5. ANTENNA TYPES

Antennas can be classified in several ways. One way is the frequency band of operation. Others include physical structure and electrical/electromagnetic design. The antennas commonly used for LMR—both at base stations and mobile units—represent only a very small portion of all the antenna types.

Most simple, nondirectional antennas are basic dipoles or monopoles. More complex, directional antennas consist of arrays of elements, such as dipoles, or use one active and several passive elements, as in the Yagi antenna.

New antenna technologies are being developed that allow an antenna to rapidly change its pattern in response to changes in direction of arrival of the received signal. These antennas and the supporting technology are called adaptive or "smart" antennas and may be used for the higher-frequency LMR bands in the future.

5.1 Dipoles and Monopoles

The vertical dipole—or its electromagnetic equivalent, the monopole—could be considered one of the best antennas for LMR applications. It is omnidirectional (in azimuth) and, if it is a half-wavelength long, has a gain of 1.64 (or G = 2.15 dBi) in the horizontal plane. A center-fed, vertical dipole is illustrated in figure 5(a). Although this is a simple antenna, it can be difficult to mount on a mast or vehicle. The ideal vertical monopole is illustrated in figure 5(b). It is half a dipole placed in half-space, with a perfectly conducting, infinite surface at the boundary.

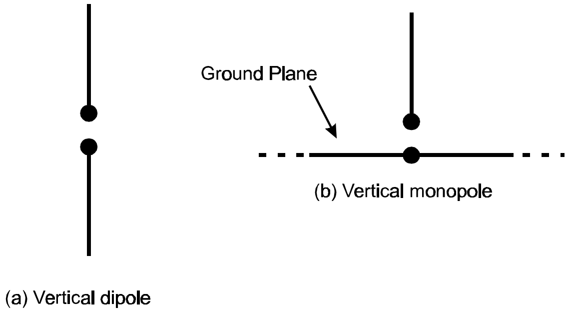


Figure 5. The vertical dipole and its electromagnetic equivalent, the vertical monopole

A monopole over an infinite ground plane is theoretically the same (identical gain, pattern, *etc.*, in the half-space above the ground plane) as the dipole in free space. In practice, a ground plane cannot be infinite, but a ground plane with a radius approximately the same as the length of the active element, is an effective, practical solution. The flat surface of a vehicle's trunk or roof can act as an adequate ground plane. Figure 6 shows typical monopole antennas for base-station and mobile applications.

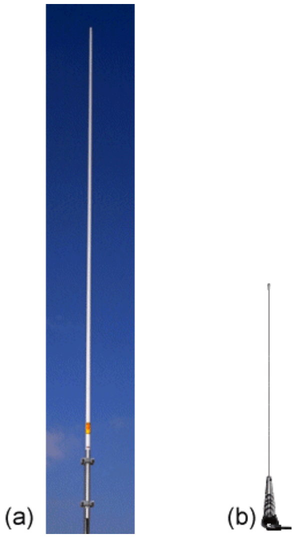


Figure 6. Typical monopole antennas for (a) base-station applications and (b) mobile applications

5.2 Base-Station Applications

For base-station installations (where an omnidirectional pattern is desired), there are two practical implementations of the vertical dipole. The first type is the sleeve antenna, as illustrated in figure 7(a). The sleeve antenna is a vertical dipole with the feed (transmission line) entering from one end of a hollow element. The second type is a monopole over a ground plane, as illustrated in figure 7(b). The monopole in this illustration uses a set of four wire elements to provide the ground plane. Figure 8 shows a typical pattern for a base-station monopole.

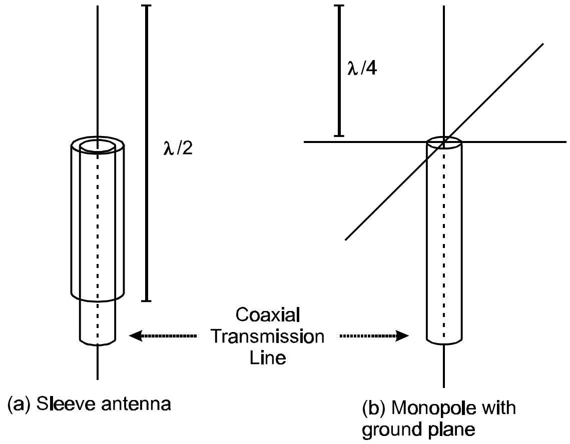


Figure 7. Omnidirectional base-station antennas

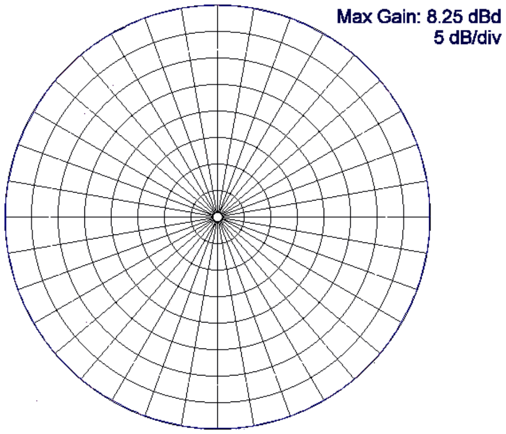


Figure 8. A monopole antenna horizontal-plane pattern, base-station application. The uniform maximum gain corresponds to the outer line on the polar plot

A variation of the dipole antenna is the folded dipole as shown in figure 9. Its radiation pattern is very similar to the simple dipole, but its impedance is higher and it has a wider bandwidth.

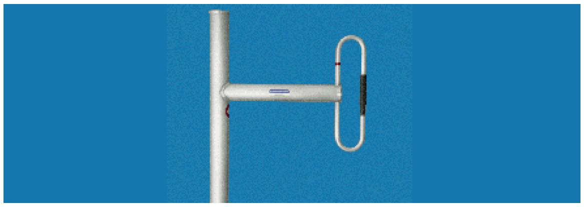
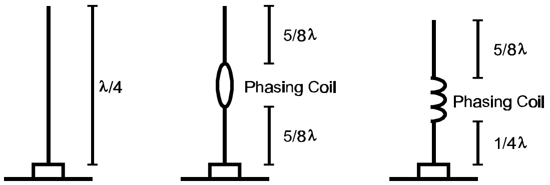


Figure 9. A folded-dipole antenna

5.2.1 Mobile Applications

Nearly all vehicular antennas are monopoles mounted over a (relatively) flat body surface (as described above). In this application, the monopole is often called a “whip” antenna. At VHF low-band, a quarter-wave monopole can be 2.5 m (approximately 8 ft) long. However, an inductor (coil) at the base of a monopole adds electrical length, so the physical length of the antenna can be shorter. Although this kind of “loaded” antenna will appear to be a quarter-wave antenna, it will have a gain value somewhat less than a true quarter-wave monopole. This disadvantage can be somewhat offset, however, by the ability to mount the (shorter) antenna in the center of a surface that will act as an acceptable ground plane (*e.g.*, the roof or trunk of the vehicle). Figure 10(a) shows an illustration of this kind of antenna.



(a) VHF low-band, base-loaded monopole, 2 dBi gain

(b) UHF mobile antenna, 5 dBi gain

(c) 800 MHz mobile antenna, 3 dBi gain

Figure 10. Typical mobile antennas

Many of the vehicular antennas at VHF high-band are quarter-wave monopoles. At 150 MHz, this would mean that a whip antenna, approximately 0.5 m (1.5 ft) long, is needed. Half-wave and 5/8 wave monopoles also are used, but they require some sort of matching network (*i.e.*, inductors and/or capacitors) in order to match the antenna impedance to that of the transmission line. These longer antennas have a gain of approximately 3 dBi.

At UHF, a quarter-wave whip is approximately 15 cm (6 in) long. Since this length is physically small, some design considerations can be used to increase the gain. For example, as shown in figure 10(b), two 5/8 wave monopoles can be “stacked” with a phasing coil between them. This is, effectively, an antenna array (see sec. 5.5) that provides a gain of approximately 5 dBi.

At 800 MHz, a quarter-wave monopole does not perform well, so the approach of stacking two monopoles, with a phasing coil between, is used. Such an antenna, illustrated in figure 10(c), looks much like a mobile cellular phone antenna and has a gain of approximately 3 dBi.

The azimuthal pattern of all monopoles is ideally a circle. In other words, the gain versus azimuth angle in the horizontal plane is constant. In practice, the pattern in the horizontal plane generally is not omnidirectional, since the portion of the vehicle used as a ground plane is not symmetric, and usually there are other obstructions. Figure 11 shows the horizontal plane pattern for an 840 MHz whip located in the center of the roof of a vehicle [13]. The dotted line in the figure shows the effects, on the pattern, of a law-enforcement light bar mounted on the roof ahead of the antenna.

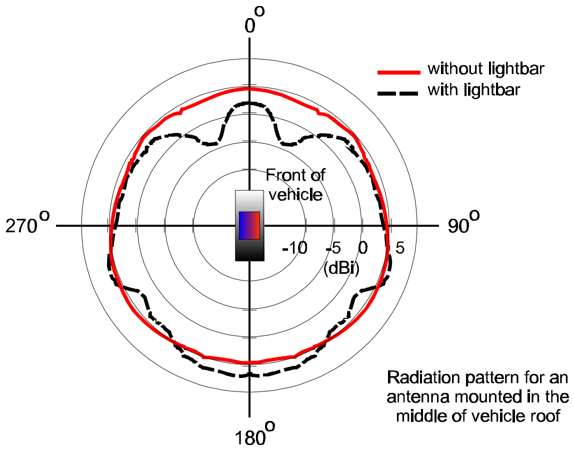
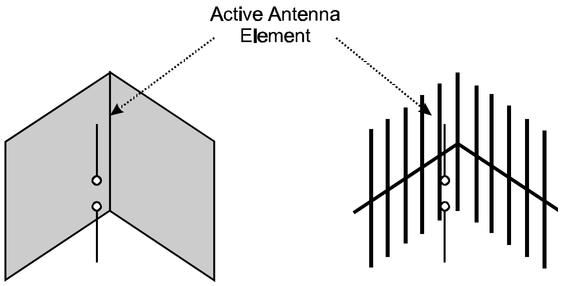


Figure 11. A mobile antenna horizontal-plane pattern [13]

5.3 Corner Reflector

An antenna comprised of one or more dipole elements in front of a corner reflector, called the corner-reflector antenna, is illustrated in figure 12. A photograph of a typical corner reflector is shown in figure 13.



(a) Solid reflector (b) Wire reflector

Figure 12. Corner-reflector antennas

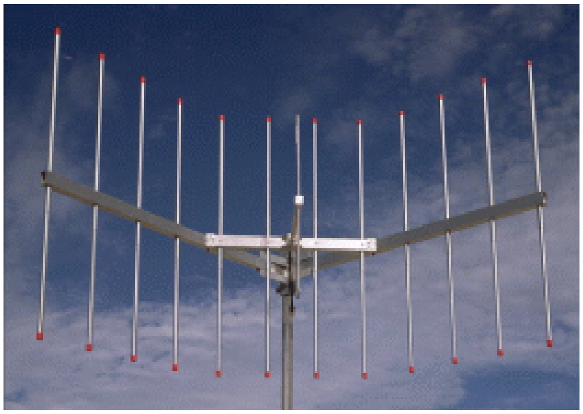


Figure 13. A typical corner-reflector antenna

This antenna has moderately high gain, but its most important pattern feature is that the forward (main beam) gain is much higher than the gain in the opposite direction. This is called the front-to-back ratio and is evident in the pattern shown in figure 14.

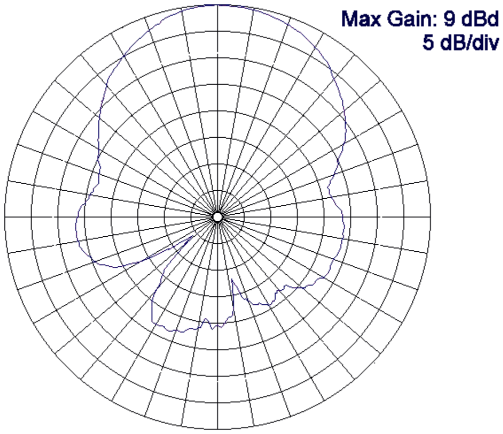


Figure 14. A corner-reflector antenna horizontal-plane pattern

5.4 Yagi

Another antenna design that uses passive elements is the Yagi antenna. This antenna, illustrated in figure 15, is inexpensive and effective. It can be constructed with one or more (usually one or two) reflector elements and one or more (usually two or more) director elements. Figure 16 shows a Yagi antenna with one reflector, a folded-dipole active element, and seven directors, mounted for horizontal polarization.

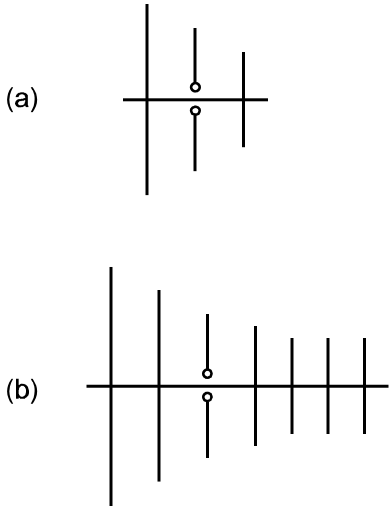


Figure 15. The Yagi antenna — (a) three elements and (b) multiple elements

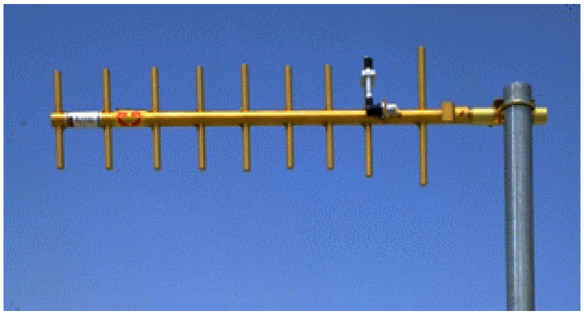


Figure 16. A typical Yagi antenna

Figure 17 is a typical pattern for a three-element (one reflector, one active element, and one director) Yagi antenna. Generally, the more elements a Yagi has, the higher the gain, and the narrower the beamwidth. This antenna can be mounted to support either horizontal or vertical polarization and is often used for point-to-point applications, as between a base station and repeater-station sites.

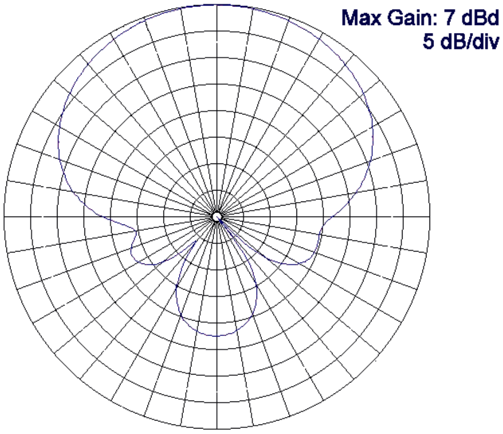


Figure 17. A Yagi antenna horizontal-plane pattern

5.5 Log-Periodic

A somewhat novel, but very useful, design is the log-periodic antenna. This antenna is based on the dipole element. As shown in the illustration of figure 18, it is in fact comprised of a set of dipoles, all active, that vary in size from smallest at the front to largest at the rear. Usually, this antenna is constructed so the antenna terminals are located at the front (on the shortest dipole). Figure 19 shows a typical installation. The key features of this antenna are, first of all, its broadband nature, and second, its relatively high front-to-back gain ratio. The latter feature is evident in the typical radiation pattern shown in figure 20.

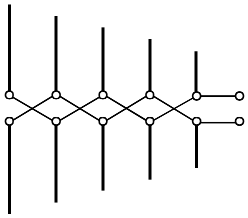


Figure 18. A log-periodic antenna

Figure 19. A typical log-periodic antenna

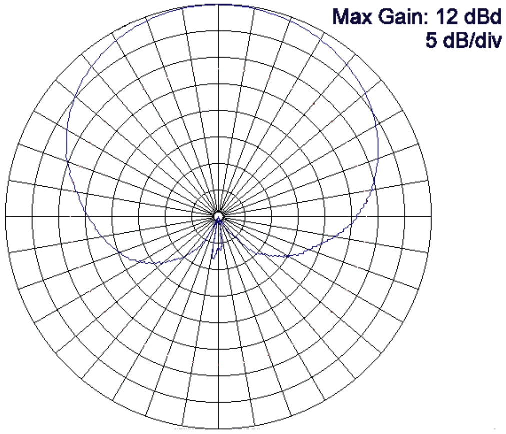


Figure 20. A log-periodic antenna horizontal-plane pattern

5.6 Arrays

An *antenna array* (or array antenna) is, much like it sounds, several elements interconnected and arranged in a regular structure to form an individual antenna. The purpose of an array is to produce radiation patterns that have certain desirable characteristics that a single element would not. A stacked dipole array, as shown in figure 21, is comprised of vertical dipole elements.

This dipole array has an omnidirectional pattern like the element dipole does; but has higher gain and a narrower main lobe beamwidth in the vertical plane. Figure 22 shows how the vertical-plane gain of the dipole element can be "enhanced" by making an array of them. Figure 22(a) represents the radiation pattern of one element. Figure 22(b) is the pattern of two elements, and figure 22(c) is for three elements.

Figure 21. A typical vertical array using folded dipoles

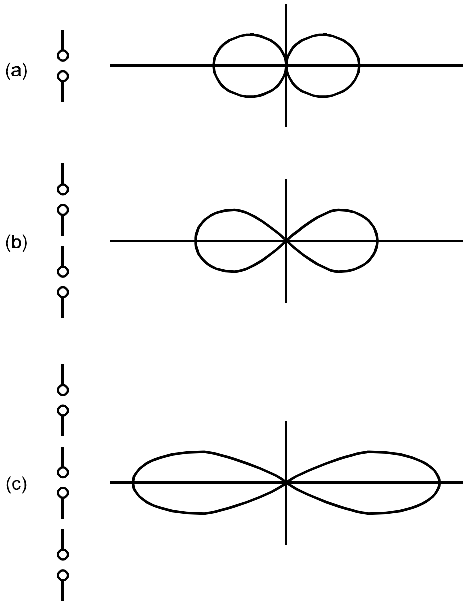


Figure 22. Vertical-plane radiation patterns for (a) single half-wave dipole, (b) two-element array, and (c) three-element array

This is called a binomial or collinear array [14]. As the number of elements is increased, the gain increases and the beamwidth decreases.

The omnidirectional coaxial collinear antenna (often referred to as an “omni”) is a very popular array design for base stations. It is comprised of quarter-wave coaxial sections with inner and outer conductors transposed at each junction.

A conceptual illustration is shown in figure 23. Although more complex than the illustration, this antenna array behaves like a series of vertical dipoles stacked one above the other. The more stacked sections, the greater the gain and the narrower the vertical beamwidth. A vertical-plane pattern for this type of antenna is shown in figure 24. Variations in electrical design can produce a downward tilt of the vertical-plane pattern as shown in figure 25. This antenna often is enclosed in a fiberglass sheath, called a *radome*, and appears as a simple pole that can be mounted off the side or on top of a mast or tower.

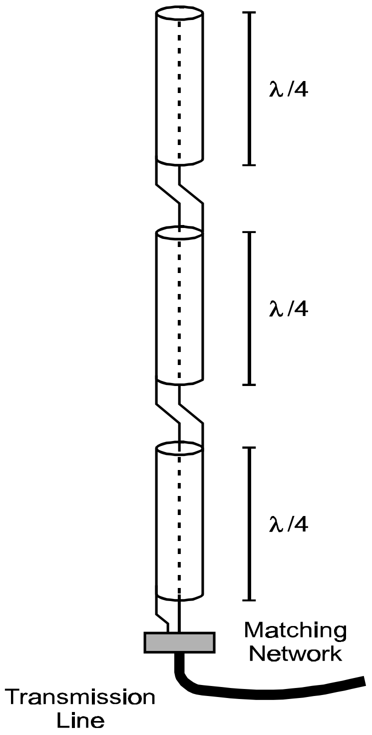


Figure 23. A coaxial collinear array

As with all antennas, the array is frequency-dependent. The gain, directivity, and radiation pattern are each a function of frequency. Some antennas will work well only for the design frequency, and their performance will degrade as the operating frequency is separated from the design frequency.

5.7 Unusual Antennas

There are many other antenna types. Most of these are beyond the scope of this report, but knowledge about some may be useful for LMR users.

While not as commonplace as wire or rod antennas, aperture antennas are by no means unusual. These antennas are implemented as an opening in a relatively large, conductive (metal) surface.

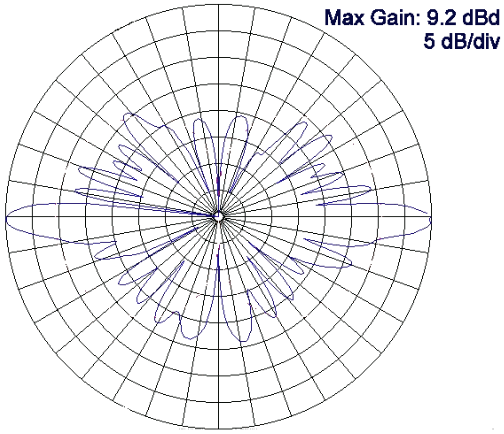


Figure 24. A vertical-plane radiation pattern without "tilt"

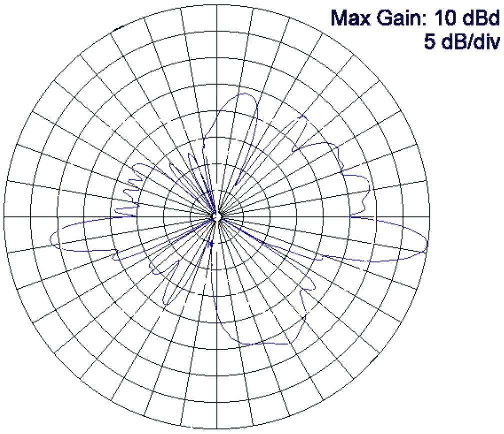


Figure 25. A vertical-plane radiation pattern with 8° "tilt"

The simplest aperture antenna is the slot antenna, which is equivalent to a dipole. As shown in figure 26, it is a long, narrow opening with terminals located at the middle of the long sides of the slot. This simple slot and more complex versions are well-suited to covert operations. They can be located on a vehicle surface and concealed behind a cover of thin insulating material. Slot antennas are common on aircraft and missiles.

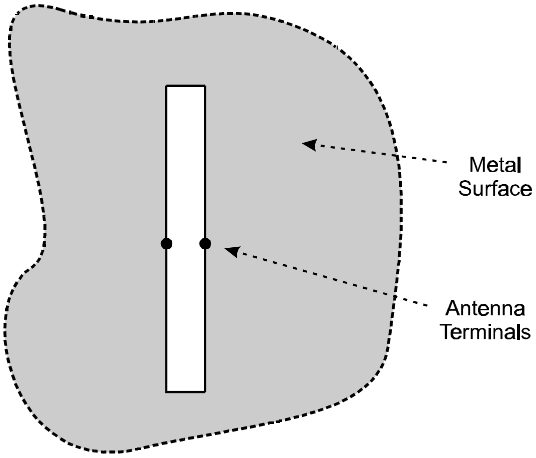


Figure 26. A slot antenna

Not so much antenna types as antenna features, broadband and multiband antennas are the result of design efforts to make an antenna perform well over a wide band of channels. There may be a trade-off in making an antenna broadband, such as a reduction in gain or an increase in physical size. The usual design goals for this type of antenna are to make the gain and radiation pattern, as well as the terminal impedance, relatively constant over the frequency range of operation. The log-periodic array is an example of a broadband antenna.

Multiband antennas are designed to operate on several bands, for example, at both VHF high-band and UHF. These antennas often involve clever designs where one part of the antenna is active for one band, and another part for a different band. Again, there will be compromises. The antenna may have lower average gain or may be physically larger than an equivalent single-band antenna.

5.8 Active Antennas

An active antenna is one that contains some electronic circuitry that can amplify a received signal at the antenna and thus avoid interference that may enter the system at the transmission line. Figure 27 shows this concept. The antenna “element” is connected to the input of an amplifier. The output terminals of the amplifier are the antenna terminals for this active antenna. The antenna element and the amplifier are included in the “active antenna,” shown as a dashed box in the figure.

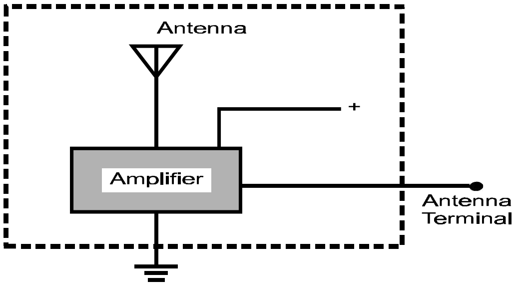


Figure 27. A simple active antenna

Another purpose of an active antenna is to transform an unusual antenna terminal impedance to a constant value that matches the characteristic impedance of the transmission line. This function is useful for some antenna designs in which a specific pattern feature is desired, but cannot be achieved without causing the antenna to have an unusual terminal impedance. An active antenna is nonreciprocal and cannot be used for transmitting.

5.9 Diversity Antennas

Diversity is a technique that improves reception of radio waves by taking advantage of the fact that signals that vary with time (*e.g.*, fading) are not the same at separated locations. In other words, the fading of a signal may be quite different for two locations separated by as little as one wavelength. To take advantage of this, two antennas, separated by some distance, are used to receive the same signal. Of the two signals, the one with the highest signal level, at any given time, is automatically sent to the receiver. This process is only useful for reception. The electronics required for this kind of signal processing are sometimes part of the antenna system.

Adaptive antennas extend the concept of diversity another step further. These antennas usually incorporate more than just two elements (*i.e.*, individual antennas) in the array. An adaptive antenna can modify its radiation pattern (within limits) in real time to ensure that the main lobe points in the direction of greatest signal level. Alternatively (or, possibly, simultaneously), the same technique can be used to point a null in the direction of an unwanted, interfering signal.