Application Note
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INTER-DIGITAL BAND-PASS FILTERS

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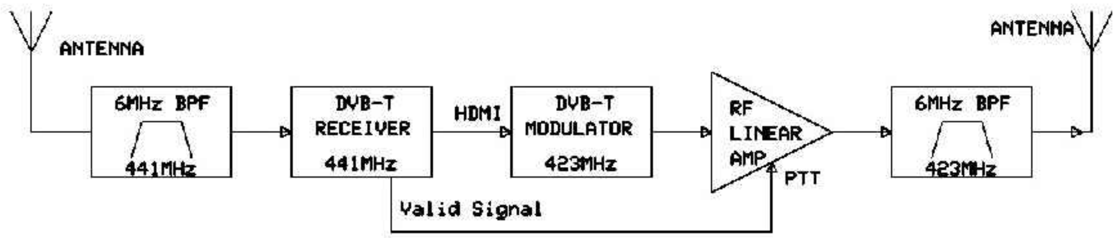

Fig. 1 A 70cm, Digital TV Repeater, block diagram.

To build an in-band Television Repeater, see Fig. 1 above, very high selectivity, band-pass filters (BPF) are mandatory on both the transmitter and receiver. On the 70cm band, 6 MHz channels are used and the typical spacing between the input and output is only 18 MHz. The purpose for the BPF on the receiver input is to prevent fundamental overload of the receiver's front end by the extremely strong, near-field signal from the transmitter. The purpose of the BPF on the transmitters' output is to prevent any out of band spurious spectrum from polluting the RF environment of adjacent channels and especially the receiver's channel.

Fig. 2 DCI ATV-BPF

DCI While there are several companies world-wide that make high quality BPF channel filters for the broadcast TV industry, I am only aware of one company that makes them commercially for the amateur radio 70cm (420-450MHz) band. That company is DCI in Canada [1] They make two versions, either a 6 pole or 8 pole filter. See Fig. 2. I am uncertain, but I believe they are made using coupled, quarter-wave, helical resonators.

They are large rack mount units (19" W x 6" H x 8" D). They are not suitable for portable, back-back operations due to their large size.

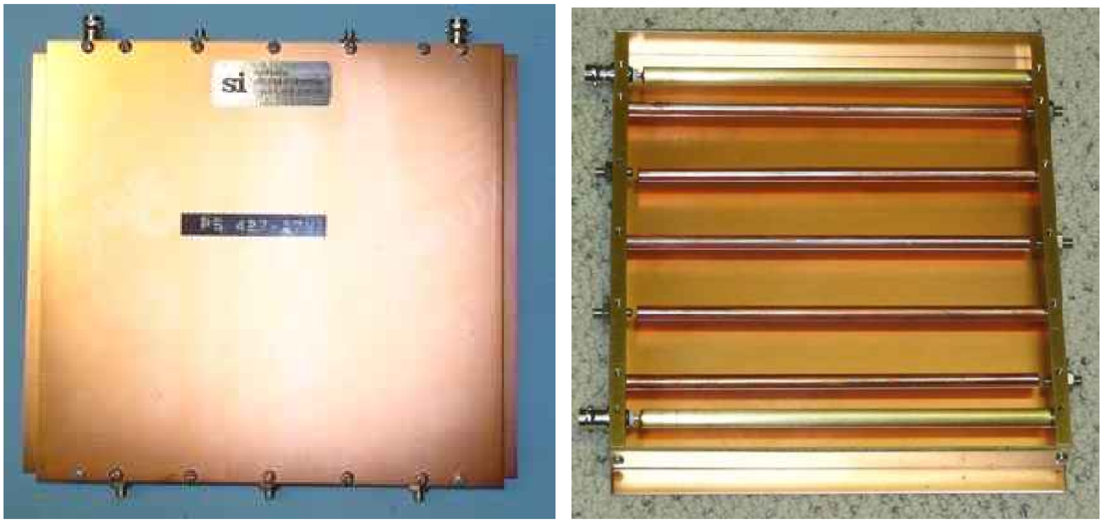

Fig. 3 Spectrum International, 70cm, ATV, Inter-Digital Band-Pass Filter

SPECTRUM INTERNATIONAL - W2CQH

The other option is to build your own Inter-Digital, Band-Pass Filter. Fig. 3 shows an example of such a filter, formerly sold by Spectrum International, Concord, MA (*no longer in business*). These were excellent filters. They were smaller and less expensive than the DCI filters. Being made of machined brass and copper, they were quite heavy at four pounds. In the 1990s, they sold for $250. The term "inter-digital" comes from the word "digit" which means "finger". In the right photo in Fig. 3, you can see the filter elements consist of five copper rods interspaced as if they were meshed fingers on your right and left hands, thus the term "inter-digital".

Fig. 4 BNC connector & input resonator

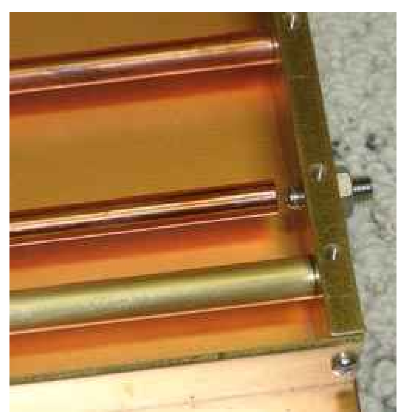

Fig. 5 Close up detail of tuning screw

The original design for the Spectrum International ATV-BPF, shown in Fig. 3, was by Reed Fisher, W2CQH. It was published in QST in 1968 [2]. Reed's design was a four pole BPF. The SI-ATV-BPF is a 5 pole resonator design. The five copper rods in Fig. 3 are each a quarter wavelength long and shorted to a wall in an interleaving pattern. The two larger brass rods at the top and bottom are also quarter wavelength long, but are simply used for the input and output coupling, see Fig. 4. Fine tuning of the BPF is accomplished by using 10/32 screws in the side walls, see Fig. 5. The small capacitance between the tip of the screw and the copper resonator rod is adjustable and provides the fine trimmer capacitance. Adding any capacitance to the end of the resonator rod lowers it's resonant frequency. Measurements made by KH6HTV on a 4 pole, 70cm, W2CQH filter, showed that using the tuning screws, the center frequency could be tuned down about 5% max. For a 5 pole, 70cm, W2CQH (Spectrum International) filter, the center frequency could be tuned down about 20 MHz, i.e. 5%. For a 7 pole, 70cm, W2CQH filter, the center frequency could be tuned down only about 4 MHz, i.e. 1% max.

Table I Critical Dimensions for Spectrum International (W2CQH type), 70cm, 5 pole, ATV, Inter-Digital, Band-Pass Filters

Item	Ch 57	Ch 60	Notes
Internal Dimensions	7.5"x 6.75"x 0.75"	7.5"x 6.64"x 0.75"	width-depth-height
In/Out Resonators	6.58" x 0.30"dia.	6.46" x 0.30"dia.	solid brass rods (2) required
Interdigital Resonators	6.65" x0.25"dia.	6.46" x 0.25"dia.	solid copper rods (5) required
In/Out Spacing	0.66"	0.63"	from side plates, resonators 1 & 7
Resonator Spacing	0.64"	0.63"	between 1 & 2 and 6 & 7
Resonator Spacing	1.20"	1.20"	between 2 & 3 and 5 & 6
Resonator Spacing	1.28"	1.28"	between 3 & 4 and 4 & 5
End Plates	7.5"x 0.75"x 0.25"	7.5"x 0.75"x 0.25"	solid brass
Side Plates	7.25"x0.75"x0.0625"	7.14"x0.75"x0.0625"	solid brass
Tuning Range	408 - 429 MHz	419 - 443 MHz	with screws
Center Freq.	423 MHz	441 MHz	
Insertion Loss	-1.8 dB	-1.5 dB	
IL ripple	± 0.3 dB	± 0.2 dB	in passband
Bandwidth	6.4 MHz	6.8 MHz	-3dB

Notes:

1. These are measurements taken from actual BPFs purchased from SI.
2. Resonators are numbered from 1 to 7 from input to output
3. Tuning Screws:10-32 screws mounted in end plates opposite open-circuit ends of resonators #2, 3, 4, 5, & 6
4. Materials: top & bottom covers - 1/16" copper plated brass plates, end plates - 1/16" brass side plates - 1/4" brass resonator rods - copper plated brass

Figs. 6 & 7 on the next page, show the frequency response curves for a Ch 57 (420-426 MHz), SI-BPF, as measured on a Rigol DSA815 spectrum analyzer with a tracking generator option. Fig. 6 is the in-band response showing the insertion loss, S21. The mid-band insertion loss was approx. -1.8dB with ± 0.3dB ripple. The -3dB bandwidth was 6.4 MHz. Fig. 7 shows the out of channel attenuation skirts for a span of 50 MHz. Attenuation on a channel 18 MHz away was measured to be about -90dB.

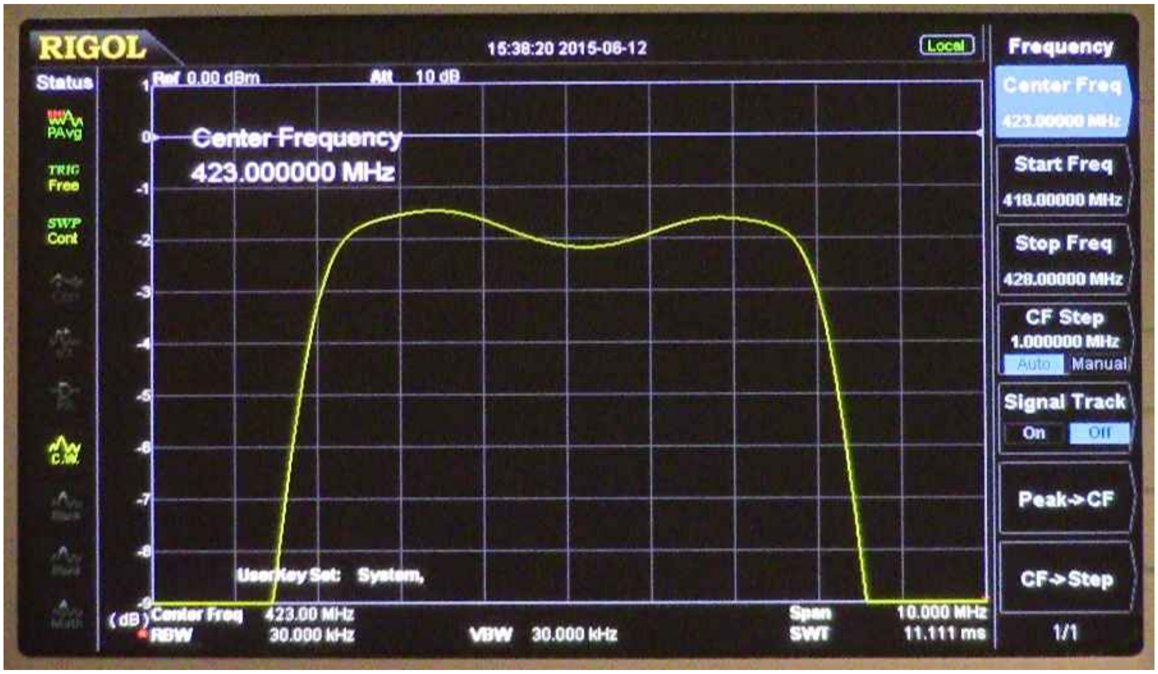

Fig. 6 Channel 60 SI-BPF --- In-Band Performance.
Center frequency = 423 MHz, 1dB/div vertical and 1 MHz/div horizontal

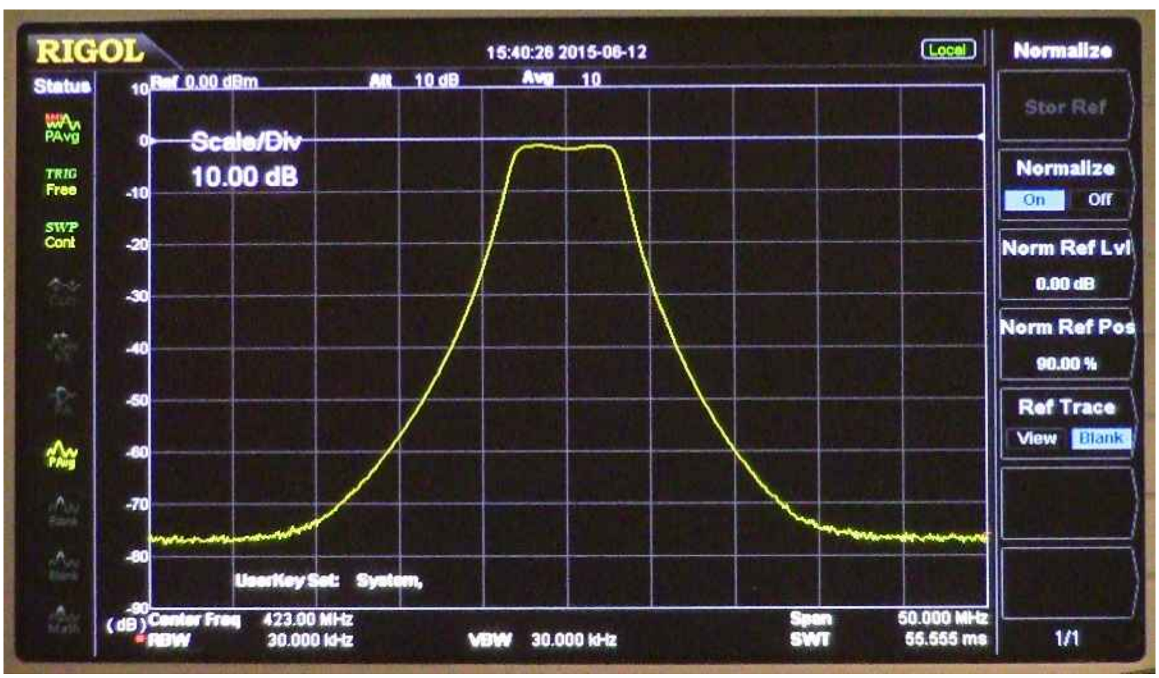

Fig. 7 Channel 60 SI-BPF --- Out of Band Performance
Center frequency = 423 MHz, 10 dB/div vertical and 5 MHz/div horizontal
Note: the network analyzer noise floor is about -75dB

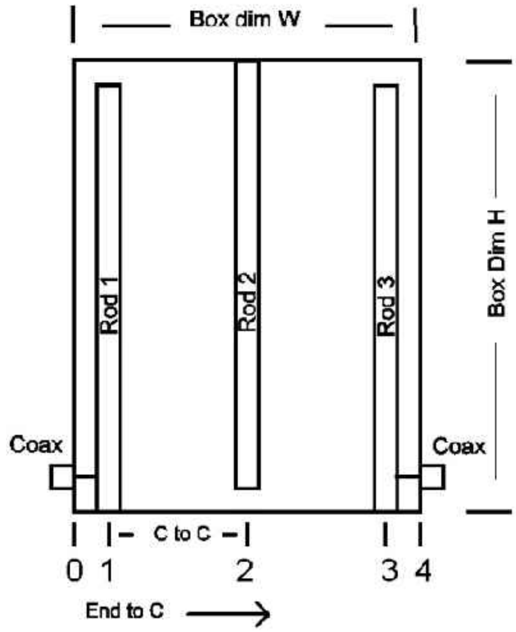

Fig. 8 Basic mechanical design of N6JH ID-BPF with taped input/output on first & last resonator rods.

N6JH BPF DESIGN Another similar design was introduced by Jerry Hinshaw, N6JH, in Ham Radio magazine in 1985 [3]. The article includes the complete BASIC language computer program to design ID-BPFs. Other hams, WA4DSY & VK3UM, have more recently posted this program on their web sites as an easy to use, on-line, calculator tool [4-5]. The major difference between the W2CQH and N6JH designs, is that the two rods which W2CQH uses simply as input/output for coupling are in fact active resonant elements for N6JH, thus they increase the filter order by two. N6JH couples into the two end resonators by a simple taping up on the rod. Thus the distinct advantage of getting more filter poles into the same size package. See Fig. 8.

The VK3UM calculator is strictly for a four (4) resonator, 70cm BPF. It asks for input parameters of: center frequency, 3dB bandwidth (caution: it is specified as ±), box depth and rod diameter. The program output is shown in Fig. 9 below. This program only predicts the -40dB bandwidth.

Fig. 9 VK3UM design for a 4 pole, channel 60 (441MHz), 6 MHz, Band-Pass Filter

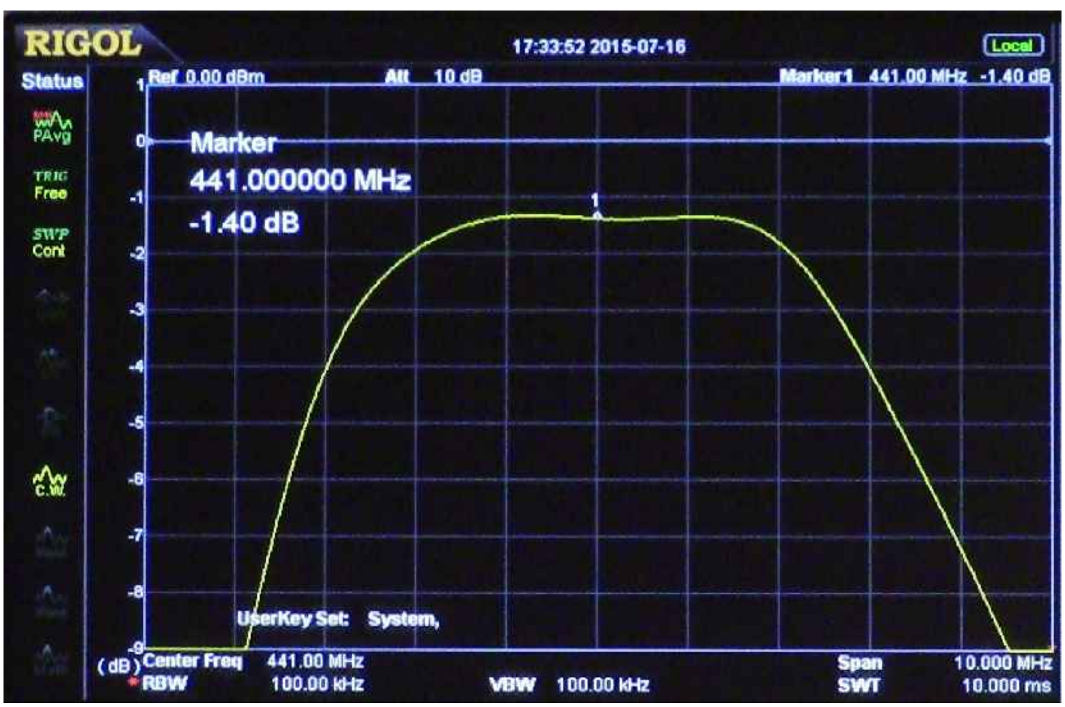

Fig. 10 Frequency Response of actual filter built by N0YE per Fig. 9 dimensions.

It is the author's opinion that the WA4DSY on-line calculator is much more versatile, compared to the VK3UM. It can be used for BPF filter designs with various number of poles and one can also specify the desired pass-band ripple. It also provides a calculated theoretical frequency response. Don Nelson, N0YE, has built the above 4 pole, channel 60 BPF, Figs. 9 & 10. It was built out of aluminum and used 4-40 tuning screws. It's parameters were then used in the WA4DSY calculator to compare results and obtain a theoretical, predicted response. The results were amazingly close between WA6DSY's predictions and the actual measured response. The insertion loss was only 1/4 dB higher than predicted. Key results were:

Table I Comparison of Theory and Actual N6JH type Filter
(443MHz, 6 MHz BW, 4 pole, 0 dB ripple)

Channel	Frequency	IL (theory)	IL (meas)
60	441 MHz	1.14 dB	1.4 dB
59	435 MHz	25.2 dB	23 dB
58	429 MHz	49.3 dB	48 dB
57	423 MHz	63.4 dB	61 dB
-3 dB Bandwidth =		6.0 MHz	6.2 MHz

To use WA4DSY's on-line calculator, one needs to enter the following design parameters: Number of Elements, Passband Ripple in dB, Center Frequency in MHz, Bandwidth in MHz, In/Out Impedance in Ohms, Ground Plane Spacing in inches, Resonator Rod Diameter in inches, End Plate to In/Out Rod Spacing in inches. The program will then calculate the correct dimensions and also generate a crude, printer 40 point, plot of the insertion loss vs. frequency.

A word of caution when using the WA4DSY calculator -- always select a slightly higher center frequency for the design to allow the use of tuning screws. Tuning screws are mandatory as slight mechanical errors in construction will result in a filter that never exactly performs as predicted. For these types of filters, we have found that it is always necessary to do a fine tuning of their frequency response using a network analyzer. A tuning screw off the high impedance end of a 1/4 λ resonator rod provides a small, adjustable amount of capacitance to lower the resonant frequency of the rod.

Using the WA4DSY calculator, a series of filters of various orders (4 & 5) and various amounts of pass-band ripple (0, 0.1, 0.2 0.5 & 1dB) were calculated to compare the predicted pass-band and stop-band performance. The results are tabulated in Table II. The conclusions that can be drawn are: (1) Increasing the number of poles (i.e. resonator rods) increases the pass-band insertion loss (2) Allowing even a small amount of pass-band ripple, such as 0.1 dB, makes a dramatic increase in the stop-band attenuation. (3) Allowing pass-band ripple vs. no ripple provides a much flatter pass-band response.

For normal amateur radio service, it appears that a 4 pole filter with 0.1dB ripple would be the best choice. For TV repeater service where more isolation is required between the receiver and a nearby transmitter, then a 5 pole filter with 0.1dB ripple is recommended. It would give over 90dB isolation for an 18 MHz repeater input/output frequency pair.

Table II --- Ch 60 (441 MHz), 6 MHz, N6JH type Band-Pass Filters
Theoretical Performance

Poles	Pass-Band Ripple	Band-Width Ripple	Ch 60 (441)	Ch 59 (435)	Ch 58 (429)	Ch 57 (423)
4	0 dB	NA	1.14 dB	25.2 dB	49.3 dB	63.4 dB
	0.1 dB	4.95 MHz	1.32 dB	33.2 dB	57.5 dB	71.8 dB
	0.2 dB	5.19 MHz	1.37 dB	33.6 dB	59.0 dB	73.3 dB
	0.5 dB	5.49 MHz	1.45 dB	35.6 dB	61.3 dB	75.6 dB
	1.0 dB	5.70 MHz	1.56 dB	37.5 dB	63.2 dB	77.6 dB
5	0 dB	NA	1.41 dB	31.5 dB	61.6 dB	78.4 dB
	0.1 dB	5.29 MHz	1.74 dB	42.7 dB	74.6 dB	92.5 dB
	0.2 dB	5.46 MHz	1.80 dB	44.4 dB	76.3 dB	94.3 dB
	0.5 dB	5.67 MHz	1.94 dB	46.8 dB	78.9 dB	96.8 dB
	1.0 dB	5.80 MHz	2.14 dB	49.1 dB	81.3 dB	99.3 dB

REFERENCES:

1. DCI - digital communications, mfgr. of BPFs for TV industry, www.dci.ca

2. "Interdigital Bandpass Filters for Amateur VHF/UHV Applications", Reed Fisher, W2CQH, QST, March 1968, pp. 32-33

3. "Computer-Aided Interdigital Bandpass Filter Design", J. Hinshaw & S. Monemzadeh, HAM RADIO, Jan. 1985, pp. 12-26

4. Dale Heatherington, WA4DSY, on-line calculator for ID-BPF, www.wa4dsy.net http://www.wa4dsy.net/cgi-bin/idbpf program in C++ can also be down-loaded

5. Doug McArthur, VK3UM, down-loadable calculator for 4 pole ID-BPF, www.vk3um.com http://www.vk3um.com/interdigital%20filter.html