

figuration of Fig 5A, the calculated impedance in the arrangement of Fig 5B is in the order of $72 + j10 \Omega$.

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.

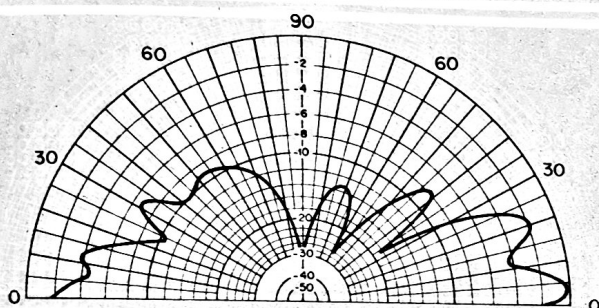


Fig 8—Calculated vertical pattern of the array of Fig 5C, assuming $\frac{1}{4}\lambda$ element spacing from a 4-inch mast. The azimuth pattern is circular within 1.5 dB, and the calculated gain is 4.4 dBi.

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 0.75λ for 2.25λ to 3.0λ .

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 watts, and the receiver has a squelch sensitivity of $0.1 \mu V$. This means there must be at least 1.9×10^{-16} watts at the 52-ohm 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-watt 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 $0.1 \mu V$ on-frequency signal in the presence of a signal 600 kHz away that is 40 dB greater than $0.1 \mu V$, 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 watts), 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.

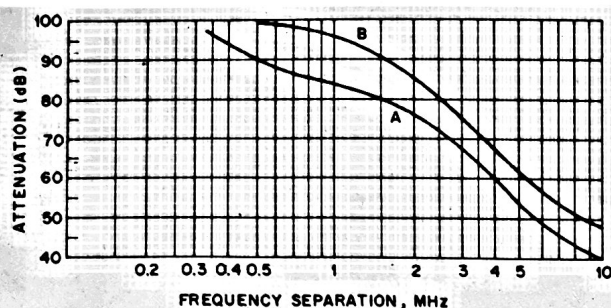


Fig 9—Typical isolation requirements for repeater transmitters and receivers operating in the 132-174 MHz band (Curve A), and the 400-512 MHz band (Curve B). Required isolation in dB is plotted against frequency separation in MHz. These curves were developed for a 100-W transmitter. For other power levels, 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.)

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 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 155 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

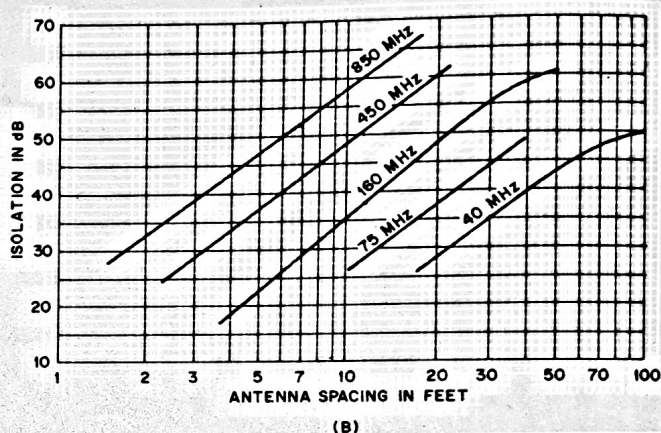
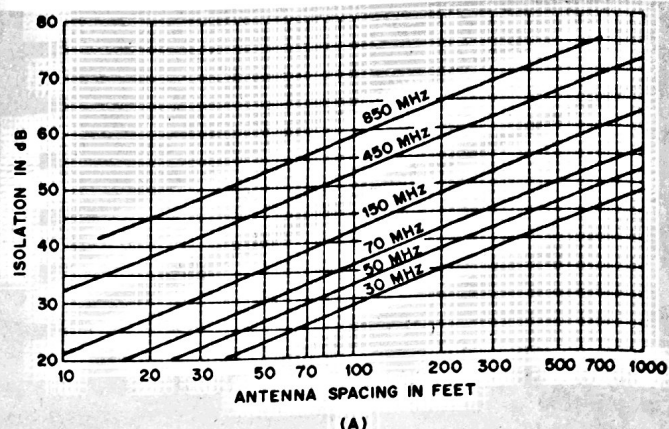


Fig 10—At A, the amount of attenuation (isolation) provided by horizontal separation of vertical dipole antennas. At B, isolation afforded by vertical separation of vertical dipoles. Spacing is that between antenna centers.

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

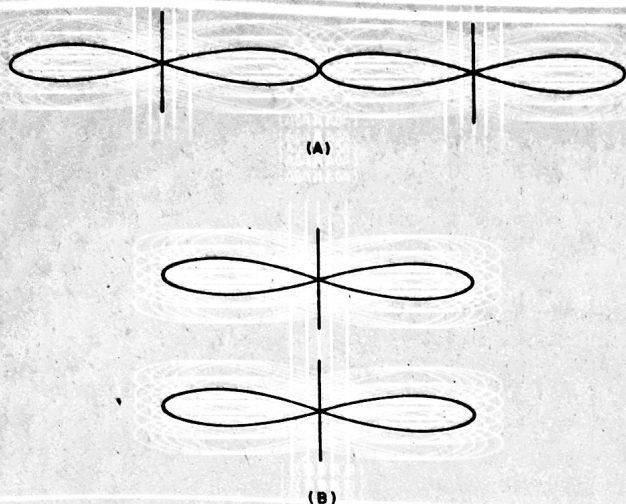


Fig 11—A relative representation of the isolation advantage afforded by separating antennas horizontally (A) and vertically (B) is shown. A great deal of isolation is provided by vertical separation, but horizontal separation requires two supports and much greater distance to be as effective. Separate-site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

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

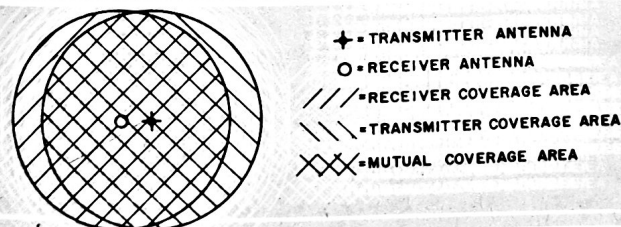


Fig 12—Coverage disparity is a major problem for separate-site repeater antennas. The transmitter and receiver coverage areas overlap, but are not entirely mutually inclusive. Solving this problem requires a great deal of experimentation, as many factors are involved. Among these factors are terrain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

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 filter) 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).

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

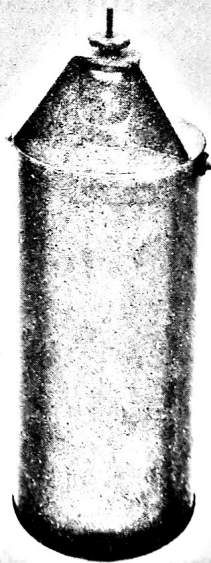


Fig 13—A coaxial cavity filter of the type used in many amateur and commercial repeater installations. Center-conductor length (and thus resonant frequency) is varied by adjustment of the knob (top).