

## A Survey of Bandpass Filters for Contesting

**Introduction** Several years ago, I ordered a pair of ICE 419B filter sets for use in my future SO2R station. It took a year to get them, they arrived not very well aligned, and both of them failed due to overheating within the first year or so. Good luck smiled on me, when N6RNO, who has no home station of his own, loaned me the two sets of W3NQN-built filters he had bought for our CQP expeditions to Tehama county, and I've been using them for several years now. I wanted to have my own filter sets, and when I heard of the TXBPF bandpass filter sets that Bob Henderson, 5B4AGN, had designed and was distributing as a group purchase in kit form, I put myself on the list for the round of kits. The kits arrived this fall, and I built them over a period of about three weeks this winter.

I really enjoyed building the filters, and learned a lot in the process. Naturally, I wanted to compare what I'd built with other filter sets, and put out a request on the NCCC reflector for the loan of other filters. ND2T loaned a pair of Dunestar 600 6-band sets he'd acquired used, and N6DE loaned three single-band Dunestar filters. I opened all of them up and studied their design, construction, and component selection, and I measured all of these filters using the DG8SAQ VNWA Vector Network Analyzer. What follows is a summary of what I think I've learned.

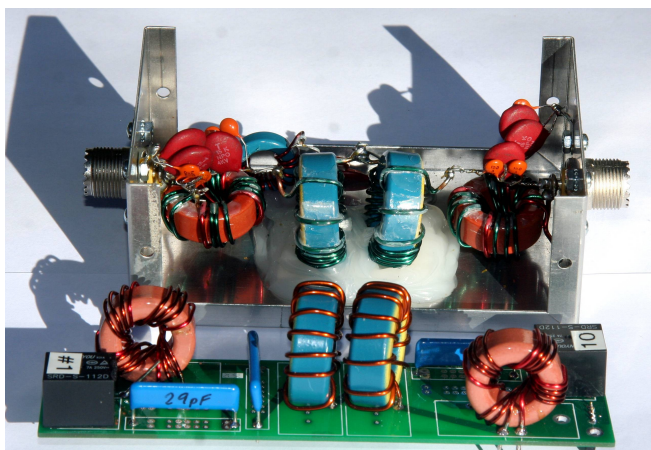


Figure 1  
W3NQN filter (top) and TXBPF filter (lower)

**Construction:** The W3NQN 6-band sets are built as individual band filters, connected between transceiver and power amplifier by an Array Solutions FM-6 switching matrix, one for each rig, with LMR240 jumpers between the filters and the FM-6.

The TXBPF 6-band filter set is built with plug-in modules that fit onto a motherboard, and all elements of the signal path utilize very well implemented microstrip wiring. Filters are switched onto the bus, one at a time, so that only the loss associated with one pair of relays is present at any time.



Figure 2 – Dunestar 600 6-band filter set

The Dunestar 6-band set has individual filters permanently mounted to a motherboard with miniature RG-174-size coax between the filters and the relay-controlled bandswitch matrix. Cable shields are carried between filters and relays, but not between the relay matrix and chassis-mounted SO239 connectors.

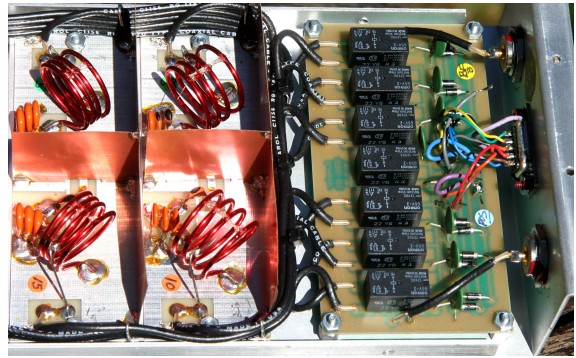


Figure 3 – Dunestar 600 RF Switching

The ICE 419B has six filters mounted to a single board, and the signal path is carried in series through relays that either bypass or switch the filter into the circuit.

One of my two ICE 419B filter sets had a bad relay for the 80M filter that failed to make good contact until hit with TX power; after hitting it with TX power it passed signal on receive. Anecdotal reports from users noted that the ICE owner (now SK) advised drilling a hole in the cover of the relay and spraying the relay with DeOxit, and my 419Bs came with that hole drilled. I did that with the 80M relay, and when I tried to measure that box, learned that all of the relays were flaky, and ended up spraying all of them. Even after multiple sprayings, operation remains erratic.

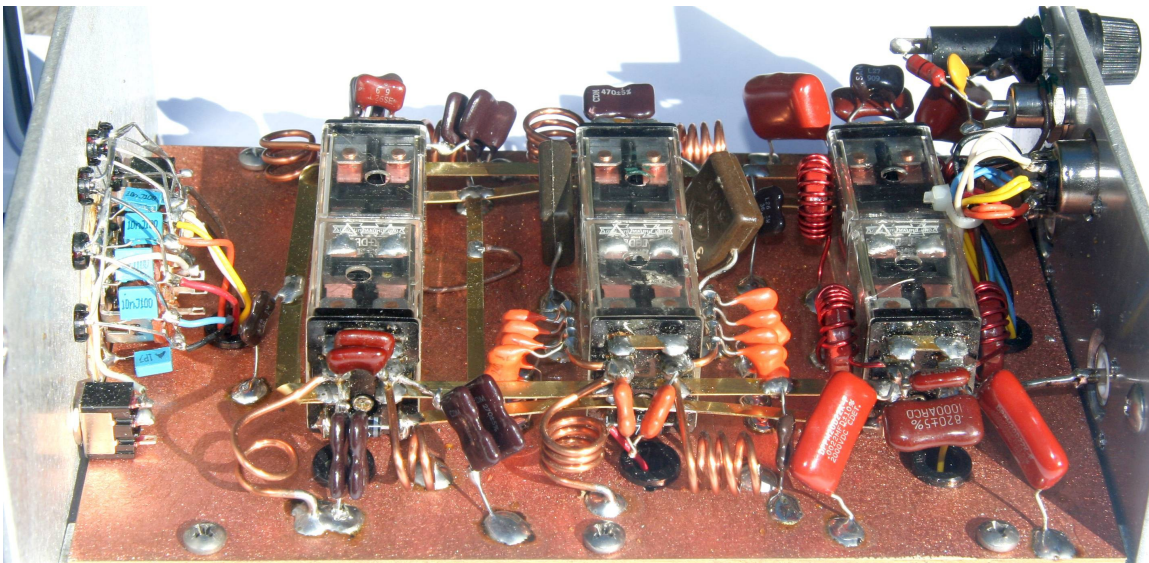


Figure 4 – ICE 419B 6-band Filter Set

**Bypass Mode:** If, like me, you operate 6M using a SteppIR, you might be concerned with how the switching matrix behaves in bypass mode. Performance is shown in the table.

<u>Filter Set</u>	<u>50 MHz Attenuation</u>	<u>50 MHz VSWR</u>
Array Solutions FM6	-0.3 dB	1.29:1
Dunestar 600	-0.17 dB	1.09:1
TXBPF	-0.08 dB	1.16:1
ICE 419B	Too erratic to measure (see text)	

The TXBPF filter set, (at right), has individual filter modules that plug onto a motherboard. Black rectangles near the left side of the photo are the bypass relays; the signal path between them is microstrip, and RG58, both center and shield, are wired to Amphenol flange-mount SO239 connectors. The result is excellent bypass performance on 6M, the best of all packages measured. A band decoder and buffered relay drivers to switch external antenna relays is on a daughterboard mounted vertically behind the rear panel (at left in the photo).

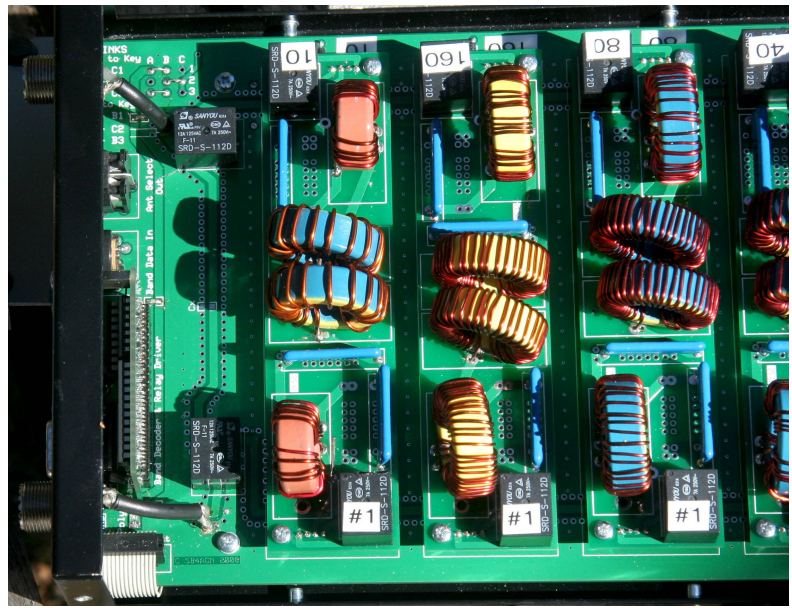
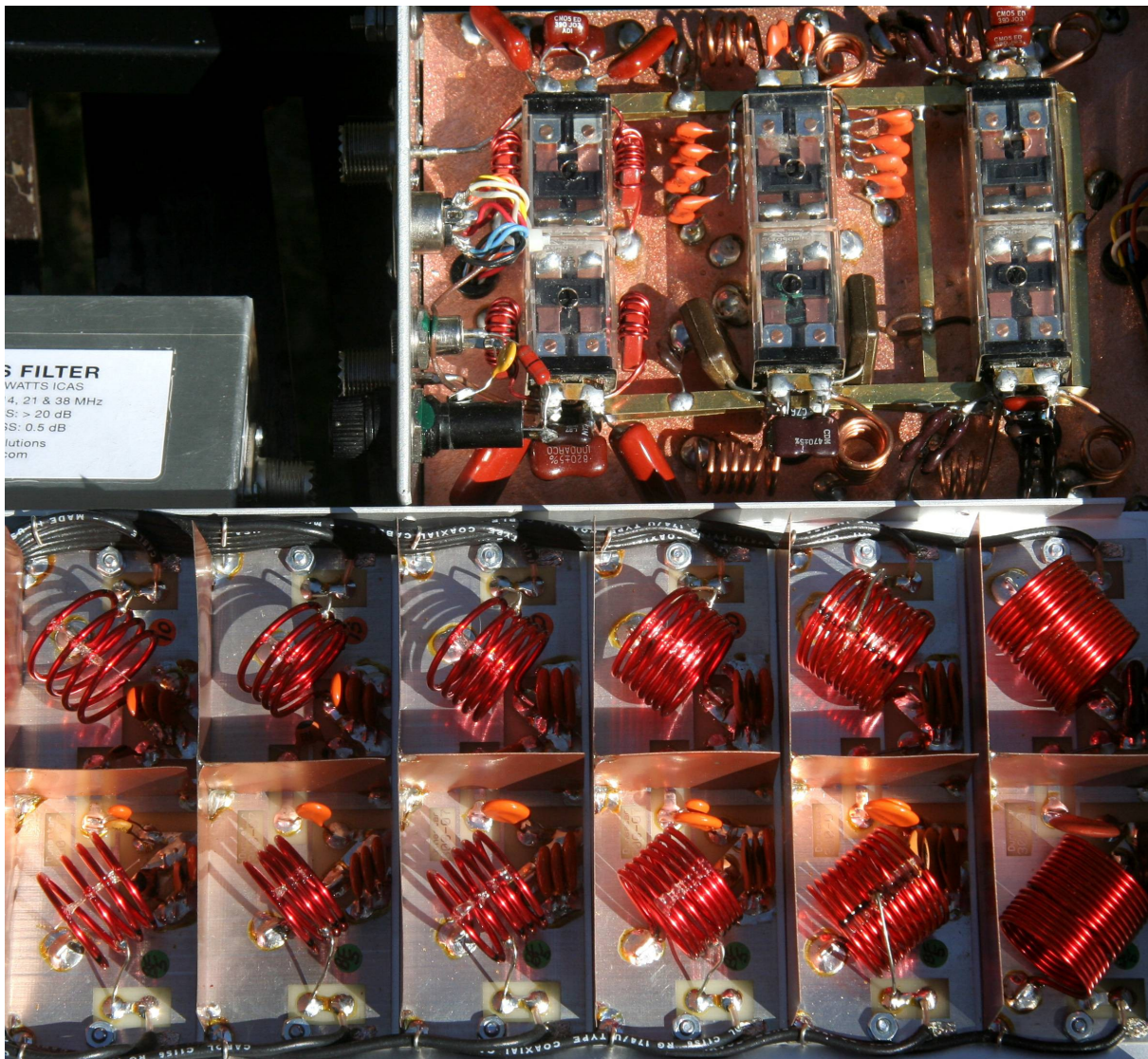


Figure 5 – TXBPF Filter Set



Figure 6 – TXBPF (above), Dunestar 600 (center), 10M W3NQN-built filter (below)



Note: The photos of Figures 6 and 7 were intentionally taken with the filter sets very close together so that their relative sizes, and the sizes of their components, can be compared. Figure 7 – ICE 419B (top) and Dunestar 600 (lower) Filter Sets

**Filter Designs:** The Dunestar filters are 2-pole designs, with tapped input and output resonator coils (connected as an auto transformer) to step up the filter impedance to a level where higher circuit Qs can be realized. The W3NQN-built filters and the TXBPF filters are 3-pole designs, also with tapped inductors as transformers, use of powdered iron cores for most of the inductors, improving their Q, and by making those input and output windings tri-filar or quadra-filar, which improves transformer coupling. The filters in the ICE 419 are simple 2-pole filters with small, un-tapped, air core inductors.

The 5B4AGN-designed TXBPF filters stick pretty closely to the designs published by W3NQN in his QST article. But like most highly creative people, W3NQN has continued to grow, and most of the W3NQN-built filters include nice modifications to his published designs that improve rejection of adjacent bands, generally at some sacrifice to rejection on other bands. Where the TXBPF filters and W3NQN-built filters differ, this is the primary reason.

**Components and Power Ratings:** All of the filter sets tested are nominally rated for CW or SSB operation at 200W PEP. Dunestar says that their filters should de-rated for RTTY operation, without saying how much, and this is good advice for all of the filters. These ratings imply low SWR at the point where the filter is inserted at the output of the transceiver – certainly under 2:1 – and dissipation within the filter can easily increase, potentially to destructive levels, with significant mismatch. Many

(most?) ham power amps can be driven to full power with 50 watts of drive, so filters actually built with components to justify the 200W rating should hold up well. The greatest stress on the filter occurs during a 100W contest, when the rig drives the antenna directly, and even greater when the SWR is high. See the reliability reports, later in this report.

It's always been true that careful component selection is critical to building reliable, high quality RF gear. I first learned this working as an EE student at RL Drake. Bob Drake taught me that "if you want to build filters and radios, you've got to wind all your own coils." Bob Henderson, 5B4AGN, reports that "Alas the generic deep red mica caps, which mostly originate in India these days have a higher than desirable ESR due to the presence of iron. These are mostly realistically rated at 500V with only limited preferred values available rated at 1kV. These caps are good for many RF purposes but not so good with power." Most of the caps in the ICE filters are "deep red micas."

ICE filter sets utilize 1kV-rated capacitors for the lower frequency band filters, but only 500V caps for the higher frequency filters. Capacitors in the Dunestar filters whose ratings I could identify are 1kV-rated, and all but a few have NPO temperature stability ratings. Except for the 160M filters, all are ceramics. The W3NQN and TXBPF filters are the best built by far, very well designed, and using inductors and capacitors capable of handling the output of a 100W transceiver. They do this by using capacitors with higher voltage ratings and lower ESR (equivalent series resistance), and by winding inductors on larger cores, and on core materials best suited to the application. The TXBPF kits are shipped with excellent close tolerance, conservatively-rated SBH-series capacitors made by Tab Components in the UK, specifically intended for use in HF transmitting filter applications. They're not cheap – \$90 for the 18 caps needed for one 6-filter set. <http://www.tabmica.co.uk/page3.html>

**Reliability:** W3NQN-built filters have an excellent record for reliability. About the only way to fry one is to run it on the wrong band or in a system with high SWR, perhaps due to antenna failure. Anecdotal reports, mostly solicited on the PVRC and NCCC email reflectors, indicate that Dunestar and ICE filters for the higher bands, especially 15M and 10M, are prone to failure, nearly always one of the low cost ceramic capacitors in the input and output resonator circuits. A few ICE 419 and Dunestar 600 users have reported failure of a single relay, but especially in the Dunestar unit the problem does not seem to be widespread. The poor power handling of ICE filters is well known, and, in my judgment, they should never be used in a 100W contest barefoot, or at more than the 50W needed to drive most amplifiers. Some Dunestar users suggest that the 300 and 600 filters hold up OK at 100W CW and SSB, but RTTY at this level can cause failures. Owners of these filters might do well to rebuild the higher band filters with SBH capacitors from Tab Components. It could be tricky fitting them into the available space, and some realignment would be required with any capacitor replacement.

**Alignment:** All of these filters are aligned by squeezing or stretching the spacing of turns on the inductors while watching a swept response on a spectrum analyzer or VNA. It's a learned skill and it can be a bit tedious to get it right, but serious effort is rewarded with lower VSWR and in-band attenuation, and increased reliability.

**Rejection of AM Broadcast Signals:** The Dunestar, TXBPF, and W3NQN-built 160M filters all provided good rejection of AM broadcast signals, nearly as good as the dedicated ICE BCB filter, and the W3NQN and TXBPF filters for higher bands are far better. 160M filter rejection at 1 MHz was -47dB for the Dunestars, -39 dB for the ICE 419s, and -42dB for the TXBPF and W3NQN-built sets. Rejection of the ICE BCB filter is -58.5dB at 1 MHz. With any of these filters, you're far less likely to need a dedicated AM broadcast filter unless you've got a close-in neighbor above about 1300 kHz.

**Insertion Loss:** Insertion loss is a function of both filter design and alignment – a filter that is out of alignment will have greater insertion loss than the same filter properly tuned. Taking circuit complexity into account, filters using powdered iron cores tend to have lower insertion loss than those using air core inductors, especially on the lower HF bands. As a group, the W3NQN and TXBPF filter sets have the lowest insertion loss. Dunestar and ICE filters use air core inductors, Dunestar filters have

relatively high insertion loss on lower bands and the highest insertion loss overall, but fairly good attenuation performance. The ICE filters have fairly low insertion loss (partly because they are the simplest filters), but the poorest attenuation, because they are the simplest filters.

**Attenuation Performance:** There are several ways to view the attenuation curves. Looking at overall attenuation outside the passband, the W3NQN filters rank first, the TXBPF set second, the Dunestar filters a notch below them, and the ICE 419B filter set a very distant fourth. But there's another important perspective – attenuation on the first adjacent bands, since that's how we contest most of the time. Studying adjacent band performance, the differences are surprising. Some filters that rate poorly for overall suppression outside the passband are superior performers on the first adjacent band! Note, for example, the superior 160M suppression of the Dunestar 80M filter, the 80M suppression of the 40M Dunestar, the 15M suppression of the 20M Dunestar, the 10M suppression of the 15M Dunestar. With few exceptions, the W3NQN-built individual band filters have the best adjacent band suppression, thanks to refinements to his designs after publication of his QST article on filters. Depending on the arrangement of your antennas and the coupling between them under various operating scenarios, you may choose one set of filters over another.

**Executive Summary and Recommendations:** If cost is no object and you don't have the time or skills to build your own, the **W3NQN-built filters** distributed by Array Solutions, with the addition of one of the several switching matrices Array Solutions offers, are the best performers. The two filter sets I tested were very well built and aligned. Approximate cost of the package I tested – six filters, the FM-6 switching matrix, and Elecraft KRC2 band decoder, is about \$1100 (plus tax and shipping).

The **Dunestar 600** is second best of the “ready built” filter sets, which, with a KRC2 band decoder costs about \$600 (plus tax and shipping). Overall performance is a good notch below the W3NQN-built filters, at about one half the cost, but their narrower bandwidth yields excellent adjacent band suppression. Insertion loss tends to be high, especially on the lower bands, the 160M, 80M, and 10M filters cover only the lower half of those bands, and alignment of the two filter sets I tested could have been better (possibly because these filters have a lot of hours on them in a contesting station). This is important, because these filters are much narrower than all others tested.

The **TXBPF filter set**, which includes a band decoder and buffered relay driver in a package about the same size as the Dunestar set, costs about \$420 (tax and shipping included), yields performance that falls between the individual W3NQN-built filters and the Dunestar 600, at about one third the cost of the W3NQN set and about \$200 less than the Dunestar 600. The TXBPF's only weak spots are somewhat inferior adjacent band performance of a few higher band filters on non-harmonically related bands (for example, 15M rejection of the 20M and 10M filters, 10M rejection of the 15M filter). Count on spending about 40 hours to build and align each set of six filters. You'll be winding a lot of coils, doing a fair amount of surface mount soldering, putting the well designed package together, and aligning the filters. I really enjoyed this project, and learned a lot from it.

Array Solutions now offers **Filter Max III**, a ready-built package similar in concept to the Dunestar 600 at a cost of about \$1,250 (including the \$329 Bandmaster Band Decoder). The Elecraft KRC2 Band Decoder (\$160) would work as well. One might hope for performance of the FilterMax III package to lie somewhere between the TXBPF and W3NQN-built implementations.

The **ICE 419-series** of filters are hardly worth considering. Their performance is, in general, significantly poorer than the Dunestars, cost is not a lot less, they have proved unreliable thanks in large part to their use of capacitors with voltage and dissipation ratings insufficient to the task. Another failure mode is the relays, which are difficult to repair or replace.

**Single band filters** built by W3NQN (\$105-\$125, depending on band) and Dunestar (\$73) are a great option for a multi-multi station where a given operating position is always on the same band (as opposed to buying complete sets for each station). Dunestar's single band filters have the same design, component values, and layouts as their multi-band filter sets, and performance is comparable.

Just as this report was being completed, 5B4AGN sent measurements for three “high power” 4O3A Series L bandpass filters designed for use on the **output** of a power amp. At a cost of \$300 each, they are an interesting alternative to stubs in filtering power amplifier harmonics. One can only guess what “high power” means to 4O3A – the product description on their website doesn't say – but their performance compares well with the 200W-rated filters. .

**Stubs:** All multi-transmitter stations can benefit from the use of stubs on antenna feedlines to attenuate harmonics of the transmitter, and to provide additional suppression of harmonically related transmitters below the operating frequency. See <http://audiosystemsgroup.com/Coax-Stubs.pdf> Stubs can add to the attenuation provided by filter sets, and they can suppress harmonics generated by the power amplifier, which these bandpass filters cannot. Good stubs typically provide more than 20dB of attenuation, which, if added to the 35 dB attenuation of a filter results in 55 dB total suppression at the stub frequency.

Plots of my measurements of most of the filters can be viewed or downloaded in pdf form at <http://audiosystemsgroup.com/BandpassFilterData.htm> They are worthy of your time to study them.

Thanks to 5B4AGN for a great design, for putting together the kits, for sage advice, and for the 4O3A filter measurements; AD6E for considerable help during construction, ND2T and N6DE for loaning filters, and to 5B4AGN and N6XI for their review of this report.

### nAttenuation and Insertion Loss in Tabular Form

	160M Filter						
	TXBPF#1	TXBPF#2	W3NQN	Dune#1	Dune#2	ICE#1	ICE#2
Reject 160	X	X	X	X	X	X	X
Reject 80	-47	-46	-50	-35	-35	-18	-17
Reject 40	-71	-71.5	-83	-57	-55	-33	-32
Reject 20	-60	-60.5	-71	-33	-32	-35	-34
Reject 15	-51	-50	-48.5	-24	-23	-38	-27
Reject 10	-70	-71	-39	-19	-19	-23	-23
Insertion	-0.22	-0.2	-0.27	-1	-1.1	-0.33	-0.5

	80M Filter						
	TXBPF#1	TXBPF#2	W3NQN	Dune#1	Dune#2	ICE#1	ICE#2
Reject 160	-42	-42	-51	-54	-56	-29	-29
Reject 80	X	X	X	X	X	X	X
Reject 40	-50	-50	-67	-37	-38	-18	-18
Reject 20	-59	-61	-60	-70	-74	-42	-45
Reject 15	-50	-51	-50	-33	-33	-32	-31
Reject 10	-45	-47	-35	-24	-23	-35	-31
Insertion	0.32	-0.3	-0.47	-0.85	-0.95	-0.28	-0.35

	40M Filter						
	TXBPF#1	TXBPF#2	W3NQN	Dune#1	Dune#2	ICE#1	ICE#2
Reject 160	-70	-69	-69	-47.5	-47	-51	-49
Reject 80	-46	-46	-44	-55	-52	-46	-60
Reject 40	X	X	X	X	X	X	X
Reject 20	-65	-68	-75	-49	-48	-53	-44
Reject 15	-49	-51	-50	-44	-45	-31	-28
Reject 10	-43	-45	-44	-42	-39	-42	-39
Insertion	-0.35	-0.34	-0.44	-0.56	-0.57	-0.64	-1.3

	20M Filter							
	TXBPF#1	TXBPF#2	W3NQN	Dune#1	Dune#2	ICE#1	ICE#2	4O3A-L
Reject 160	-88	-83	-44	-48	-47	-48	-45	-70
Reject 80	-64	-65	-39	-42	-41.5	-43	-41	-60
Reject 40	-41	-41	-55	-40	-40.5	-47	-42	-43.5
Reject 20	X	X	X	X	X	X	X	X
Reject 15	-37	-35	-26	-42	-40	-37	-24	-54
Reject 10	-58	-59	-70	-48	-47	-31	-46	-48
Insertion	-0.35	-0.35	-0.32	-0.63	-0.57	-0.75	-0.74	-0.23

	15M Filter							
	TXBPF#1	TXBPF#2	W3NQN	Dune#1	Dune#2	ICE#1	ICE#2	4O3A-L
Reject 160	-82	-84	-90	-50	-50	-47	-43	-90
Reject 80	-88	-80	-85	-44	-44	-40	-37	-90
Reject 40	-65	-65	-62	-39	-39.5	-36	-33	-62
Reject 20	-35	-36	-35.5	-42	-43	-43	-50	-40
Reject 15	X	X	X	X	X	X	X	X
Reject 10	-34	-34	-65	-53	-51	-31	-36	-49
Insertion	-0.6	-0.65	-0.65	-0.8	-0.77	-0.75	-1	-0.46

	10M Filter							
	TXBPF#1	TXBPF#2	W3NQN	Dune#1	Dune#2	ICE#1	ICE#2	4O3A-L
Reject 160	-85	-85	-90	-53	-53	-46	-41	-90
Reject 80	-82	-83	-90	-47	-47	-39	-36	-90
Reject 40	-74	-71	-82	-42.5	-42.5	-35	-31.5	-90
Reject 20	-47	-48	-64	-40	-40.5	-32	-27.5	-70
Reject 15	-26	-27	-60	-36	-38	-38	-44	-42.5
Reject 10	X	X	X	X	X	X	X	X
Insertion	-0.67	-0.7	-0.72	-0.9	-0.8	-1.3	-1.4	-0.7