A Trap-Filter Duplexer for 2-Meter Repeaters

Keeping Transmitter Power out of the Receiver Line

BY EDWARD P. TILTON,* W1HDQ

A common problem in vhf repeaters is desensitization of the receiver when the transmitter comes on. Almost everyone who has set up a repeater with the customary 600-kHz frequency separation between transmitter and receiver is familiar with it. High-Q coaxial tank circuits in the receiver line may help, but even well-made devices of this kind are of limited value, and insertion loss may be prohibitive.

The filter shown here was built at the suggestion of A. H. Groff, KØVQM, who supplied details of a similar filter that he built for MARS frequencies. His channels, 142.155 and 143.46 MHz, are more than twice the usual separation of in-band 2-meter repeaters, but his reported 80-dB isolation encouraged us to try the idea for 146.34–146.94 MHz and similar in-band frequencies used in 2-meter repeaters.

KØVQM used 3/16-inch sheet aluminum for sides and partitions. This being difficult to handle, if you're not well equipped with tools, we tried thinner sheet metal and bent-up partitions and sides, aiming for dimensions that would permit using a standard aluminum chassis for the housing. Results were good enough so that we feel that repeater operators may find this version useful.

The equivalent circuit, Fig. 1, was suggested by KØVQM to explain operation of the filter. This circuit could actually be built, and it might help in some repeater applications where frequency separation and other desensitization factors are not too severe. More on the nature of the problem later; for now let's imagine that the circuit of Fig. 1 is connected in the coaxial line to the repeater receiver, by means of J_1 and J_2.

The circuits at the middle, L_2-C_2 and L_3-C_3, are tuned to the receiving frequency. They peak rather broadly, being loaded down by the antenna on the input side and the receiver on the output. The link L_5-L_6 represents low-impedance coupling between these two circuits, achieved in the KØVQM filter by the "aperture" in a partial shield between the two lines.

* VHF Editor, *QST*.

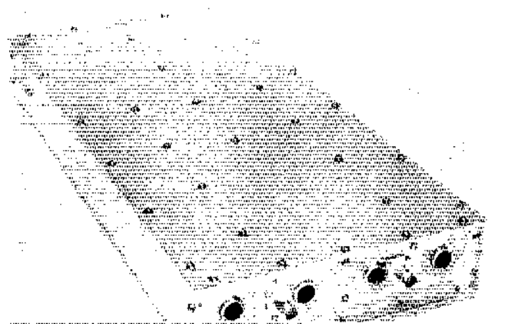
The circuits L_1-C_1 and L_4-C_4 are transmitter-frequency suck-out traps, coupled to the receive-frequency circuits through apertures in the partitions that separate them physically. These apertures, at the hot end of the lines, are represented in Fig. 1 by the capacitors C_5 and C_6. The trap circuits tune very sharply, as they must if they are to have negligible effect on reception of a signal only 600 kHz away. All this may help to make Fig. 2 and the interior photograph of the filter a bit more intelligible to anyone not acquainted with linear circuits and aperture coupling. Features of the equivalent circuit are marked on the sketch of the interior, Fig. 2.

Construction

The 3/16-inch sheet aluminum used by KØVQM will make a desirably sturdy assembly, and no bending of parts is involved. If this technique is used, we suggest making the assembly an inch longer than the one described, to allow the capacitors to tune the lines with wider spacing, in the interests of ease of adjustment. Our design is for inclusion in a standard 8- by 17- by 2-inch chassis, if the builder wishes. With a bottom cover, and partitions made from bent-up sheet metal fastened to both top and bottom, stability of the finished product should be adequate.

We used 0.04-inch sheet brass for end plates, because it works so nicely, and can be silver-plated readily. Brass facilitates soldering-in the lines, and is recommended for auxilliary end plates even if an aluminum chassis is used, as the best possible electrical contact between the lines and the end plate at the grounded end is a must. Do not attempt use of a conventional variable capacitor; anything but air insulation at the hot ends of the lines will degrade the circuit Q markedly. Highest obtainable circuit Q is a must, for really high rejection of the unwanted frequency and minimum insertion loss on the desired one.

The four lines are 5/8-inch (outside diameter) hard-drawn copper tubing, obtainable at plumb-



Exterior view of the completed duplexer, looking at the grounded end of the tuned lines. It will be seen that these project through the end plate about 1/8 inch, for good soldering on both inside and outside surfaces. Silver-plated brass or copper is recommended, but plating is not mandatory.

ing supply houses and some hardware stores. We bought two 36-inch lengths to make four 16½-inch lines. These solder into holes in the end plate (right side of Fig. 2), projecting through the plate about ⅛ inch, to allow for good soldering inside and out. The holes were made with a ⅝-inch chassis punch, in preference to a drill, the punch giving a smoother hole and better fit. Reaming the hole for a press fit to the tubing is also good. Filing the hole to fit may also be satisfactory, if done with care. A close fit is important, as the solder should be mainly for strengthening the joint and maintaining alignment, not to achieve electrical contact

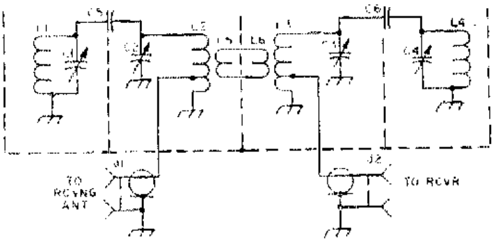


Fig. 1—Equivalent circuit of the trap filter. The two tuned circuits at the center represent the two middle lines of the filter, which are tuned to the receiving frequency of the repeater. The two outer circuits are suck-out traps tuned to the transmitting frequency. Aperture coupling between sections is simulated by the capacitors C_5 and C_6 and the link between the receiver tuned circuits.

The stationary plate of each tuning capacitor is a 1-inch square piece of brass or copper, soldered to the other end of the line. The movable plate is a 1-inch disk of the same material soldered to the end of a 10-32 brass screw. The latter runs through the brass end plate, to which brass nuts have been soldered on either side, to make a bearing for the adjusting screw.

Soldering was done with a 300-watt iron. Do not try it with anything smaller. A torch is preferable, if you're experienced in its use. The bearing nuts can be soldered to the brass plate easily if they are run onto a 10-32 screw to a "finger-tight" condition, and soldered in place, taking care not to run the solder up over the nut and onto the holding screw.

We are indebted to W1CER for an easy way to solder the disks to the adjusting screws. He suggested chucking the screw in a drill press vertically, running a brass nut onto the bottom end, and then bringing this down against the center of the disk, resting on a flat piece of wood on the drill-press table. The assembly can be held in alignment this way while soldering. Don't let go too soon; using that much heat requires an appreciable cooling-off time, before the joint is mechanically solid. Some similar holding arrangement is also a great aid in doing a neat job of soldering the plates onto the line ends.

Joining of the lines and the end plates also calls for some kind of jig or fixture. We clamped one line in a vice between wood blocks, and then lined it up vertically with a square and a level. The end plate was then pushed on, adjusted carefully to a level position, and soldered in place. A piece of wood planed to the right thickness can be used as a separator between this line and the next one to be soldered, to help maintain alignment.

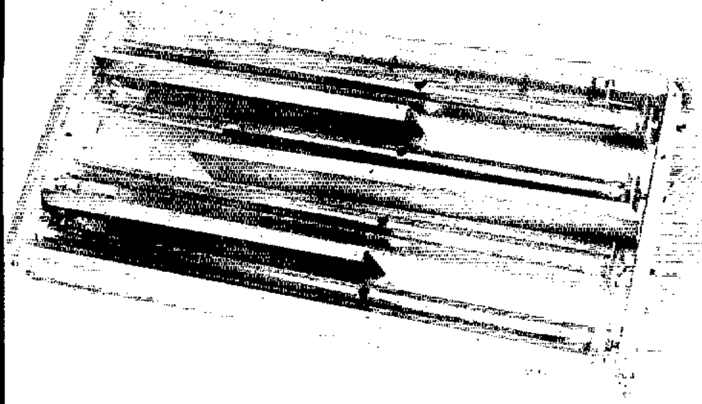
Don't be alarmed if your handiwork comes out looking like something less than the product of a precision machine shop. Individual line sections roughly 2 by 2 inches in size, with the tuned inner conductors approximately centered therein, is good enough. What *is* important is the best possible rf path between the lines and the end plate at the grounded end. Silver plating helps here, and is recommended. Three ways to do the job are outlined in any edition of our *Radio Amateur's VHF Manual*. Again we acknowledge the assistance of W1CER, who furnished the plating solution and a silver anode, for use in the method he originally outlined in Chapter 13 of the *Manual*. It is easily done, and in this instance a great help in soldering. Don't let lack of silver-plating facilities stop you, however. The filter will work well unplated, if the principles are followed otherwise.

Mechanical rigidity is very important, as even minute changes in line capacitance or inductance cannot be permitted. The lines are supported about 10 inches out from the grounded end by means of ¾-inch ceramic cone standoffs. Do not go farther out on the line, as even the best insulation near the hot end will affect the *Q* adversely.

Some features of the filter may show in the photographs but not in the drawings. We made the partitions adjustable in length, to check the effect of different size apertures, settling on those given in the drawings as most desirable for our purposes. With the line lengths used, our 1-inch capacitor plates tune the lines at quite close spacings, and tuning is tricky. We added L-shaped capacitor tabs to the side walls of the filter, with a surface 1 by ¾ inches in size spaced about 1/16 inch from the side of the line, near the open end. This allows greater spacing of the tuning disks from the fixed plates on the line ends, giving some vernier effect.

Input and output coupling leads are ¼-inch straps of flashing copper, soldered to the lines at points 1⅞ inch out from the grounded ends, and bent parallel to the lines and about 5/16 inch from them, running to BNC fittings on the end plate.

Partitions and end plates are 2 inches high when bent, with ⅜-inch lips top and bottom, and on one end in the case of the partitions. Whether you use a standard chassis or make the whole assembly of sheet metal as was done here will have some bearing on how the metal work is done. Partitions will be the same either way, but the end plates will be simple flat pieces that fasten to the ends of the chassis, whereas ours have lips bent over on all four edges. A chassis cover plate will be 8 by 17 inches, instead of the larger size used here for top and bottom plates.



Looking into the filter from the top, we see the disk-type tuning capacitors at the right. Each tuned line is supported on a cone insulator, to provide rigidity, as tuning for optimum performance is critical. Though a handmade assembly is shown, the dimensions are such that a standard 8 by 17-inch chassis could be used.

Holes in the bottom of the assembly drilled for mounting the cone standoffs can be a bit larger than necessary to pass the mounting screws. This will allow some movement of the cone before tightening in place, to correct any small misalignment of the four lines.

Adjustment

One problem with fm equipment is that precise adjustment of receiving gear may not be easy if you do not have test equipment designed for fm servicing. Our duplexer can be tested much more readily with an unmodulated signal source and an a-m receiver equipped with an S-meter than with the repeater transmitter and receiver. A signal generator that can be moved to any desired frequency is also useful as a signal simulator. No modulation is necessary, and the generator need not be accurately calibrated, if you can listen to the repeater transmitter and zero the generator on it with the aid of an a-m detector. (This same technique is useful in solving other frequency problems with fm gear.)

Put your signal source on the receiving frequency of the repeater first. With the duplexer in the receiver line, tune C_2 and C_3 for maximum signal. These circuits tune uncritically, but a relatively weak signal will help in optimum tuning.

Now put the signal source on the transmitting frequency, and tune in the signal on the receiver. Leaving C_2 and C_3 as set, adjust C_1 and C_4 for minimum signal. These circuits tune *very* sharply, and you may be surprised at the depth of the suck-out of the unwanted signal. Unless you started with a receiver-blocking signal, the signal may disappear completely, in which case increase the strength of the signal source and repeak the suck-out capacitors. Tighten the lock nuts just enough so that the screws will not move unless turned with a screwdriver. Final adjustment should be checked with the duplexer in the posi-

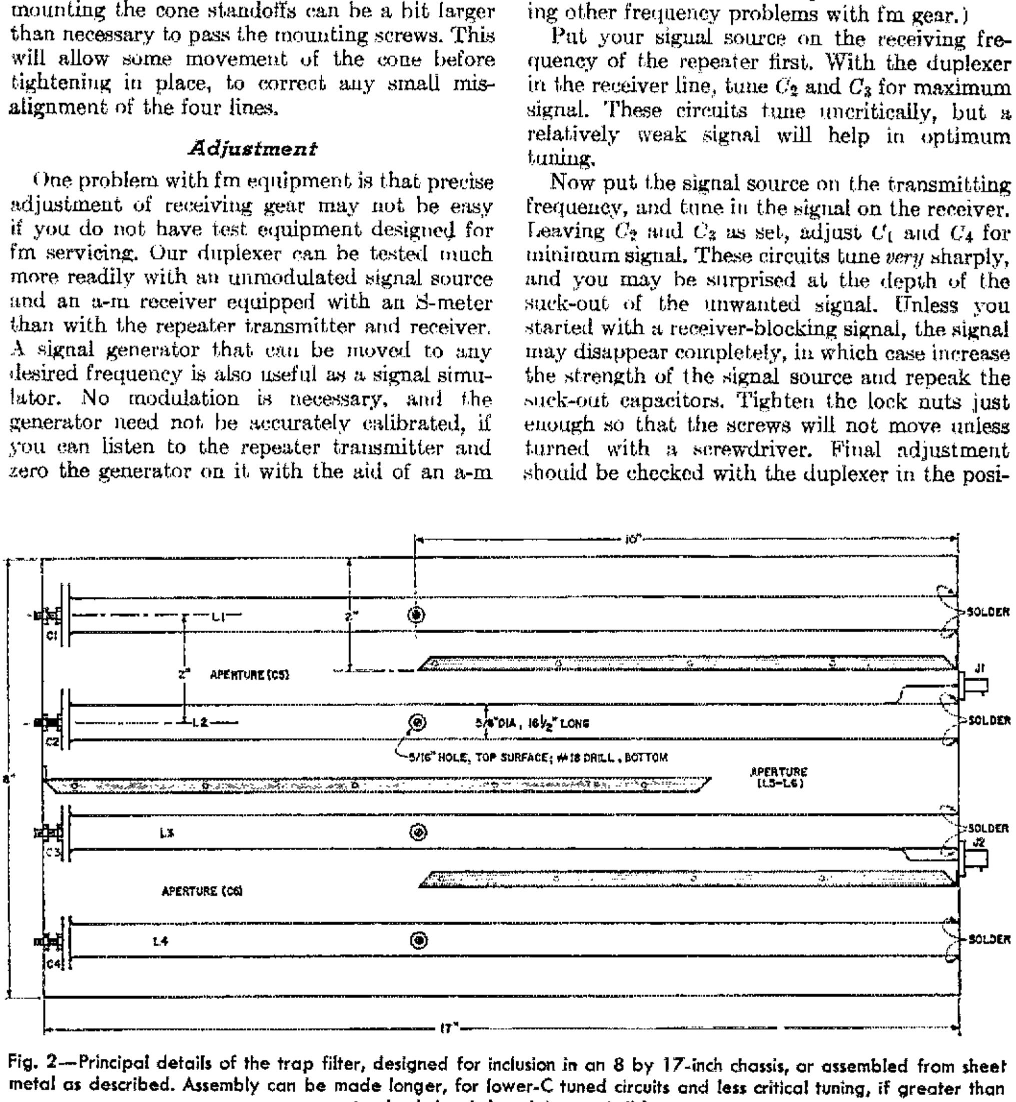


Fig. 2—Principal details of the trap filter, designed for inclusion in an 8 by 17-inch chassis, or assembled from sheet metal as described. Assembly can be made longer, for lower-C tuned circuits and less critical tuning, if greater than standard chassis length is permissible.

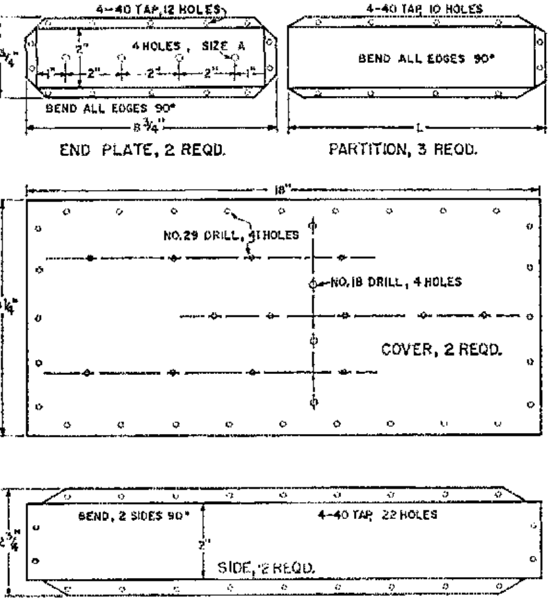


Fig. 3—Metal work suggestions for duplicating the filter described. As some dimensions will depend on available materials and assembly methods used, dimensions given should be regarded as approximate only. End plates are silver-plated brass. The size-A holes are No. 10 drill, for the tuned end of the filter, and ⅝-inch diameter for the grounded end of the lines. Two different-size partitions are needed, dimension L being 13 inches for the center one and 10 inches for the two on either side. No side plates would be needed if a chassis is used, and only one cover plate would be required. The 4 holes for mounting the line supports are needed in the bottom cover (or chassis surface) only.

tion in which it is to be used, as best rejection is achieved only with very precise adjustment, and even the slight mechanical stresses introduced in the mounting process may detune it appreciably.

Performance

With the simple procedure outlined, we came up with a rejection of the unwanted frequency higher than we could measure by simple methods, but it was determined to be well in excess of 50 dB. Insertion loss at the desired frequency was only about 1 dB. Either quality can be improved by adjustment of the aperture sizes, but at the expense of the other quality.

It should be emphasized that there are many causes of receiver desensitization in vhf repeaters, some of which are only slightly affected by a device of this kind. Achieving high isolation between transmitter and receiver is rather like curing most TVI problems, in that a combination of factors is usually involved. As with TVI prevention and cure, you "peel them off in layers," and often no one corrective measure does the whole job. Keeping transmitter rf power out of the receiver antenna line will do little good if transmitter and receiver shielding is inadequate, or if power cables tend to couple transmitter power into the receiver. Solutions for these problems almost exactly follow TVI-proofing practice, which is well established.

The transmitter power level and the separation between the transmitting and receiving antennas are two obvious factors, having obvious but not necessarily easy solutions. Proper use of the duplexer makes both relatively unimportant. The duplexer is very helpful in the situation common to many repeaters: lack of space on a tower for appreciable vertical spacing of vertical radiators. A duplexer cured receiver problems in one repeater that used ground planes 10 feet apart, whereas a 60-foot or greater separation would have been needed without it.

A common but frequently neglected cause of receiver desensitization is the radiation of broadband noise by the transmitter. This varies greatly with transmitter design, but is to be expected in most commercial fm transmitters designed to operate over wide frequency ranges without major retuning. Noise from the transmitter is discussed in detail in two very useful articles in *Ham Radio.*[1,2] Incidentally, the footnote reference in the second article to the first gives the wrong year. They're both 1969 issues — and well worth your time.

Our duplexer was first checked on a repeater using the same equipment as that treated by W6GDO in the second of the referenced articles — and it did only a perceptible amount of good. In tests at various levels of transmitter power and with different antenna separations, we measured only 2½ to 4 dB improvement in receiver desensitization with the duplexer; not enough to be worth the trouble of building and adjusting it. But with other signal sources and other receivers we made complete cures in situations where the receiver performance had been degraded by as much as 16 dB when the transmitter came on.

This led us to try running the duplexer in the transmitter line, just out of curiosity, tuning the rejection circuits to knock out radiated noise at the receiving frequency. Transmitter power had to be reduced, from 50 watts down to 17, to prevent flashover in the duplexer. At this level an initial desensitization of 11 dB was reduced to a barely detectable 2 dB with the duplexer in the circuit. Transmitter power loss was only 3 watts in 17, or under 1 dB. The right way to solve this problem is to fix the transmitter, as outlined by W6GDO,[2] but it is interesting to see how much the duplexer helped when used in this originally-unintended way. It would appear from this that the duplexer might help in other situations where cross-modulation and other forms of receiver overloading are encountered from signal sources of fixed frequency.

[1] Murphy, "Receiving System Degradation in FM Repeaters," *Ham Radio*, May, 1969, p. 36.

[2] O'Brien, "Improving the FM Repeater Transmitter for Amateur Use," *Ham Radio*, October, 1969, p. 24.

Reducing Transmitter Noise

Our Motorola transmitter being similar to the one modified by W6GDO, we made his recommended changes first. Then some additional work was done to improve circuit selectivity. Modifications currently in the transmitter are as follows:

7V7 First Doubler — 10 pF added, plate to ground. 7C5 Tripler — 10 pF grid to ground, and a 20-pF miniature mica trimmer, plate to ground. 7C5 Second Doubler — 20-pF miniature mica trimmer, grid to ground, and 11-pF miniature air trimmer (Johnson 189-504-5), plate to ground. 2E26 Doubler-Driver — 11-pF miniature air trimmer, grid to ground. 829B Amplifier — 11-pF miniature butterfly (Johnson 160-211), grid to grid, rotor grounded. This was mounted in a hole drilled in the edge of the chassis, to permit tuning with the bottom cover on.

Variable capacitors were set to the highest value that would permit tuning the associated circuits with their core slugs. Two turns were removed from the top ends of the 73-MHz coils, L_3 and L_4, and the air trimmers were set so that the circuits tune with their brass studs near to the all-out position. Brass slugs lower circuit Q as they are run into the coils, so this improves circuit selectivity markedly. The transmitter was tuned up for maximum grid drive and output with the bottom cover off, and only slight repeaking was needed after the cover was installed.

Though W6GDO reports that only a slight improvement in receiver desensitization resulted from critical tuning of the transmitter circuits, we found transmitter adjustment to be all-important. With weak signals on the repeater input frequency, tuning the transmitter circuits for minimum noise in the receiver made the difference between complete readability and complete inaudibility. With the duplexer in the receiver line it is now possible to practically eliminate receiver desensitization, even with close antenna spacings.

Transmitter adjustments for this ideal result are so close to those for maximum transmitter output that there is no discernible loss in radiated power. Very likely the rather critical tuning is the result of steps taken to improve the circuit Q all along the line — but it would have been interesting to have tried transmitter adjustment before the circuit modifications were made.

Comment from KØVQM

Line Length: The lines should preferably not be shortened below about 0.22 wavelength, as this makes tuning increasingly difficult.

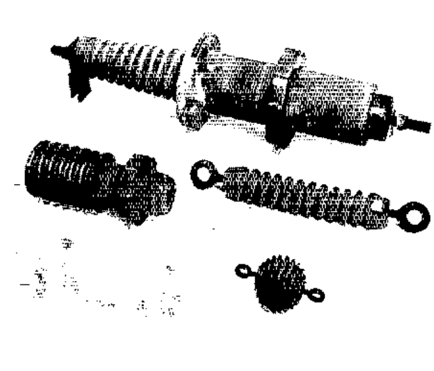
Coupling: The primary coupling aperture, between L_2 and L_3, should be adjusted for near critical coupling for a given input and output loop size, with the trap circuits detuned. The size of the input and output loops determines the loaded Q of the lines, and consequently the bandpass. They should be of equal size and should be adjusted, along with the primary coupling aperture, for minimum bandwidth consistent with insertion-loss considerations. The secondary coupling apertures and line spacing between L_1 and L_2, and L_3 and L_4 are major factors affecting notch depth and shape. Moving the trap lines with respect to the bandpass lines can make the difference between a 60-dB and an 80-dB notch depth. The antivibration supports (the cone insulators in our version) allow some experimentation with this, without rebuilding the filter.

Use as a diplexer: The high attenuation at the transmitting frequency would indicate the possibility of combining this filter with a suitable transmitting version to form a diplexer utilizing one antenna for both transmitting and receiving. It is anticipated that this should provide adequate isolation for repeater work with a transmission loss under 1 dB and a receiver loss of less than 1.5 dB.

Effect of Temperature Changes: It is suspected that there may be some detuning with large temperature variations. This has not been verified, but should be taken into account when the installation is made, and temperature change kept to a minimum, if possible.

Dimensions for the MARS Frequencies: Inside of case — 8¾ by 20½ inches. Lines — ½-inch tubing, 19½ inches long. Apertures — 8½-inch openings for rejection coupling, 4-inch opening for bandpass coupling. These dimensions give 80 dB rejection at 143.46 MHz with 1.2 dB insertion loss at 142.155 MHz. Tuning disks are ¾-inch diameter. No plates on line ends. QST

From the Museum of Amateur Radio



Here are some insulators, both feed-through and strain. Many old timers will recall the little round one and the longer-type. These are all Electrose except for the glass one which is the first Pyrex antenna insulator made by Corning. It is quite massive. The design was suggested to Corning by W1TK and six were made. As far as is known, this insulator is unique.—W1ANA