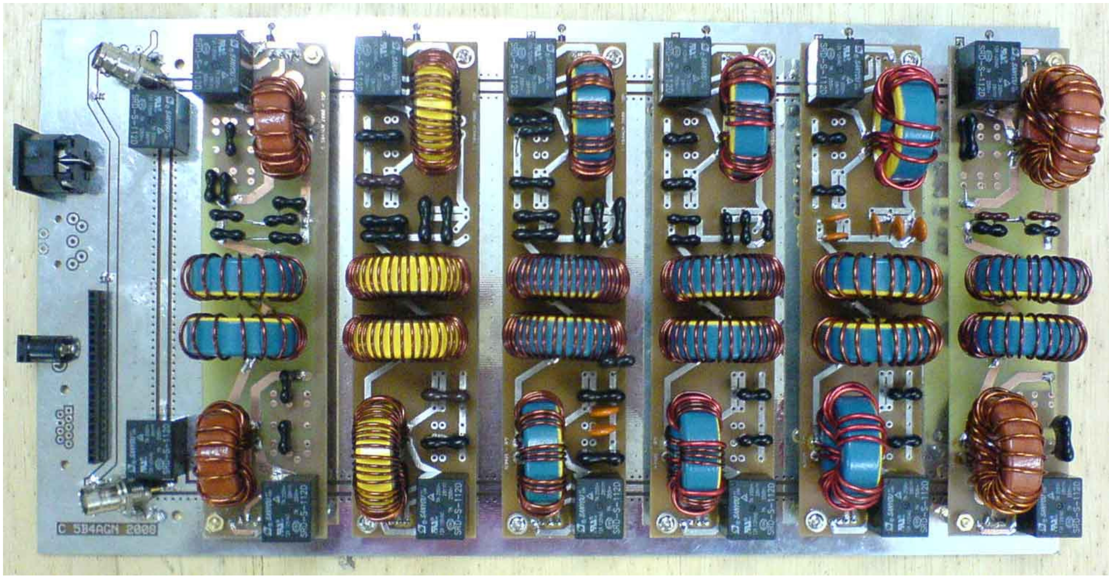
Multi-band TX BPF Project

Prototype Review



Bob Henderson. 5B4AGN

July 2008

Executive Summary

The prototype test phase is complete. A full set of filters for 160-10m have been assembled and mated to their supporting motherboard.

Performance of the W3NQN filters is "best in class" on the important performance criteria, these being insertion loss (IL) and attenuation on neighbouring contest bands. Each prototype filter has been adjusted and its performance measured using professional test equipment. (HP8568B spectrum analyser and an HP8444A tracking generator) All were found to meet or exceed the established criteria.

Extensive use of groundplane and 50-ohm microstrip feeders on the motherboard has provided good isolation between filters, avoiding the need for individual screening. Band switching relays are mounted on the individual plug-in boards for ease of maintenance.

Some problems were experienced in the prototype filters for 10m and 15m due to increased groundplane capacitance causing unacceptable levels of insertion loss. A modified layout has been devised and tested. This will be used for our production filter boards.

The motherboard also has a relay switched 'by-pass' facility for the non-contest bands. An unforeseen problem with the prototype layout was that the microstrip lines, which serve us so well when filters are selected, behave like unterminated reactive stubs when on by-pass. This creates an unacceptably high by-pass SWR. Efforts to compensate for this reactance were not satisfactory, so the motherboard has been re-tracked to take the input and output strip-lines out of circuit on by-pass. By-pass SWR is now OK to 50MHz, and isolation of the by-pass line when filters are in use is still more than satisfactory.

An additional header has been added to the motherboard layout providing for connection of a 7 way manual selector switch and LED indicators, where required.

Whilst no absolute guarantee of success can be given, as much as economically possible has been done to ensure production boards will be of serviceable quality. It is now time to place our production orders.

1. Introduction

A short discussion on the role of transceiver band-pass filters in multi-transmitter environments might perhaps make a useful opener.

The casual observer may be forgiven for assuming the role of transmitting BPFs to be the removal of harmonics from the transmitter output. After all, this would seem to be implied by the term. The truth is somewhat different.

Why is harmonic filtering not the issue? Well…mostly because harmonics aren't particularly troublesome at the transceiver output. This is for two reasons: Firstly, the vast majority of modern transceivers use push-pull output stages, which inherently suppress even harmonics. (With reasonable balance >40dB suppression can be realised.). With the exception of 15m our HF contest bands have an even harmonic relationship so we benefit directly from this effect. Secondly, a typical transceiver's output LPFs do a pretty good job of suppressing 3rd and higher harmonics.

Our transmitting BPFs are anyway located upstream of where the significant harmonic energy is generated, so they can't help even if we want them to. When it comes to troublesome harmonic energy our old friend the "linear" amplifier is the villain of the piece. These are a harmonic playground! Linears (at least the tube variety) almost inevitably operate in single ended configuration and employ single pi-section output filtering. Serious harmonic suppression must therefore be dealt with at the amplifier output, typically through use of coaxial stubs.

So we have established that TX harmonic suppression isn't the job of our transceiver BPFs. Just what then is their role?

The primary benefit from these filters is derived when receiving. Here they prevent the huge RF fields created by transmitters operating on other bands from reaching the receiver front-end where they can cause blocking, spurious mixing products and in extreme cases, even flames. This could be achieved through deployment of much cheaper receive only BPFs, were access to the receive path easy. Alas in many modern transceivers, it is not.

Still, take heart, our transmitting BPFs do have an important role to play in the transmit signal path between transceiver and amplifier, albeit not one of harmonic suppression. Along with the many benefits provided by modern transceivers come one or two ills. Notable amongst these is wide-band synthesiser noise. Unconstrained this can be a significant problem in multi-station environments. These BPF's will deal nicely with this problem for us.

2. Design Criteria

- Individual filters to be assembled on fractional Euro-card PCB.
- Filter select relays to be located on individual filter boards.
- Individual filters plug-in to motherboard or may be used stand-alone.
- Motherboard to accommodate 6 plug-in filters and by-pass relays.
- DB9 male connector on MB wired for plug-in replacement of Dunestar 600.

- Filter switching compatible with current sourcing & sinking drivers i.e. link configurable for Dunestar +ve or –ve keying.
- Motherboard to use HD ground plane and deploy strip-line feed system.
- SIL header provided on Motherboard to support add-in Yaesu/Elecraft compatible Band Data Decoder and antenna relay driver module.
- Insertion loss 0.5dB or better
- f/2 attenuation >35dB
- 2f attenuation >45dB

3. PCB Layouts

Free layout software available from ExpressPCB in the US was used to create the layouts.

http://www.expresspcb.com/

This was chosen because it came at the right price and because it is remarkably easy to use. The downside of this approach is that output files are encoded, preventing shopping around for best production price. That said ExpressPCB prices fall well within the range of acceptability, largely due to current weakness of the dollar.

Filter and motherboard lay-outs both used extensive groundplane on double sided FR4 material with plated through holes.

4. Filter Prototype

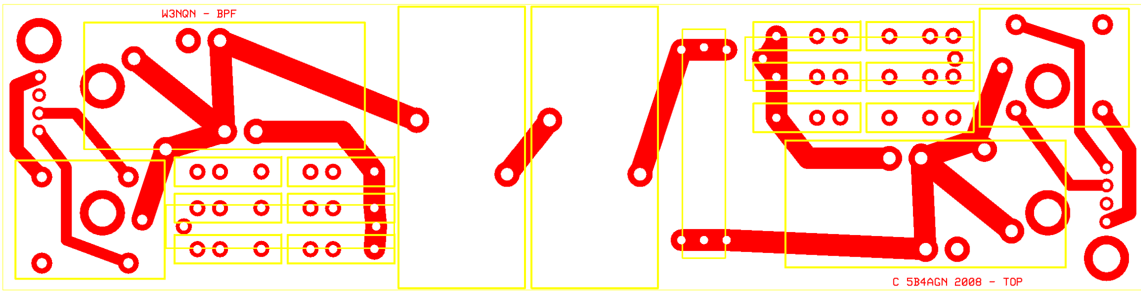
Prototype filter boards were ordered in June and delivered in the last week of the month.

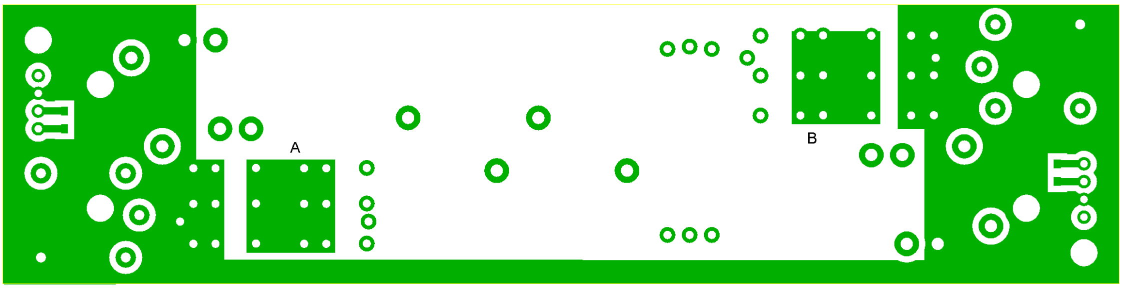
160 – 40m filters were assembled with all components fitting properly. On test these easily met established criteria for IL, 2/f and f/2. The 20m filter also met the targets but achieving <0.5dB IL proved rather challenging. 10 & 15m filters were problematic. Assembly was straight forward but adjustment failed to yield acceptable IL. It proved impossible to better 0.8dB at 15m and 0.9dB at 10m. In both cases 2f and f/2 criteria were met.

These difficulties have subsequently been attributed to the use of an extensive groundplane on the filter board. (Seemed like a good idea at the time.) For the most part, extensive groundplane is good but not where low capacitance to ground is a requirement. The problem area is the junction of C2 & L2. Stray capacitance to ground Cs is substantially insignificant at 160m where C2 is 250pF but is seriously significant at 10m where C2 is only around 12pF. That <0.5dB IL at 20m was so hard won, suggests Cs may be material even at 14MHz.

A modified filter PCB layout was developed with reduced tracking and ground plane in the critical area. Double-sided kitchen-sink specials were fabricated, albeit without plated through holes. The 15 & 10m filters were re-assembled on the modified layout boards. The IL problem was solved without detracting from performance against 2f & f/2 criteria

The revised filter boards are closer to W3NQN's original construction on fully insulated board inside a metal box. In this plug-in version, the groundplane on the motherboard serves the same function as W3NQN's metal boxes. (Space has been provided on the motherboard for vertical shields between modules, but its use has proven unnecessary.) Top and bottom foils for the modified filter board are displayed below.





During final review with Ian, GM3SEK a decision was taken to further reduce stray capacitance through removal of the fills at A & B above. Instead an array of unconnected plated through holes will be provided, offering increased component flexibility. When series parallel combinations at C1 & C3 are employed these will be hard wired as required. Production filter boards will be based on the above reduced ground plane layout and will incorporate this further change.

5. Motherboard Prototype

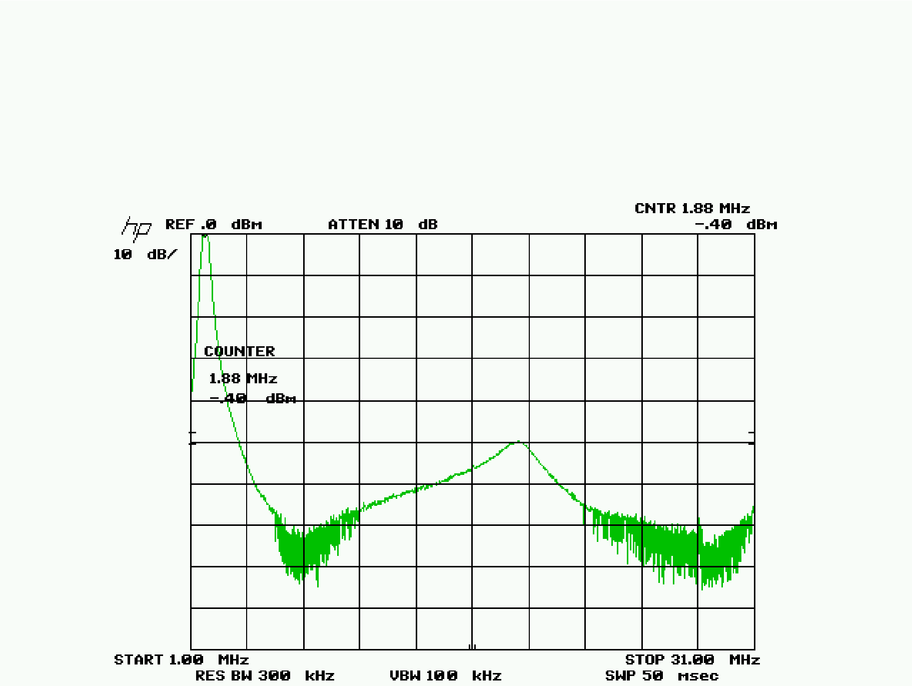
The motherboard prototype was ordered in early July and delivered on the 14^{th}. It has been fully assembled except for DB9 and 5-way DIN connectors for which I still await delivery. Assembly was straight forward with all components fitting easily.

The six individual band filter assemblies have been attached to the motherboard in the prescribed order. No problems were encountered.

6. Filter Performance Measurements

These were made using an HP8568B spectrum analyzer and HP8444A tracking generator. Plots for each of the filters follow:-

160m



Insertion loss 0.4dB. 2f attenuation 48dB.

80m

Insertion loss 0.3dB. 2f attenuation 50dB. f/2 attenuation 45dB.

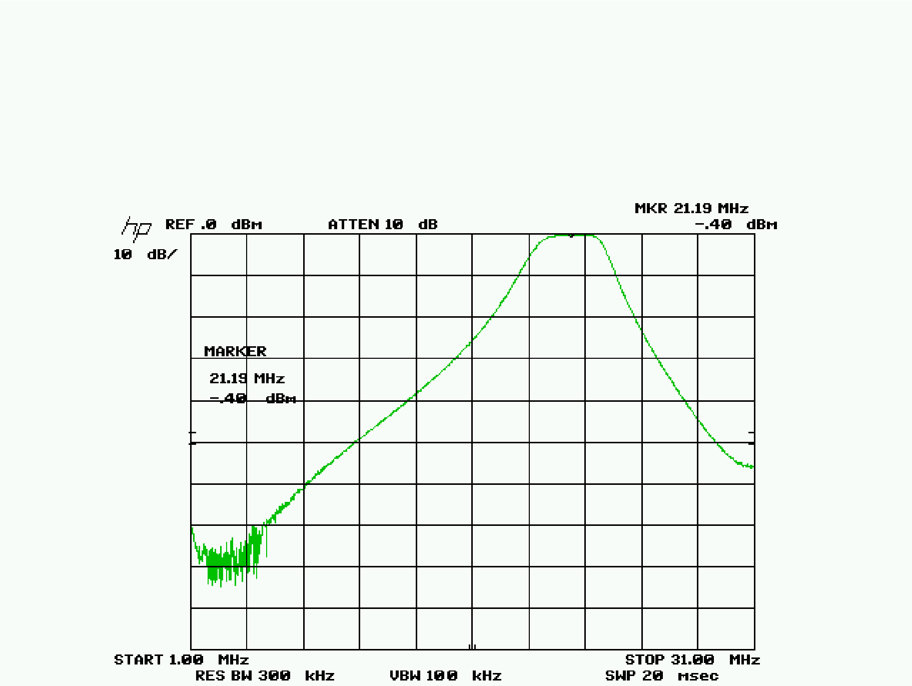
40m

Insertion loss 0.4dB. 2f attenuation 60dB. f/2 attenuation 45dB.

20m

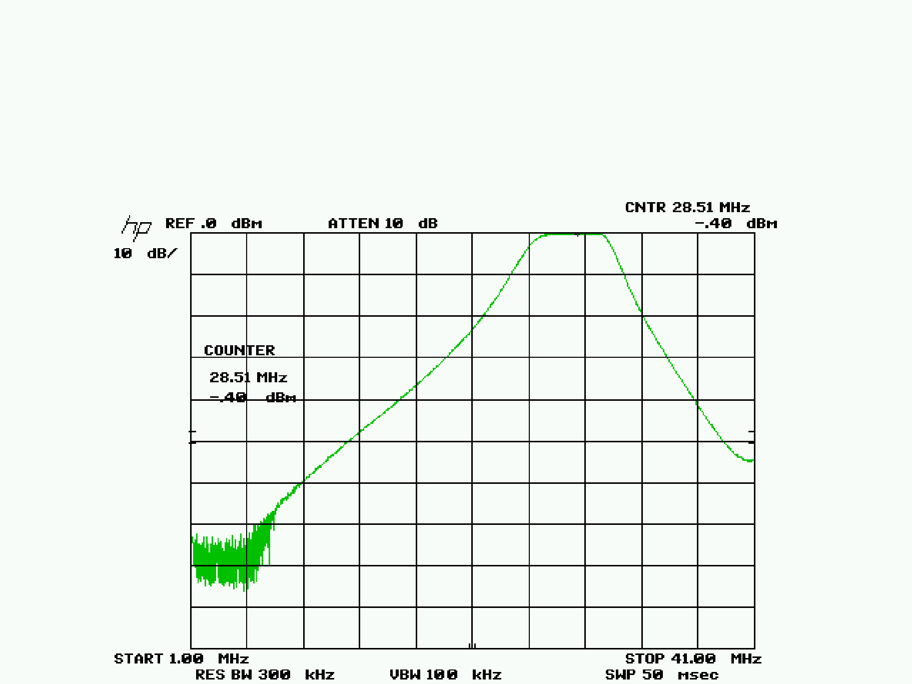
Insertion loss 0.4dB. 2f attenuation 57dB. f/2 attenuation 40dB.

15m



Insertion loss 0.4dB. 20m attenuation 35dB. 10m attenuation 48dB.

10m



Insertion loss 0.4dB. f/2 attenuation 45dB. 15m attenuation 25dB.

7. Performance Comparisons

The following table incorporates our prototype figures into a table produced by Peter Pfann, DL2NBU when he built W3NQN filters for the Bavarian Contest Club in 2002. The table provides useful comparison with sample filters from Dunestar and ICE.

Frequency	1.81-1.89	3.50-3.80	7.00-7.20	14.0-14.35	21.0-21.45	28.0-29.0
10m Dunestar	53dB	48dB	43dB	41dB	35dB	0.9dB*
10m ICE	74dB	71dB	65dB	36dB	16dB	0.4dB
10m DL-NQN	72dB	69dB	74dB	38dB	18dB	0.4dB
10m 5B-NQN	80dB	80dB	70dB	45dB	25dB	0.4dB
15m Dunestar	50dB	45dB	40dB	43dB	1.0dB	51dB
15m ICE	73dB	61dB	46dB	21dB	0.3dB	11dB
15m DL-NQN	76dB	78dB	58dB	28dB	0.4dB	60dB
15m 5B-NQN	80dB	80dB	60dB	35dB	0.4dB	48dB
20m Dunestar	48dB	43dB	40dB	0.8dB	45dB	45dB
20m ICE	66dB	70dB	39dB	0.4dB	19dB	29dB
20m DL-NQN	75dB	61dB	38dB	0.4dB	43dB	32dB
20m 5B-NQN	75dB	60dB	40dB	0.4dB	38dB	57dB
40m Dunestar	48dB	51dB	0.6dB	49dB	44dB	45dB
40m ICE	77dB	35dB	0.5dB	25dB	34dB	43dB
40m DL-NQN	67dB	42dB	0.4dB	82dB	56dB	47dB
40m 5B-NQN	70dB	45dB	0.4dB	60dB	50dB	45dB
80m Dunestar	50dB	1.0dB	37dB	58dB	32dB	23dB
80m DL-NQN	40dB	0.4dB	53dB	65dB	53dB	39dB
80m 5B-NQN	45dB	0.3dB	50dB	60dB	50dB	40dB
160mDunestar	1.2dB	35dB	57dB	33dB	24dB	19dB
160m DL-NQN	0.3dB	48dB	90dB	65dB	60dB	70dB
160m 5B-NQN	0.4dB	48dB	>80dB	60dB	60dB	80dB

* Dunestar IL at 28.5MHz. (1.2dB @ 28.75MHz, 2.0dB @ 29.0MHz)

Best performance is indicated by figures in green and worst in red. Worst does not necessarily mean inadequate, though in some cases it means exactly that. Our prototype filters fair well with a lot of green figures and no red. The BCC filters were built using air-wound coils at L1 & L2 for 20, 15 & 10m. This was essentially a cost saving measure but happens to provide superior attenuation of signals in the next higher band. However, this benefit comes at a price, as can be seen by comparison with our figures for the next lower band. You can interpret the figures for yourself but I think I'll stick with toroids. Provision for use of air-wound coils has however been incorporated in the modified filter PCB layout, to provide for experimentation.

8. Component Selection

The toroids used were those specified by Ed Wetherhold, W3NQN in his original design. These are capable of handling the heat dissipation of filters intended for 200W continuous carrier use.

Capacitors are a different matter entirely. The Tusonix 3 & 4kV rated NP0 capacitors used by Ed, are no longer available. In the prototype filter set I used series parallel combinations of

500V & 1kV micas and some 1kV, NP0 Ceramite ceramics. I have tested each of the prototypes with 100W continuous for 5 minutes and a number of the capacitors get noticeably warm to the touch but I am pleased to report, nothing caught fire! I would not recommend using a filter built with these capacitors at 200W.

The table below compiled by Peter Pfann, DL2NBU nicely illustrates the capacitor issue.

Band	**Power**	**VSWR**	**C1/C3**		**C2**	
160m	100 W	1:1	279 V	1.41 A	492 V	1,41 A
		3:1	418 V	2,15 A	781 V	2.13 A
160m	200 W	1:1	395 V	2.00 A	696 V	2,00 A
		3:1	588 V	3,04 A	1101 V	3.01 A
80m	100 W	1:1	209 V	1.84 A	461 V	1,53 A
		3:1	307 V	2,70 A	658 V	2.18 A
80m	200 W	1:1	296 V	2.60 A	651 V	2,16 A
		3:1	435 V	3,68 A	930 V	3.09 A
40m	100 W	1:1	279 V	1.51 A	510 V	1,39 A
		3:1	419 V	2,27 A	838 V	2.28 A
40m	200 W	1:1	395 V	2.14 A	721 V	1,96 A
		3:1	592 V	3,21 A	1185 V	3.22 A
20m	100 W	1:1	278 V	1.84 A	553 V	1.42 A
		3:1	414 V	2.75 A	866 V	2.22 A
20m	200 W	1:1	392 V	2.60 A	782 V	2.01 A
		3:1	586 V	3.89 A	1225 V	3.14 A
15m	100 W	1:1	280 V	2.00 A	707 V	1.41 A
		3:1	413 V	2.96 A	1030 V	2.06 A
15m	200 W	1:1	396 V	2.82 A	1000 V	2.00 A
		3:1	584 V	4.19 A	1457 V	2.91 A
10m	100 W	1:1	270 V	1.96 A	675 V	1.52 A
		3:1	407 V	3.03 A	1005 V	2.26 A
10m	200 W	1:1	382 V	2.77 A	955 V	2.15 A
		3:1	576 V	4.29 A	1421 V	3.20 A

Peter goes on to say, "As you can gather from the table, a bad VSWR stresses the capacitors somewhat more than higher power does. It is a matter of choice what maximum power and VSWRs the capacitors are rated for. For 200W and VSWR 3:1, C1 and C3 should be rated for 1000V and C2 for 2000V.

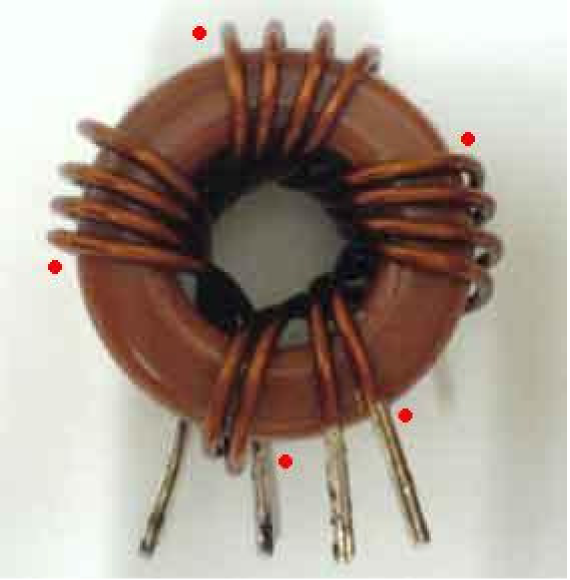
The reactive power carried by C1/C3 is up to 2500W, and by C2 even up to 4500W. To avoid heat dissipation in the capacitors, it follows that the Q must be outstandingly high, aiming for at least 5000. Therefore, for all of the higher bands, only RF-rated capacitors can be considered. Tests with multiple paralleled silver mica capacitors, then connected in series, showed no noticeable heating with 100W continuous power on 160/80/40/20m. On 15 and 10m the capacitors merely became very warm."

9. Toroid Winding – more fun than you ever dared wish for.

L2a or L2b for 15m filter

Note the left hand wire emerges from the top of the core. This is essential for compatibility with filter PCB tracking.

L1 or L3 for 10m filter



Note the right hand wires emerge from the top of the core. This is opposite sense to L2 winding instruction.

Dependent upon band, L1 & L3 are tri-filar or quadri-filar wound. Use 2 pieces of wire to wind these coils. It makes no sense to use 3 or 4 pieces, soldering the ends together. Wind a single layer first. This will be the low impedance part of the winding. I placed kinks at the end of the wire used for the single layer winding to avoid confusion later. The kinked bits have been cut off the coil pictured above as it is now ready to be installed. Looking at the picture above the right hand most wire is the ground end. The two middle wires are the ends of the low and high impedance parts of the inductor, which will be joined together via PCB tracking to become our 50 ohm input. The left most wire is the high impedance point which will connect with C1 or C3 as appropriate. The red dots have been added to track progress of the single layer winding around the core.

The above picture illustrates the location of the quadrifilar junctions where they pass around the outside of the core without needing to be soldered together. These are the two exterior turns visible between the two left hand terminations.

N.B.

Turns in toroidal inductors are counted by the number of times a wire passes through the core and NOT the number of times it loops around it.

In the original W3NQN articles he specifies different gauge wire for the single and multiple layer windings of L1 & L3. I followed Ed's lead and found this made for easier identification of connections on completed inductors. Alas a single gauge of wire is specified for 20, 15 & 10m filters. Use of wire with differently coloured enamel may be worthy of consideration.

10. Filter Set-up and Test

While access to a spectrum analyser & tracking generator OR a vector network analyser (VNA) is not mandatory for successful adjustment of these filters, either will make the process a whole lot easier. Their use is therefore strongly recommended.

Each filter comprises three separately resonant circuits: L1, C1; L2, C2 and L3, C3.
L1, C1 & L3, C3 are the input and output parallel tuned circuits. These must be tuned to within 0.6% of the centre frequency of the band for which they are intended and each within 0.2% of the same frequency. Failure to achieve this will prejudice achievement of good return loss performance.

The input and output parallel tuned circuits should be tuned as follows: Connect the test equipment using RG174, soldered directly to the filter boards with short pigtails (do all tuning before installing the relays). A signal should be injected into the 50 ohm tap of the inductor via a relatively high value resistor. Say 2k ohms. This avoids heavily damping the tuned circuit and provides for a good peak at resonance. Injecting signal directly from a 50 ohm source will damp the circuit yielding a very wide and flat peak. This will make it impossible to accurately tune the circuit. The detector, which maybe a spectrum analyser, VNA or even an oscilloscope should be loosely coupled to the inductor via a single turn loop through the core. To allow for stray capacitance, all adjustments should be made using a groundplane at the correct final spacing below the board. If you wish, you can plug the filter into the motherboard for a ground plane (but still make direct connections to the filter - not through the relays).

Small adjustments can be made by compressing or spreading the turns on the toroids. More dramatic adjustments to resonate L1 and L3 should be made by changing C1 and C3 - do not add or remove any turns. Once L1, C1 & L3, C3 meet the 0.6% and 0.2% criteria, then L2a, L2b and C2 should be added to the filter assembly. L2a and/or L2b should be adjusted to achieve best return loss. You can adjust turns spacing on either or both of L2a or L2b, and you can also change the number of turns on either toroid (they do not have to be equal). It may be more convenient to pre-adjust L2a, L2b and C2 for series resonance on a spare filter board, and then transfer those components onto the correct board for final adjustment for minimum return loss at the centre frequency. This can also be achieved with 10 Watts from your transceiver, a dummy load and an SWR bridge.

Whatever method you chose to adjust the filters, the final testing of insertion loss and return loss (SWR) should be made at full transmitting power levels into a dummy load, across the whole band.

11. Other Tests

A) Filter sensitivity to location on motherboard

Tests were carried out to assess whether performance of 10 & 15m filters are affected by their position on the motherboard. The use of a strip-line feed was chosen to minimise such risk but concern remained over possible problems arising due to un-terminated stub effects of strip-line beyond the filter in use. In particular the planned location of our 10m filter at the front of the strip was cause for concern.

Measurements of IL, 2f & f/2 performance for our 10m filter were made with it located in its designated location at the start of the strip and again in the 15m filter designated position at the strip end. IL, 2f & f/2 figures remained consistent between locations, although VHF stop-band improved when the filter was located in its designated slot. This is of somewhat academic interest as VHF stop-band is not significant to our purpose.

A similar test was carried out on the 15m filter with similar results. From this I conclude we can safely stick with our rather quaint scheme of filter location on the motherboard. In so doing we retain Dunestar compatible connectivity through the PCB mount DB9 connector.

B) Filter by-pass

While all filters provide good performance a problem affects our by-pass arrangement. Measured SWR was 1.05:1 at 1.8MHz rising to >3:1 at 28MHz. This is clearly not acceptable.

The by-pass switching arrangement mirrors that of our filters, in that either end of the by-pass strip-line is attached to the pole of a c/o relay. The relay connects the by-pass strip between input and output strips when no filter is selected. It disconnects the by-pass strip, grounding it when a filter is selected. This seemed like a good idea at the time. Clearly it isn't quite as good as it seemed!

Efforts have been made to address this through addition of 230nH series inductance at the centre of the by-pass strip-line. This cancelled the capacitive reactance of input and output strip-lines restoring acceptable by-pass SWR at HF. However, the added inductor combines with input/output strip-line capacitance to form an LPF. Whilst of little consequence to our intended purpose this would cause problems for users with 1.8-50MHz transceivers as the LPF cut-off is below 50MHz. Consequently the by-pass scheme has been redesigned to disconnect input and output stubs on by-pass. The motherboard layout has now been changed to reflect this.

The new by-pass scheme has been verified through removal of by-pass relays, reconnecting them in the new configuration using stiff wires.

C) Port to port isolation with no filter selected and by-pass disabled. i.e. I/O open circuit
.

Greater than 80dB measurement limit. No problem.

12. Conclusion

The PCB prototype phase of the project may now be considered successfully completed. Identification of the stray capacitance problem on the filter PCB and the by-pass problem on the motherboard together justify our investment in the approach. Higher quality production boards should result.

What remains before participants are encouraged to start building their filters is a build repeatability assessment.

The issue is this:

Good quality RF mica caps are believed to be the best option. Use of Tab Mica devices will require just three capacitors per filter. However a potential problem exists in that AL values for Micrometals toroids have 5% tolerance. The question is whether enough adjustment of L1, L3 is available with specified turns to rely upon meeting our 0.6% and 0.2% criteria with pre-determined capacitor values for C1 & C3. The difficulty with L1 & L3 is that we can't simply add or remove a turn. Due to the tri-filar and quadri-filar nature of these inductors we would need to add or remove three or four turns at a time, which is far too much to be useful.

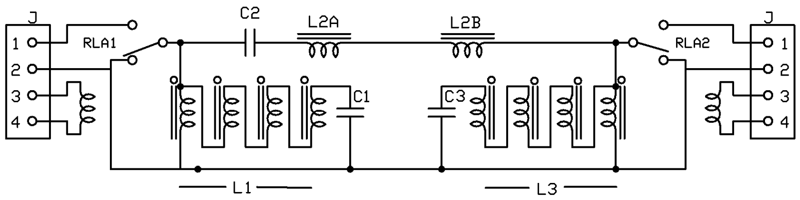
Ian, GM3SEK has already invested in a set of Tab Mica capacitors of the values specified by W3NQN. With access to a set of production filter boards Ian is well placed to assess whether these values are right for our boards and his cores. Once this has been determined I propose to order a second set of Tab Mica caps so between us we can develop an insight to repeatability.

If this looks to be a problem a different build approach will need to be adopted, under which empirical determination of required values for C1, C3 will need to be made on a filter by filter basis. This might go something like…

1. Wind L1
2. Resonate at desired frequency with poly trimmer as C1.
3. Measure value of poly trimmer. (Accurate capacitance meter required)
4. Adjust spread of L1 turns to bring poly trimmer as close as possible to specified value for C1.
5. Measure poly trimmer.
6. Order C1 from Tab Mica at value determined in 5 above.
7. Repeat above for L3, C3.

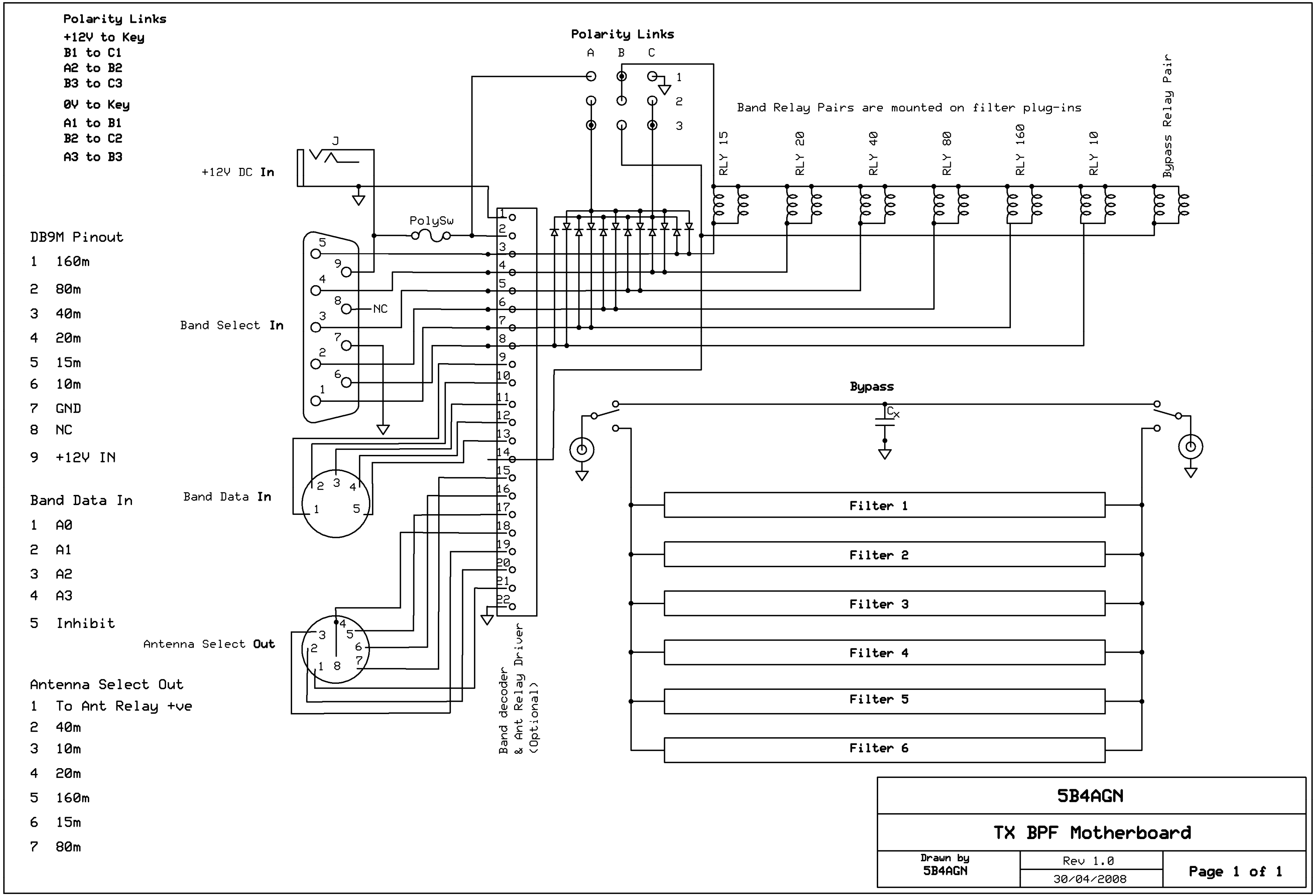
Arrangements for prototyping a Band Data Decoder & Relay Driver module are now in hand.

Relays shown not energised.



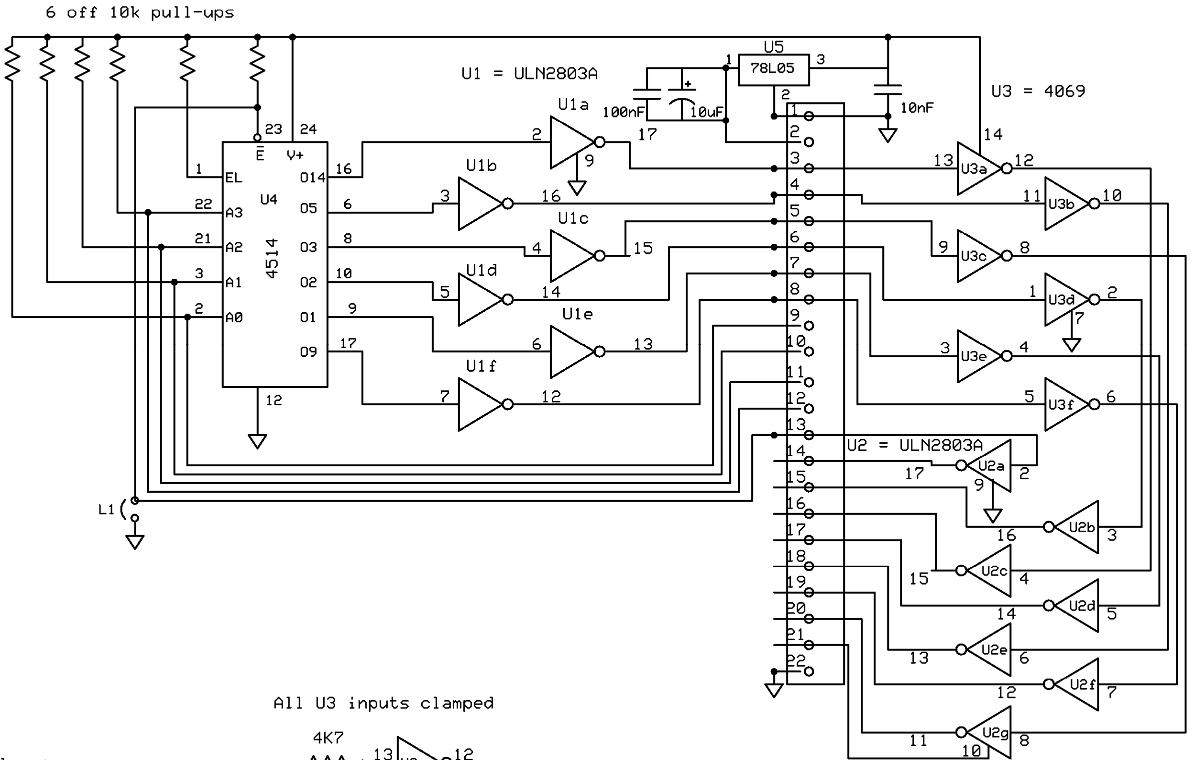
	160	80	40	20	15	10
L1, L3	16.46uH	4.93uH	3.96uH	1.27uH	1.053uH	0.761uH
Core	T130-6	T130-17	T130-17	T130-17	T130-0	T106-0
Turns	10 + 30 quadrif	11 + 22 trifilar	7 + 21 quadrif	5 + 10 trifilar	5 + 15 quadrif	4 + 12 quadrif
L2a, L2b	14.8, 14.2uH	5.97, 5.97	4.13, 4.13	1.7, 1.48uH	1.87, 1.87uH	1.10, 1.26uH
Core	T130-6	T130-17	T130-17	T130-17	T130-17	T130-17
Turns	39, 38	37, 37	30,30	18, 17	19,19	14,15
C1, C3	440pF	375pF	125pF	90pF	53pF	40pF
C2	250pF	155pF	60pF	36pF	15pF	13pF

5B4AGN		
W3NQN - BPF		
Drawn by 5B4AGN	Rev 1.0 26/04/2008	Page 1 of 1

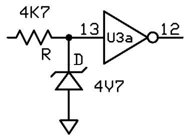

Polarity Links
+12V to Key
B1 to C1
A2 to B2
B3 to C3
0V to Key
A1 to B1
B2 to C2
A3 to B3
Polarity Links
A B C
Band Relay Pairs are mounted on filter plug-ins
RLY 15
RLY 20
RLY 40
RLY 80
RLY 160
RLY 10
Bypass Relay Pair
J
+12V DC In
PolySw
DB9M Pinout
1 160m
2 80m
3 40m
4 20m
5 15m
6 10m
7 GND
8 NC
9 +12V IN
NC
Band Select In
Band Data In
1 A0
2 A1
3 A2
4 A3
5 Inhibit
Band Data In
Antenna Select Out
Antenna Select Out
1 To Ant Relay +ve
2 40m
3 10m
4 20m
5 160m
6 15m
7 80m
Band decoder
& Ant Relay Driver
(Optional)
Bypass
Cx
Filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
5B4AGN
TX BPF Motherboard
Drawn by
5B4AGN
Rev 1.0
30/04/2008
Page 1 of 1

SIL Connections

1 GND
2 +12V
3 15M Filter Select
4 20M Filter Select
5 40M Filter Select
6 80M Filter Select
7 160M Filter Select
8 10M Filter Select
9 A0 Band Data in
10 A1 Band Data in
11 A2 Band Data in
12 A3 Band Data in
13 Bypass Inhibit in
14 Bypass enable
15 80m Antenna Select
16 15m Antenna Select
17 160m Antenna Select
18 20m Antenna Select
19 10m Antenna Select
20 40m Antenna Select
21 Diode Cathodes to Ant Relay +ve
22 GND



All U3 inputs clamped



5B4AGN		
Band Data Decode & Antenna Relay Driver module		
5B4AGN	Rev 1.0 03/05/2008	Page 1 of 1

Useful References

- Clean up your signals W3NQN Parts 1 & 2.
  http://www.k0to.us/HAM/Articles/W3NQN%20MayJune%201998%20article.pdf

- BCC Filter project. Peter Pfann, DL2NBU (In German)
  http://www.bavarian-contest-club.de/projects/bandpassfilter/100W-BP.pdf

Useful Suppliers

- Tab Mica
  http://www.tabmica.co.uk/page7.html

- Just Radios (Capacitors) Canada
  http://www.justradios.com/

- The Toroid King
  http://www.kitsandparts.com/toroids.php