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QST Issue: Sep 1988
Title: Band-Pass Filters for HF Transceivers
Author: Lew Gordon, K4VX

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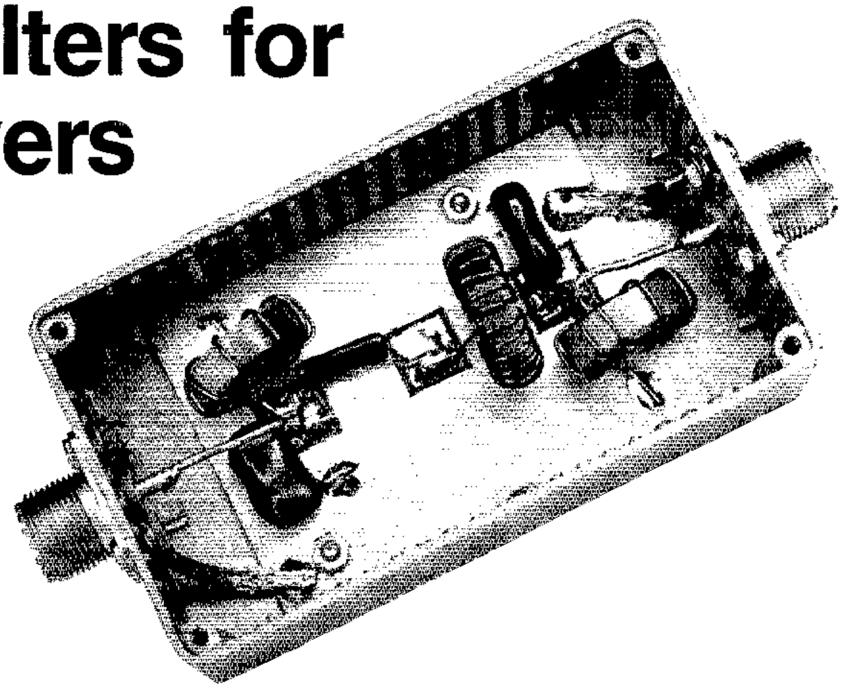
Band-Pass Filters for HF Transceivers



Do your multiple-transmitter Field Day or contest efforts suffer from intrastation interference? These handy and inexpensive filters can help!

By Lew Gordon, K4VX
PO Box 105
Hannibal, MO 63401

One of the more aggravating aspects of competitive Amateur Radio operation comes when you're all set up for Field Day or a DX contest in a multiple-transmitter category and you discover an intrastation interference problem. All that planning and anticipation appears to be headed down the drain! Frustrations and tempers immediately mount: Someone yells "Eighty meters is wiping me out!" or someone else screams "Every time you transmit, all I hear is noise!" Anyone who has participated in a Field Day operation with more than one transmitter can probably relate to this situation.

Although interference caused by receiver front-end overload from adjacent transmitters has existed since the earliest days of multiple-transmitter operations, the mutual interference problem has been exacerbated in the last few years by widespread use of all-solid-state synthesized exciters. These rigs have not only greatly expanded operating ease and capabilities, but recent designs are providing receivers with greater stability, sensitivity and selectivity, and, as new devices and techniques are introduced, greater dynamic ranges than have previously been possible.

There is a shortcoming in the new generation of transceivers, however: Phase noise.[1] Reducing phase noise is a problem that radio design engineers have been attacking for years with varying degrees of success. Not only is phase noise transmitted (and propagated by the ionosphere) along with your signal on the band on which you are operating, but some noise energy is also transmitted on adjacent bands. Adjacent-band phase-noise interference is not usually a major problem unless stations are operating in close physical proximity, as is the case in Field Day or multitransmitter contest operations.

In seeking a solution to the intrastation interference problem that I could apply in my multitransmitter DX-contest station, I first entertained the idea of constructing large, high-power-handling band-pass filters for each transmitter. These filters would not only reduce the transmitted noise spectrum from each exciter, but would reduce receiver front-end overload problems as well, because each operating position would transmit *and* receive through a band-pass filter. I quickly retreated from this idea, however, as the expense of the components required to handle 1500 W of RF while providing an acceptable SWR to the transmitter would be excessive.

After considering the problem for a while, it occurred to me that the phase-noise spectrum is not generated in the amplifiers, so filters between the exciters and amplifiers, constructed with components that could handle 100 W of exciter output, would do the job nicely. In addition, this scheme would provide filtering during receiving, helping to reduce front-end overload problems. The best part is that even if you use all new components, the cost of these filters should not exceed $10 each. All that's necessary for tune up is a dip meter and a general coverage receiver. These filters were first described in an article I wrote for the *National Contest Journal*.[2]

Filter Design and Construction

The filter design I chose is a three-section Butterworth band-pass filter (See Fig 1). I chose this design to minimize insertion loss, produce a flat response across each band and maintain a 50-Ω impedance. The impedance match is very important with solid-state transceivers, if maximum power output is to be obtained from the exciters. I derived the component values in Table 1 by iterating the design formulas until standard-value capacitors could be used without compromising insertion loss, bandwidth, or performance.

A single-sided 2- × 4-inch PC board is used to mount the components for each filter. Three square pads, each approximately 0.4 inch per side, are required

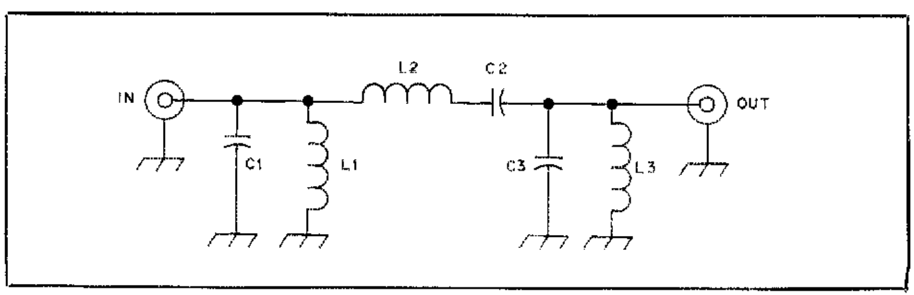


Fig 1—Schematic diagram of the three-pole Butterworth band-pass filters.

[1]Notes appear on p 23.

Table 1
HF Band-Pass Filter Specifications

Band (MHz)	C1/C3 (pF)	C2 (pF)	L1/L3 (μH)	L2 (μH)	T-68-6 core L1/L3 (no. turns)	T-68-6 core L2	T-80-6 core L1/L3 (no. turns)	T-80-6 core L2	F_r (MHz)
1.8	4000	400	2.2	22	22	69	23	70	1.75
3.5	2000	200	1.1	11	16	48	16	50	3.38
7	1000	100	0.55	5.5	11	35	11	35	6.78
14	500	50	0.28	2.8	8	25	8	25	13.56
21	330	33	0.18	1.8	7	20	7	20	20.65
28	250	25	0.14	1.4	6	17	6	18	27.39

Toroidal Inductors

The inductors used in Lew's filters can be wound on a number of different toroidal cores, or they can be made from air-wound inductor stock. Toroidal inductors are preferred to air-core coils because the magnetic field of a toroidal inductor is contained almost entirely in the core, so toroidal inductors usually need not be shielded from other circuit components. This property allows filters with toroidal inductors to be built more easily, and into smaller enclosures, than those with air-wound coils.

The choice of toroidal cores for the inductors in Lew's filters depends mostly on exciter power level. For 100-W transmitters, cores as small as ½-inch OD (T-50-XX cores) can be used for the coils if there is little perceptible heating of the inductors when power is applied to the filters. If the core material saturates—which occurs when the flux density in the core rises beyond the safe region as a result of excessive applied power—the core can be destroyed. This is less likely to occur in the 0.68- and 0.80-inch OD cores (T-68-XX and T-80-XX, respectively).

Mix-6 powdered-iron material is used for the inductors in this article because its frequency response and Q characteristics are suitable, and because, for the inductances needed in these filters, relatively few turns are required on mix-6 cores. Which core to use is related to a compromise between the number of turns on the toroids and the ease of tuning the filters. Inductors made using T-80-6 or T-68-6 cores require about the same number of turns for a given inductance, but the turns will be spread over a larger area on the larger core, leaving more room for turn-spacing adjustments. If smaller (T-68) cores are used, the turns come closer to filling the core, making tuning easier.

Similarly, if you wind the inductors on T-50-6 cores (½-inch OD), the inductor turns will cover the cores more completely. Also, an inductor wound on a T-50-6 core requires more turns for a given inductance than one wound on a T-68-6 or T-80-6 core. Tuning these smaller inductors is easier, because removing one turn from a coil with 20 turns of wire is easier than removing ½ turn from a coil with 10 turns! Also, the placement of the remaining turns is less critical to inductor value on a coil with more turns. Using smaller cores is fine as long as the core material doesn't saturate when power is applied to the filter.

Choosing toroidal cores is easy to do. Using a scientific calculator, the inductance values given in Table 1 and published values for the number of turns necessary for a given inductance on a certain core, you can determine the coil-winding information for that core. Each toroidal core has an A_L value, which simply represents the number of microhenrys that 100 turns of wire will produce on that core. The A_L values for common cores are given in manufacturer's literature, *The ARRL Handbook* and other sources.† To calculate the number of turns necessary for a given inductance on a toroidal core, use

$$N = 100 \times \sqrt{L/A_L} \quad \text{(Eq 1)}$$

where

N = number of turns
L = required inductance in μH
A_L = no. of μH per 100 turns

For a 5.5-μH inductor (the value of L2 in the 40-meter filter) on a T-68-6 core (A_L = 47),

$$N = 100 \times \sqrt{5.5/47} = 34 \text{ turns.} \quad \text{(Eq 2)}$$

Wound on a T-50-6 core (A_L = 40), the same inductor would require

$$N = 100 \times \sqrt{5.5/40} = 37 \text{ turns.} \quad \text{(Eq 3)}$$

The smaller size of the T-50 core and the few extra windings makes tuning a bit easier, and reduces the chance of changing the inductor value by accidentally rearranging the winding during handling. After building filters using smaller inductors, make sure the cores don't heat perceptibly during operation, or they may be damaged.—*Rus Healy, NJ2L*

†A_L values and other winding information for powdered-iron toroids is given in M. Wilson, ed., *The 1988 ARRL Handbook* (Newington: ARRL, 1987), p 2-34.

(see Fig 2). This layout is simple enough that the boards can be prepared using an X-acto® knife, although if construction of many boards is anticipated (or if "ugly" construction offends you), etched PC boards might be desirable. Each filter is mounted in an aluminum enclosure. Install SO-239, BNC, or phono connectors at each end of the enclosures for input and output connections. The filter pictured in the title photograph is built in a Hammond 1590N enclosure.

A parts-placement diagram for the filter components is shown in Fig 3. All inductors can be wound on Amidon or Palomar T-68-6 toroids, although larger T-80-6 toroids may be used, if desired.[3] In an early design using T-50-2 toroids, the windings became warm with 100 W output, so I decided to use larger T-68-6 cores. (See the sidebar, "Toroidal Inductors.") All inductors are wound with no. 20 enameled wire, with the exception of L2 on the 3.5- and 7-MHz filters, which must be wound with no. 24 or smaller wire if T-68-6 cores are used. If you use T-80-6 cores, you can use larger wire for these inductors. In winding the inductors, start with the number of turns specified in Table 1, and space the turns evenly over about 75% of the core. Leave three or four inches of extra wire on each inductor for adjustments.

I used silver-mica capacitors in all the filters, but polystyrene capacitors can be substituted, and they're cheaper. The capacitors you use should be rated at 500 V or more. If you have access to an impedance bridge or capacitance meter, you could use 20%-tolerance disc-ceramic capacitors with adequate voltage ratings, after finding those close enough in value to do the job.

Tuning the Filters

Final adjustment of the inductors requires a dip meter. (If you have access to a network analyzer or impedance bridge, so much the better, but a dip meter will work fine for this job.) Solder each capacitor across its corresponding inductor to make a parallel LC circuit. Leave sufficient space between the leads to couple the dip meter into the circuit. The values for F_r in Table 1 are the resonant frequencies for C1/L1, C2/L2 and C3/L3 for each filter. Adjust the dip-meter frequency and watch for a dip. Be sure to couple the dip meter very lightly to the circuit being measured, and look for the frequency that produces a barely observable dip. Because my dip meter is 25 years old, I use a general coverage receiver to verify the meter's frequency readings. Of course, this is a good practice any time you use a dip meter.

Fine adjustment of the resonant frequencies specified in Table 1 can usually be done by spreading or compressing the coil turns on the cores. If necessary, add or remove one turn at a time from each coil until resonance occurs near the specified F_r. When the resonances correspond to the F_r

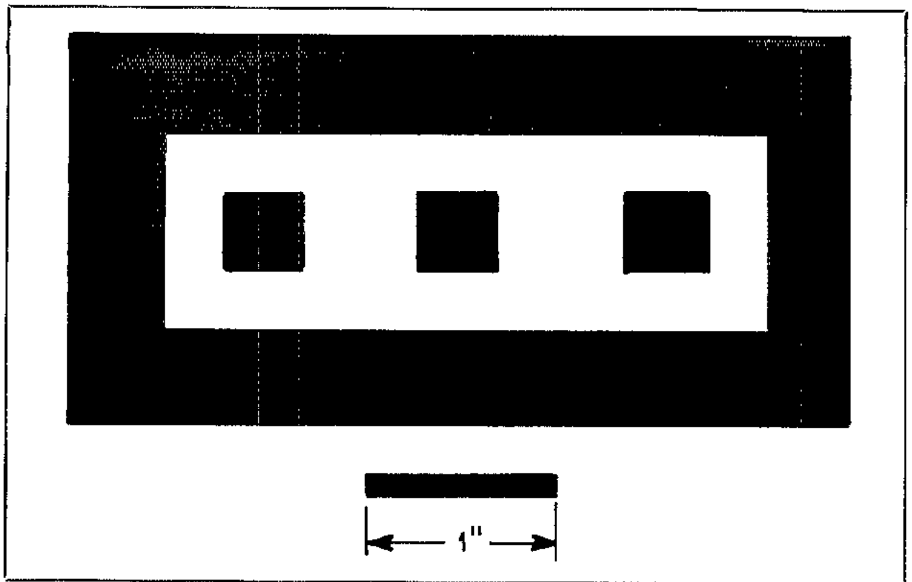


Fig 2—Full-size, foil-side PC board pattern for the three-pole band-pass filters. Shaded areas represent unetched copper foil. Components are soldered on the foil side.

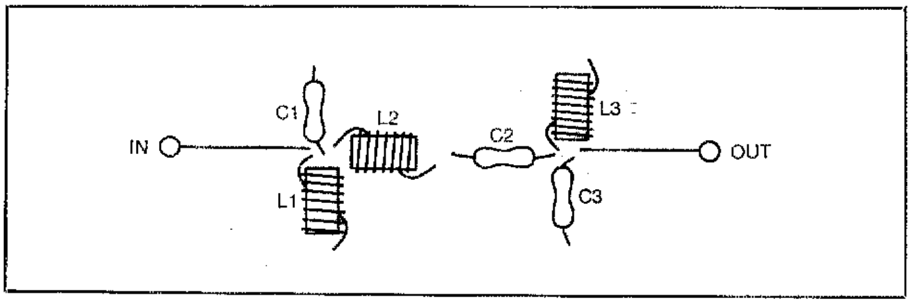


Fig 3—Parts-placement diagram for the three-pole band-pass filters. Input and output connections can be made with small coaxial cable or short lengths of hookup wire. Be sure to make a good connection from the ground foil of the PC board to the enclosure and connector grounds. See the title photograph.

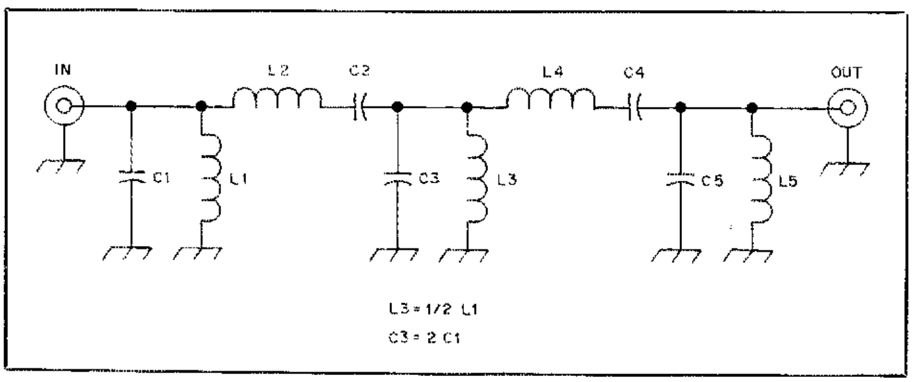


Fig 4—Schematic of a five-pole Butterworth band-pass filter. The same construction techniques as used for the three-pole filters should be used when building five-pole versions.

values in Table 1, unsolder the capacitors. Then, without disturbing the placement of the turns on the core, coat the inductors with Q Dope® or spray paint, and trim the leads to about ¾ inch. When the inductors have dried, solder them to the designated spots on the PC board. Solder in the capacitors and mount the filters in the enclosures.

If you have access to a network analyzer, you can use it to help optimize the overall filter performance. Using a borrowed HP-8656B signal generator and a 50-Ω terminated RF voltmeter, I measured the filter characteristics shown in Table 2.[4]

The insertion loss of these filters is less than 0.5 dB across the bands for which they are built, so obtaining adequate amplifier drive when transmitting through the filters should not be a problem. The major advantage of these filters is the near-total

Table 2

Filter Loss v Frequency*

Band (MHz)	*Loss (dB) at freq (MHz)*				
	3.5	*7*	*14*	*21*	*28*
3.5	<0.5	29	50	>65	>65
7	30	<0.5	32	41	49
14	56	32	<0.5	16	40
21	63	44	8	<0.5	15

*Not measured at 1.8 or 28 MHz.

elimination of the phase-noise interference they provide when transmitters and receivers are operated on adjacent bands in close proximity to each other. Although the isolation they provide between the 14- and 21-MHz bands, and between the 21- and 28-MHz bands, is less than the isolation possible between bands that differ in frequency by a 2:1 or greater ratio, the filters are good enough to practically eliminate phase noise and effectively reduce intermodulation problems at my station. On 28 MHz, I can barely detect the noise from the 21-MHz transmitter, where the filter attenuation is only 15 dB (I don't use a filter on the 28-MHz rig). The relatively low attenuation of the 21-MHz filter at 28 MHz may be a result of the fact that the 21-MHz filter I use was constructed using air-wound no. 14 wire in self-supporting coils (instead of toroidal inductors) for L1 and L3 in that filter. The close proximity of these air-wound coils allows mutual coupling, which deteriorates filter performance. If you build these filters using air-wound inductors, use shields between the inductors to reduce coupling. Toroidal forms should be used, if possible.

If problems with phase-noise interference persist after installation of these filters, five-pole Butterworth filters may solve the problem. (A five-pole filter is essentially two cascaded three-pole filters.) The center section of the filter combines the output section of one three-pole filter with the input section of the other, and should have twice the capacitance and half the inductance of the end sections of the corresponding three-pole filters to maintain 50-Ω impedance (see Fig 4). Rejection should be considerably more than the values shown in Table 2. F_r is the same for the center section as for the others. Insertion loss for the five-pole filters will be slightly greater than the three-pole versions, but this is a small price to pay for interference-free operation. If a five-pole filter doesn't do the job, you may want to seriously consider replacing the troublesome transceiver!

In the past, vast improvements in selectivity, sensitivity and dynamic range that we enjoy today in Amateur Radio equipment have come about as direct results of amateurs making their feelings about equipment performance known to manufacturers. Manufacturers should seriously consider incorporating additional bidirectional filtering in their transceiver designs—users

(continued on page 23)

Table 1
Command Functions

Terminal Menu Commands	*Function*
CONTROL T	Toggle transmit mode on
CONTROL R	Toggle receive mode on
CONTROL S	Change data rate
CONTROL CLEAR	Clear type-ahead buffer
BACK S	Backspace in type-ahead buffer
TAB (1, 2 or 3)	Move type-ahead buffer data into user buffer 1, 2 or 3
ESC (1, 2 or 3)	Move user buffer into type-ahead
Disk Menu Commands	*Function*
T	Transmit message from disk buffer to the CP
R	Store received data in disk buffer
C	Clear the disk buffer
O	Toggle receive mode on or off
S	Save the message in the disk buffer to a file on disk
L	Load a message from a disk file into the disk buffer
P	Print a message from the disk buffer

by replacing step 6 with the following procedure:

6a) Press the S key.

6b) Enter the file name (D:RY1.LIS, for example).

6c) Press the RETURN key.

Transmitting a Disk File

1) Press the SELECT key.

2) Press the L key.

3) Enter the file name (D:RY1.LIS, for example).

4) Press the RETURN key.

5) Press the T key.

The information stored in the file named D:RY1.LIS will be transmitted after the T key is pressed. Both programs are returned to the terminal screen before the disk message is sent.

Obtaining The Programs

Plug-in cartridge versions of both programs are available from me for $35 each. Disk, cassette and EPROM-only versions are $15 each. (The ARRL and *QST* in no way warrant this offer.) The assembler source-code listings for each program are available from the ARRL for $5 each to cover photocopying and handling costs.

You can purchase the EPROM only and build your own cartridge[10] by following the instructions given in the August 1986 article (see note 3). The cartridges are by far the easiest to use. This is particularly true if you change operating modes often.

Summary

I've enjoyed operating Baudot and ASCII RTTY with these programs. They're similar in structure and, with a little practice, are easy to use. The disk-storage and user-buffer features greatly enhance performance. Disk files can be used to store all sorts of information about your QTH, equipment, other hobbies and pictures or calendars!

Most any modem or CP will work with the Baudot RTTY program, but some modems, designed to accommodate Baudot RTTY only, may require modification to operate properly on ASCII. That's because the ASCII RTTY data rate is higher than that used with Baudot RTTY. Check your modem specifications; the maximum data rate should be at least 110 bauds in order to run ASCII RTTY at 100 WPM. If necessary, contact the modem manufacturer and see if they can supply you with any required modification information.

You can test both programs by copying ARRL bulletins transmitted by W1AW. The bulletins are first transmitted in Baudot at 60 WPM, then in ASCII at 100 WPM. Check *QST* for the current W1AW operating schedule.

Notes

[1] S. Stuntz, "A CW Keyboard Program for Atari Computers," *QST*, Feb 1985, pp 32-33.
[2] S. Stuntz, "A CW Receive Program for Atari Computers," *QST*, Nov 1985, pp 51-53; Feedback, *QST*, Feb 1986, p 53.
[3] S. Stuntz, "A CW Program Cartridge for the Atari Computer," *QST*, Aug 1986, pp 34-36; Feedback, *QST*, Apr 1987, p 59.
[4] R. Frohne, "Replacement Detector," Technical Correspondence, *QST*, Jul 1987, p 41.
[5] R. Lewis, "Split-Screen RTTY for Atari Computers," *QST*, May 1987, pp 16-20.
[6] S. Stuntz, "A Packet Terminal for Atari Computers," *QST*, Nov 1987, pp 15-17; Feedback, *QST*, Jan 1988, p 49.
[7] T. Miller, "A Cheap n' Easy Modem," *QST*, Jun 1988, pp 15-21.
[8] T. Miller and E. Hare, "A Simple Tuning Indicator," *QST*, Jul 1988, pp 28-31. See Feedback, this issue, p 48.
[9] S. Stuntz, "Easy RS-232-C," Technical Correspondence, *QST*, Apr 1988, p 46.
[10] Cartridge cases and PC boards are available from Best Electronics, 2021 The Alameda, Suite 290, San Jose, CA 95126, tel 408-243-6950. Cartridge cases, $1.50 each; PC boards, $1 each (minimum order, $5). The ARRL and *QST* in no way warrant this offer.

Steve Stuntz has a BSEE degree and is a licensed professional engineer in the state of Colorado. He is the Director of the System Planning and Analysis Division of the Western Area Power Administration. Steve's responsible for planning improvements to the high-voltage transmission system in Colorado and Wyoming to accommodate future energy requirements. Steve has been a ham for 28 years; he received his Novice ticket when he was 13 years old. As an amateur, Steve enjoys QRP CW work and designing computer applications for Amateur Radio. Steve's other interests include biking, skiing and hiking.

Band-Pass Filters for HF Transceivers

(continued from page 19)

not be forced to add these devices. We cannot control the received spectrum before it reaches our gear, but we *can* control the transmitted spectrum. I think that a few less memories, fewer confusing front-panel buttons, and a little more attention by some manufacturers to a clean output spectrum would be appreciated by everyone.

If your local radio club plans a serious multiple-transmitter effort for Field Day, you may want to consider making it a club project to construct these filters. Many of the components are probably available among your membership from junk boxes or "retired" projects. These filters could keep your club's Field Day effort, or your next multitransmitter contest effort, from turning into a disaster!

Notes

[1] For more information on phase noise, see J. Grebenkemper, "Phase Noise and Its Effects on Amateur Communications," *QST*, Mar 1988, pp 14-20, and Apr 1988, pp 22-25. Also see Feedback, *QST*, May 1988, p 44.
[2] L. Gordon, "Bandpass Filters for Transmitters," *National Contest Journal*, Mar/Apr 1987, pp 19-20.
[3] Amidon toroidal cores are available from Amidon Associates, 12033 Otsego St, N Hollywood, CA 91607. Palomar toroids can be obtained from Palomar Engineers, PO Box 455, 1924-F W Mission Rd, Escondido, CA 92025, tel 619-747-3343.
[4] Rejection values for 1.8, 24.9 and 28-MHz filters were not measured. Because of its close proximity to the 21- and 28-MHz bands, no filter component values for the 24.9-MHz band are given in Table 1.

Lew Gordon has been a licensed ham since he was 17 years old in 1947, and earned his Extra Class ticket in 1952. He has held K4VX since 1973. Lew earned a BS degree in physics from Purdue University and did graduate-level work at Georgetown University. Presently, Lew is a semiretired systems engineering consultant for government and private agencies. Lew's wife holds NSØZ, and his daughter is licensed as NØHVY.

An active member of the Society of Midwest Contesters, Lew's main love in Amateur Radio is antenna-system design and construction. His antenna farm is currently composed of eight towers ranging in height from 50 to 170 feet, and includes rotatable antennas for 40 through 10 meters. All his antennas are homemade, except for one 2-element 40-meter beam. His other radio interests include using computers to optimize antenna designs and to perform contest-log duping.