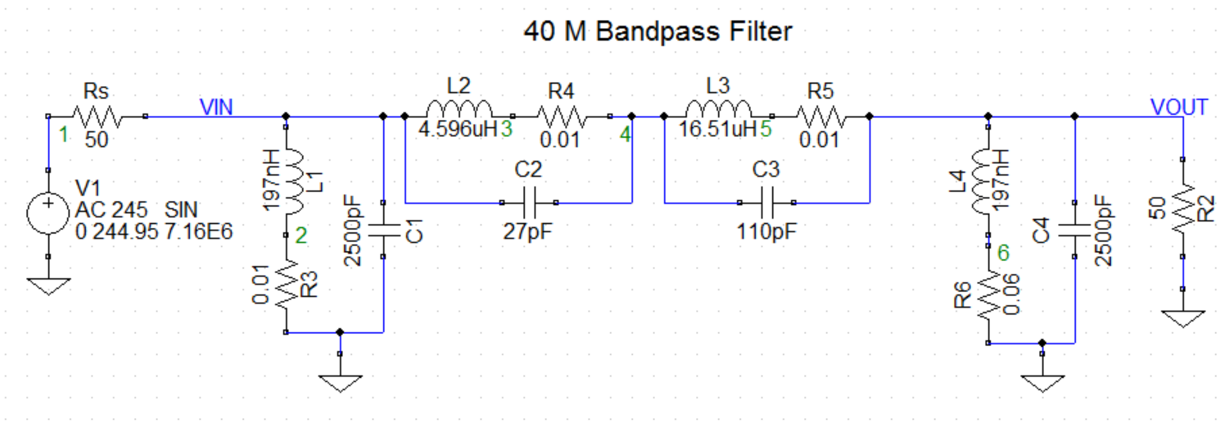


Figure 3.3 TOPSPICE Schematic for 40 M BPF (Single Windings)

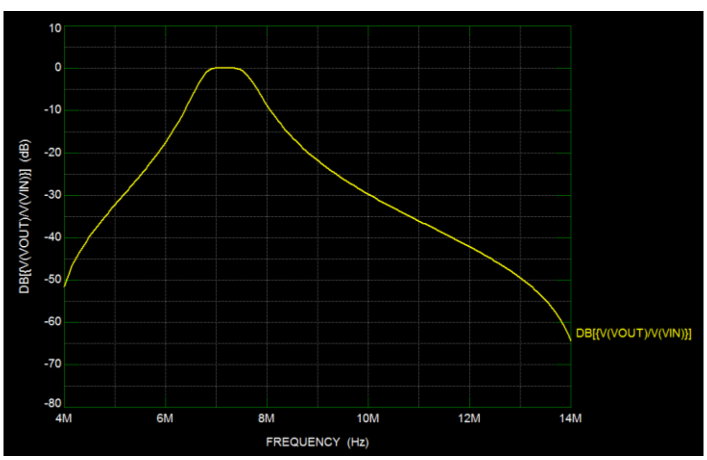


Figure 3.4 40 M BPF Response

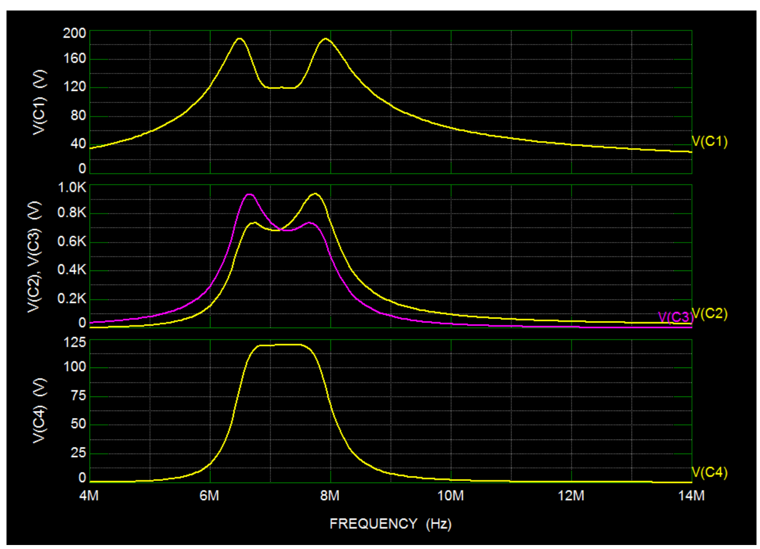


Figure 3.5 Capacitor Voltages 40 M BPF Figure 3.3

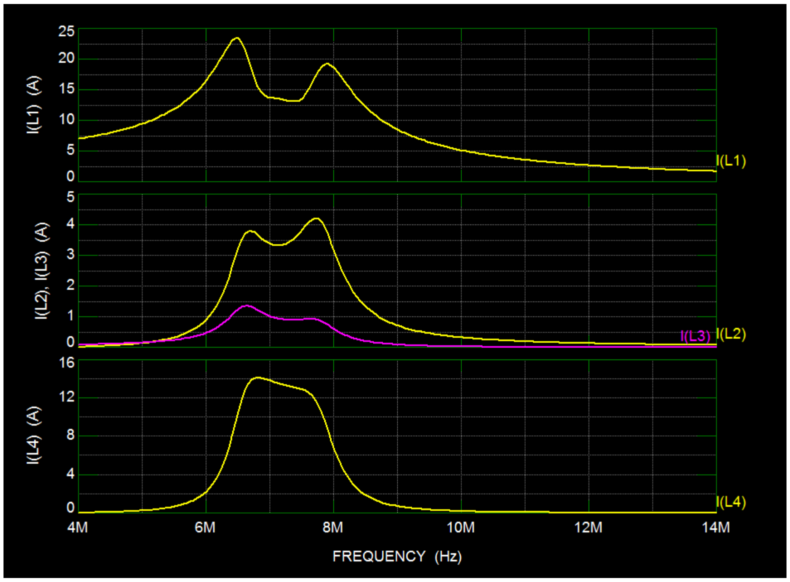


Figure 3.6

Simulation Results for TOPSPICE Schematic in Figure 3.3

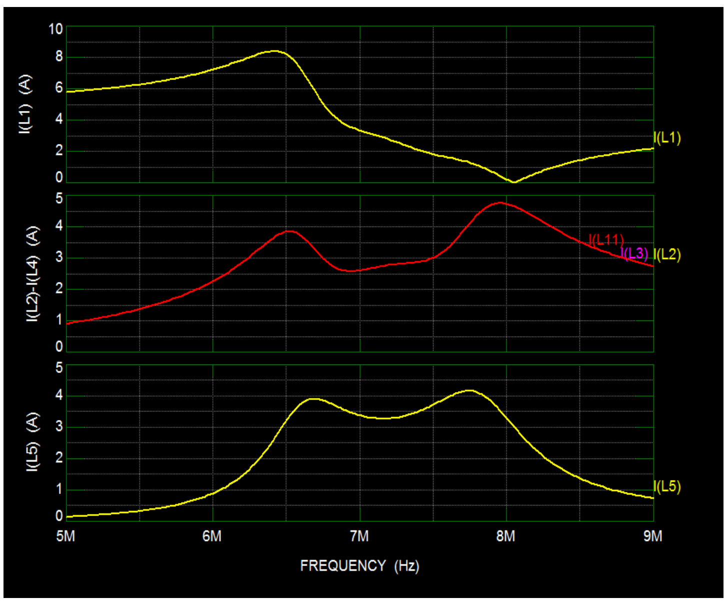


Figure 3.7

Current Through the Five Windings of the Quintifilar Toroid Comprising L_1

Notice that summing the first five currents in Figure 3.7 equals the total current in L1 in Figure 3.6. { L_1 in Figure 3.6 is the equivalent of $L_1 + L_4 + L_{11}$ in Figure 3.7 }

Figure 3.8 is the schematic for the simulations in Figure 3.7.

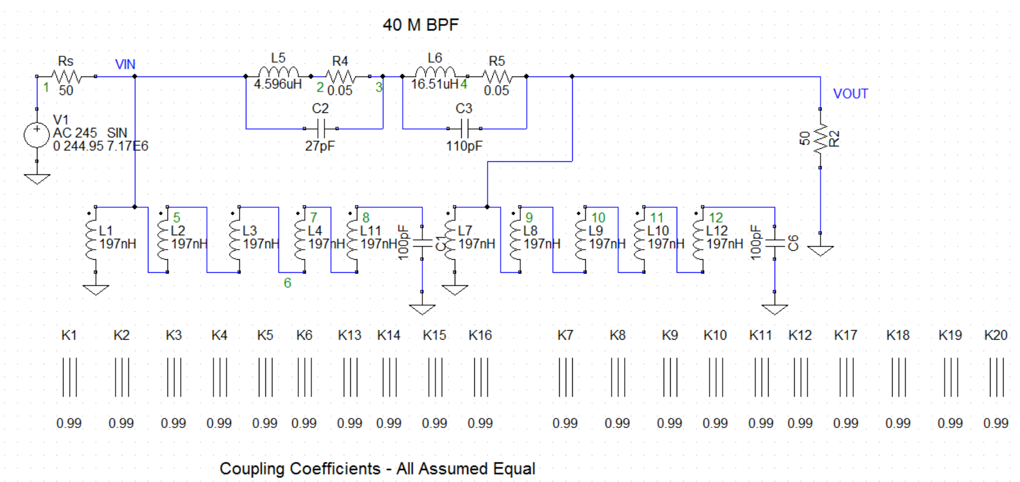


Figure 3.8 Quintifilar Turns on L1-L4 & L11 on Input and L7-L10 & L12 on the Output

20 M Bandpass Filter

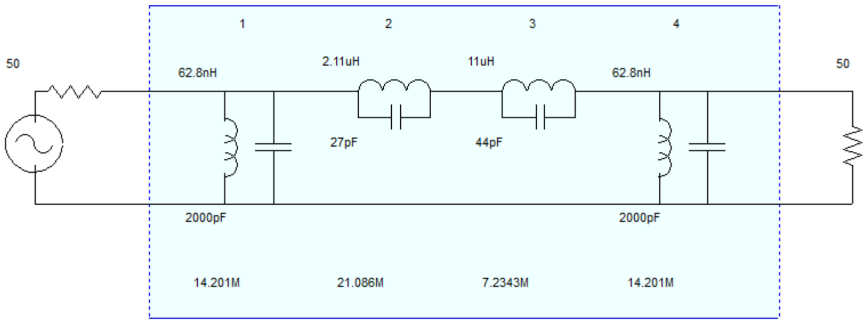


Figure 4.1 ELSIE Design 20 M BPF

The resonant frequencies for each resonator are shown

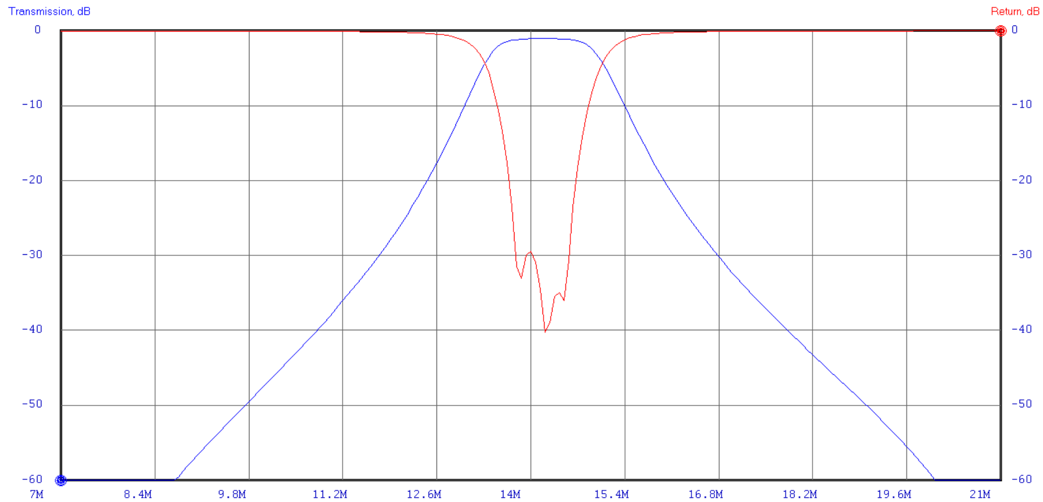


Figure 4.2 ELSIE Predicted 20 M BPF Performance

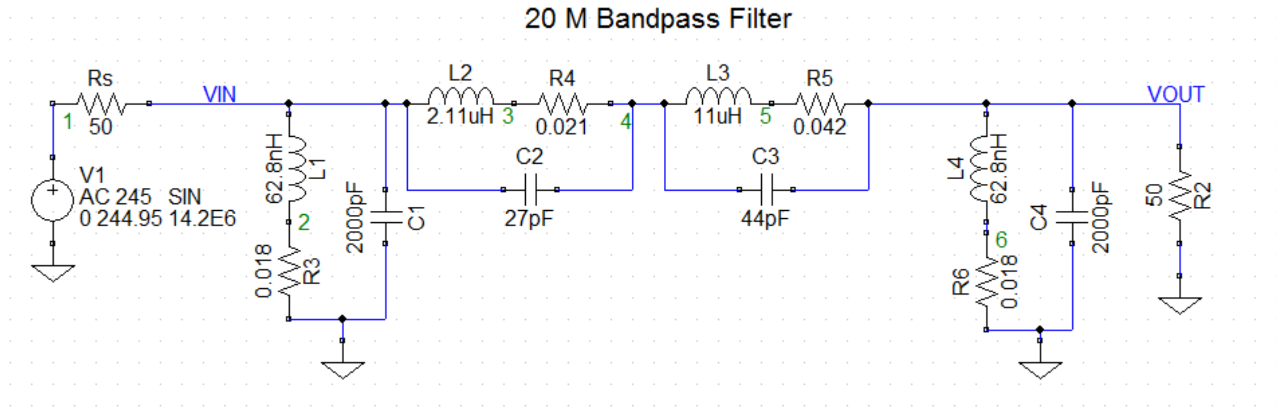


Figure 4.3 TOPSPICE Schematic of 20 M BPF (Single Windings)

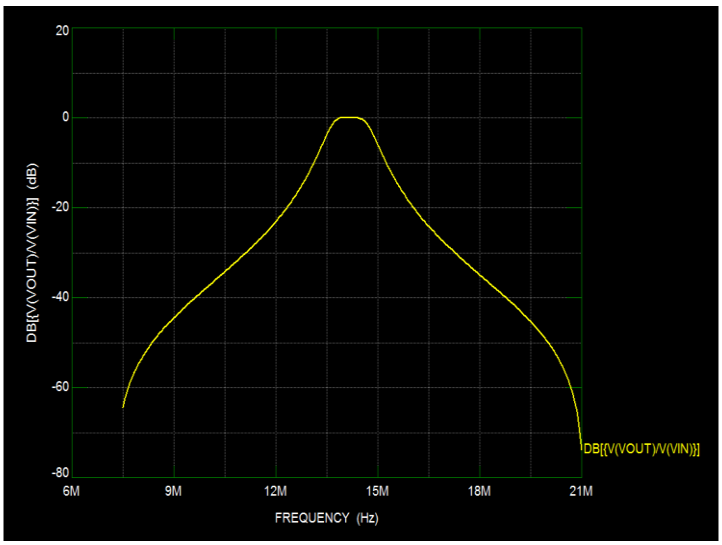
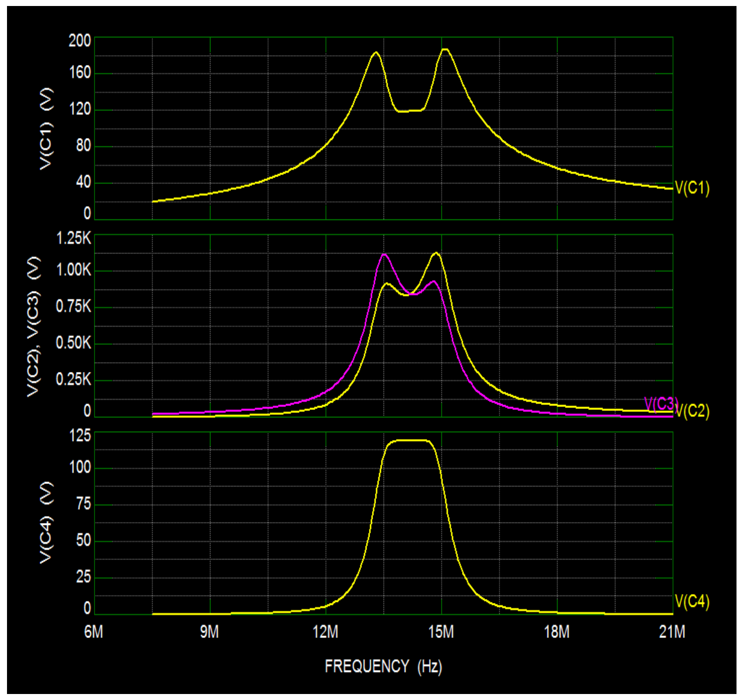


Figure 4.4 TOPSPICE Simulation Results

Figure 4.5 Maximum Voltages Predicted →



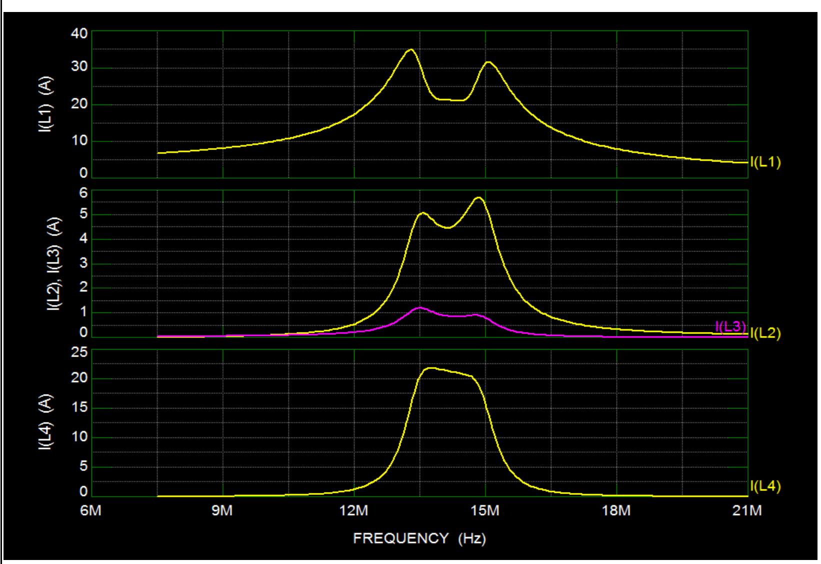


Figure 4.6

Simulation Results for Schematic in Figure 4.3

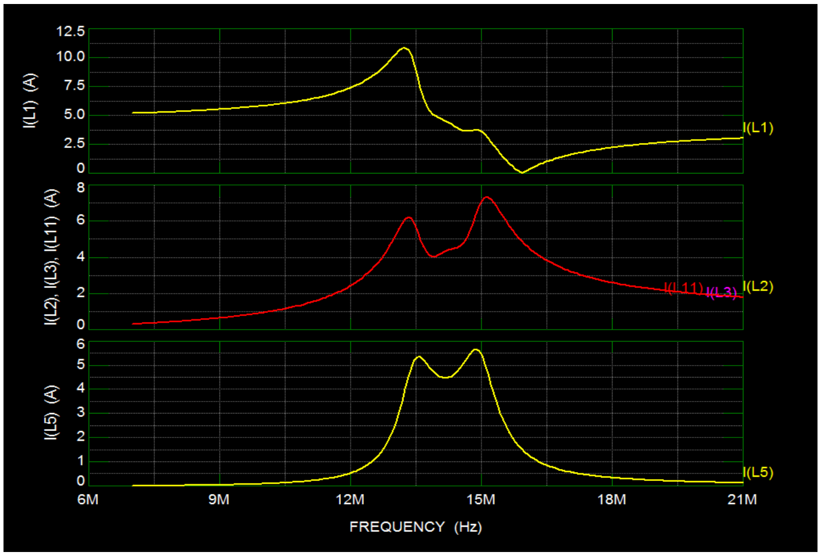


Figure 4.7

Including the inherent coil resistance in the quadrifilar realization changed the peak current in L_1 by only ~ 60 mA.

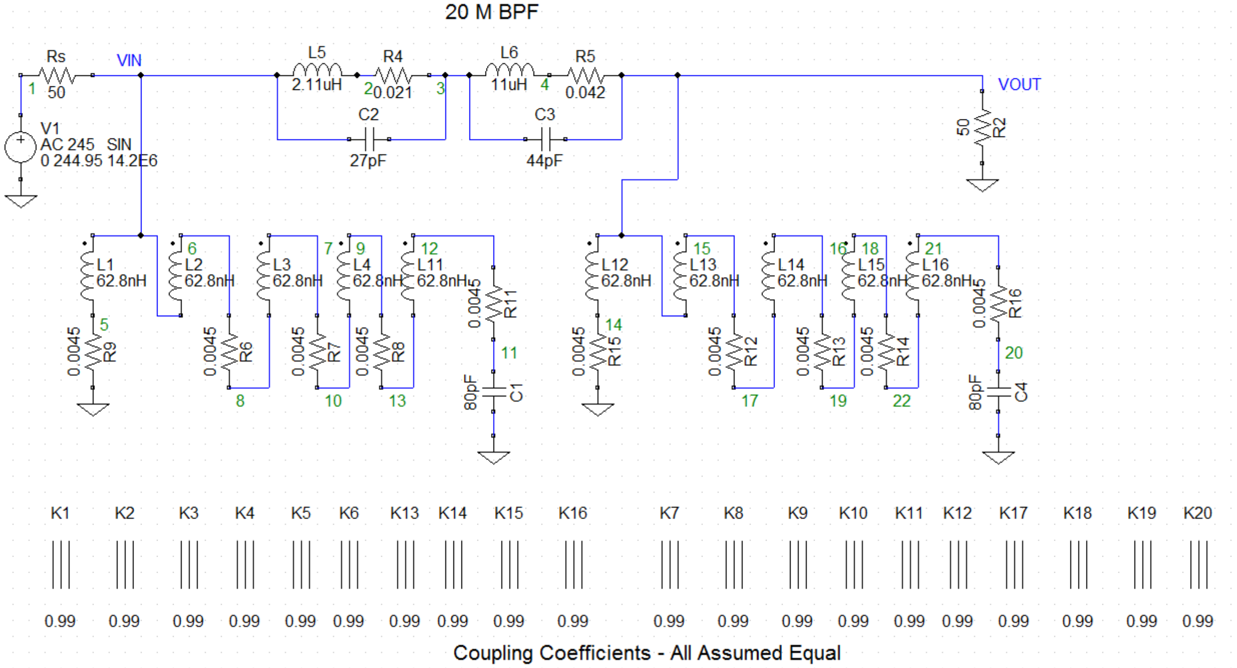


Figure 4.8 20 M BPF With Quitifilar Windings and Associated Resistance in Each

Coupling Coefficients

Quadrifilar Windings		
K1	L1	L2
K2	L1	L3
K3	L1	L4
K4	L2	L3
K5	L2	L4
K6	L3	L4

Quadrifilar Windings		
K1	L1	L2
K2	L1	L3
K3	L1	L4
K4	L1	L5
K5	L2	L3
K6	L2	L4
K7	L2	L5
K8	L3	L4
K9	L3	L5
K10	L4	L5

In the TOPSPICE simulation schematics, one notes a large number of items running along the bottom with designations of K_M to K_N. These are the coupling coefficients associated with each winding of the multi-winding toroids. Each coupling coefficient was set equal to 0.99 for these analyses.

For example, in the table above for the quadrifilar windings,

K_1 accounts for the coupling between L_1 and L_2 while K_2 accounts for the coupling between L_1 and L_3, etc.

For the remaining filters, 15 m and 10 m, only the currents will be assessed for the as-built configuration. The original article did not include any design for 10 m so one is offered here in its absence.

15 M Bandpass Filter

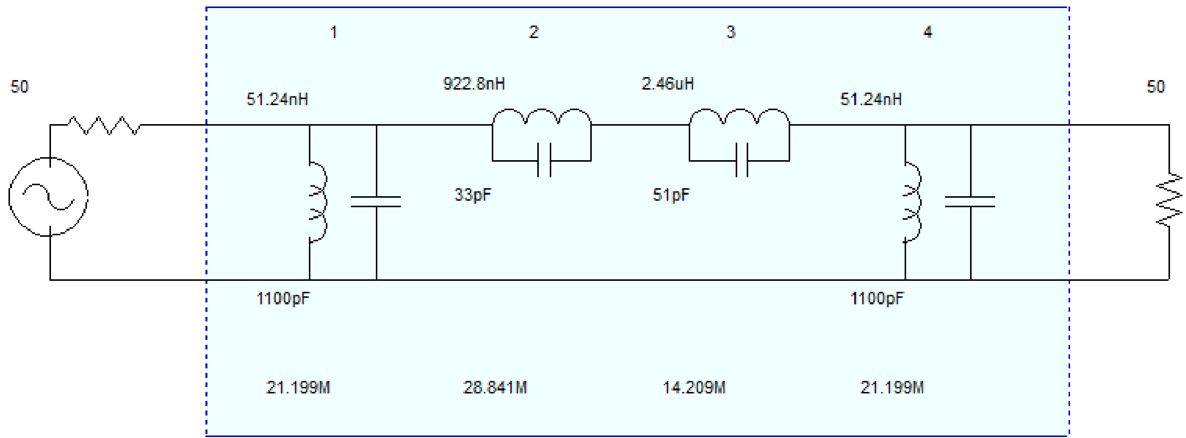


Figure 5.1 15 M Bandpass Filter Schematic

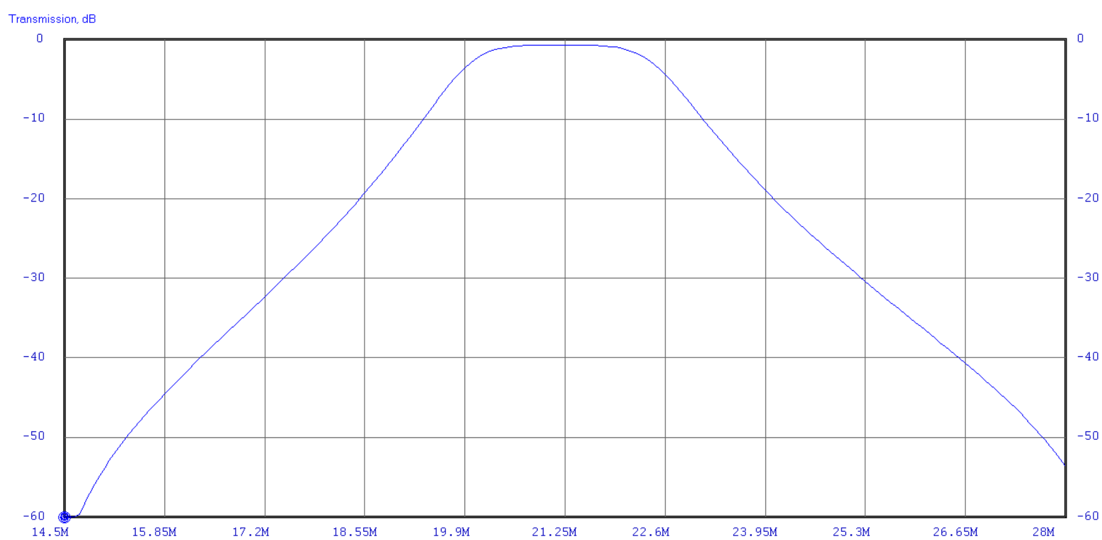


Figure 5.2 ELSIE Predicted Frequency Response for 15 M Filter

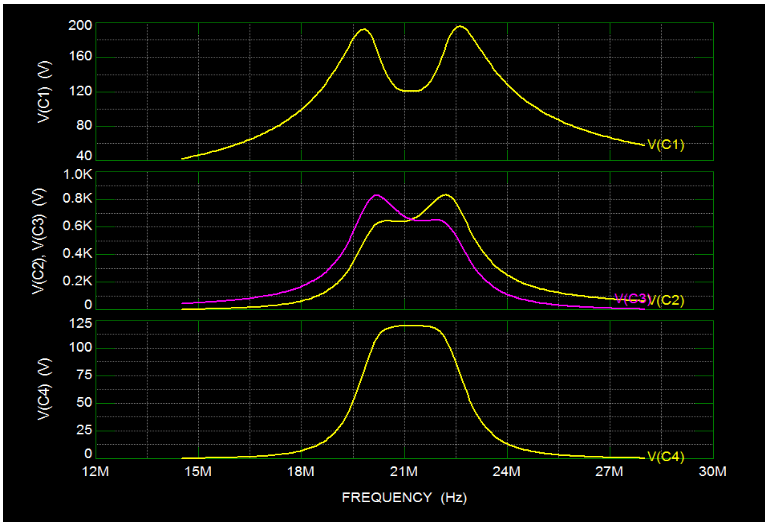


Figure 5.3

Capacitor voltages in the 15 M bandpass filter

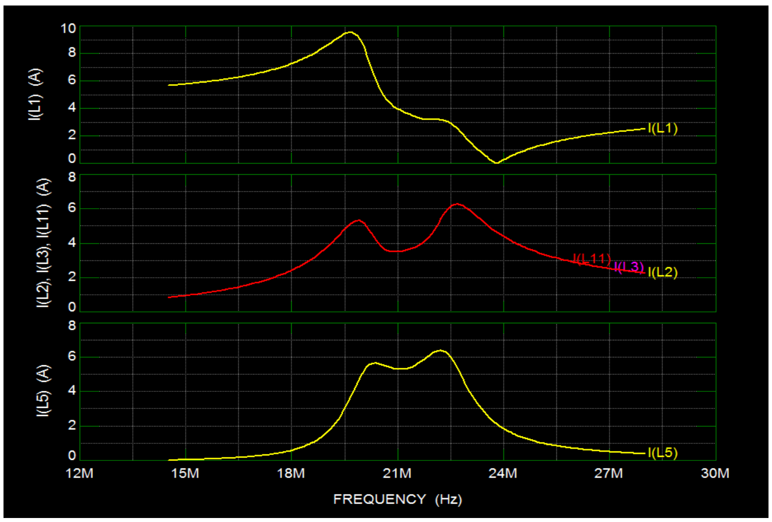
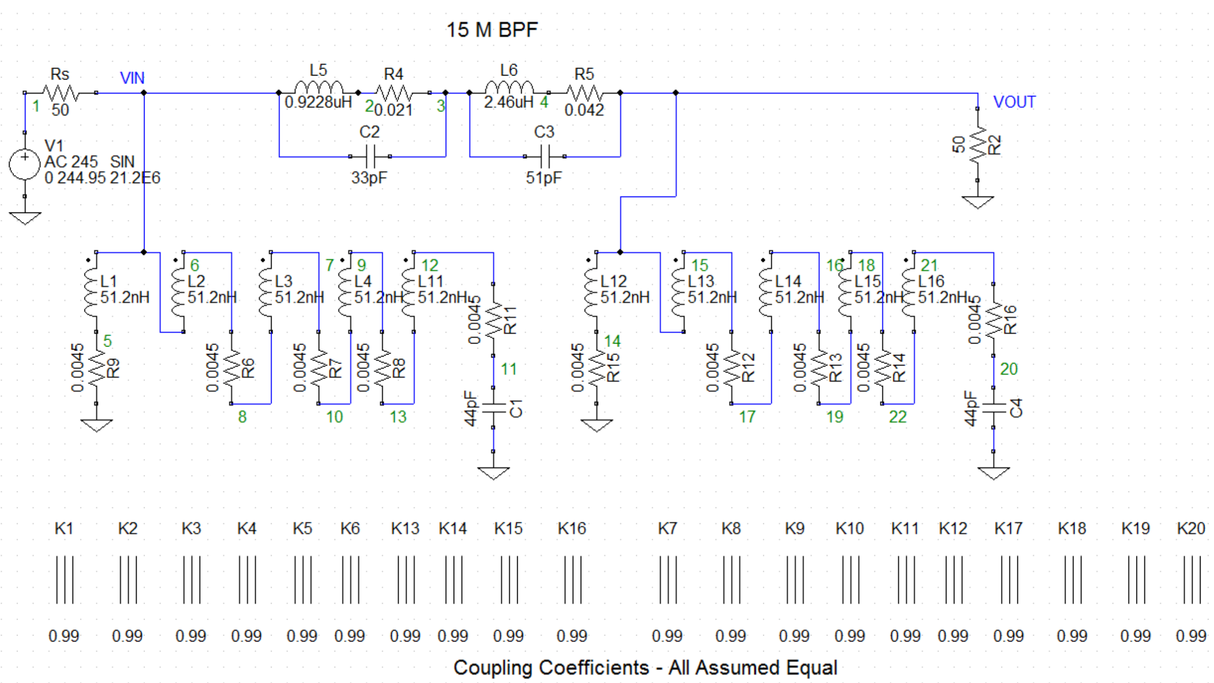


Figure 5.4

Actual inductor currents in the physical realization of the 15 m filter. See associated schematic below in Figure 5.5.



10 M

High-pass Filter

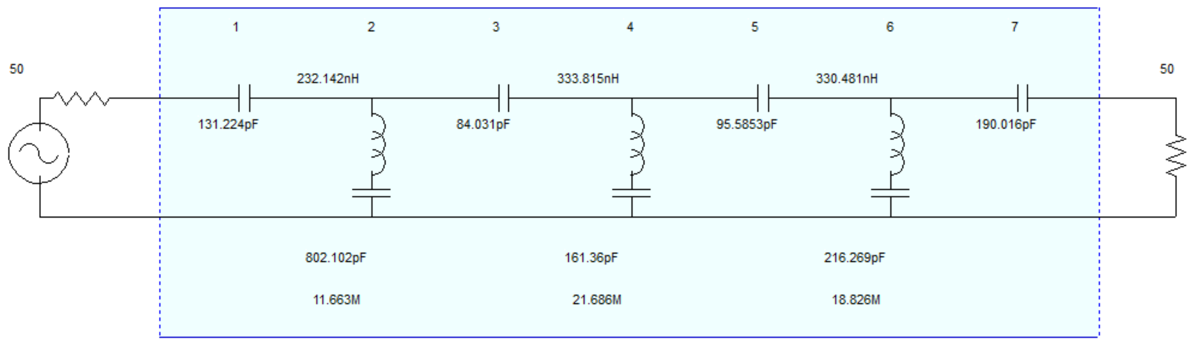


Figure 6.1 A N=7 Cauer High-Pass Filter

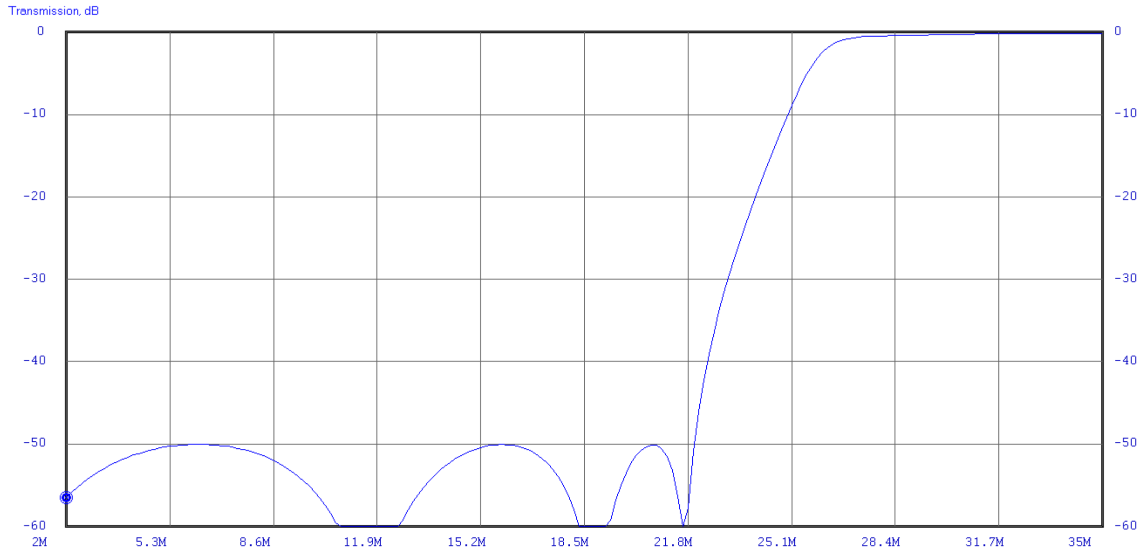


Figure 6.2 ELSIE Theoretical Performance

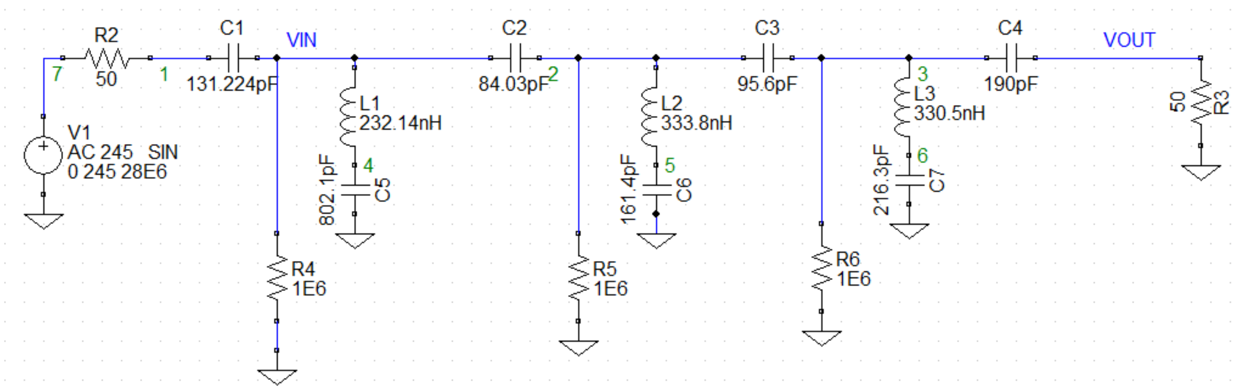


Figure 6.3 TOPSPICE Schematic

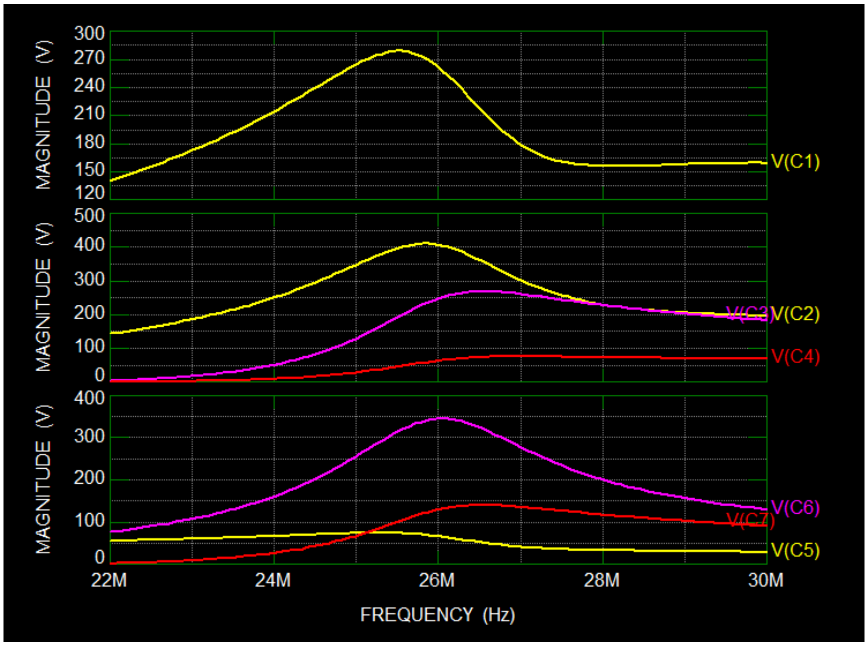


Figure 6.4

Respective Capacitor Voltages

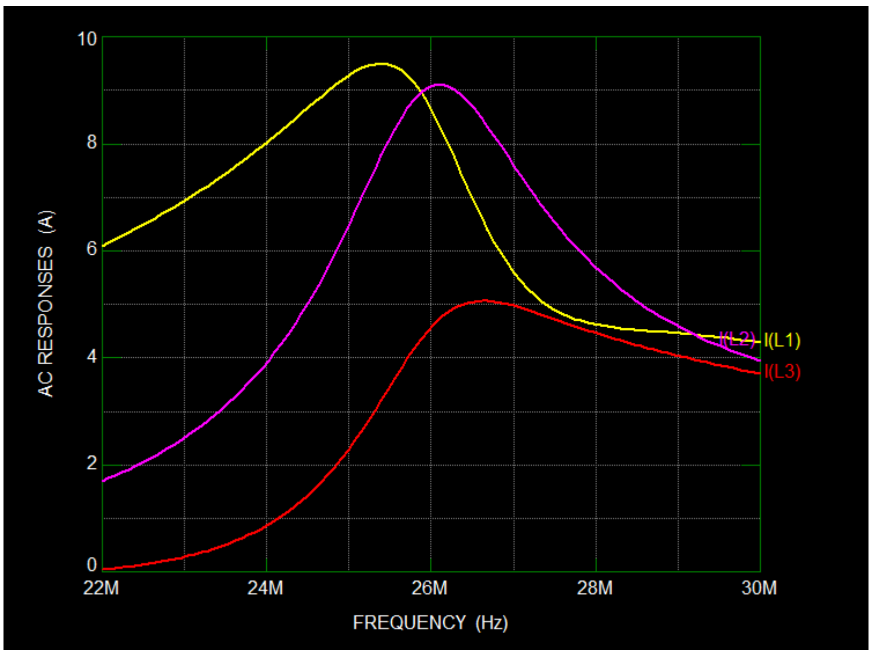


Figure 6.5

Respective Inductor Currents

Inductor Calculations

Most amateurs are familiar with the expression for calculating the number of turns required on an inductor.

$$N = 100\sqrt{\frac{L_{\text{Required}}}{A_L}}$$

I have performed those calculations here for each inductance value required and compared the calculated turns to those sited in the QST design article. The following table contains these calculations and comparisons.

Toroid Type	AL	Inductance	Calc Turns	QST Design	
T94-2	84	11.17	36.466	36	
		14.17	41.072	40	
		8.965	32.669	32	
		19.4	48.058	47	
		16.51	44.334	44	
		11	36.187	35	160m
					80m
					40m
T94-6	70	4.72	25.967	26	20m
		4.926	26.528	25	15m
		4.596	21.438	24	10m
T94-17	29	1.57	23.268	20	
		2.11	26.974	25	
T80-17	22	1.28	24.121	20	
		0.9228	20.481	18	
T80-6	45	2.46	23.381	22	
		0.232	7.180		
		0.333	8.602		
		0.33	8.563		

As my design/analysis activities continue I will add to this document.

Discussion

Clearly from the analysis presented herein, one must be cautious about voltages and currents in these filters. Further evaluation into the capacitor realizations is necessary. Placing double-size capacitors in series to divide up the high-voltage requirements comes at both added cost and additional parasitics. The cost may possibly be less, however, in that 500 V silver mica capacitors are less expensive than 1 KV types, for example.

Of some concern, but to a lesser degree, is the required trace widths to handle associated current densities if a PCB is used; the current plan. Also from the ampacity table included in this write-up, current handling capabilities of the wire used on the toroids must be considered. It may turn out that these filters are rated at 100 W rather than 150 W just to control parts requirements to reasonable costs.

It is envisioned that each resonant circuit will be mounted on the PCB, both inductor and capacitor(s), but not connected to its nearest neighbors. A one-to-two turn inductive winding will be passed through each toroid and this connected to the input port of a one-port vector network analyzer. Using this instrument, adjustments will be made to bring each resonator to the proper resonant frequency. Once all the resonators are tuned, all the interconnections will be made and the network analyzer used in its conventional two-port mode, tuning for optimum return loss in the passband while also monitoring S_{21} in other frequency ranges of interest.

Now the arduous task of vendor identification for parts with the criteria of minimizing costs. In conjunction with this, based on availability, I will need to determine which capacitors will be "doubled" in order to handle the anticipated high voltages and/or reduce associated costs.

KØZR

[i] "Receiver Band-Pass Filters Having Maximum Attenuation in Adjacent Bands," QEX, July/Aug 1999
[ii] "Receiver Band-Pass Filters Having Maximum Attenuation in Adjacent Bands," Ed Wetherhold, W3NQN, July/August 1999 QEX

[iii] ELSIE – a free LC filter design software package for windows. "Free" up to 3rd order class of filters

[iv] TOPSPICE – version 8.05a used in the accompanying simulations