Contest Bandpass Filters

Build a set of W3NQN filters for multi-operator contesting

My first multi-operator experience was a ham-camping trip with my brother Bill (NG4T) in 2000. After installing a couple of wire antennas in the trees we discovered that when one of us was transmitting the other couldn't receive anything but interference. I later learned that simultaneous operation of two radio transmitters in close proximity on separate bands will overload and desensitize the radio's receivers. A bandpass filter for each radio can be used to reduce this problem but the filter must be able to withstand the transmitter's power.

Building a set of bandpass filters has been on my "to do" list since that first camping trip. All components have been readily available except the high voltage NP0 capacitors that Ed Wetherhold, W3NQN, used in his original construction article[1]. I recently discovered a source for these capacitors from the TXBPF project[2]. These mica capacitors are designed for RF transmitter filters and are available in 1 pF steps from 10 to 3500 pF[3].

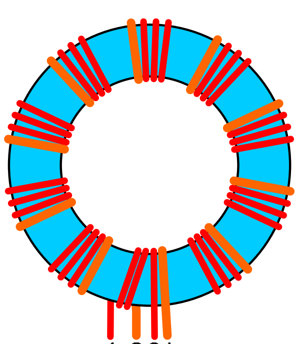
I considered building the TXBPF but realized that each operator would need a six filter set as it is intended for single radio use and does not prevent operators from choosing the same band on which to transmit. A six band filter with two automatic band decoders and relay switching was also considered but the cost of large PC boards was prohibitive. In the end, I decided that a set of six filters in one enclosure would be the most economical. Each operator would simply select a band filter that was not in use.

Construction

A PC board was designed to allow the input and output SO-239 connectors on each filter to be soldered directly to the board[4]. The board layout is similar to the TXBPF in an attempt to use the same capacitor values, as some of the values differ slightly from the original W3NQN article. The PC board was developed using ExpressPCB and six filter boards were ordered.

Toroids

In hindsight, I highly recommend the use of different color enameled wire to distinguish between the primary and secondary turns on the L1 and L3 toroids. Winding the relatively stiff #16 and #18 wire will leave you with sore fingers and a few blisters so you may want to wind only a few at one sitting.



The TXBPF pictorial winding guide was very helpful for the first quadrifilar toroid. Study this guide, paying particular attention to the completion of the first Hi-Z layer and start of the second Hi-Z layer. For the 40m quadrifilar toroid shown at left, wire 1 (orange) is the Low-Z primary start and wire 2 is the primary end, wire 3 (red) is the Hi-Z secondary start and wire 4 is the secondary end. Table 1 is a compilation of the toroids for each band with type of toroid, wire size, wire length, and number of turns. I add a couple of inches to each listed wire length to ensure sufficient lengths. Table 2 lists the toroid types, quantities, colors, and dimensions for easy identification.

Enclosure

One large enclosure was selected to house all six filters. Although, slightly larger than necessary, it was about the same cost as six individual enclosures. The optional chassis was added to provide a good ground plane. The filters are mounted on 2.5 inch centers with 0.75 inch between boards. Two pan head screws and nuts are used for each SO-239 to secure the filter to the front and rear panels. For alignment, the connectors were first installed onto the front and rear panels and the PC boards were tack soldered into place. The boards were then removed for final soldering. The PC boards are supported in the middle by two plastic standoffs and plastic screws.

Band	Inductor	Toroid	No. & Type of Turns	µH	#Turns Gauge	#16 (Inch)	#18 (Inch)
10m	L1	T106-0	4 Quadrifilar	0.761	4T #16	8.0	-
	L3				12T #16	19.6	-
	L2A	T130-17	14,15	1.10	14T #16	23.5	-
	L2B			1.26	15T #16	25.1	-
15m	L1	T130-0	5 Quadrifilar	1.053	5T #16	10.0	-
	L3				15T #16	25.0	-
	L2A	T130-17	19,19	1.87	19T #16	31.0	-
	L2B			1.88	19T #16	31.0	-
20m	L1	T130-17	5 Trifilar	1.27	5T #16	10.2	-
	L3				10T #16	17.8	-
	L2A	T130-17	18,17	1.70	18T #16	30.0	-
	L2B			1.48	17T #16	28.5	-
40m	L1	T130-17	7 Quadrifilar	3.96	7T #16	13.0	-
	L3				21T #18	-	33.0
	L2A	T130-17	30,30	4.13	30T #18	-	48.0
	L2B			4.13	30T #18	-	48.0
80m	L1	T130-17	11 Trifilar	4.93	11T #16	19.0	-
	L3				22T #18	-	34.0
	L2A	T130-17	37,37	5.97	37T #18	-	58.0
	L2B			5.97	37T #18	-	57.0
160m	L1	T130-6	10 Quadrifilar	16.46	10T #16	17.5	-
	L3				30T #18	-	45.7
	L2A	T130-6	39,38	14.8	39T #18	-	60.0
	L2B			14.2	38T #18	-	59.0

Table 1

Qty	Type	Color	Diameter
2	T106-0	Tan	1.06”
2	T130-0	Tan	1.30”
4	T130-6	Yellow/Clear	1.30”
16	T130-17	Blue/Yellow	1.30”

Table 2

Assembly
First, solder the L1/C1 and L3/C3 components on the filter boards. Each L1/C1 and L3/C3 circuit should be adjusted to resonate within ±0.6% of the desired filter center frequency by compressing/spreading turns. Then, each L1/C1 and L3/C3 pair should be adjusted to be resonant at the same frequency ±0.2%. When this has been accomplished it is time to install and adjust L2a, L2b, and C2 for final tuning. The L2a/L2b/C2 circuit is adjusted by removing turns (if required), with final tweaking accomplished by compressing/spreading turns. Table 3 lists the pertinent data for tuning the filters.

Band (m)	Band Start (MHz)	Band End (MHz)	Band Center (MHz)	BPF Start (MHz)	BPF End (MHz)	BPF Center (MHz)	- 0.6% (MHz)	+ 0.6% (MHz)
160	1.800	2.000	1.90	1.753	1.995	1.870	1.859	1.881
80	3.500	4.000	3.74	3.366	4.067	3.700	3.678	3.722
40	7.000	7.300	7.15	6.740	7.584	7.150	7.107	7.192
20	14.000	14.350	14.17	13.740	16.120	14.882	14.793	14.972
15	21.000	21.450	21.22	20.430	22.040	21.220	21.092	21.347
10	28.000	29.700	28.84	27.180	30.600	28.839	28.666	29.012

Table 3

5B4AGN Tuning Instructions
The following procedure was taken directly from 5B4AGN's TXBPF Assembly Tuning document[5]:

Tuning the input and output circuits of the filters requires a signal source and a detector. Suitable combinations include:

- A spectrum analyzer and tracking generator
- A vector network analyzer
- A ham band transmitter with accurate frequency readout and an oscilloscope

Whichever set-up is used the process is substantially similar. The signal source must provide a low level signal to the Lo-Z input of L1 or L3 via a 2.7K resistor. The resistor is present to reduce the loading effect of the signal source upon the tuned circuit. This to ensure the Q of the circuit is maintained and the peak response at resonance is sharp.

If your signal source is a tracking generator or VNA then its full output can be input directly to circuit via the 2.7K resistor. If you are using your ham band transmitter as the signal source, its output should be reduced to 5 watts or less and fed into a 50Ω dummy load. Output in parallel with the dummy load is then fed to the Lo-Z winding of the tuned circuit via the 2.7K resistor. Whichever detector you use, it should be loosely coupled to the toroid via a single turn loop. Loose coupling is necessary to maintain circuit Q and that sharp peak at resonance.

With a frequency domain analyzer such as SA+TG combo or VNA, the resonant frequency of the circuit will be clearly displayed. It can be adjusted via spreading and compression of turns on the toroid to achieve the required resonance. Spreading turns will take it higher in frequency and compressing lower. With a ham band TX and scope you have a time domain display, which is a little less convenient. Adjust the TX frequency for maximum signal on the scope display. Compression and spreading of coil turns adjusts the resonant frequency to the required point. After each spread or compression, you should manually check the resonant frequency by adjusting the TX frequency for maximum signal on the scope.

Table 4 lists the turns specified by W3NQN for L2a and L2b and the number of turns 5B4AGN ended up with after tuning the filters using the Tab Mica capacitors.

Band	W3NQN		5B4AGN	
	L2a	**L2b**	**L2a**	**L2b**
160m	39	38	38	38
80m	37	37	36	35
40m	30	30	29	29
20m	18	17	18	17
15m	19	19	18	17
10m	14	15	14	14

Table 4

I strongly recommend that you start out with Ed's suggested number of turns and be prepared to remove turns during tuning. Adding turns is a lot tougher to do, though you could pad C2 instead. Neither is a great idea. Starting with too many turns and reducing is clearly the most sensible option.

The key factor in final tuning of your filters is to maximize return loss, or in other words, minimize SWR, and do so consistently across the band. My experience to date has convinced me that with either a spectrum analyzer plus tracking generator combo or with a vector network analyzer, the easiest way to proceed is to adjust for minimum pass band ripple. I have found this translates directly to best return loss performance.

Having now tuned four sets of filters, my own technique involves winding L2a and L2b to W3NQN specifications with turns evenly displaced around the core. I then mount them on the PC board without soldering and check the pass-band. If it seems I have too many turns, I remove one turn from the core which has most then check again. I continue this process one turn at a time until the balance just tips indicating not quite enough inductance. I then solder in both L2a and L2b and compress a few turns at a time until a flat pass-band is achieved.

All of this is well and good for those with elaborate equipment but for those who haven't, the alternative involves your ham band TX an SWR bridge and a 50 ohm dummy load. For initial set-up 5W output is fine assuming you have an SWR bridge which is good at that power level. Sweep the filter with RF from one band edge to the other, if lowest SWR is at the bottom of the band and rises as you go HF then L2a, b have too many turns. Remove one turn from L2a or L2b and try again. Continue removing one turn at a time until you have a flat SWR across the band. Then achieve fine adjustment via turns compression and spreading as mentioned above.

Whether you adjust your filters using elaborate equipment or the lowly SWR bridge at 5W, final check-out should be done at the 100W level into a dummy load. Your SWR bridge should hold close to 1:1 across the whole band. A soak test for half an hour at full power with 1:1 dits from a keyer is useful to make sure nothing is getting unhealthily hot.

Filter Tuning

As luck would have it my oscilloscope quit working just before completing this project. I was fortunate to have a friend lend me his Ten-Tec TAPR Vector Network Analyzer[6]. The VNA features SMA connectors so adapters were required for tuning.

Initial tuning required an adapter made from an SMA female connector with 2.7K resistor connected to a PL-259 via 50Ω coax for injecting the VNA (Transmit) into the L1/C1 and L3/C3 circuits. The VNA sensor (Receive) is made from a wire loop connecting the center through the L1 and L3 toroids and then soldered to the shell of an SO-239 connector. I found it easier to place a VNA marker at the bandpass filter center frequency and then spread or compress the toroid wires to align the L1/C1 and L3/C3 resonances on that marker. Once this was accomplished I added C2, L2a, and L2b to the circuit and performed final tuning.

Two adapters (PL-259 to SMA female) were required for final tuning to connect the VNA cables to the filters. Tuning results were disastrous at first because I left the 2.7K resistor in the circuit which severely distorted the curves.

Set the VNA to display S11 (passband return-loss) and S21 (insertion loss) curves. Adjust the toroids to get three distinct nulls on the S11 curve and minimal ripple and insertion loss on the S21 curve. Good figures to strive for are -25dB minimum passband return-loss (S11), ±0.05 dB passband ripple (S21), and -0.4 dB insertion loss (S21).

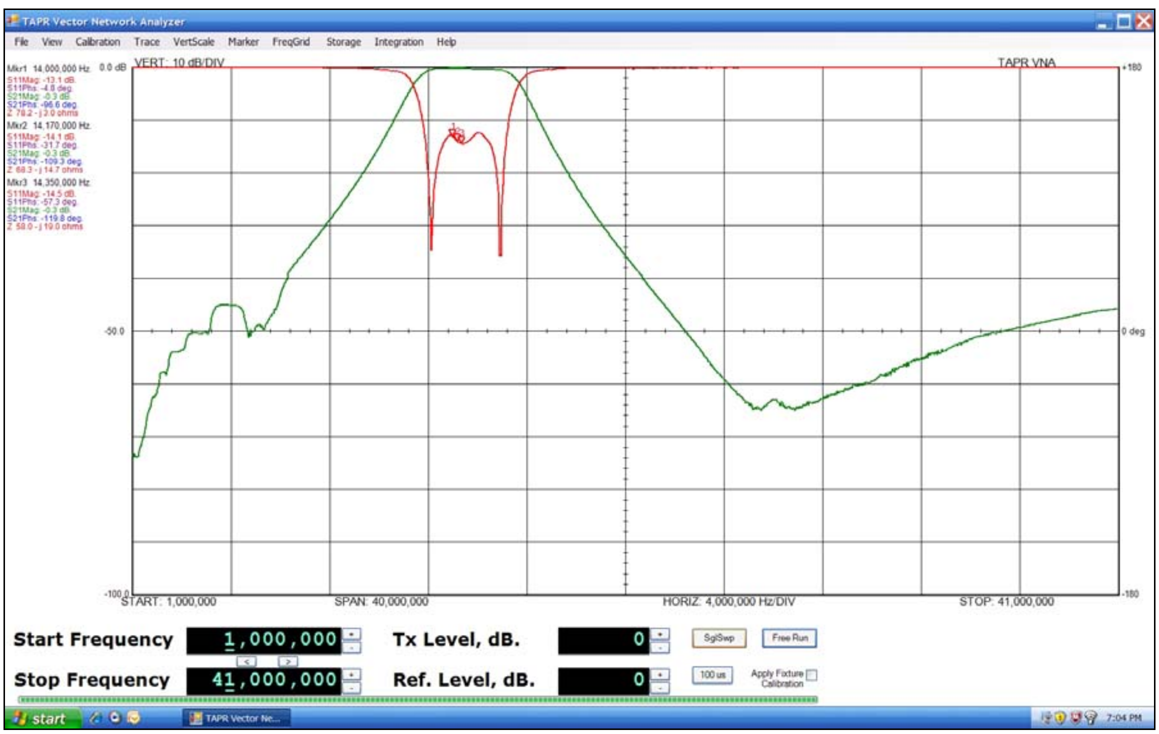


Figure 1

Figure 1 is a plot of the 20m filter being tuned with the S21 curve (green) and the S11 curve (red). The values listed at the upper left are as follows:

Marker1: 14.000 MHz
S11 Magnitude: -13.1 dB
S21 Magnitude: -0.3 dB

Marker 2: 14.170 MHz
S11 Magnitude: -14.1 dB
S21 Magnitude: -0.3 dB

Marker 3: 14.350 MHz
S11 Magnitude: -14.5 dB
S21 Magnitude: -0.3 dB

The S21 insertion loss of -0.3 dB is excellent and the passband ripple is very low but the middle null return loss is not quite deep enough. Multiple attempts to get the classic three null response (typical of three resonator bandpass filters) was unsuccessful. I finally settled on the highest return loss value while minimizing insertion loss and pass band ripple.

Initial Testing

For those unfamiliar with transmit bandpass filters there are a couple of warnings. First, the filters are intended to go between a 100 watt transceiver and a matched antenna or linear amplifier input. Do not use a transceiver with an internal antenna tuner in an attempt to match a high SWR antenna through the filter. For example, if your antenna is a G5RV, place the antenna tuner after the filter. The tuner will present a high SWR to your transceiver during tuning and the transceiver's output fold-back circuitry will protect the filter and transceiver. The second warning is to ensure that the appropriate filter is used for each band. For example, do not transmit a 100 watt 10m signal into a 15m bandpass filter or you will fry the filter capacitors. A good test for verifying you have the correct bandpass filter is to listen to the band before transmitting. If you cannot hear band noise then you are probably using the wrong bandpass filter between your transceiver and the antenna.

Initial testing consisted of placing the 20m bandpass filter between my transceiver and a resonant 20m dipole. A comparison of signal strengths with and without the filter revealed no discernable signal drop in received signals. Switching the radio to any other band (10m, 15m, 40m, 80m, or 160m) dropped the S meter to zero. This receive test was successfully completed for all six filters.

Transmit testing consisted of transmitting 5 watt CW signals into each filter into a dummy load. The SWR was monitored and each filter capacitor was touched to see if any were becoming warm. This test was repeated at 100 watts with no problems detected.

On-The-Air

Ten years later, Bill and I set out on anther ham-camping trip but this time we were armed with bandpass filters. The campsite was setup with three antennas that were within 50 feet of each other: G5RV at 40 feet, 10m Moxon at 20 feet, and a 15m Moxon at 25 feet. Bill selected the G5RV with an LDG autotuner after the bandpass filter for some 20m CW. I connected to the 10m bandpass filter to a 10m Moxon for a little SSB and PSK. Over the next three days we tried all combinations of bands, filters, and antennas. The results were most gratifying as we were both able to transmit simultaneously without the slightest hint of interference.

73,
Allen, KG4JJH

References

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