1-20 CATALOG OF ANTENNAS

Antennas can be made by combining different elements in configurations which will give us a seemingly limitless number of different antennas. A catalog of basic antenna types and their characteristics is presented as a quick reference. The list of major divisions of antenna types, along with common examples, will help in the selection of the right design. The definitions of pattern types are from IEEE STD 145-1983. Details of analysis and design will be given later.

Directional Antenna An antenna having the property of radiating or receiving more effectively in some directions than others.

Fan-Beam Antenna An antenna producing a major lobe whose transverse cross section has a large ratio of major to minor dimensions.

Omnidirectional Antenna An antenna having an essentially nondirectional pattern in a given plane of the antenna and a directional pattern in any orthogonal plane.

Pencil Beam Antenna An antenna whose radiation pattern consists of a single main lobe with narrow principal plane beamwidths and sidelobes having relatively low levels.

1. Small resonant. Omnidirectional; usually linear polarization. Examples: Dipole (small, $\lambda/2$, sleeve, monopole), loop, slot
2. Conformal. Unidirectional; linear or circular polarization; narrow bandwidth. Examples: Microstrip patch, slot, cavity-mounted elements.
3. End-fire. Pencil beam, slow-wave line structure. Examples: Helical wire, cigar, Yagi-Uda, dielectric rod.
4. Long-wire. End-fire pencil beam except for polarization null on axis. Examples: Beverage, vee, rhombic.
5. Leaky wave. Pencil or fan beam, fast-wave structure. Examples: Waveguide with holes or slots.
6. Self-scaling. Unidirectional or bidirectional, wide bandwidths. Examples: Spirals (equiangular, conical, Archimedian), log-periodics.
7. Horns. Unidirectional or fan-beam, bandwidth determined by feed waveguide. Examples: Sectoral, pyramidal, conical, corrugated, biconical.
8. Reflector. Uses free space for feeding large aperture; bandwidth and polarization determined by feed antenna; pencil or fan beam. Examples: Paraboloidal, parabolic cylinder, dual (Cassegrain, Gregorian, offset), offset-fed, corner.
9. Lens. Uses free space to feed large aperture with feed antenna mounted behind aperture; pencil or fan beam. Examples: Dielectric, waveguide flat plate, artificial, bootlace.

1-20.1 Small Resonant Antennas

Small resonant antennas are small relative to a wavelength and have low gain (Figure 1-10). Both the dipole and its dual, the slot (Figure 1-11), are resonant antennas. Two straight rods make up the dipole, split near the middle, and fed from a balanced line. A narrow slot, cut in a ground plane, resonates with an equivalent magnetic current standing wave. If the slot radiates on both sides of the ground plane, then both the dipole and the slot have the same pattern magnitude with differing polarizations. The slot is replaced by an equivalent magnetic current, and then the antennas have dual symmetry. The pattern has a null in the direction of the dipole or slot axis and a broad beam everywhere else. Long elements (>1λ) give additional nulls. After the dipole is rotated about its axis, the problem remains the same: an operation showing the circular symmetry of the pattern. The polarization, the direction of the electric field, is in the same direction as the current (rod). The electric field across the narrow width of the slot establishes the polarization.

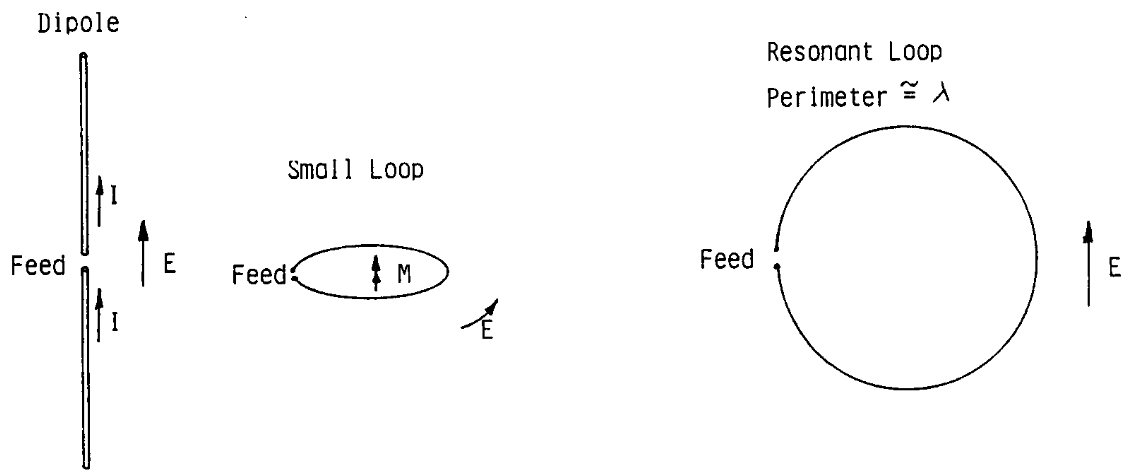

Figure 1-10 Small resonant antennas

Because the dipole and the slot have the same pattern, they have the same directivity for a given length. Given the input impedance of one, we find the input impedance of the other through the Babinet-Booker principle, since the dipole and slot are complementary antennas. When short, these antennas are difficult to match and suffer from low efficiency. But when they are a resonant length (≈ λ/2), the radiation resistance far exceeds the material loss resistance. The result is excellent efficiency and input match. Gain ranges from 1.7 to about 5 dB. The bandwidth of the dipole to nearly can be increased to nearly an octave by using a flat bow-tie also called a *Brown* antenna (Figure 1-12), which can be either solid or a wire frame

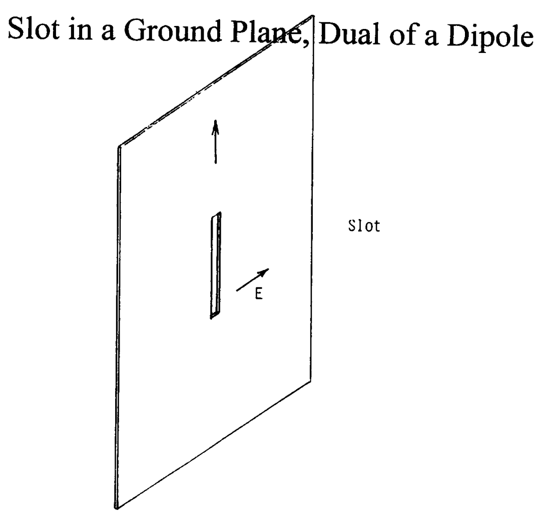

Figure 1-11 Slot in ground plane

A closed loop resonates (Figure 1-10) when it is approximately one wavelength in circumference and has an approximately sinusoidal current distribution. The feed point occurs at the split on the loop. The direction of the electric field across the gap establishes the far-field polarization and the direction of the null in the pattern. The loop's exact shape has only a minor effect on the pattern, and its gain is about the same as that of a one-wavelength dipole (3.8 dB). The bandwidth of the resonant loop antenna roughly equals that of the half-wave dipole.

A single rod, normal to a ground plane and fed from a coax center conductor, forms a monopole antenna. It radiates on only one side of the ground plane. Its dual is a cavity-backed slot limited to radiation on one side only. By using the method of images, an equivalent dipole is analyzed to find the pattern above the ground plane. The monopole gain is twice the gain of the equivalent dipole, and its impedance is half as great. The cavity-backed slot (Figure 1-13) has twice the gain but double the input impedance of the slot radiating on both sides.

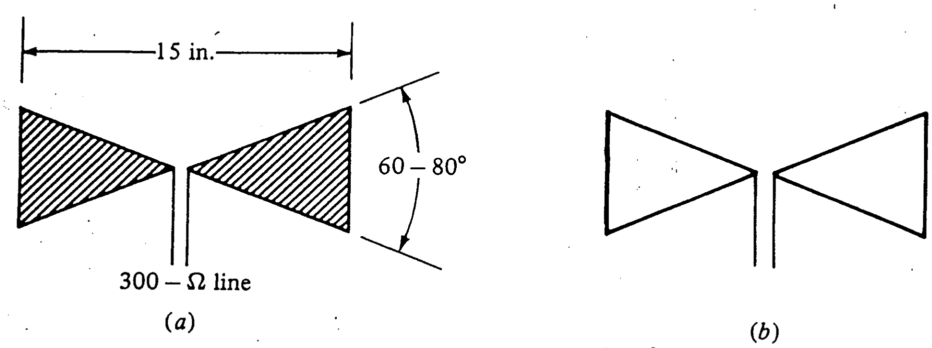

Figure 1-12 Bow-tie or Brown antenna

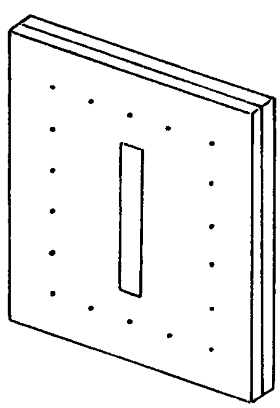

Figure 1-13 Stripline fed slot with ground plane that limits radiation

A sleeve around the input region and extending out the arms of the dipole or monopole increases the impedance bandwidth of the antenna. The pattern remains about the same. Because the standing wave current magnitude remains nearly constant with changing frequency at the feed, the end of the sleeve, so does the input impedance. The ratio of the highest to lowest frequency of operation can be from 2:1 to 3:1.

$$\frac{h}{\lambda}=\frac{1}{4\sqrt{1+20(nD)^{5/2}\sqrt{D/\lambda}}}$$

$$R_r \cong (25.3h/\lambda)^2$$

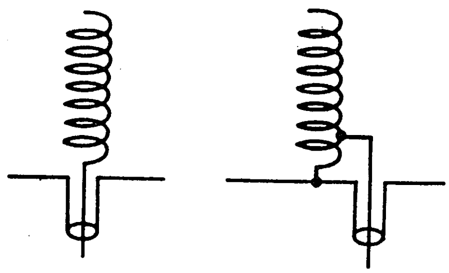

Figure 1-14 Normal mode helix with monopole pattern

Most dipole, loop, and sleeve dipoles must be placed over a ground plane. The ground plane limits the radiation directions and increases the gain. The spacing over the ground plane determines the exact increase when the antenna is analyzed as a two-element array; the second element comes from the image. Because these antennas have wide beamwidths, they are greatly affected by nearby structures and antennas. The monopole can be wound into a helix (Figure 1-14) to decrease its height, but this normal mode helix has reduced bandwidth.

1-20.2 Conformal Antennas

Conformal antennas mount with low profiles on the outsides of vehicles. They must assume the shape of the object. The microstrip patch antenna (Figure 1-15) has a large number of applications because it can radiate both linear and circular polarizations. Photoetching a variety of cavity shapes (rectangular and circular, most commonly) on one side of a dielectric slab forms the antenna. A metal ground plane remains intact on the second side of the slab. A micro-strip line on the substrate or a coax probe from below feeds the antenna. A nonradiating feed circuit can be etched on the same dielectric slab. The ground plane limits the radiation to the half plane, and, combined with an effective two-slot radiation from adjacent edges, the patch has about 7 dB gain. The impedance bandwidth is very narrow, but the patch can meet the requirements of many systems.

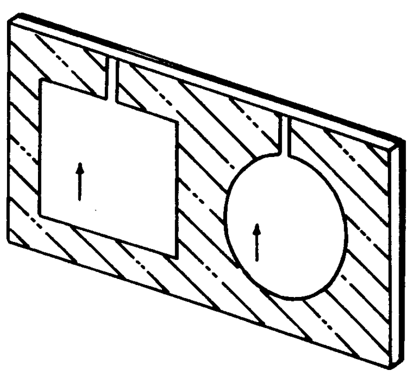

Figure 1-15 Rectangular and circular microstrip patches etched on substrate with ground plane

A cavity-backed slot (Figure 1-13) can also be made conformal by cutting a slot in one of the ground planes of stripline and forming a cavity by using plated-through holes or edge plating between the ground planes. It is fed below from stripline feed networks. The single slot radiator has a greater beamwidth in the E plane than the microstrip patch antenna because there is only one radiating slot. For a given volume both antennas (patch and stripline slot) have about the same bandwidth.

An annular slot radiates a pattern and a polarization similar to those of a monopole. The power spreads from a coax input with the center conductor connected across a cavity to the inner metal circle and the shield to the ground plane below. Shorting pins connect the two ground planes beyond the slot and impress a field across the ring slot.
Many other types of antennas, such as traveling wave antennas, can be made conformal, and that leaves open the number of possible conformal antennas. Because the volume of conformal antennas is limited, so will be the input impedance bandwidth.

1-20.3 End-Fire Antennas

An end-fire antenna radiates in the direction of a wave traveling along the structure away from the feed point. If the structure lies along the z axis, then the peak of the beam also will be in the z direction. Most end-fire antennas radiate from surface wave structures that slow the traveling wave velocity below the speed of light (that is, they increase the effective propagation constant). To achieve a single unidirectional beam centered on the z axis, the effective propagation constant must be matched to the length of the antenna. A wave propagating along the structure with the free-space velocity and radiating uniformly along the axis has a simple formula for directivity = $4L/\lambda$. To double the gain (directivity), it is necessary to double the length L. Any realizable radiation structure will impart some pattern from an incremental segment and increase gain. If the wave velocity is slowed, then the gain increases up to a point. Increased slowing increases the sidelobes and decreases gain. The optimum slowing is found from the Hansen and Woodyard criterion, which gives a directivity $\approx 7.4L/\lambda$. Figure 1-16 shows the pattern of a uniform distribution traveling-wave end-fire distribution 4λ-long with the Hansen and Woodyard phasing.

An end-fire helical antenna consists of a helical coil of wire each turn of which is approximately one wavelength long. A short helical antenna, by matching its modes to the length, adjusts its effective propagation constant over nearly a 1.7:1 range of frequencies so that a single end-fire beam is achieved. The rotating traveling wave radiates a circular polarized wave in the same sense as the winding. Matched pairs of helical antennas with opposite senses of windings provide circular polarization standards. These determine the polarization sense of test antennas by comparing the responses.

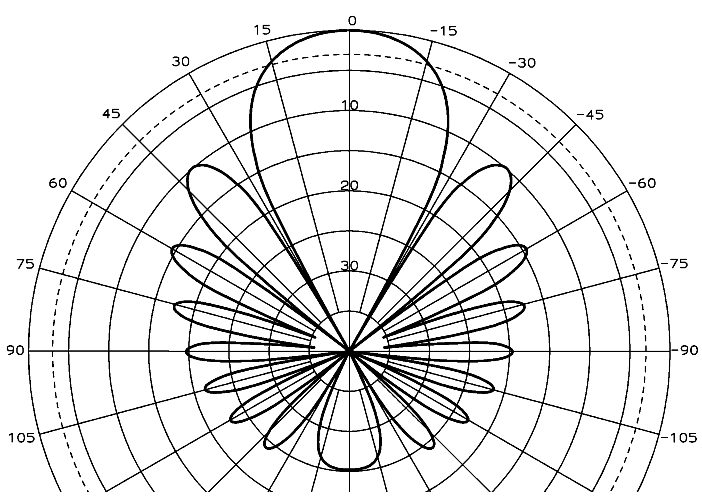

Figure 1-16 Pattern of 4λ-long traveling-wave end-fire uniform distribution with Hansen and Woodyard phasing

The helical antenna (Figure 1-17) mode transition consists of a coax mounted to a small ground plane. The helix is fed from the center conductor of the coax. As the length increases, the helical antenna frequency bandwidth shrinks, but the gain increases. The antenna's directivity will exceed the Hansen and Woodyard criterion because the single-turn pattern narrows the beamwidth and reduces sidelobes.

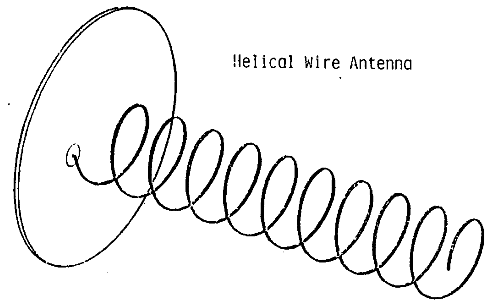

Figure 1-17 Axial-mode helical-wire antenna

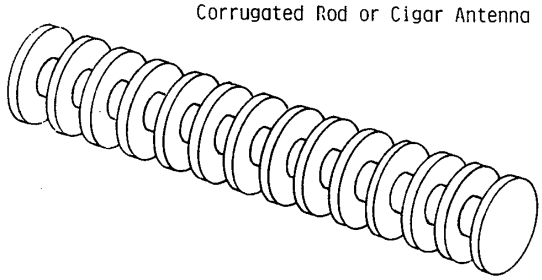

Figure 1-18 Corrugated-rod (Cigar) antenna

The cigar or corrugated-rod antenna (Figure 1-18) is a stack of alternating diameter disks. It supports a surface wave in a hybrid mode which maintains linear polarization. The response and design parameters for antennas using closely spaced circular disks can be found exactly, but antennas can be made by using other shapes as well. Empirical designs, using other shapes, start from a known solution, and the dimensions of the parts are adjusted to achieve the proper phase velocity for a given length. Good operation occurs only over a narrow bandwidth that decreases for increased gain (length). The maximum directivity is about $8L/\lambda$. The structure can be excited by a combination of a linearly polarized radiator (dipole or loop) and a reflector element to achieve a unidirectional wave in the direction of the rod.

A dielectric rod supports a hybrid mode (linear polarization) surface wave. Like the others, it produces an end-fire pattern when its effective propagation constant matches its length. It is usually fed by a circular waveguide operating in the TE_{11} mode (Figure 1-19). The rod could just as well be square or rectangular and be fed from a rectangular waveguide. Tapering the rod increases the bandwidth and establishes an amplitude taper on the rod.

A Yagi-Uda end-fire antenna couples power from a fed element to a reflector element and a series of director elements (Figure 1-20). It can be analyzed as an array or as a surface wave device. Because it radiates linear polarization, the hybrid mode approximates its response and establishes an upper bound on directivity for a given length. The antenna elements consist of dipoles or loops adjusted to give the proper phasing through mutual coupling to approximate a surface wave response. Like the others, its bandwidth decreases with increased gain.

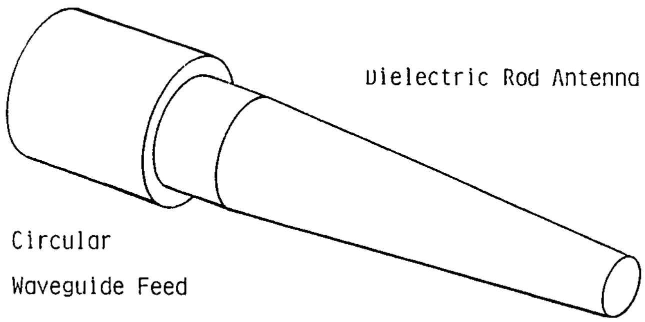

Figure 1-19 Dielectric-rod (Polyrod) surface-wave antenna

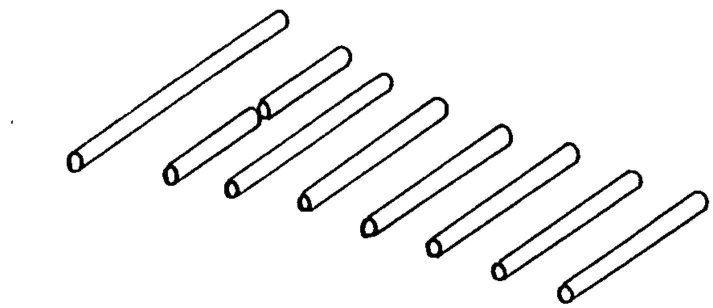

Figure 1-20 Yagi-Uda dipole antenna

Flat structures, such as dielectric slabs on ground planes and corrugated surfaces, support surface waves. These surfaces shape the beams of antennas by capturing some of the radiated power and redirecting it into an end-fire pattern. The surfaces can have positive effects over narrow bandwidths, but they cause pattern distortion in other cases. All surface wave radiators capture power from some primary radiator, dipole or waveguide, and direct its radiation. Simple periodic structures can be solved with boundary matching, but tapered and modulated structures can be used as well. Without waiting for solutions, antennas using them can be designed empirically. Do not be limited to regular structures matching coordinate systems.

1-20.4 Leaky Wave Antennas

Leaky wave antennas radiate from structures whose relative propagation constant is less than 1. The wave is no longer bound to the surface; instead, it constantly leaks power along its length and attenuates the traveling wave. The radiation maximum occurs at an angle (Figure 1-21) to the direction of wave propagation determined by the relative propagation constant.

$$e^{-jPkz} \qquad \theta_{\max} = \cos^{-1} P \qquad P < 1$$

Waveguides are fast wave structures. When opened by holes or slots, the fast leaky waves radiate from the openings. Small openings have little effect on the internal wave and the unperturbed waveguide phase velocity determines the radiation direction, although radiation implies a changed phase velocity. A waveguide with a series of resonant-length slots in the walls can be analyzed as an array (Figure 1-22). Terminating the guide with a short circuit establishes a standing wave (P = 0) and gives a broadside pattern (θ = 90°). A matched load on the end of the waveguide leads to a nonresonant design whose beam direction is determined by the waveguide propagation constant.

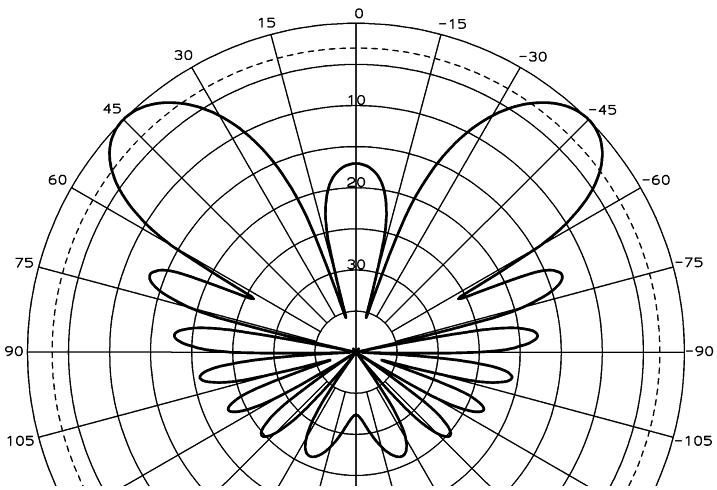

Figure 1-21 Pattern of leaky-wave antenna 4λ-long

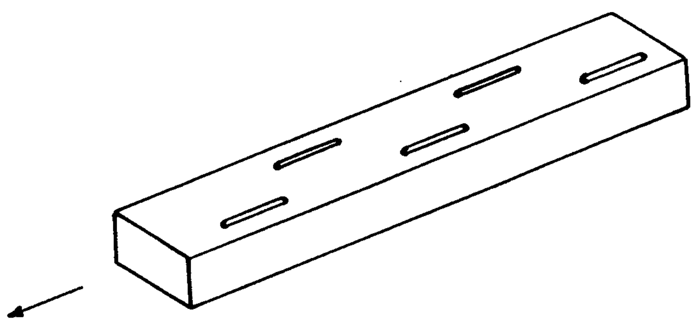

Figure 1-22 Waveguide slot array

Waveguide structures with holes or nonresonant-length slots radiate leaky waves (Figures 1-23 - 1-25). Each opening radiates a small portion of the passing internal wave. The amplitude distribution can be controlled by varying the openings. To obtain uniform radiation along the length, the first opening can radiate only a small portion of the available power and the openings further along will then radiate more and more of the remaining power in the traveling wave.

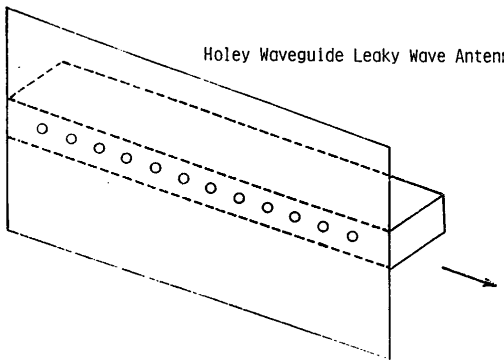

Figure 1-23 Holey waveguide leaky-wave antenna

If the antenna has circular symmetry about the z axis, we can estimate the directivity. For broadside radiation from a uniform distribution, directivity is $2L/\lambda$ where L is the length. As the antenna beam is scanned off broadside, it broadens because the projected area shrinks. But because the pattern is multiplied by sin 0 when the average radiation intensity is calculated, the product remains constant. The gain for a scanned linear aperture with circular symmetry remains constant. The pattern gain may drop because the pattern of the incremental radiator (slot or dipole) will decrease the off-broadside gain, but $2L/\lambda$ remains a good estimate.

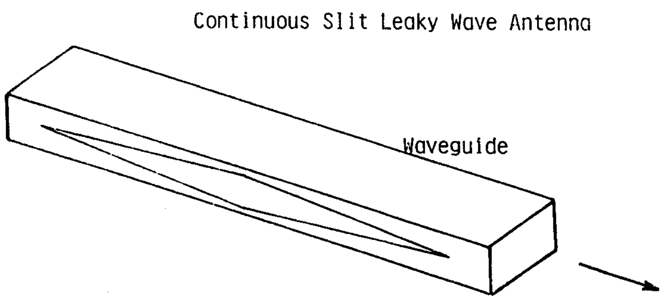

Figure 1-24 Continuous-slit leaky-wave antenna

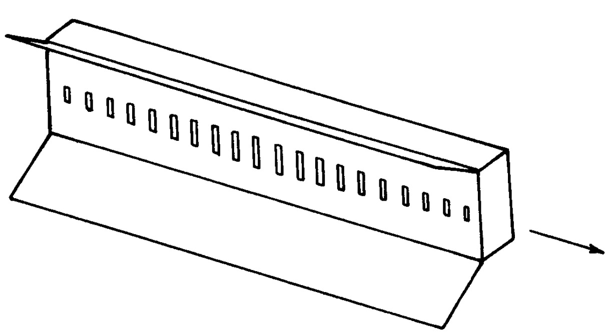

Figure 1-25 Top-wall slotted-waveguide leaky-wave antenna. Sidewalls reduce vertical beamwidth

1-20.5 Long Wire Antennas

A long wire loaded on the end would radiate an end-fire beam except that the pattern of the incremental radiator, the current element, has a null along the axis. This null splits the beam around the wire. Long wire antennas have good directivity but poor gain, since some of the input power is lost in the load. The length of the wire determines the beam direction. A single long wire high over a ground plane is called a Beverage antenna. Two Beverage antennas fed out of phase and so angled that their maximums are aligned form a V antenna. Two V antennas make up a rhombic antenna. The second V, attached to the ends of the first, brings the ends back to a point where a load connects them. These antennas are used to radiate sky waves for ionosphere hopping.

1-20.6 Self-scaling Antennas

Self-scaling antennas contain in themselves their own scale models. They divide into continuous scaling and log-periodic scaling types. Continuous scaling antennas depend only on angles for dimensions, and without any characteristic length, they can have large continuous bandwidths. The log-periodic antenna scales itself at discrete frequencies with response variations within the scaling period. Both a flat equiangular (log) two-arm spiral and a conical equiangular two-arm spiral antenna (projection on a cone) depend only on angles for dimensions. They radiate circular polarization. The flat spiral radiates equally on both sides with opposite senses of polarization. Its directivity may be doubled by backing it with a cavity (Figure 1-26), which eliminates the opposite-sense radiation. When a spiral is projected on a cone (Figure 1-27), its changed shape increases the radiation in the direction of the cone apex. Archimedian spirals exhibit wide bandwidths, as do the equiangular spirals, but they require loads on the ends of the arms to eliminate end reflections.

The log-periodic antenna is usually linearly polarized, although it can be used in a pair to obtain circular polarization. It scales itself at discrete frequencies, usually with dipoles, and its response varies between the scalings. A central transmission line feeds each dipole or other element (Figure 1-28). The mutual coupling between elements broadens the response between the resonant frequencies of the elements. The gain ranges from 7 to 12 dB.

Self-scaling antennas have limited gain because, at any one frequency, they radiate over a limited active region. Like all end-fire antennas, the length of the active region determines gain. The higher-frequency portion of the antenna must act as a transmission line between the feed and the active region. The transmission line portion is a slow-wave structure moving to a radiating fast-wave structure in the active region with its backfire radiation. Past the active region little power is left to radiate. Because of their ability to scale themselves, self-scaling antennas have bandwidths measured in octaves.

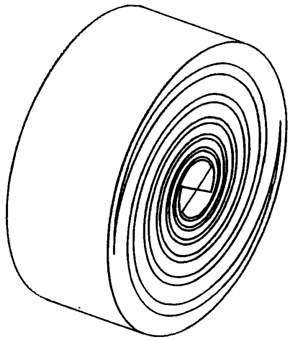

Figure 1-26 Cavity-backed Log-spiral antenna

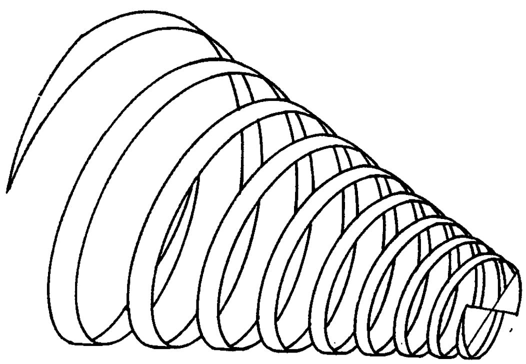

Figure 1-27 Conical Log-spiral antenna

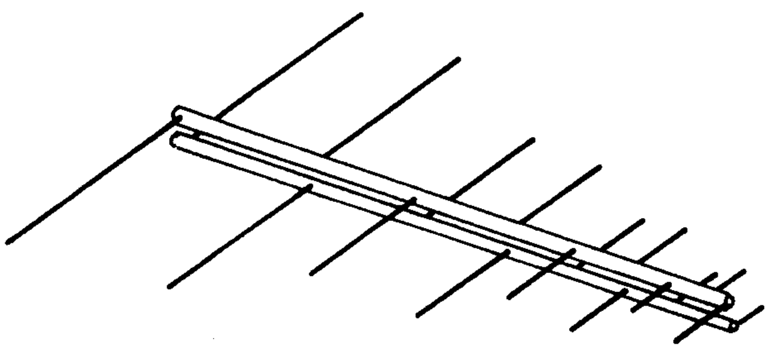

Figure 1-28 Log-periodic dipole antenna

1-20.7 Horn Antennas

A horn is an aperture antenna fed from a waveguide mode in an expanded waveguide. If the expanded waveguide cross section increases slowly, the waveguide mode amplitude distribution translates to the aperture plane. The increased length along the slant walls compared with the direct path to the aperture causes a phase error in the aperture. The phase distribution is approximately quadratic. Given two horns with the same aperture, the horn with the longer slant length has the greater gain. The horn can achieve very pure linear polarization, which makes it useful in antenna measurements both as a source and as a gain standard.

The aperture efficiency is a product of the amplitude taper efficiency, determined by the amplitude distribution of the waveguide mode, and the phase error efficiency, determined by the quadratic phase distribution. In Table 1-4 the aperture efficiencies of different horns, each with a 0.3-λ maximum aperture phase error, are compared. Increasing the phase deviation in the aperture will decrease the aperture efficiency at different rates for the various horns. The efficiency of a corrugated-wall horn decreases more slowly than that of a smooth-wall horn. The corrugated-wall horn will eventually have better efficiency for a given aperture phase deviation.

Table 1-4 Aperture Efficiencies of Horns

Horn Type	Wall Type	Efficiency, %	Loss, dB
Pyramidal	Smooth	50.5	2.97
Pyramidal	Corrugated	48.8	3.12
Conical	Smooth	63.4	1.98
Conical	Corrugated	57.4	2.41

The pyramidal horn (Figure 1-29) fulfills many requirements for antennas. It starts in a rectangular waveguide operating in the TE_{10} mode. The waveguide walls flare out to the aperture. The waveguide mode establishes a constant aperture amplitude distribution in the E plane. The H plane has a cosine distribution. Horns with greatly differing beamwidths are designed by varying the aperture plane dimensions. When a horn is flared only in the *H* plane, the *E*-plane pattern remains broad while the *H*-plane pattern narrows. Similarly, a horn flared only in the *E*-plane retains a broad *H*-plane pattern as the *E*-plane pattern narrows. The Fourier transform relation, wide aperture lengths give narrow beamwidths (Section 2-2), is used to design the antenna. The usual horn has approximately equal beamwidths in both planes, but the pyramidal horn can provide controlled beamwidths in both planes.

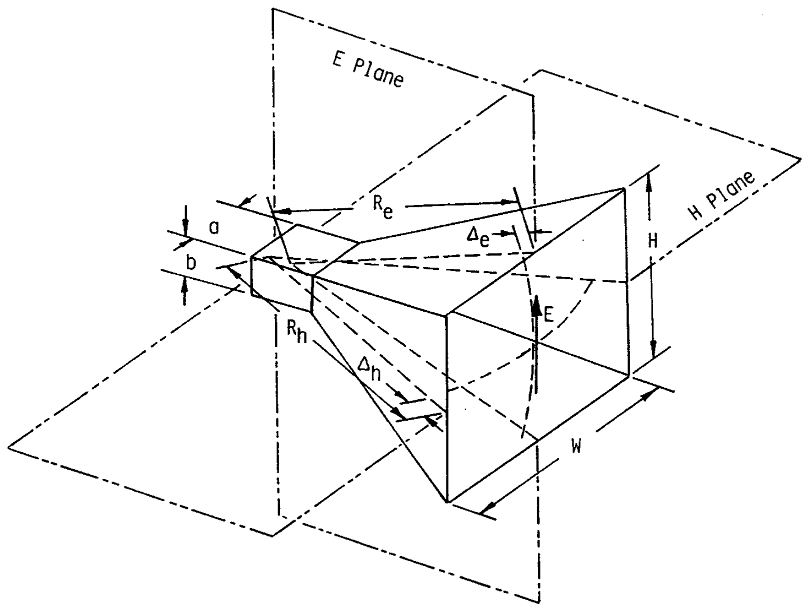

Figure 1-29 Pyramidal horn and orientation of *E*- and *H*-planes

A circular waveguide excited in the TE_{11} mode feeds the conical horn, a truncated circular cone attached to a circular waveguide. The horn has good aperture efficiency. Because the *E*- and *H*-plane dimensions are the same, the ratio of the beamwidths is fixed. For a maximum slant length deviation of 0.3-λ from the central length, the *H*-plane beamwidth is approximately 1.21 times the *E*-plane beamwidth. Dual polarized antennas are easily constructed because the circular waveguide can be fed from any polarization. Of course, the pyramidal horn can be fed from a square waveguide and achieve dual polarization.

Corrugated-wall horns have equal *E*- and *H*-plane amplitude distributions. The corrugations, cut normal to the direction of propagation, excite higher-order waveguide modes. A combination of the TE_{11} and TM_{11} modes, a hybrid HE_{11} mode, feeds the aperture of the corrugated-wall conical horn. The hybrid mode has circular symmetry and gives equal E- and H-plane beamwidths. The fields vanish on the walls when the corrugated surface is capacitive (slots λ/4 to λ/2 deep). Because the fields vanish on the walls, there is no edge diffraction to radiate sidelobes. Corrugations in the *E*-plane walls of a pyramidal horn taper the distribution to a cosine-like amplitude that produces H-plane beamwidths and sidelobe levels. Square corrugated horns have equal *E*- and *H*-plane beamwidths to both polarizations.

External corrugations around the aperture plane of the horn achieve the same effect as wall corrugations by forcing the fields to zero on the walls of the *E*-plane. In a circular horn, this is called a coaxial or choke horn. It is a good design for small apertures in which internal corrugations are expensive to machine. Over narrow bandwidths the corrugation depths can be varied to excite a series of modes to match the focal plane fields of a parabolic reflector. Rectangular horns may also use external corrugations along the *E*-plane walls.

In stepped multimode horns abrupt steps are used in the input waveguide to generate higher-order modes. The step discontinuity generates higher-order modes to satisfy the boundary conditions at the step. The increased waveguide dimensions and symmetry select the propagating higher-order mode. The distance between the step and the aperture establishes the phase shift between modes. Each mode travels with a different phase velocity. The rectangular stepped horn (box horn) steps in the H-plane to generate the TE_{30} mode. The combination of the TE_{10} and TE_{30} modes flattens the H-plane amplitude distribution. A step in a circular waveguide excites the TM_{11} symmetrical mode from an input TE_{11} mode. When combined in the aperture with the right phase, the sum produces the $HE_{11}$of the corrugated-wall horn.

The bandwidth of a horn is determined by the input waveguide for large apertures. Central ridges increase the bandwidth of waveguide by lowering the cutoff frequency. Near-decade bandwidths are possible from horns with ridges. The ridges also serve as impedance transformers between the coax input and the radiating aperture impedance.

A biconical horn flares from the conductors of a coax line into two cones. The coax excites a spherical mode field between the cones that has circular symmetry. The distance between the cones at the aperture plane along with the phase error loss determines the gain of the antenna. Equation $2L/\lambda$ puts an upper bound on the gain for long cones.

1-20.8 Reflector Antennas

A parabolic reflector is the cheapest large-aperture (gain) antenna. When fed from an antenna at its focus, it collimates the power into a large-aperture plane, the projected area of the reflector. The length of the aperture in various pattern planes and the amplitude distribution determine the beam-width. Reflectors with elliptical edge shapes produce fan beams with the narrow beamwidth in the plane containing the major axis (Figure 1-30).

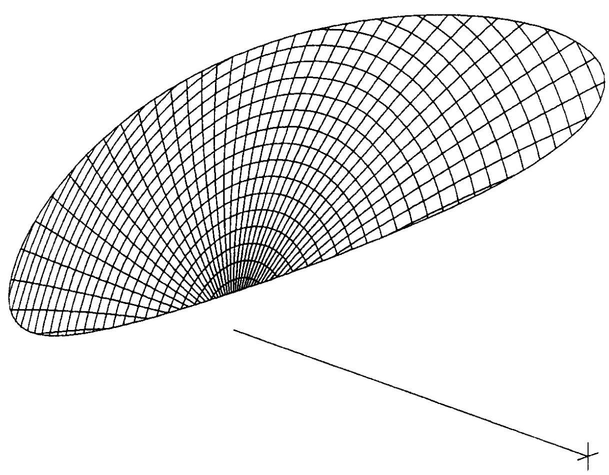

Figure 1-30 Elliptical-rim offset-fed paraboloidal reflector

The feed for optimum gain has its 10-dB beamwidth approximately equal to the subtended angle of the reflector. The minimum sum of amplitude taper loss and feed spillover loss occurs nearly at this point. The gain can be estimated from Eq. (1-10) by using an aperture efficiency of 55%. The beamwidth is approximately 70º λ/D

where D is the diameter.

A dual-reflector antenna increases the effective focal length of the main reflector. The Cassegrain (Figure 1-31*a*) has a hyperbolic subreflector to spread the feed energy out to the main reflector. One focus of the hyperbola is at the focus of the main reflector; the other focus is at the feed antenna. The Gregorian antenna (Figure 1-31*b*) uses an elliptical subreflector. Because of the added losses of the subreflector blockage, dual-reflector antennas become effective only when the main reflector is large.

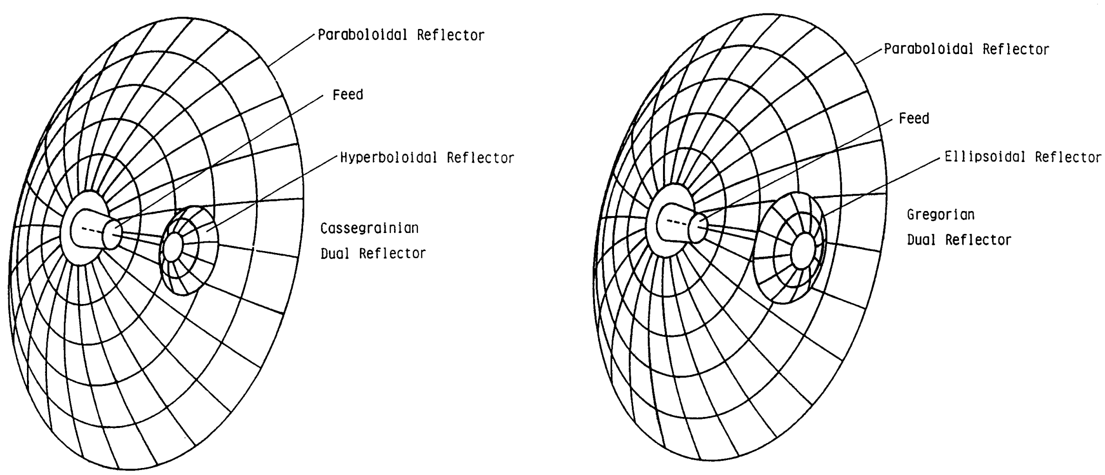

Figure 1-31 Dual-reflector antennas: (*a*) Cassegrain, (*b*) Gregorian

A cylindrical reflector uses a parabola in one plane to form the beam (Figure 1-32). A line feed forms the beam in the other plane. A phased array feed can scan the beam in one plane while mechanical rotation scans the beam in the other plane.

The central blockage of the center-fed reflector reduces the gain and increases the sidelobe level of the antenna. An offset-fed reflector eliminates these problems. The reflector is formed out of a piece of an imaginary larger reflector. The feed is still located at the focus, but it is pointed toward the center of the reflector. Dual reflectors can also be offset. Large feed structures require offset designs to eliminate blockage problems.

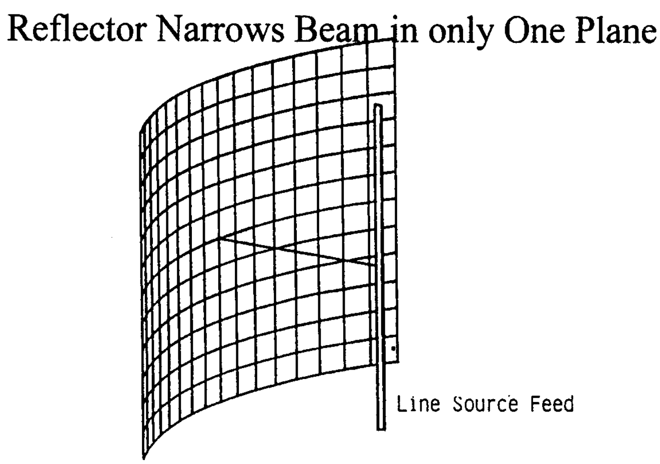

Figure 1-32 Cylindrical-parabolic reflector antenna

Spherical reflectors can be scanned to large angles by moving the feed. Moving the feed to scan a parabolic reflector degrades the pattern. The wave no longer focuses to a point in a spherical reflector but instead focuses to a line. The feed must be a line source to match the incident fields.

Shaped reflectors are of two types. Cassegrain subreflector shaping coupled with minor main reflector shaping can increase the gain of the total antenna by improving the flatness of the aperture field. A parabolic reflector has a built-in amplitude taper because of the increased distance to the reflector from the feed as the angle increases off the axis. A shaped subreflector directs more power toward the edge of the main reflector to improve flatness. The second type of shaped reflector produces a prescribed pattern, such as cosecant squared, by distorting the reflector from a parabola. The gain decreases from the expected gain of the aperture as more of the power is spread out to shape the beam.

Flat plates are used as reflectors. A corner reflector gives an effective array of dipoles through images to increase the gain. It restricts the directions of possible radiation and reflects energy in the forward direction. By combining the direct radiation, reflections, and edge diffractions from the corners, we find the total pattern (GTD). A large corner reflector restricts the power to one- fourth of the radiation sphere and would increase the gain by 9 dB if diffraction effects were not present. The exact increase depends on the interaction of the dipole and its images. A ground plane increases the gain of an antenna by restricting radiation directions and reducing back-lobe radiation.

1-20.9 Lens Antennas

Ever-increasing bandwidth requirements force the use of higher and higher frequencies. Mechanical tolerances and losses limit the choice of antennas. Optical methods become more attractive. The great amount of work in optics can be directly applied after the effects of the large wavelengths for optics are considered. Reflectors become impractical because of the tolerance require merits and the necessity of having large feed structures. The frequencies must be detected at the antenna to eliminate transmission line losses and to avoid the associated increased noise temperature of the system. The large blockage causes loss and high sidelobe levels. The feed of a lens remains out of the aperture.

Lenses divide into three types. A dielectric lens is designed directly from optics, and the aperture of the antenna is equal to the projection of the rim shape. Artificial dielectrics can be made by embedding small metal objects in a foam matrix; this allows for varying the effective dielectric constant by varying the density. In the third type metal strips are used as waveguides to increase the phase velocity by acting as parallel-plate waveguides when the electric field is parallel to the plates. The waveguide increases the phase velocity of the waves to produce an effective index of refraction less than 1.

The lens can be zoned by removing multiples of wavelengths from the thickness. Zoning narrows the frequency bandwidth and causes shadowing losses at the zone transitions.

1-21 Relation between Beamwidths

The pattern approximation $\cos^{2N}(\vartheta/2)$ can be used to find a relation between beamwidths at different pattern levels. The exponent N for any beamwidth level is found from an expression similar to Eq. (1-20). By using this N and the new beamwidth level, the new beamwidth can be found. With a nomograph (Figure 1-33) these expressions can be solved by drawing two lines. The left-hand scale is the pattern level in decibels. The right-hand scale is the beam-width. The unmarked diagonal scales are the exponent N. Draw a line from the pattern level to the beamwidth. Through the intersection of the diagonal N draw a second line from the new pattern level to the beamwidth scale (the right axis). Read the beamwidth at the new level. Multiply the left linear scale by any convenient factor to extend its range.

Example An antenna has a 45° 3-dB beamwidth centered on 0 = 0 (a limitation of the approximation). Find the 10-dB beamwidth. Draw a line from the 3-dB point on the left-hand scale through the diagonal to the leftmost beamwidth scale at the 45° point. Draw a second line from the 10-dB pattern level scale (at the left) through the intersection of the first line and the diagonal to the beamwidth scale. Read the beamwidth, by using the same scale as with the first line, as 82°.

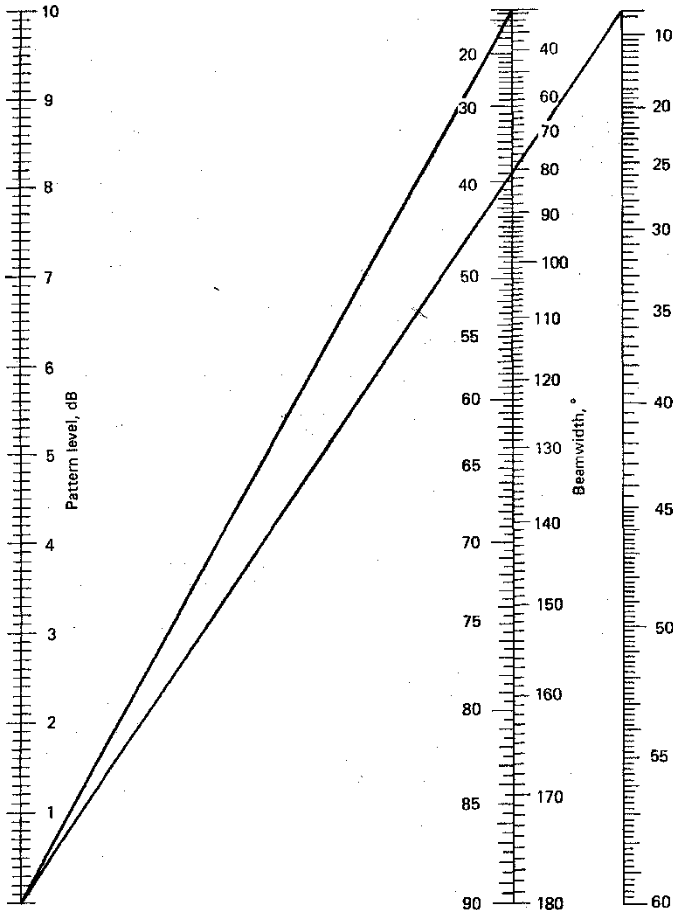

Figure 1-33 Approximate relationship of beamwidths at different levels