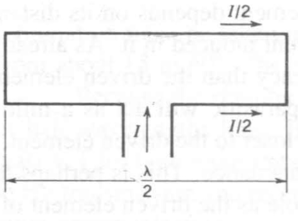

FIGURE 9-24 Folded dipole.

If elements of unequal diameters are used, transformation ratios from 1.5 to 25 are practicable, and if greater ratios are required, more arms can be used. Although the folded dipole has the same radiation pattern as the ordinary dipole, it has many advantages: its higher input impedance and its greater bandwidth (as explained in Section 9-8), as well as ease and cost of construction and impedance matching.

The Yagi-Uda antenna A Yagi-Uda antenna is an array consisting of a driven element and one or more parasitic elements. They are arranged collinearly and close together, as shown in Figure 9-25, together with the optical equivalent and the radiation pattern.

Since it is relatively unidirectional, as the radiation pattern shows, and has a moderate gain in the vicinity of 7 dB, the Yagi antenna is used as an HF transmitting antenna. It is also employed at higher frequencies, particularly as a VHF television receiving antenna. The back lobe of Figure 9-25*b* may be reduced, and thus the *front-to-back ratio* of the antenna improved, by bringing the radiators closer. However, this has the adverse effect of lowering the input impedance of the array, so that the separation shown, 0.1λ, is an optimum value.

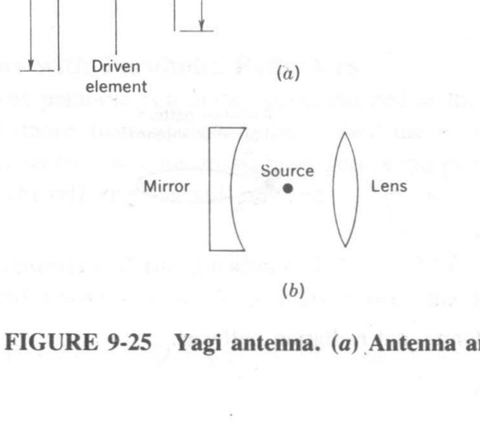

FIGURE 9-25 Yagi antenna. (*a*) Antenna and pattern; (*b*) optical equivalent.

The precise effect of the parasitic element depends on its distance and tuning, i.e., on the magnitude and phase of the current induced in it. As already mentioned, a parasitic element resonant at a lower frequency than the driven element (i.e., longer) will act as a mild reflector, and a shorter parasitic will act as a mild "director" of radiation. As a parasitic element is brought closer to the driven element, it will load the driven element more and reduce its input impedance. This is perhaps the main reason for the almost invariable use of a folded dipole as the driven element of such an array.

The Yagi antenna admittedly does not have high gain, but it is very compact, relatively broadband because of the folded dipole used and has quite a good unidirectional radiation pattern. As used in practice, it has one reflector and several directors which are either of equal length or decreasing slightly away from the driven element. Finally, it must be mentioned that the folded dipole, along with one or two other antennas, is sometimes called a *supergain antenna,* because of its good gain and beamwidth per unit area of array.

9-6.3 Nonresonant Antennas—The Rhombic

A major requirement for HF is the need for a multiband antenna capable of operating satisfactorily over most or all of the 3- to 30-MHz range, for either reception or transmission. One of the obvious solutions is to employ an array of nonresonant antennas, whose characteristics will not change too drastically over this frequency range.

A very interesting and widely used antenna array, especially for point-to-point communications, is shown in Figure 9-26. This is the *rhombic antenna,* which consists of nonresonant elements arranged differently from any previous arrays. It is a planar rhombus which may be thought of as a piece of parallel-wire transmission line bowed in the middle. The lengths of the (equal) radiators vary from 2 to 8 λ, and the radiation angle, ϕ, varies from 40 to 75°, being mostly determined by the leg length.

The four legs are considered as nonresonant antennas. This is achieved by treating the two sets as a transmission line correctly terminated in its characteristic impedance at the far end; thus only forward waves are present. Since the termination absorbs some power, the rhombic antenna must be terminated by a resistor which, for transmission, is capable of absorbing about one-third of the power fed to the antenna. The terminating resistance is often in the vicinity of 800 Ω and the input impedance varies from 650 to 700 Ω. The directivity of the rhombic varies from about 20 to 90°, increasing with leg length up to about 8 λ. However, the power absorbed by the

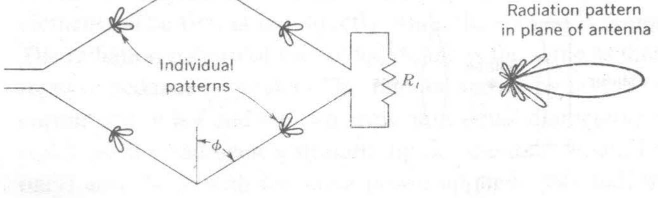

FIGURE 9-26 Rhombic antenna and radiation patterns.

termination must be taken into account, so that the *power gain* of this antenna ranges from about 15 to 60°. The radiation pattern is unidirectional as shown (Figure 9-26).

Because the rhombic is nonresonant, it does not have to be an integral number of half-wavelengths long. It is thus a broadband antenna, with a frequency range at least 4:1 for both input impedance and radiation pattern. The rhombic is ideally suited to HF transmission and reception and is a very popular antenna in commercial point-to-point communications.

9-7 UHF AND MICROWAVE ANTENNAS

Transmitting and receiving antennas designed for use in the UHF (0.3–3 GHz) and microwave (1–100 GHz) regions tend to be directive—some highly so. This condition results from a combination of factors, of which the first is undoubtedly feasibility. The dimensions of an antenna must generally be several wavelengths in order for it to have high gain. At the frequencies under discussion, antennas need not be physically large to have multiple-wavelength dimensions, and consequently several arrangements and concepts are possible which might have been out of the question at lower frequencies. A number of UHF and microwave applications, such as radar, are in the direction-finding and measuring field, so that the need for directional antennas is widespread. Several applications, such as microwave communications links, are essentially point-to-point services, often in areas in which interference between various services must be avoided. The use of directional antennas greatly helps in this regard. As frequencies are raised, the performance of active devices deteriorates. That is to say, the maximum achievable power from output devices falls off, whereas the noise of receiving devices increases. It can be seen that having high-gain (and therefore directional) antennas helps greatly to overcome these problems.

The VHF region, spanning the 30–300 MHz frequency range, is an "overlap" region. Some of the HF techniques so far discussed can be extended into the VHF region, and some of the UHF and microwave antennas about to be discussed can also be used at VHF. It should be noted that the majority of antennas discussed in Section 9-8 are VHF antennas. One of the most commonly seen VHF antennas used around the world is the Yagi-Uda, most often used as a TV receiving antenna.

9-7.1 Antennas with Parabolic Reflectors

The parabola is a plane curve, defined as the locus of a point which moves so that its distance from another point (called the *focus*) plus its distance from a straight line (*directrix*) is constant. These geometric properties yield an excellent microwave or light reflector, as will be seen.

Geometry of the parabola Figure 9-27 shows a parabola *CAD* whose focus is at *F* and whose axis is *AB*. It follows from the definition of the parabola that

$$FP + PP' = FQ + QQ' = FR + RR' = k \qquad \textbf{(9-8)}$$

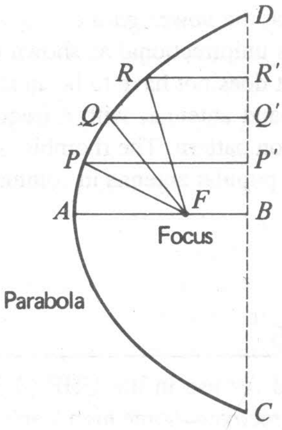

FIGURE 9-27 Geometry of the parabola.

where k = a constant, which may be changed if a different shape of parabola is required

AF = focal length of the parabola

Note that the ratio of the focal length to the mouth diameter (AF/CD) is called the *aperture* of the parabola, just as in camera lenses.

Consider a source of radiation placed at the focus. All waves coming from the source and reflected by the parabola will have traveled the same distance by the time they reach the directrix, no matter from what point on the parabola they are reflected. *All such waves will be in phase.* As a result, radiation is very strong and concentrated along the AB axis, but cancellation will take place in any other direction, because of path-length differences. The parabola is seen to have properties that lead to the production of concentrated beams of radiation.

A practical reflector employing the properties of the parabola will be a three-dimensional *bowl-shaped* surface, obtained by revolving the parabola about the axis AB. The resulting geometric surface is the *paraboloid,* often called a *parabolic reflector* or *microwave dish.* When it is used for reception, exactly the same behavior is manifested, so that this is also a high-gain receiving directional antenna reflector. Such behavior is, of course, predicted by the *principle of reciprocity,* which states that the properties of an antenna are independent of whether it is used for transmission or reception. The reflector is directional for reception because only the rays arriving from the BA direction, i.e., normal to the directrix, are brought together at the focus. On the other hand, rays from any other direction are canceled at that point, again owing to path-length differences. The reflector provides a high gain because, like the mirror of a reflecting telescope, it collects radiation from a large area and concentrates it all at the focal point.

Properties of paraboloid reflectors The directional pattern of an antenna using a paraboloid reflector has a very sharp main lobe, surrounded by a number of minor lobes which are much smaller. The three-dimensional shape of the main lobe is like that of a fat cigar (Figure 9-27), in the direction *AB*. If the *primary*, or *feed*, antenna is nondirectional, then the paraboloid will produce a beam of radiation whose width is given by the formulas.

$$\phi = \frac{70\lambda}{D} \tag{9-9}$$

$$\phi_0 = 2\phi \tag{9-9'}$$

where λ = wavelength, m

ϕ = beamwidth between half-power points, degrees

ϕ_0 = beamwidth between nulls, degrees

D = mouth diameter, m

Both equations are simplified versions of more complex ones, but they apply accurately to large apertures, that is, large ratios of mouth diameter to wavelength. They are thus accurate for small beamwidths. Although Equation (9-9′) is fairly universal, Equation (9-9) contains a restriction. It applies in the specific, but common, case of illumination which falls away uniformly from the center to the edges of the paraboloid reflector. This decrease away from the center is such that power density at the edges of the reflector is 10 dB down on the power density at its center. There are two reasons for such a decrease in illumination: (1) No primary antenna can be truly isotropic, so that some reduction in power density at the edges must be accepted. (2) Such a uniform decrease in illumination has the beneficial effect of reducing the strength of minor lobes. Note that the whole area of the reflector is illuminated, despite the decrease toward the edges. If only half the area of the reflector were illuminated, the reflector might as well have been only half the size in the first place.

EXAMPLE 9-4 Calculate the beamwidth between nulls of a 2-m paraboloid reflector used at 6 GHz. *Note:* Such reflectors are often used at that frequency as antennas in outside broadcast television microwave links.

SOLUTION

$$\phi_0 = 2 \times \frac{70\lambda}{D} = 140 \times \frac{0.05}{2}$$
$$= 3.5^\circ$$

The gain of an antenna using a paraboloid reflector is influenced by the aperture ratio (D/λ) and the uniformity (or otherwise) of the illumination. If the antenna is lossless, and its illumination falls away to the edges as previously discussed, then the power gain, as a good approximation, is given by

$$A_p = 6\left(\frac{D}{\lambda}\right)^2 \tag{9-10}$$

where A_p = directivity (with respect to isotropic antenna)
G_p = power gain if antenna is lossless
D = mouth diameter of reflector, m

It will be seen later in this section how this relationship is derived from a more fundamental one. It is worth pointing out that the power gain of an antenna with a uniformly illuminated paraboloid, *with respect to a half-wave dipole,* is given by a formula approximately the same as Equation (9-10).

EXAMPLE 9-5 **Calculate the gain of the antenna of Example 9-4.**

SOLUTION

$$A_p = 6\left(\frac{D}{\lambda}\right)^2 = 6\left(\frac{200}{5}\right)^2 = 9600$$

Example 9-5 shows that the *effective radiated power* (ERP) of such an antenna would be 9600 W if the actual power fed to the primary antenna were 1 W. The ERP is the product of power fed to the antenna and its power gain. It is seen that very large gains and narrow beamwidths are obtainable with paraboloid reflectors—excessive size is the reason why they are not used at lower frequencies, such as the VHF region occupied by television broadcasting. In order to be fully effective and useful, a paraboloid must have a mouth diameter of at least 10 λ. At the lower end of the television band, at 63 MHz, this diameter would need to be at least 48 m. These figures illustrate the relative ease of obtaining high directive gains from practical microwave antennas.

Feed mechanisms The primary antenna is placed at the focus of the paraboloid for best results in transmission or reception. The direct radiation from the feed, which is not reflected by the paraboloid, tends to spread out in all directions and hence partially spoils the directivity. Several methods are used to prevent this, one of them being the provision of a small spherical reflector, as shown in Figure 9-28, to redirect all such

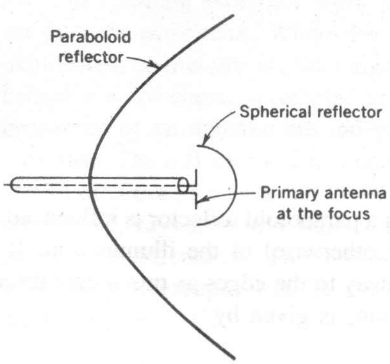

FIGURE 9-28 Center-fed paraboloid reflector with spherical shell.