antenna, no matter what value that impedance may be. For example, the impedance of a resonant half-wave dipole may be low at the center of the antenna and high at the ends, but it is purely resistive in all cases, even though its magnitude changes.

The feed point impedance is important in determining the appropriate method of matching the impedance of the antenna and the transmission line. The effects of mismatched antenna and feed line impedances are described in detail in the **Transmission Lines** chapter of this book. Some mistakenly believe that a mismatch, however small, is a serious matter. This is not true. The significance of a perfect match becomes more pronounced only at VHF and higher, where feed line losses are a major factor. Minor mismatches at HF are rarely significant.

21.1.5 Impedance and Height Above Ground

The feed point impedance of an antenna varies with height above ground because of the effects of energy reflected from and absorbed by the ground. For example, a ½ λ (or half-wave) center-fed dipole will have a feed point impedance of approximately 75 Ω in free space far from ground, but **Fig 21.2** shows that only at certain electrical heights above ground will the feed point impedance be 75 Ω. The feed point impedance will vary from very low when the antenna is close to the ground to a maximum of nearly 100 Ω at 0.34 λ above ground, varying between ±5 Ω as the antenna is raised farther. The 75 Ω feed point impedance is most likely to be realized in a practical installation when the horizontal dipole is approximately ½, ¾ or 1 wavelength above ground. This is why few amateur λ/2 dipoles exhibit a center-fed feed point impedance of 75 Ω, even though they may be resonant.

Fig 21.2 compares the effects of perfect ground and typical soil at low antenna heights. The effect of height on the radiation resistance of a horizontal half-wave antenna is not drastic so long as the height of the antenna is greater than 0.2 λ. Below this height, while decreasing rapidly to zero over perfectly conducting ground, the resistance decreases less rapidly with height over actual lossy ground. At lower heights the resistance stops decreasing at around 0.15 λ, and thereafter increases as height decreases further. The reason for the increasing resistance is that more and more energy from the antenna is absorbed by the earth as the height drops below ¼ λ, seen as an increase in feed point impedance.

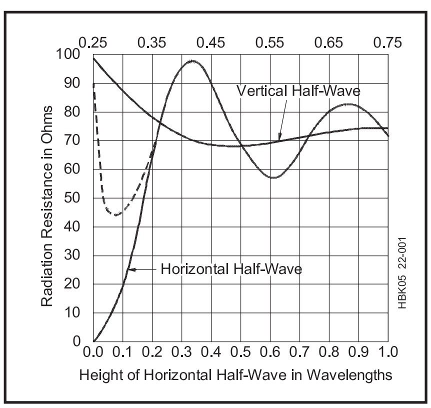

Fig 21.2 — Curves showing the radiation resistance of vertical and horizontal half-wavelength dipoles at various heights above ground. The broken-line portion of the curve for a horizontal dipole shows the resistance over *average* real earth, the solid line for perfectly conducting ground.

21.1.6 Antenna Bandwidth

The *bandwidth* of an antenna refers generally to the range of frequencies over which the antenna can be used to obtain a specified level of performance. The bandwidth can be specified in units of frequency (MHz or kHz) or as a percentage of the antenna's design frequency.

Popular amateur usage of the term antenna bandwidth most often refers to the 2:1 SWR bandwidth, such as, "The 2:1 *SWR bandwidth* is 3.5 to 3.8 MHz" or "The antenna has a 10% SWR bandwidth" or "On 20 meters, the antenna has an SWR bandwidth of 200 kHz." Other specific bandwidth terms are also used, such as the *gain bandwidth* (the bandwidth over which gain is greater than a specified level) and the *front-to-back ratio bandwidth* (the bandwidth over which front-to-back ratio is greater than a specified level).

As operating frequency is lowered, an equivalent bandwidth in percentage becomes narrower in terms of frequency range in kHz or MHz. For example, a 5% bandwidth at 21 MHz is 1.05 MHz (more than wide enough to cover the whole band) but at 3.75 MHz only 187.5 kHz! Because of the wide percentage bandwidth of the lower frequency bands 160 meters is 10.5% wide, 80 meters is 3.4% wide) it is difficult to design an antenna with a bandwidth sufficient to include the whole band.

It is important to recognize that SWR bandwidth does not always relate directly to gain bandwidth. Depending on the amount of feed line loss, an 80 meter dipole with a relatively narrow 2:1 SWR bandwidth can still radiate a good signal at each end of the band, provided that an antenna tuner is used to allow the transmitter to load properly. Broadbanding techniques, such as fanning the far ends of a dipole to simulate a conical type of dipole, can help broaden the SWR bandwidth.

21.1.7 Effects of Conductor Diameter

The impedance and resonant frequency of an antenna also depend on the diameter of the conductors that make up its elements in relation to the wavelength. As diameter of a conductor increases, its capacitance per unit length increases and inductance per unit length decreases. This has the net effect of lowering the frequency at which the antenna element is resonant, as illustrated in **Fig 21.3**. The larger the conductor diameter in terms of wavelength, the smaller its *length-to-diameter ratio (l/d)* and the lower the frequency at which a specific length of that conductor is ½ wavelength long electrically, in free space.

$$l/d = \frac{\lambda/2}{d} = \frac{300}{2f \times d} \qquad (1)$$

where f is in MHz and d is in meters. For example, a ½ wavelength dipole for 7.2 MHz made from #12 AWG wire (0.081 inch dia) has an l/d ratio of

$$l/d = \frac{300}{2f \times d} = \frac{300}{2 \times 7.2 \times \frac{0.081\,\text{in}}{39.37\,\text{in/m}}} = 10{,}126$$

The effect of l/d is accounted for by the factor K which is based on l/d. From Fig 21.3 an l/d ratio of 10,126 corresponds to K ≈ 0.975, so the resonant length of that ½ wave dipole would be 0.975 × (300 / 2f) = 20.31 meters instead of the free-space 20.83 meters.

Most wire antennas at HF have l/d ratios in the range of 2500 to 25,000 with K = 0.97 to 0.98. The value of K is taken into account in the classic formula for ½ wave dipole length, 468/f (in MHz). If K = 1, the formula would be 492/f (in MHz). (This is discussed further in the following section on Dipoles and the Half-Wave Antenna.)

For single-wire HF antennas, the effects

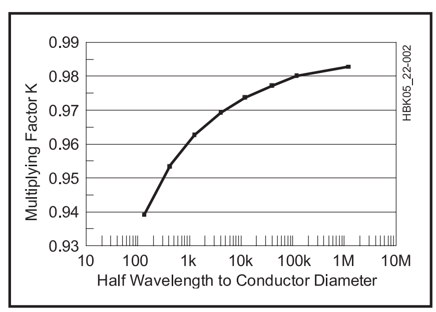

Fig 21.3 — Effect of antenna diameter on length for half-wavelength resonance, shown as a multiplying factor, K, to be applied to the free-space, half- wavelength equation.

of ground and antenna construction make a precise accounting for K unnecessary in practice. At and above VHF, the effects of l/d ratio can be of some importance, since the wavelength is small.

Since the radiation resistance is affected relatively little by l/d ratio, the decreased L/C ratio causes the Q of the antenna to decrease. This means that the change in antenna impedance with frequency will be less, increasing the antenna's SWR bandwidth. This is often used to advantage on the lower HF bands by using multiple conductors in a cage or fan to decrease the l/d ratio.

21.1.8 Radiation Patterns

Radiation patterns are graphic representations of an antenna's directivity. Two examples are given in **Figs 21.4** and **21.5**. Shown in polar coordinates (see the math references in the **Electrical Fundamentals** chapter for information about polar coordinates), the angular scale shows direction and the scale from the center of the plot to the outer ring, calibrated in dB, shows the relative strength of the antenna's radiated signal (gain) at each angle. A line is plotted showing the antenna's relative gain (transmitting and receiving) at each angle. The antenna is located at the exact center of the plot with its orientation specified separately.

The pattern is composed of *nulls* (angles at which a gain minimum occurs) and *lobes* (a range of angles in which a gain maximum occurs). The *main lobe* is the lobe with the highest amplitude unless noted otherwise and unless several plots are being compared, the peak amplitude of the main lobe is placed at the outer ring as a 0 dB reference point. The peak of the main lobe can be located at any angle. All other lobes are *side lobes* which can be at any angle, including to the rear of the antenna.

Fig 21.4 is an *azimuthal* or *azimuth pattern* that shows the antenna's gain in all horizontal directions (azimuths) around the antenna. As with a map, 0° is at the top and bearing angle increases clockwise. (This is different from polar plots generated for mathematical functions in which 0° is at the right and angle increases counter-clockwise.)

Fig 21.5 is an *elevation pattern* that shows the antenna's gain at all vertical angles. In this case, the horizon at 0° is located to both sides of the antenna and the zenith (directly overhead) at 90°. The plot shown in Fig 21.5 assumes a ground plane (drawn from 0° to 0°) but in free-space, the plot would include the missing semicircle with –90° at the bottom. Without the ground reference, the term "elevation" has little meaning, however.

You'll also encounter E-plane and H-plane radiation patterns. These show the antenna's radiation pattern in the plane parallel to the E-field or H-field of the antenna. It's important to remember that the E-plane and H-plane do not have a fixed relationship to the Earth's surface. For example, the E-plane pattern from a horizontal dipole is an azimuthal pattern, but if the same dipole is oriented vertically, the E-plane pattern becomes an elevation pattern.

Antenna radiation patterns can also be plotted on rectangular coordinates with gain on the vertical axis in dB and angle on the horizontal axis as shown in **Fig 21.6**. This is particularly useful when several antennas are being compared. Multiple patterns in polar coordinates can be difficult to read, particularly close to the center of the plot.

The amplitude scale of antenna patterns is almost always in dB. The scale rings can be calibrated in several ways. The most common is for the outer ring to represent the peak amplitude of the antenna's strongest lobe as 0 dB. All other points on the pattern represent *relative gain* to the peak gain. The antenna's *absolute gain* with respect to an isotropic (dBi) antenna or dipole (dBd) is printed as a label somewhere near the pattern. If several antenna radiation patterns are shown on the same plot for comparison, the pattern with the largest gain value is usually assigned the role of 0 dB reference.

The gain amplitude scale is usually divided in one of two ways. One common division is to have rings at 0, –3, –6, –12, –18, and –24 dB. This makes it easy to see where the gain has fallen to one-half of the reference or peak value (–3 dB), one-quarter (–6 dB), one-sixteenth (–12 dB), and so on. Another popular division of the amplitude scale is 0, –10, –20, –30, and –40 dB with intermediate rings or tick marks to show the –2, –4, –6, and –8 dB levels. You will encounter a number of variations on these basic scales.

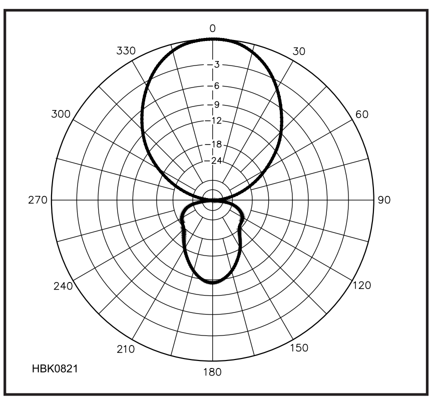

Fig 21.4 — Azimuthal pattern of a typical three-element Yagi beam antenna in free space. The Yagi's boom is along the 0° to 180° axis.

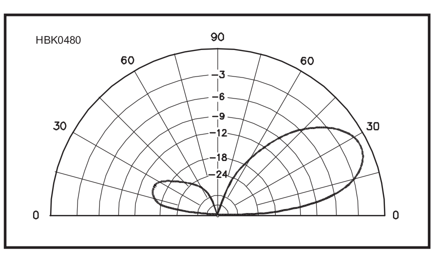

Fig 21.5 — Elevation pattern of a 3 element Yagi beam antenna placed ½ λ above perfect ground.

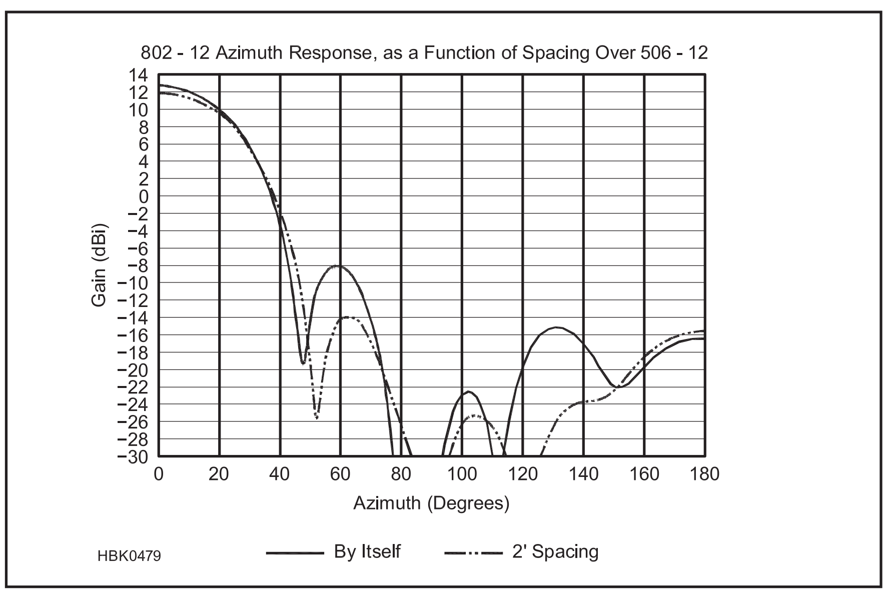

Fig 21.6 — Rectangular azimuthal pattern of an 8 element 2 meter Yagi beam antenna by itself and with another identical antenna stacked two feet above it. This example shows how a rectangular plot allows easier comparison of antenna patterns away from the main lobe.