

# Repeater Antenna Systems

There is an old adage in Amateur Radio that goes “If your antenna did not fall down last winter, it wasn’t big enough.” This adage might apply to antennas for MF and HF work, but at VHF things are a bit different, at least as far as antenna size is concerned. VHF antennas are smaller than their HF counterparts, but yet the theory is the same; a dipole is a dipole, and a Yagi is a Yagi, regardless of frequency. A 144-MHz Yagi may pass as a TV antenna, but most neighbors can easily detect a radio hobbyist if a 14-MHz Yagi looms over his property.

Repeater antennas are discussed in this chapter. Because the fundamental operation of these antennas is no different than presented in Chapter 2, there is no need to delve into any exotic theory. Certain considerations must be made and certain precautions must be observed, however, as most repeater operations—amateur and commercial—take place at VHF and UHF.

### Basic Concepts

The antenna is a vital part of any repeater installation. Because the function of a repeater is to extend the range of communications between mobile and portable stations, the repeater antenna should be installed in the best possible location to provide the desired coverage. This usually means getting the antenna as high above average terrain as possible. In some instances, a repeater may need to have coverage only in a limited area or direction. When this is the case, antenna installation requirements will be completely different, with certain limits being set on height, gain and power.

#### *Horizontal and Vertical Polarization*

Until the upsurge in FM repeater activity several years ago, most antennas used in amateur VHF work were horizontally polarized. These days, very few repeater groups use horizontal polarization. (One of the major reasons for using horizontal polarization is to allow separate repeaters to share the same input and/or output frequencies with closer than normal geographical spacing.) The vast majority of VHF and UHF repeaters use vertically polarized antennas, and all the antennas discussed in this chapter are of that type.

#### *Transmission Lines*

Repeaters provide the first venture into VHF and UHF work for many amateurs. The uninitiated may not be aware that the transmission lines used at VHF become very important because feed-line losses increase with frequency.

The characteristics of feed lines commonly used at VHF are discussed in Chapter 24. Although information is provided for RG-58 and RG-59, these should not be used except for very short feed lines (25 feet or less). These cables are very lossy at VHF. In addition, the losses can be much higher if the fittings and connections are not carefully installed.

The differences in loss between solid polyethylene dielectric types (RG-8 and RG-11) and those using foam polyethylene (FM8 and FM11) are significant. If you can afford the line with the least loss, buy it.

If coaxial cable must be buried, check with the cable manufacturer before doing so. Many popular varieties of coaxial cable should not be buried, as the dielectric can become contaminated from mois-

ture and soil chemicals. Some coaxial cables are labeled as non-contaminating. Such a label is the best way to be sure your cable can be buried without damage.

## Matching

Losses are lowest in transmission lines that are matched to their characteristic impedances. If there is a mismatch at the end of the line, the losses increase.

The *only* way to reduce the SWR on a transmission line is by matching the line *at* the antenna. Changing the length of a transmission line does not reduce the SWR. The SWR is established by the impedance of the line and the impedance of the antenna, so matching must be done at the antenna end of the line.

The importance of matching, as far as feed-line losses are concerned, is sometimes overstressed. But under some conditions, it is necessary to minimize feed-line losses related to SWR if repeater performance is to be consistent. It is important to keep in mind that most VHF/UHF equipment is designed to operate into a 50-Ω load. The output circuitry will not be loaded properly if connected to a mismatched line. This leads to a loss of power, and in some cases, damage to the transmitter.

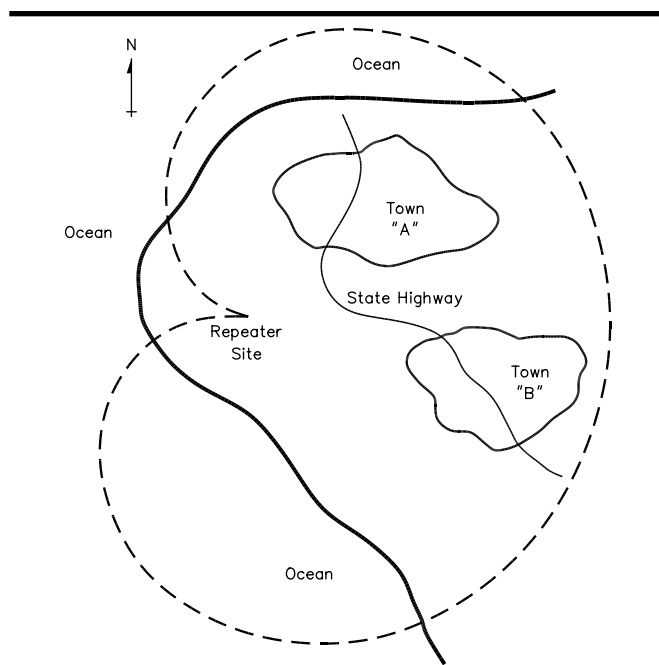
## Repeater Antenna System Design

Choosing a repeater or remote-base antenna system is as close as most amateurs come to designing a commercial-grade antenna system. The term *system* is used because most repeaters utilize not only an antenna and a transmission line, but also include duplexers, cavity filters, circulators or isolators in some configuration. Assembling the proper combination of these items in constructing a reliable system is both an art and a science. In this section prepared by Domenic Mallozzi, N1DM, the functions of each component in a repeater antenna system and their successful integration are discussed. While every possible complication in constructing a repeater is not foreseeable at the outset, this discussion should serve to steer you along the right lines in solving any problems encountered.

### The Repeater Antenna

The most important part of the system is the antenna itself. As with any antenna, it must radiate and collect RF energy as efficiently as possible. Many repeaters use omnidirectional antennas, but this is not always the best choice. For example, suppose a group wishes to set up a repeater to cover towns A and B and the interconnecting state highway shown in **Fig 1**. The X shows the available repeater site on the map. No coverage is required to the west or south, or over the ocean. If an omnidirectional antenna is used in this case, a significant amount of the radiated signal goes in undesired directions. By using an antenna with a cardioid pattern, as shown in Fig 1, the coverage is concentrated in the desired directions. The repeater will be more effective in these locations, and signals from low-power portables and mobiles will be more reliable.

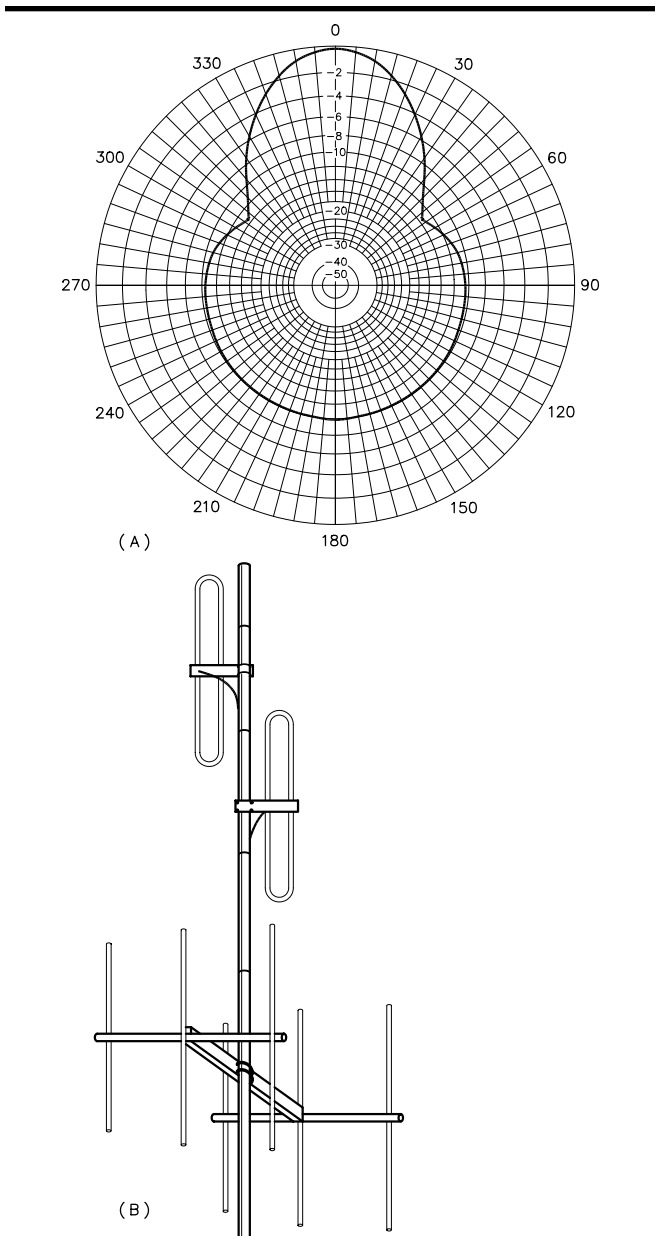
In many cases, antennas with special patterns are more expensive than omnidirectional models. This is an obvious consideration in designing a repeater antenna system.



**Fig 1**—There are many situations where equal repeater coverage is not desired in all directions from the “machine.” One such situation is shown here, where the repeater is needed to cover only towns A and B and the interconnecting highway. An omnidirectional antenna would provide coverage in undesired directions, such as over the ocean. The broken line shows the radiation pattern of an antenna that is better suited to this circumstance.

Over terrain where coverage may be difficult in some direction from the repeater site, it may be desirable to skew the antenna pattern in that direction. This can be accomplished by using a phased-vertical array or a combination of a Yagi and a phased vertical to produce a “keyhole” pattern. See **Fig 2**.

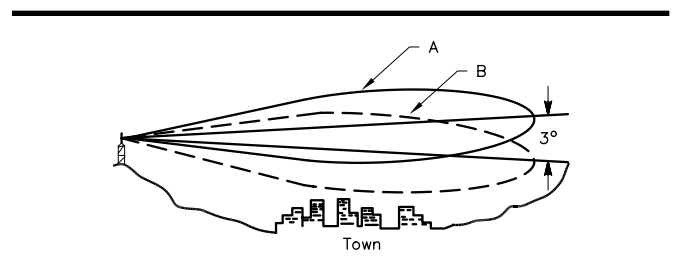
As repeaters are established on 440 MHz and above, many groups are investing in high-gain omnidirectional antennas. A consequence of getting high gain from an omnidirectional antenna is vertical beamwidth reduction. In most cases, these antennas are designed to radiate their peak gain at the horizon, resulting in optimum coverage when the antenna is located at a moderate height over normal terrain. Unfortunately, in cases where the antenna is located at a very high site (overlooking the coverage area) this is not the most desirable pattern. In a case like this, the vertical pattern of the antenna can be tilted downward to facilitate coverage of the desired area. This is called *vertical-beam downtilt*.



**Fig 2**—The “keyhole” horizontal radiation pattern at A is generated by the combination of phased Yagis and vertical elements shown at B. Such a pattern is useful in overcoming coverage blockages resulting from local terrain features. (Based on a design by Decibel Products, Inc)

An example of such a situation is shown in **Fig 3**. The repeater site overlooks a town in a valley. A 450-MHz repeater is needed to serve low power portable and mobile stations. Constraints on the repeater dictate the use of an antenna with a gain of 11 dBi. (An omnidirectional antenna with this gain has a vertical beamwidth of approximately 6°.) If the repeater antenna has its peak gain at the horizon, a major portion of the transmitted signal and the best area from which to access the repeater exists *above* the town. By tilting the pattern down 3°, the peak radiation will occur in the town.

Vertical-beam downtilt is generally produced by feeding the elements of a collinear vertical array slightly out of phase with each other. Lee Barrett, K7NM, showed such an array in *Ham Radio*. (See the [Bibliography](#) at the end of this chapter.) Barrett gives the geometry and design of a four-pole array with progressive phase delay,



**Fig 3**—Vertical-beam downtilt is another form of radiation-pattern distortion useful for improving repeater coverage. This technique can be employed in situations where the repeater station is at a greater elevation than the desired coverage area, when a high-gain omnidirectional antenna is used. Pattern A shows the normal vertical-plane radiation pattern of a high-gain omnidirectional antenna with respect to the desired coverage area (the town). Pattern B shows the pattern tilted down, and the coverage improvement is evident.

and a computer program to model it. The technique is shown in **Fig 4**.

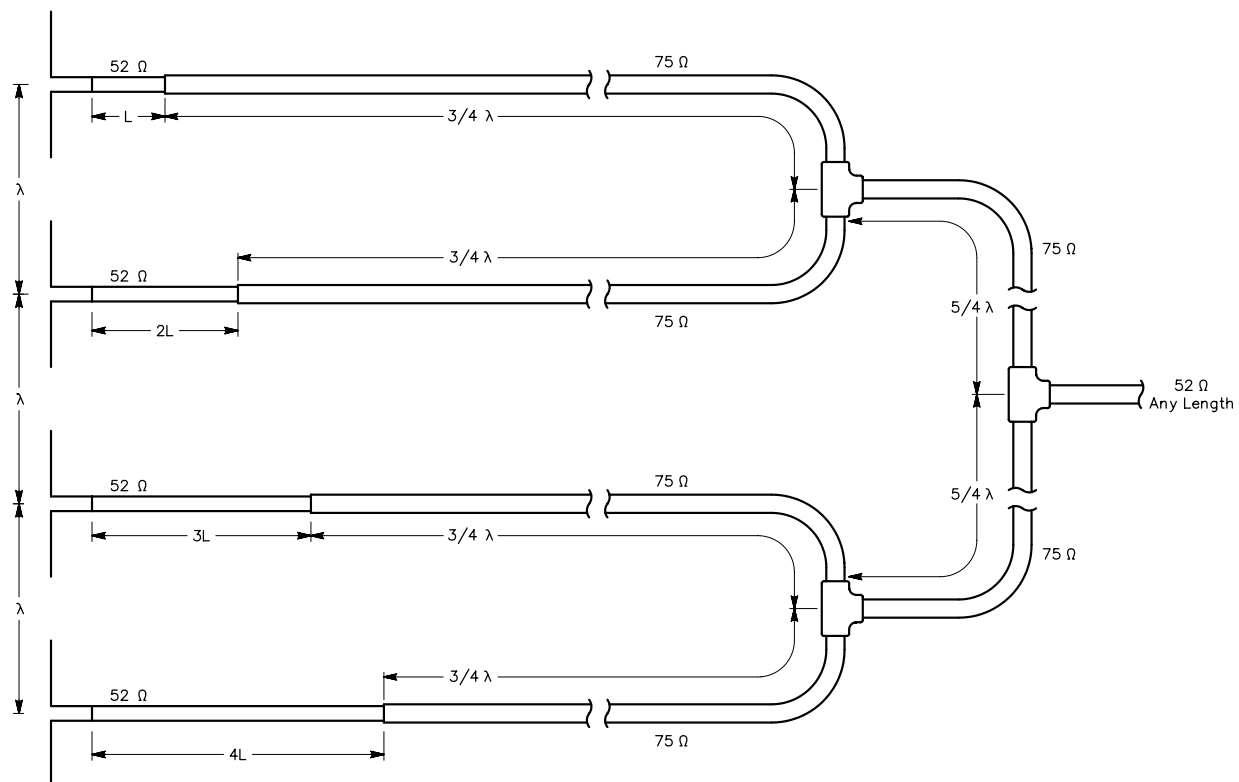
Commercial antennas are sometimes available (at extra cost) with built-in downtilt characteristics. Before ordering such a commercial antenna, make sure that you really require it; they generally are special order items and are not returnable.

There are disadvantages to improving coverage by means of vertical-beam downtilt. When compared to a standard collinear array, an antenna using vertical-beam downtilt will have somewhat greater extraneous lobes in the vertical pattern, resulting in reduced gain (usually less than 1 dB). Bandwidth is also slightly reduced. The reduction in gain, when combined with the downtilt characteristic, results in a reduction in total coverage area. These trade-offs, as well as the increased cost of a commercial antenna with downtilt, must be compared to the improvement in total performance in a situation where vertical-beam downtilt is required.

### Top Mounting and Side Mounting

Amateur repeaters often share towers with commercial and public service users. In many of these cases, other antennas are at the top of the tower, so the amateur antenna must be side mounted. A consequence of this arrangement is that the free-space pattern of the repeater antenna is distorted by the tower. This effect is especially noticeable when an omnidirectional antenna is side mounted on a structure.

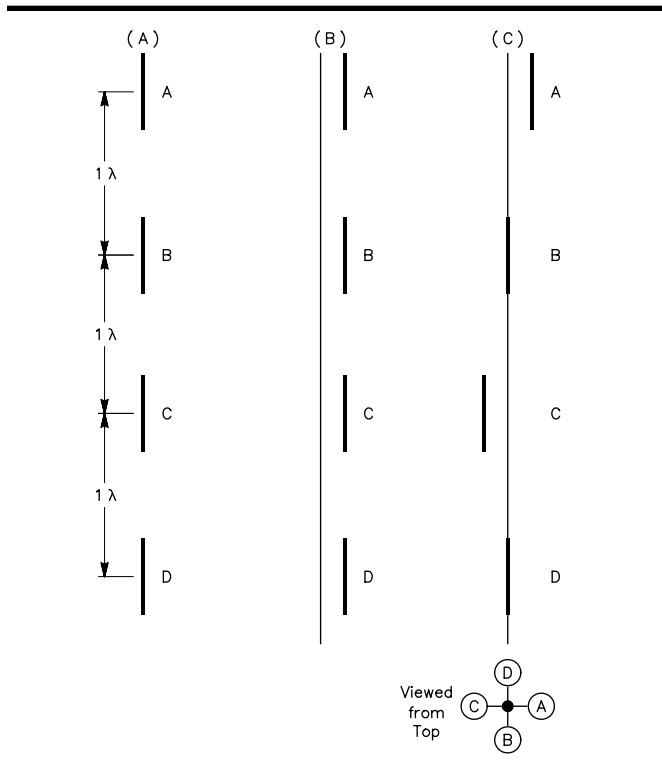
The effects of supporting structures are most pronounced at close antenna spacings to the tower and with large support dimensions. The result is a measurable increase in gain in one direction and a partial null in the other direction (sometimes 15 dB deep). The shape of the supporting structure also influences pattern distortion. Many antenna manufacturers publish radiation patterns showing the effect of side mounting antennas in their catalogs.



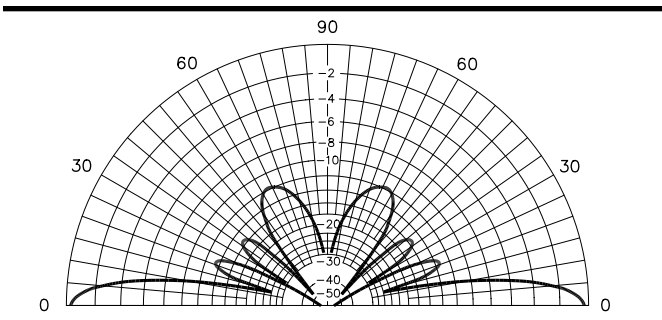
**Fig 4**—Vertical-beam downtilt can be facilitated by inserting 52- $\Omega$  delay lines in series with the 75- $\Omega$  feed lines to the collinear elements of an omnidirectional antenna. The delay lines to each element are progressively longer so the phase shift between elements is uniform. Odd  $1/4\text{-}\lambda$  coaxial transformers are used in the main (75- $\Omega$ ) feed system to match the dipole impedances to the driving point. Tilting the vertical beam in this way often produces minor lobes in the vertical pattern that do not exist when the elements are fed in phase.

Side mounting is not always a disadvantage. In cases where more (or less) coverage is desired in one direction, the supporting structure can be used to advantage. If pattern distortion is not acceptable, a solution is to mount antennas around the perimeter of the structure and feed them with the proper phasing to synthesize an omnidirectional pattern. Many manufacturers make antennas to accommodate such situations.

The effects of different mounting locations and arrangements can be illustrated with an array of exposed dipoles, **Fig 5**. Such an array is a very versatile antenna because, with simple rearrangement of the elements, it can develop either an omnidirectional pattern or an offset pattern. Drawing A of Fig 5 shows a basic collinear array of four vertical  $1/2\text{-}\lambda$  elements. The vertical spacing between adjacent elements is  $1\lambda$ . All elements are fed in phase. If this array is placed in the clear and supported by a nonconducting mast, the calculated radiation resistance of each dipole element is on the order of  $63\ \Omega$ . If the feed line is completely decoupled, the resulting azimuth pattern is omnidirectional. The vertical-plane pattern is shown in **Fig 6**.



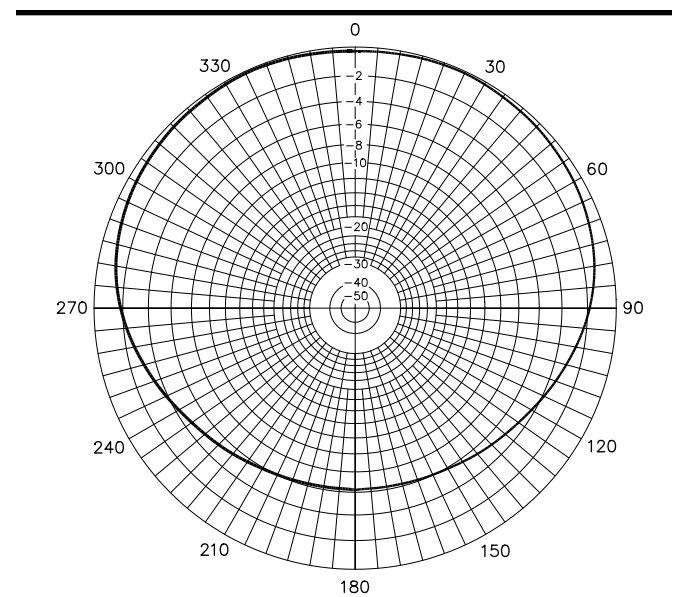
**Fig 5—Various arrangements of exposed dipole elements. At A is the basic collinear array of four elements. B shows the same elements mounted on the side of a mast, and C shows the elements in a side-mounted arrangement around the mast for omnidirectional coverage. See text and Figs 6 through 8 for radiation pattern information.**



**Fig 6—Calculated vertical-plane pattern of the array of Fig 5A, assuming a nonconducting mast support and complete decoupling of the feeder. In azimuth the array is omnidirectional. The calculated gain of the array is  $8.6\text{ dBi}$  at  $0^\circ$  elevation; the  $-3\text{ dB}$  point is at  $6.5^\circ$ .**

If this array is placed in the clear and supported by a nonconducting mast, the calculated radiation resistance of each dipole element is on the order of  $63\ \Omega$ . If the feed line is completely decoupled, the resulting azimuth pattern is omnidirectional. The vertical-plane pattern is shown in **Fig 6**.

Fig 5B shows the same array in a side mounting arrangement, at a spacing of  $1/4\lambda$  from a conducting mast. In this mounting arrangement, the mast takes on the role of a reflector, producing an F/B ratio on the order of  $5.7\text{ dB}$ . The azimuth pattern is shown in **Fig 7**. The vertical pattern is not significantly different from that of Fig 6, except the four small minor lobes (two on either side of the vertical axis) tend to become distorted. They are not as “clean,” tending to merge into one minor lobe at some mast heights. This apparently is a function of currents in the supporting mast. The proximity of the mast also alters the feed-point impedance. For elements that are resonant in the configuration of Fig 5A, the calculated impedance in the arrangement of Fig 5B is in the order of  $72 + j10\ \Omega$ .



**Fig 7—Calculated azimuth pattern of the side-mounted array of Fig 5B, assuming  $1/4\text{-}\lambda$  spacing from a 4-inch mast. The calculated gain in the favored direction, away from the mast and through the elements, is  $10.6\text{ dBi}$ .**

If side mounting is the only possibility and an omnidirectional pattern is required, the arrangement of Fig 5C may be used. The calculated azimuth pattern takes on a slight cloverleaf shape, but is within 1.5 dB of being circular. However, gain performance suffers, and the idealized vertical pattern of Fig 6 is not achieved. See Fig 8. Spacings other than  $\frac{1}{4}\lambda$  from the mast were not investigated.

One very important consideration in side mounting an antenna is mechanical integrity. As with all repeater components, reliability is of great importance. An antenna hanging by the feed line and banging against the tower provides far from optimum performance and reliability. Use a mount that is appropriately secured to the tower and the antenna. Also use good hardware, preferably stainless steel (or bronze). If your local hardware store does not carry stainless steel hardware, try a boating supplier.

Be certain that the feed line is properly supported along its length. Long lengths of cable are subject to contraction and expansion with temperature from season to season, so it is important that the cable not be so tight that contraction causes it to stress the connection at the antenna. This can cause the connection to become intermittent (and noisy) or, at worst, an open circuit. This is far from a pleasant situation if the antenna connection is 300 feet up a tower, and it happens to be the middle of the winter!

### Effects of Other Conductors

Feed-line proximity and tower-access ladders or cages also have an effect on the radiation patterns of side-mounted antennas. This subject was studied by Connolly and Blevins, and their findings are given in *IEEE Conference Proceedings* (see the Bibliography at the end of this chapter). Those considering mounting antennas on air conditioning evaporators or maintenance penthouses on commercial buildings should consult this article. It gives considerable information on the effects of these structures on both unidirectional and omnidirectional antennas.

Metallic guy wires also affect antenna radiation patterns. Yang and Willis studied this and reported the results in *IRE Transactions on Vehicular Communications*. As expected, the closer the antenna is to the guy wires, the greater the effect on the radiation patterns. If the antennas are near the point where the guy wires meet the tower, the effect of the guy wires can be minimized by breaking them up with insulators every  $0.75\lambda$  for  $2.25\lambda$  to  $3.0\lambda$ .

### ISOLATION REQUIREMENTS IN REPEATER ANTENNA SYSTEMS

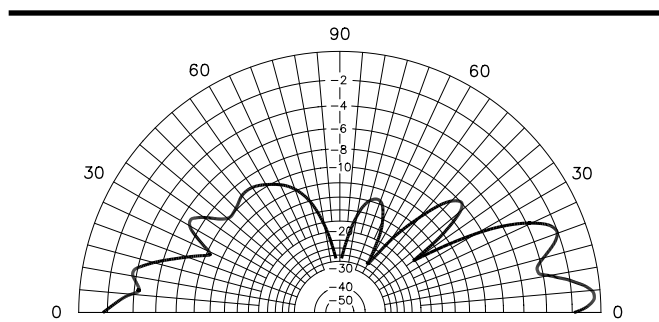
Because repeaters generally operate in full duplex (the transmitter and receiver operate simultaneously), the antenna system must act as a filter to keep the transmitter from blocking the receiver. The degree to which the transmitter and receiver must be isolated is a complex problem. It is quite dependent on the equipment used and the difference in transmitter and receiver frequencies (offset). Instead of going into great detail, a simplified example can be used for illustration.

Consider the design of a 144-MHz repeater with a 600-kHz offset. The transmitter has an RF output power of 10 W, and the receiver has a squelch sensitivity of  $0.1\ \mu\text{V}$ . This means there must be at least  $1.9 \times 10^{-16}\ \text{W}$  at the  $52\text{-}\Omega$  receiver-antenna terminals to detect a signal. If both the transmitter and receiver were on the same frequency, the isolation (attenuation) required between the transmitter and receiver antenna jacks to keep the transmitter from activating the receiver would be

$$\text{Isolation} = 10 \log \frac{10 \text{ watts}}{1.9 \times 10^{-16} \text{ watts}} = 167 \text{ dB}$$

Obviously there is no need for this much attenuation, because the repeater does not transmit and receive on the same frequency.

If the 10-W transmitter has noise 600 kHz away from the carrier frequency that is 45 dB below the carrier power, that 45 dB can be subtracted from the isolation requirement. Similarly, if the receiver can detect a  $0.1\ \mu\text{V}$  on-frequency signal



**Fig 8**—Calculated vertical pattern of the array of Fig 5C, assuming  $\frac{1}{4}\lambda$  element spacing from a 4-inch mast. The azimuth pattern is circular within 1.5 dB, and the calculated gain is 4.4 dBi.

in the presence of a signal 600 kHz away that is 40 dB greater than 0.1  $\mu\text{V}$ , this 40 dB can also be subtracted from the isolation requirement. Therefore, the isolation requirement is

$$167 \text{ dB} - 45 \text{ dB} - 40 \text{ dB} = 82 \text{ dB}$$

Other factors enter into the isolation requirements as well. For example, if the transmitter power is increased by 10 dB (from 10 to 100 W), this 10 dB must be added to the isolation requirement. Typical requirements for 144 and 440-MHz repeaters are shown in **Fig 9**.

Obtaining the required isolation is the first problem to be considered in constructing a repeater antenna system. There are three common ways to obtain this isolation:

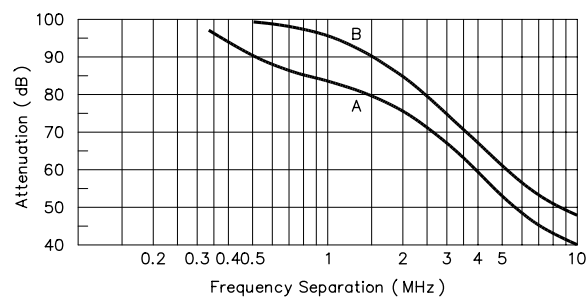
- 1) Physically separate the receiving and transmitting antennas so the combination of path loss for the spacing and the antenna radiation patterns results in the required isolation.
- 2) Use a combination of separate antennas and high-Q filters to develop the required isolation. (The high-Q filters serve to reduce the physical distance required between antennas.)
- 3) Use a combination filter and combiner system to allow the transmitter and receiver to share one antenna. Such a filter and combiner is called a *duplexer*.

Repeaters operating on 28 and 50 MHz generally use separate antennas to obtain the required isolation. This is largely because duplexers in this frequency range are both large and very expensive. It is generally less expensive to buy two antennas and link the sites by a committed phone line or an RF link than to purchase a duplexer. At 144 MHz and higher, duplexers are more commonly used. Duplexers are discussed in greater detail in a later section.

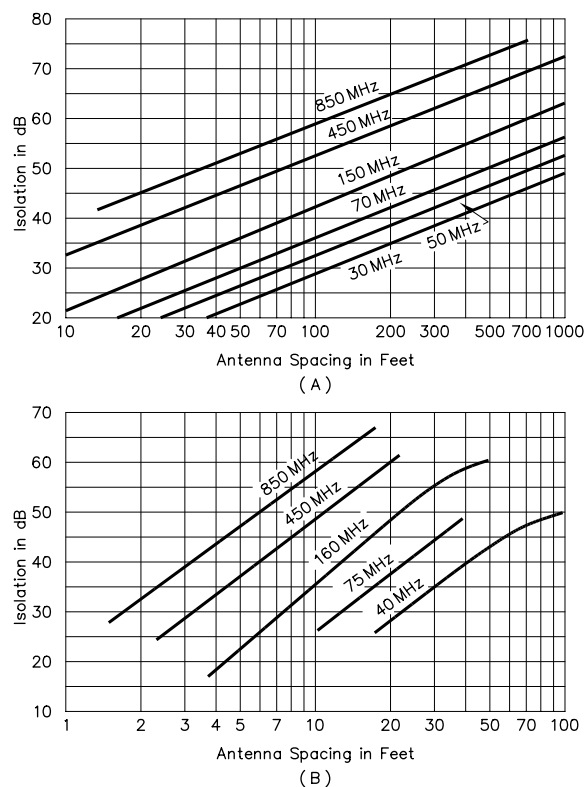
### Separate Antennas

Receiver desensing (gain limiting caused by the presence of a strong off-frequency signal) can be reduced, and often eliminated, by separation of the transmitting and receiving antennas. Obtaining the 55 to 90 dB of isolation required for a repeater antenna system requires separate antennas to be spaced a considerable distance apart (in wavelengths).

**Fig 10** shows the distances required to obtain specific values of isolation for vertical dipoles having horizontal separation (at A) and vertical



**Fig 9**—Typical isolation requirements for repeater transmitters and receivers operating in the 132-174 MHz band (Curve A), and the 400-512 MHz band (Curve B). Required isolation in dB is plotted against frequency separation in MHz. These curves were developed for a 100-W transmitter. For other power levels, the isolation requirements will differ by the change in decibels relative to 100 W. Isolation requirements will vary with receiver sensitivity. (The values plotted were calculated for transmitter-carrier and receiver-noise suppression necessary to prevent more than 1 dB degradation in receiver 12-dB SINAD sensitivity.)



**Fig 10**—At A, the amount of attenuation (isolation) provided by horizontal separation of vertical dipole antennas. At B, isolation afforded by vertical separation of vertical dipoles.



separation (at B). The isolation gained by using separate antennas is subtracted from the total isolation requirement of the system. For example, if the transmitter and receiver antennas for a 450-MHz repeater are separated horizontally by 400 feet, the total isolation requirement in the system is reduced by about 64 dB.

Note from Fig 10B that a vertical separation of only about 25 feet also provides 64 dB of isolation. Vertical separation yields much more isolation than does horizontal separation. Vertical separation is also more practical than horizontal, as only a single support is required.

An explanation of the significant difference between the two graphs is in order. The vertical spacing requirement for 60 dB attenuation (isolation) at 150 MHz is about 43 feet. The horizontal spacing for the same isolation level is on the order of 700 feet. Fig 11 shows why this difference exists. The radiation patterns of the antennas at A overlap; each antenna has gain in the direction of the other. The path loss between the antennas is given by

$$\text{Path loss (dB)} = 20 \log \frac{4\pi d}{\lambda}$$

where

d = distance between antennas

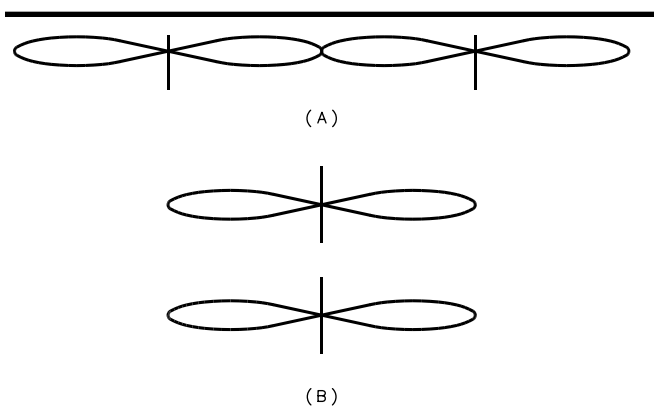
λ = wavelength, in the same units as d

The isolation between the antennas in Fig 11A is the path loss less the antenna gains. Conversely, the antennas at B share pattern nulls, so the isolation is the path loss added to the depth of these nulls. This significantly reduces the spacing requirement for vertical separation. Because the depth of the pattern nulls is not infinite, some spacing is required. Combined horizontal and vertical spacing is much more difficult to quantify because the results are dependent on both radiation patterns and the positions of the antennas relative to each other.

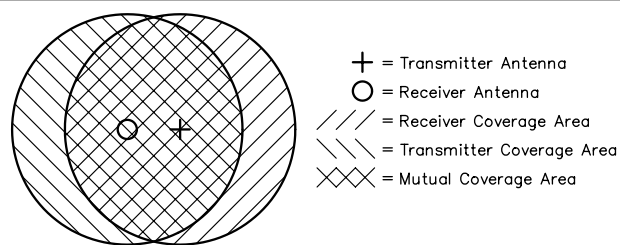
Separate antennas have one major disadvantage: They create disparity in transmitter and receiver coverage. For example, say a 50-MHz repeater is installed over average terrain with the transmitter and repeater separated by 2 miles. If both antennas had perfect omnidirectional coverage, the situation depicted in Fig 12 would exist. In this case, stations able to hear the repeater may not be able to access it, and vice versa. In practice, the situation can be considerably worse. This is especially true if the patterns of both antennas are not omnidirectional. If this disparity in coverage cannot be tolerated, the solution involves skewing the patterns of the antennas until their coverage areas are essentially the same.

### Cavity Resonators

As just discussed, receiver desensing can be reduced by separating the transmitter and receiver antennas. But the amount of transmitted energy that reaches the receiver input must often be decreased even farther. Other nearby transmitters can cause desensing as well. A *cavity resonator* (cavity fil-



**Fig 11—A relative representation of the isolation advantage afforded by separating antennas horizontally (A) and vertically (B) is shown. A great deal of isolation is provided by vertical separation, but horizontal separation requires two supports and much greater distance to be as effective. Separate-site repeaters (those with transmitter and receiver at different locations) benefit much more from horizontal separation than do single-site installations.**



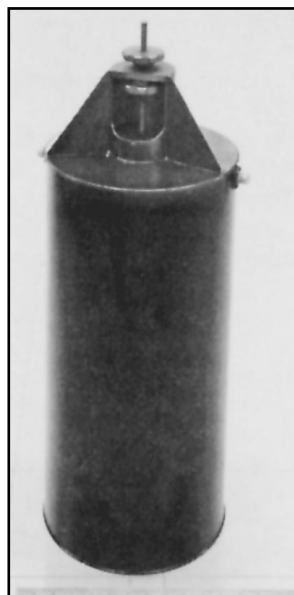
**Fig 12—Coverage disparity is a major problem for separate-site repeater antennas. The transmitter and receiver coverage areas overlap, but are not entirely mutually inclusive. Solving this problem requires a great deal of experimentation, as many factors are involved. Among these factors are terrain features and distortion of the antenna radiation patterns from supports.**



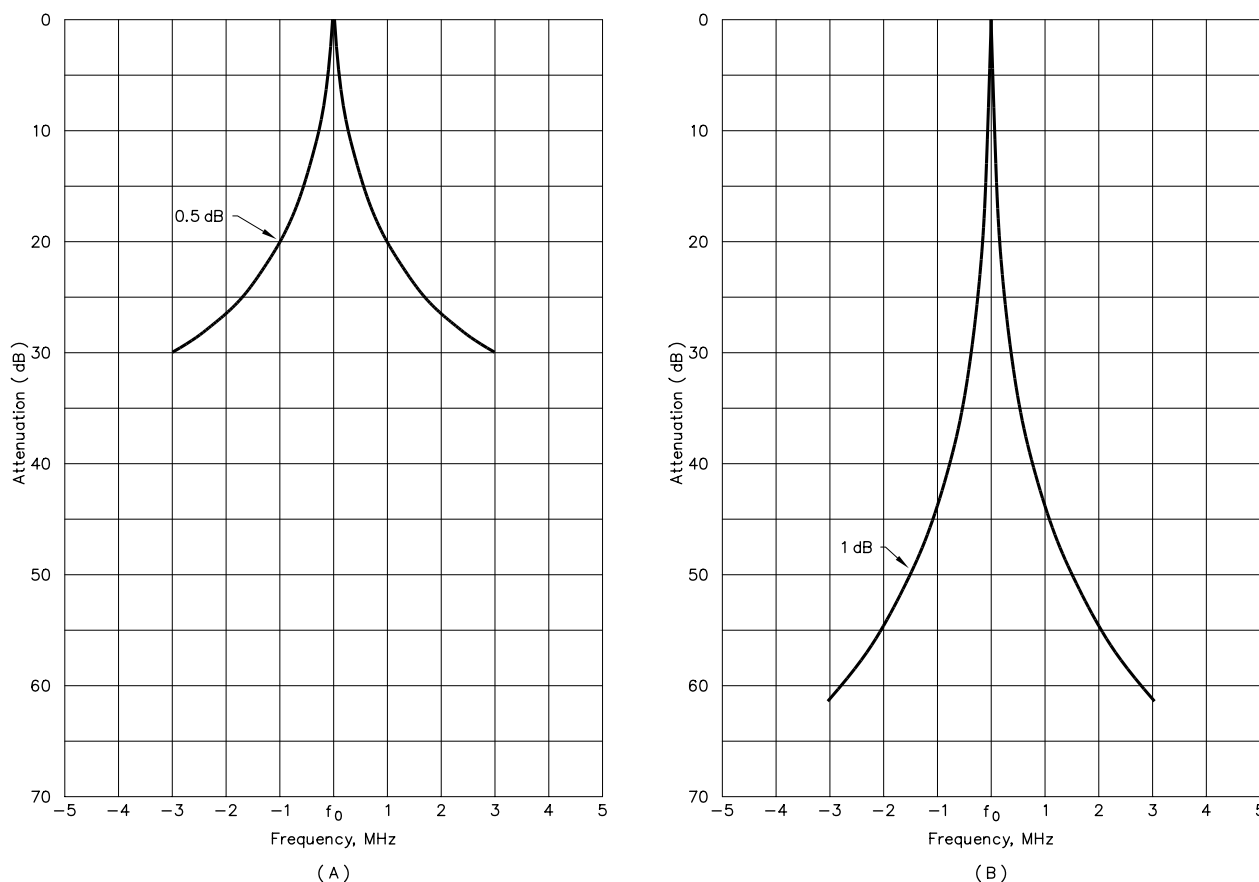
ter) can be helpful in solving these problems. When properly designed and constructed, this type of resonator has very high Q. A commercially made cavity is shown in **Fig 13**.

A cavity resonator placed in series with a transmission line acts as a band-pass filter. For a resonator to operate in series, it must have input and output coupling loops (or probes).

A cavity resonator can also be connected across (in parallel with) a transmission line. The cavity then acts as a band-reject (notch) filter, greatly attenuating energy at the frequency to which it is tuned. Only one coupling loop or probe is required for this method of filtering. This type of cavity could be used in the receiver line to “notch” the transmitter signal. Several cavities can be connected in series or parallel to increase the attenuation in a given configuration. The graphs of **Fig 14** show the attenuation of a single cavity (A) and a pair of cavities (B).



**Fig 13**—A coaxial cavity filter of the type used in many amateur and commercial repeater installations. Center-conductor length (and thus resonant frequency) is varied by adjustment of the knob (top).



**Fig 14**—Frequency response curves for a single cavity (A) and two cavities cascaded (B). These curves are for cavities with coupling loops, each having an insertion loss of 0.5 dB. (The total insertion loss is indicated in the body of each graph.) Selectivity will be greater if lighter coupling (greater insertion loss) can be tolerated.

The only situation in which cavity filters would not help is the case where the off-frequency noise of the transmitter was right on the receiver frequency. With cavity resonators, an important point to remember is that addition of a cavity across a transmission line may change the impedance of the system. This change can be compensated by adding tuning stubs along the transmission line.

## Duplexers

The material in this section was prepared by Domenic Mallozzi, N1DM. Most amateur repeaters in the 144, 220 and 440-MHz bands use duplexers to obtain the necessary transmitter to receiver isolation. Duplexers have been commonly used in commercial repeaters for many years. The duplexer consists of two high-Q filters. One filter is used in the feed line from the transmitter to the antenna, and another between the antenna and the receiver. These filters must have low loss at the frequency to which they are tuned while having very high attenuation at the surrounding frequencies. To meet the high attenuation requirements at frequencies within as little as 0.4% of the frequency to which they are tuned, the filters usually take the form of cascaded transmission-line cavity filters. These are either band-pass filters, or band-pass filters with a rejection notch. (The rejection notch is tuned to the center frequency of the other filter.) The number of cascaded filter sections is determined by the frequency separation and the ultimate attenuation requirements.

Duplexers for the amateur bands represent a significant technical challenge, because in most cases amateur repeaters operate with significantly less frequency separation than their commercial counterparts. Information on home construction of duplexers is presented in a later section of this chapter. Many manufacturers market high quality duplexers for the amateur frequencies.

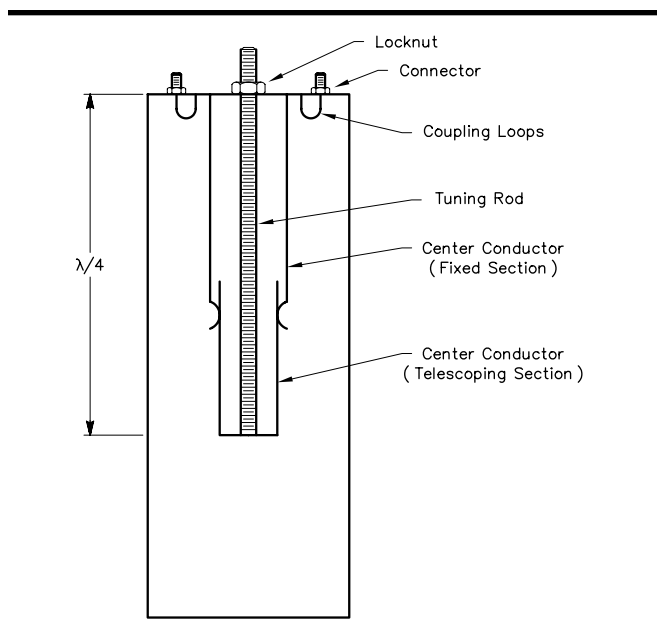
Duplexers consist of very high Q cavities whose resonant frequencies are determined by mechanical components, in particular the tuning rod. **Fig 15** shows the cutaway view of a typical duplexer cavity. The rod is usually made of a material which has a limited thermal expansion coefficient (such as Invar). Detuning of the cavity by environmental changes introduces unwanted losses in the antenna system. An article by Arnold in *Mobile Radio Technology* considered the causes of drift in the cavity (see the [Bibliography](#) at the end of this chapter). These can be broken into four major categories.

- 1) Ambient temperature variation (which leads to mechanical variations related to the thermal expansion coefficients of the materials used in the cavity).
- 2) Humidity (dielectric constant) variation.
- 3) Localized heating from the power dissipated in the cavity (resulting from its insertion loss).
- 4) Mechanical variations resulting from other factors (vibration, etc).

In addition, because of the high Q nature of these cavities, the insertion loss of the duplexer increases when the signal is not at the peak of the filter response. This means, in practical terms, less power is radiated for a given transmitter output power. Also, the drift in cavities in the receiver line results in increased system noise figure, reducing the sensitivity of the repeater.

As the frequency separation between the receiver and the transmitter decreases, the insertion loss of the duplexer reaches certain practical limits. At 144 MHz, the minimum insertion loss for 600 kHz spacing is 1.5 dB per filter.

Testing and using duplexers requires some special considerations (especially as frequency increases). Because duplexers are very high Q de-



**Fig 15—Cutaway view of a typical cavity. Note the relative locations of the coupling loops to each other and to the center conductor of the cavity. A locknut is used to prevent movement of the tuning rod after adjustment.**

vices, they are very sensitive to the termination impedances at their ports. A high SWR on any port is a serious problem, because the apparent insertion loss of the duplexer will increase, and the isolation may appear to decrease. Some have found that, when duplexers are used at the limits of their isolation capabilities, a small change in antenna SWR is enough to cause receiver desensitization. This occurs most often under ice-loading conditions on antennas with open-wire phasing sections.

The choice of connectors in the duplexer system is important. BNC connectors are good for use below 300 MHz. Above 300 MHz, their use is discouraged because even though many types of BNC connectors work well up to 1 GHz, older style standard BNC connectors are inadequate at UHF and above. Type N connectors should be used above 300 MHz. It is false economy to use marginal quality connectors. Some commercial users have reported deteriorated isolation in commercial UHF repeaters when using such connectors. The location of a bad connector in a system is a complicated and frustrating process. Despite all these considerations, the duplexer is still the best method for obtaining isolation in the 144 to 925-MHz range.

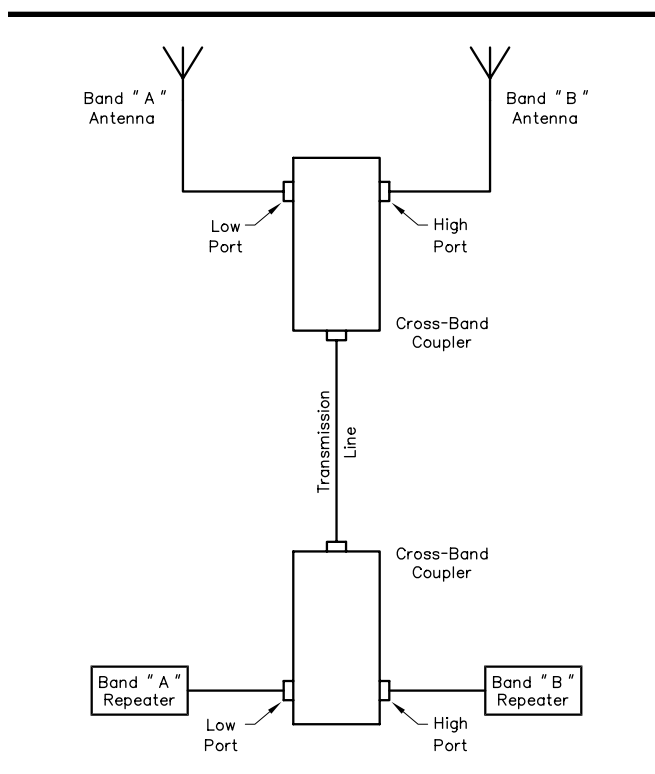
## ADVANCED TECHNIQUES

As the number of available antenna sites decreases and the cost of various peripheral items (such as coaxial cable) increases, amateur repeater groups are required to devise advanced techniques if repeaters are to remain effective. Some of the techniques discussed here have been applied in commercial services for many years, but until recently have not been economically justified for amateur use.

One technique worth consideration is the use of *cross-band* couplers. To illustrate a situation where a cross-band coupler would be useful, consider the following example. A repeater group plans to install 144 and 902-MHz repeaters on the same tower. The group intends to erect both antennas on a horizontal cross-arm at the 325-foot level. A 325-foot run of  $\frac{7}{8}$ -inch Heliac costs approximately \$1400. If both antennas are to be mounted at the top of the tower, the logical approach would require two separate feed lines. A better solution involves the use of a single feed line for both repeaters, along with a cross-band coupler at each end of the line.

The use of the cross-band coupler is shown in **Fig 16**. As the term implies, the coupler allows two signals on different bands to share a common transmission line. Such couplers cost approximately \$200 each. In our hypothetical example, this represents a saving of \$1000 over the cost of using separate feed lines. But, as with all compromises, there are disadvantages. Cross-band couplers have a loss of about 0.5 dB per unit. Therefore, the pair required represents a loss of 1.0 dB in *each transmission path*. If this loss can be tolerated, the cross-band coupler is a good solution.

Cross-band couplers do not allow two repeaters *on the same band* to share a single antenna and feed line. As repeater sites and tower space become more scarce, it may be desirable to have two repeaters on the same band share the same antenna. The solution to this problem is the use of a *transmitter multicoupler*. The multicoupler is related to the duplexers discussed earlier. It is a cavity filter and combiner which allows multiple transmitters and receivers to share the same an-



**Fig 16—Block diagram of a system using cross-band couplers to allow the use of a single feed line for two repeaters. If the feeder to the antenna location is long (more than 200 feet or so), cross-band couplers may provide a significant saving over separate feed lines, especially at the higher amateur repeater frequencies. Cross-band couplers cannot be used with two repeaters on the same band.**

tenna. This is a common commercial practice. A block diagram of a multicoupler system is shown in Fig 17.

The multicoupler, however, is a very expensive device, and has the disadvantage of even greater loss per transmission path than the standard duplexer. For example, a well-designed duplexer for 600 kHz spacing at 146 MHz has a loss per transmission path of approximately 1.5 dB. A four-channel multicoupler (the requirement for two repeaters) has an insertion loss per transmission path on the order of 2.5 dB or more. Another constraint of such a system is that the antenna must present a good match to the transmission line at all frequencies on which it will be used (both transmitting and receiving). This becomes difficult for the system with two repeaters operating at opposite ends of a band.

If you elect to purchase a commercial base station antenna that requires you to specify a frequency to which the antenna must be tuned, be sure to indicate to the manufacturer the intended use of the antenna and the frequency extremes. In some cases, the only way the manufacturer can accommodate your request is to provide an antenna with some vertical-beam uptilt at one end of the band and some downtilt at the other end of the band. In the case of antennas with very high gain, this in itself may become a serious problem. Careful analysis of the situation is necessary before assembling such a system.

### Diversity Techniques for Repeaters

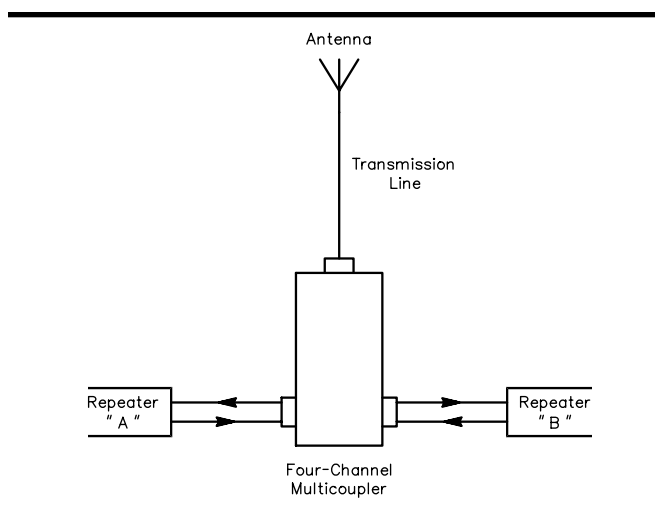
Mobile flutter, “dead spots” and similar problems are a real problem for the mobile operator. The popularity of hand-held transceivers using low power and mediocre antennas causes similar problems. A solution to these difficulties is the use of some form of diversity reception. Diversity reception works because signals do not fade at the same rate when received by antennas at different locations (space diversity) or of different polarizations (polarization diversity).

Repeaters with large transmitter coverage areas often have difficulty “hearing” low power stations in peripheral areas or in dead spots. Space diversity is especially useful in such a situation. Space diversity utilizes separate receivers at different locations that are linked to the repeater. The repeater uses a circuit called a *voter* that determines which receiver has the best signal, and then selects the appropriate receiver from which to feed the repeater transmitter. This technique is helpful in urban areas where shadowing from large buildings and bridges causes problems. Space-diversity receiving, when properly executed, can give excellent results. But with the improvement come some disadvantages: added initial cost, maintenance costs, and the possibility of failure created by the extra equipment required. If installed and maintained carefully, problems are generally minimal.

A second improvement technique is the use of circularly polarized repeater antennas. This technique has been used in the FM broadcast field for many years, and has been considered for use in the mobile telephone service as well. Some experiments by amateurs have proved very promising, as discussed by Pasternak and Morris (see the [Bibliography](#) at the end of this chapter).

The improvement afforded by circular polarization is primarily a reduction in mobile flutter. The flutter on a mobile signal is caused by reflections from large buildings (in urban settings) or other terrain features. These reflections cause measurable polarization shifts, sometimes to the point where a vertically polarized signal at the transmitting site may appear to be primarily horizontally polarized after reflection.

A similar situation results from multipath propa-



**Fig 17—Block diagram of a system using a transmitter multicoupler to allow a single feed line and antenna to be used by two repeaters on one band. The antenna must be designed to operate at all frequencies that the repeaters utilize. More than two repeaters can be operated this way by using a multicoupler with the appropriate number of input ports.**

gation, where one or more reflected signals combine with the direct signal at the repeater, having varying effects on the signal. The multipath signal is subjected to large amplitude and phase variations at a relatively rapid rate.

In both of the situations described here, circular polarization can offer considerable improvement. This is because circularly polarized antennas respond equally to all linearly polarized signals, regardless of the plane of polarization. At this writing, there are no known sources of commercial circularly polarized omnidirectional antennas for the amateur bands. Pasternak and Morris describe a circularly polarized antenna made by modifying two commercial four-pole arrays.

### EFFECTIVE ISOTROPIC RADIATED POWER (EIRP)

It is useful to know effective isotropic radiated power (EIRP) in calculating the coverage area of a repeater. The FCC formerly required EIRP to be entered in the log of every amateur repeater station. Although logging EIRP is no longer required, it is still useful to have this information on hand for repeater coordination purposes and so system performance can be monitored periodically.

Calculation of EIRP is straightforward. The PEP output of the transmitter is simply multiplied by the gains and losses in the transmitting antenna system. (These gains and losses are best added or subtracted in decibels and then converted to a multiplying factor.) The following worksheet and example illustrates the calculations.

Feed-line loss	_____	dB
Duplexer loss	_____	dB
Isolator loss	_____	dB
Cross-band coupler loss	_____	dB
Cavity filter loss	_____	dB
<hr/>		
Total losses (L)	_____	dB

$$G \text{ (dB)} = \text{antenna gain (dBi)} - L$$

where G = antenna system gain. (If antenna gain is specified in dBd, add 2.14 dB to obtain the gain in dBi.)

$$M = 10^{G/10}$$

where M = multiplying factor

$$\text{EIRP (watts)} = \text{transmitter output (PEP)} \times M$$

#### Example

A repeater transmitter has a power output of 50 W PEP (50-W FM transmitter). The transmission line has 1.8 dB loss. The duplexer used has a loss of 1.5 dB, and a circulator on the transmitter port has a loss of 0.3 dB. There are no cavity filters or cross-band couplers in the system. Antenna gain is 5.6 dBi.

Feed-line loss	1.8	dB
Duplexer loss	1.5	dB
Isolator loss	0.3	dB
Cross-band coupler loss	0	dB
Cavity filter loss	0	dB
<hr/>		
Total losses (L)	3.6	dB

Antenna system gain in dB = G = antenna gain (dBi) – L

G = 5.6 dBi – 3.6 dB = 2 dB

Multiplying factor = M =  $10^{G/10}$

M =  $10^{2/10} = 1.585$

EIRP (watts) = transmitter output (PEP) × M

EIRP = 50 W × 1.585 = 79.25 W

If the antenna system is lossier than this example, G may be *negative*, resulting in a multiplying factor less than 1. The result is an EIRP that is less than the transmitter output power. This situation can occur in practice, but for obvious reasons is not desirable.

## Assembling a Repeater Antenna System

This section will aid you in planning and assembling your repeater antenna system. The material was prepared by Domenic Mallozzi, N1DM. Consult [Chapter 23](#) for information on propagation for the band of your interest.

First, a repeater antenna selection checklist such as this will help you in evaluating the antenna system for your needs.

Gain needed	_____	dBi
Pattern required	_____	Omnidirectional
	_____	Offset
	_____	Cardioidal
	_____	Bidirectional
	_____	Special pattern (specify)
Mounting	_____	Top of tower
	_____	Side of tower
	(Determine effects of tower on pattern. Is the result consistent with the pattern required?)	
Is downtilt required?	_____	Yes
	_____	No
Type of RF connector	_____	UHF
	_____	N
	_____	BNC
	_____	Other (specify)
Size (length)	_____	
Weight	_____	
Maximum cost	\$_____	

**Table 1** has been compiled to provide general information on commercial components available for repeater and remote-base antenna systems. The various components are listed in a matrix format by manufacturer, for equipment designed to operate in the various amateur bands. See [Chapter 21](#) for supplier information for these components. Although every effort has been made to make this data complete, the ARRL is not responsible for omissions or errors. The listing of a product in Table 1 does not constitute an endorsement by the ARRL. Manufacturers are urged to contact the editors with updating information.

Even though almost any antenna can be used for a repeater, the companies indicated in the *Antennas* column in Table 1 are known to have produced heavy-duty antennas to commercial standards for repeater service. Many of these companies offer their antennas with special features for repeater service (such as vertical-beam downtilt). It is best to obtain catalogs of current products from the manufacturers listed, both for general information and to determine which special options are available on their products.

**Table 1**  
**Product Matrix Showing Repeater Equipment and Manufacturer by Frequency Band**

Source	Antennas							Duplexers				Cavity Filters			
	28	50	144	222	450	902	1296	144	222	450	902	144	222	450	902
Austin Ant	S	S	S	S	S	S	S								
Celwave	C	C	C	C	C	C		C	C	C	C	C	C	C	C
Comet			C		C	C	C								
Cushcraft		C	C	C	C										
Dec Prod		C	C	C	C	C		C	C	S	S	C		C	
RF Parts			C	C	C		C								
Sinclair	C	C	C	C				C	C	C		C		C	C
TX/RX								C	C	C		C	C	C	C
Wacom								C	C	C	C	C	C	C	C

Source	Isolators/Circulators						Transmitter Combiners				Cross-Band Couplers			
	28	50	144	222	450	902	144	222	450	902	0-174 450-512	0-512 800-960	50-174 806-960	406-512 806-960
Celwave			C	C	C	C	C	C	C	C		S		
Dec Prod			C		C	C		C	C	C				
Sinclair			C		C	C	C	S		C				
TX/RX			C	C	C	C	C	C	C	C	C	C	C	C
Wacom			C	C	C	C	C	C	C	C	C			C

Abbreviated names above are for the following manufacturers: Austin Antenna, Celwave RF Inc, Cushcraft Corp, Decibel Products Inc, RF Parts, Sinclair Radio Laboratories Inc, TX/RX Systems Inc and Wacom Inc. A manufacturers' contact list appears in Chapter 21.

Key to codes used:  
 C = in-stock catalog item  
 S = available special order

Note: Coaxial cable is not listed, because most manufacturers sell only to dealers.



# A 144 MHz Duplexer

Obtaining sufficient isolation between the transmitter and receiver of a repeater can be difficult. Many of the solutions to this problem compromise receiver sensitivity or transmitter power output. Other solutions create an imbalance between receiver and transmitter coverage areas. When a duplexer is used, insertion loss is the compromise. But a small amount of insertion loss is more than offset by the use of one antenna for both the transmitter and receiver. Using one antenna assures equal antenna patterns for both transmitting and receiving, and reduces cost, maintenance and mechanical complexity.

As mentioned earlier in this chapter, duplexers may be built in the home workshop. Bob Shriner, WA0UZO, presented a small, mechanically simple duplexer for low-power applications in April 1979 *QST*. Shriner's design is unique, as the duplexer cavities are constructed of circuit board material. Low cost and simplicity are the result, but with a trade-off in performance. A silver-plated version of Shriner's design has an insertion loss of approximately 5 dB at 146 MHz. The loss is greater if the copper is not plated, and increases as the inner walls of the cavity tarnish.

This duplexer construction project by John Bilodeau, W1GAN, represents an effective duplexer. The information originally appeared in July 1972 *QST*. It is a time proven project used by many repeater groups, and can be duplicated relatively easily. Its insertion loss is just 1.5 dB.

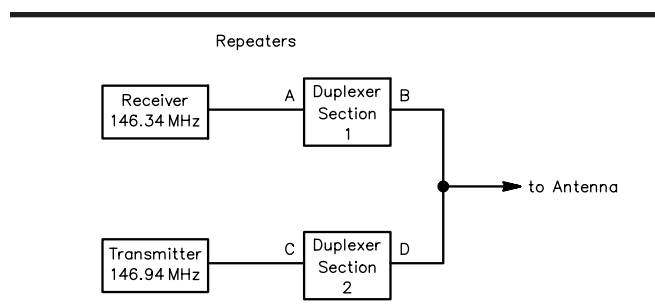
**Fig 18** will help you visualize the requirements for a duplexer, which can be summed up as follows. The duplexer must attenuate the transmitter carrier to avoid overloading the receiver and thereby reducing its sensitivity. It must also attenuate any noise or spurious frequencies from the transmitter on or near the receiver frequency. In addition, a duplexer must provide a proper impedance match between transmitter, antenna, and receiver.

As shown in Fig 18, transmitter output on 146.94 MHz going from point C to D should not be attenuated. However, the transmitter energy should be greatly attenuated between points B and A. Duplexer section 2 should attenuate any noise or signals that are on or near the receiver input frequency of 146.34 MHz. For good reception the noise and spurious signal level must be less than  $-130$  dBm ( $0$  dBm = 1 milliwatt into  $50 \Omega$ ). Typical transmitter noise 600 kHz away from the carrier frequency is 80 dB below the transmitter power output. For 60 W of output (+48 dBm), the noise level is  $-32$  dBm. The duplexer must make up the difference between  $-32$  dBm and  $-130$  dBm, or 98 dB.

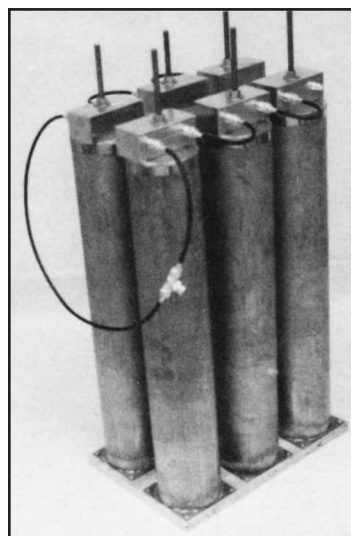
The received signal must go from point B to A with a minimum of attenuation. Section 1 of the duplexer must also provide enough attenuation of the transmitter energy to prevent receiver overload. For an average receiver, the transmitter signal must be less than  $-30$  dBm to meet this requirement. The difference between the transmitter output of +48 dBm and the receiver overload point of  $-30$  dBm, 78 dB, must be made up by duplexer section 1.

## THE CIRCUIT

**Fig 19** shows the completed six-cavity du-



**Fig 18**—Duplexers permit using one antenna for both transmitting and receiving in a repeater system. Section 1 prevents energy at the transmitter frequency from interfering with the receiver, while section 2 attenuates any off-frequency transmitter energy that is at or near the receiver frequency.



**Fig 19**—A six-cavity duplexer for use with a 144-MHz repeater. The cavities are fastened to a plywood base for mechanical stability. Short lengths of double-shielded cable are used for connections between individual cavities. An insertion loss of less than 1.5 dB is possible with this design.



146.94 MHz is 1.5 dB. Response curves for a six-cavity duplexer are given in **Fig 22**.

### Construction

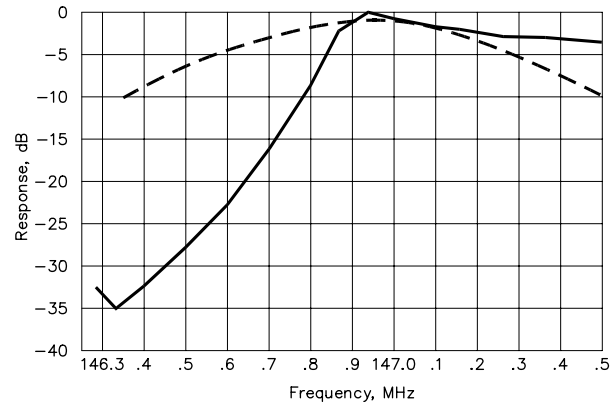
The schematic diagram for the duplexer is shown in **Fig 23**. Three parts for the duplexer must be machined; all others can be made with hand tools. A small lathe can be used to machine the brass top plate, the threaded tuning plunger bushing, and the Teflon insulator bushing. The dimensions of these parts are given in **Fig 24**.

Type DWV copper tubing is used for the outer conductor of the cavities. The wall thickness is 0.058 inch, with an outside diameter of  $4\frac{1}{8}$  inches. You will need a tubing cutter large enough to handle this size (perhaps borrowed or rented). The wheel of the cutter should be tight and sharp. Make slow, careful cuts so the ends will be square. The outer conductor is  $22\frac{1}{2}$  inches long.

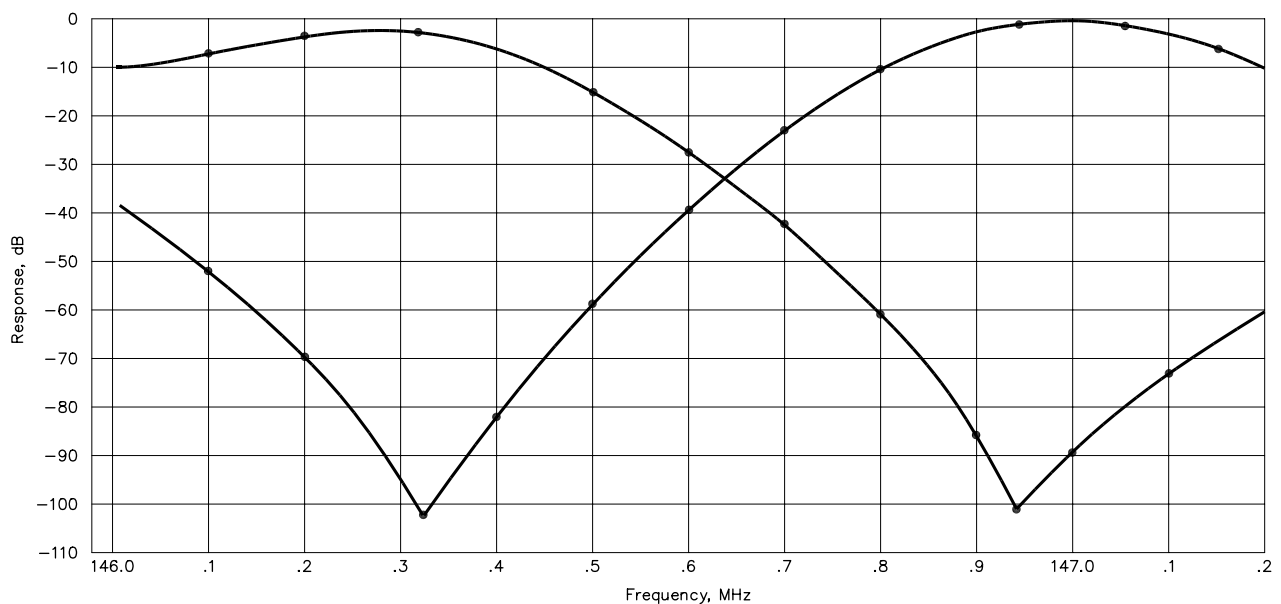
The inner conductor is made from type M copper tubing having an outside diameter of  $1\frac{3}{8}$  inches. A 6-inch length of 1-inch OD brass tubing is used to make the tuning plunger.

The tubing types mentioned above are designations used in the plumbing and steam-fitting industry. Other types may be used in the construction of a duplexer, but you should check the sizes carefully to assure that the parts will fit each other. Tubing with a greater wall thickness will make the assembly heavier, and the expense will increase accordingly.

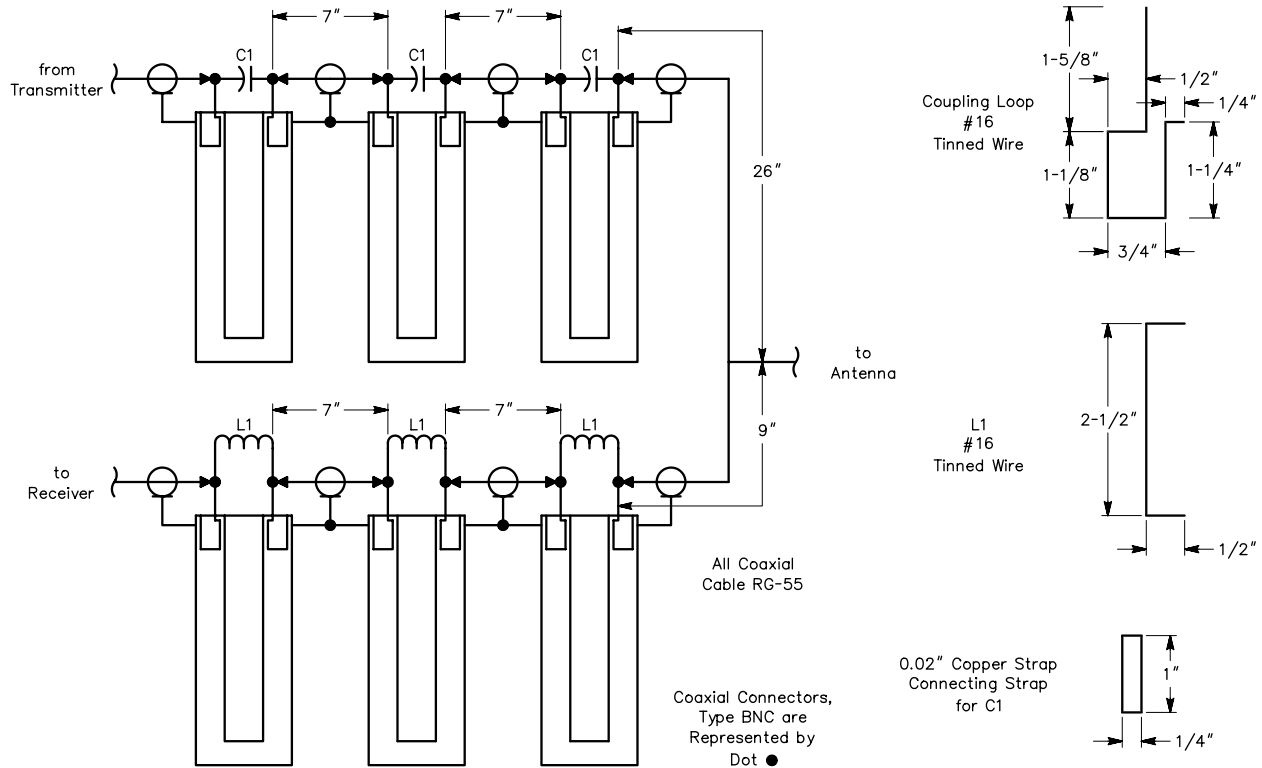
Soft solder is used throughout the assembly. Unless you have experience with silver solder, do not



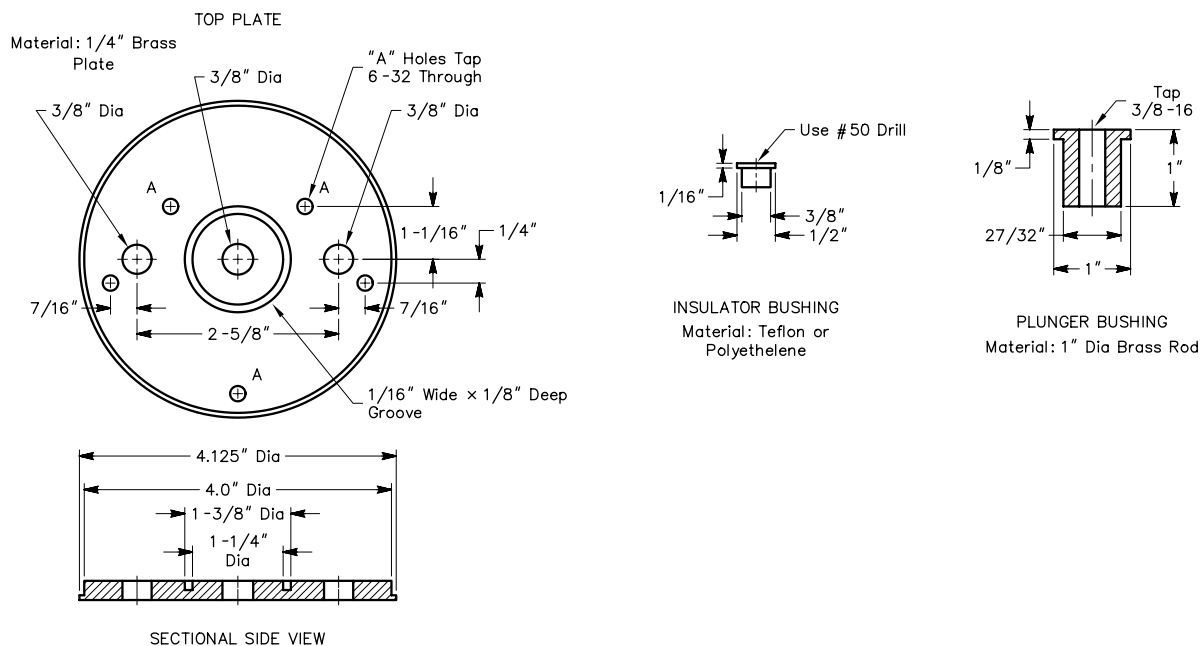
**Fig 21**—Typical frequency response of a single cavity of the type used in the duplexer. The dotted line represents the passband characteristics of the cavity alone; the solid line for the cavity with a shunt capacitor connected between input and output. An inductance connected in the same manner will cause the rejection notch to be above the frequency to which the cavity is tuned.



**Fig 22**—Frequency response of the six-cavity duplexer. One set of three cavities is tuned to pass 146.34 MHz and notch 146.94 MHz (the receiver leg). The remaining set of three cavities is tuned to pass 146.94 MHz and notch 146.34 MHz. This duplexer provides approximately 100 dB of isolation between the transmitter and receiver when properly tuned.



**Fig 23—Diagram of the six-cavity duplexer. Coaxial cable lengths between cavities are critical and must be followed closely. Double shielded cable and high quality connectors should be used throughout. The sizes and shapes of the coupling loops, L1, and the straps for connecting C1 should be observed. C1—1.7-11 pF circuit-board mount, E. F. Johnson 189-5-5 or equiv. Set at 3/4 closed for initial alignment.**



**Fig 24—Dimensions for the three parts that require machining. A small metal-working lathe should be used for making these parts.**

use it. Eutectic type 157 solder with paste or acid flux makes very good joints. This type has a slightly higher melting temperature than ordinary tin-lead alloy, but has considerably greater strength.

First solder the inner conductor to the top plate (Fig 25). The finger stock can then be soldered inside the lower end of the inner conductor, while temporarily held in place with a plug made of aluminum or stainless steel. While soldering, do not allow the flame from the torch to overheat the finger stock. The plunger bushing is soldered into the tuning plunger and a 20-inch length of threaded rod is soldered into the bushing.

Cut six slots in the top of the outer conductor. They should be  $\frac{5}{8}$  inch deep and equally spaced around the tubing. The bottom end of the 4-inch tubing is soldered to the square bottom plate. The bottom plates have holes in the corners so they can be fastened to a plywood base by means of wood screws. Because the center conductor has no support at one end, the cavities must be mounted vertically.

The size and position of the coupling loops are critical. Follow the given dimensions closely. Both loops should be  $\frac{1}{8}$  inch away from the center conductor on opposite sides. Connect a solder lug to the ground end of the loop, then fasten the lug to the top plate with a screw. The free end of the loop is insulated by Teflon bushings where it passes through the top plate for connection to the BNC fittings.

Before final assembly of the parts, clean them thoroughly. Soap-filled steel wool pads and hot water work well for this. Be sure the finger stock makes firm contact with the tuning plunger. The top plate should fit snugly in the top of the outer conductor—a large hose clamp tightened around the outer conductor will keep the top plate in place.

### ADJUSTMENT

After the cavities have been checked for band-pass characteristics and insertion loss, install the anti-resonant elements, C1 and L1. (See Fig 21.) It is preferable to use laboratory test equipment when tuning the duplexer. An option is to use a low power transmitter with an RF probe and an electronic voltmeter. Both methods are shown in Fig 26.

With the test equipment connected as shown in Fig 26A, adjust the signal generator frequency to the desired repeater input frequency. Connect a calibrated step attenuator between points X and

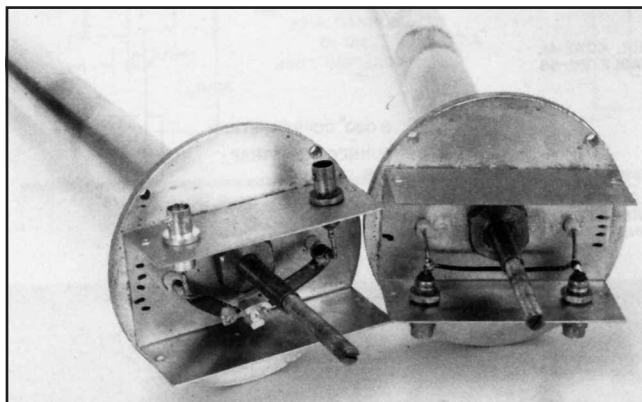


Fig 25—Two of the center conductor and top plate assemblies. In the assembly at the left, C1 is visible just below the tuning shaft, mounted by short straps made from sheet copper. The assembly on the right has L1 in place between the BNC connectors. The Miniboxes are fastened to the top plate by a single large nut in these units. Using screws through the Minibox into the top plate, as described in the text, is preferred.

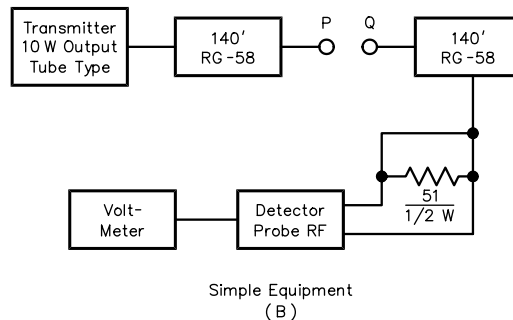
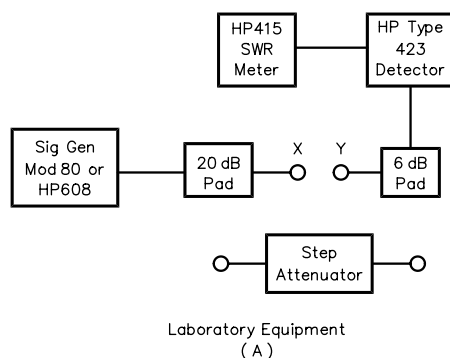


Fig 26—The duplexer can be tuned by either of the two methods shown here, although the method depicted at A is preferred. The signal generator should be modulated by a 1-kHz tone. If the setup shown at B is used, the transmitter should not be modulated, and should have a minimum of noise and spurious signals. The cavities to be aligned are inserted between X and Y in the setup at A, and between P and Q in B.

Y. With no attenuation, adjust the HP-415 for 0 on the 20-dB scale. You can check the calibration of the 415 by switching in different amounts of attenuation and noting the meter reading. You may note a small error at either high or very low signal levels.

Next, remove the step attenuator and replace it with a cavity that has the shunt inductor, L1, in place. Adjust the tuning screw for maximum reading on the 415 meter. Remove the cavity and connect points X and Y. Set the signal generator to the repeater output frequency and adjust the 415 for a 0 reading on the 20-dB scale.

Reinsert the cavity between X and Y and adjust the cavity tuning for minimum reading on the 415. The notch should be sharp and have a depth of at least 35 dB. It is important to maintain the minimum reading on the meter while tightening the locknut on the tuning shaft.

To check the insertion loss of the cavity, the output from the signal generator should be reduced, and the calibration of the 415 meter checked on the 50-dB expanded scale. Use a fixed 1-dB attenuator to make certain the error is less than 0.1 dB. Replace the attenuator with the cavity and read the loss. The insertion loss should be 0.5 dB or less. The procedure is the same for tuning all six cavities, except that the frequencies are reversed for those having the shunt capacitor installed.

### Adjustment with Minimum Equipment

A transmitter with a minimum of spurious output should be used for this method of adjustment. Most modern transmitters meet this requirement. The voltmeter in use should be capable of reading 0.5 V (or less), full scale. The RF probe used should be rated to 150 MHz or higher. Sections of RG-58 cable are used as attenuators, as shown in Fig 26B. The loss in these 140-foot lengths is nearly 10 dB, and helps to isolate the transmitter in case of mismatch during tuning.

Set the transmitter to the repeater input frequency and connect P and Q. Obtain a reading between 1 and 3 V on the voltmeter. Insert a cavity with shunt capacitors in place between P and Q and adjust the cavity tuning for a minimum reading on the voltmeter. (This reading should be between 0.01 and 0.05 V.) The rejection in dB can be calculated by

$$\text{dB} = 20 \log (V1/V2)$$

This should be at least 35 dB. Check the insertion loss by putting the receiver on the repeater output frequency and noting the voltmeter reading with the cavity out of the circuit.

A 0.5-dB attenuator can be made from a 7-foot length of RG-58. This 7-foot cable can be used to check the calibration of the detector probe and the voltmeter.

Cavities with shunt inductance can be tuned the same way, but with the frequencies reversed. If two or more cavities are tuned while connected together, transmitter noise can cause the rejection readings to be low. In other words, there will be less attenuation.

### Results

The duplexer is conservatively rated at 150 W input, but, if constructed carefully, should be able to handle as much as 300 W. Silver plating the interior surfaces of the cavities is recommended if input power is to be greater than 150 W. A duplexer of this type with silver plated cavities has an insertion loss of less than 1 dB, and a rejection of more than 100 dB. Unplated cavities should be disassembled at least every two years, cleaned thoroughly, and then retuned.

### Miscellaneous Notes

- 1) Double-shielded cable and high-quality connectors are *required* throughout the system
- 2) The SWR of the antenna should not exceed 1.2:1 for proper duplexer performance.
- 3) Good shielding of the transmitter and receiver at the repeater is essential.
- 4) The antenna should have four or more wavelengths of vertical separation from the repeater.
- 5) Conductors in the near field of the antenna should be well bonded and grounded to eliminate noise.
- 6) The feed line should be electrically bonded and mechanically secured to the tower or mast.

- 7) Feed lines and other antennas in the near field of the repeater antenna should be well bonded and as far from the repeater antenna as possible.
- 8) Individual cavities can be used to improve the performance of separate antenna or separate site repeaters.
- 9) Individual cavities can be used to help solve intermodulation problems.

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