arrow, and take light readings at a number of different positions.

After all the readings have been taken and recorded, we plot those values on a sheet of polar graph paper, like that shown in **Fig 10**. The values read on the meter are plotted at an angular position corresponding to that for which each meter reading was taken. Following this, we connect the plotted points with a smooth curve, also shown in Fig 10. When this is finished, we have completed a radiation pattern for the flashlight.

Antenna Pattern Measurements

Antenna radiation patterns can be constructed in a similar manner. Power is fed to the antenna under test, and a field-strength meter indicates the amount of signal. We might wish to rotate the antenna under test, rather than moving the measuring equipment to numerous positions about the antenna. Or we might make use of antenna reciprocity, since the pattern while receiving is the same as that while transmitting. A source antenna fed by a low-power transmitter illuminates the antenna under test, and the signal intercepted by the antenna under test is fed to a receiver and measuring equipment. Additional information on the mechanics of measuring antenna patterns is contained in Chapter 27, Antennas and Transmission-Line Measurements.

Some precautions must be taken to assure that the measurements are accurate and repeatable. In the case of the flashlight, let's assume that the separation between the light source and the light meter is 2 meters, about 6.5 feet. The wavelength of visible light is about one-half micron, where a micron is one-millionth of a meter.

For the flashlight, a separation of 2 meters between source and detector is $2.0/(0.5 \times 10^{-6}) = 4$ million λ, a very large number of wavelengths. Measurements of practical HF or even VHF antennas are made at much closer distances, in terms of wavelength. For example, at 3.5 MHz a full wavelength is 85.7 meters, or 281.0 feet. To duplicate the flashlight-to-light-meter spacing in wavelengths at 3.5 MHz, we would have to place the field-strength measuring instrument almost on the surface of the Moon, about a quarter-million miles away!

The Fields Around an Antenna

Why should we be concerned with the separation between the source antenna and the field-strength meter, which has its own receiving antenna? One important reason is that if you place a receiving antenna very close to an antenna whose pattern you wish to measure, mutual coupling between the two antennas may actually alter the pattern you are trying to measure.

This sort of mutual coupling can occur in the region very close to the antenna under test. This region is called the *reactive near-field* region. The term "reactive" refers to the fact that the mutual impedance between the transmitting and receiving antennas can be either capacitive
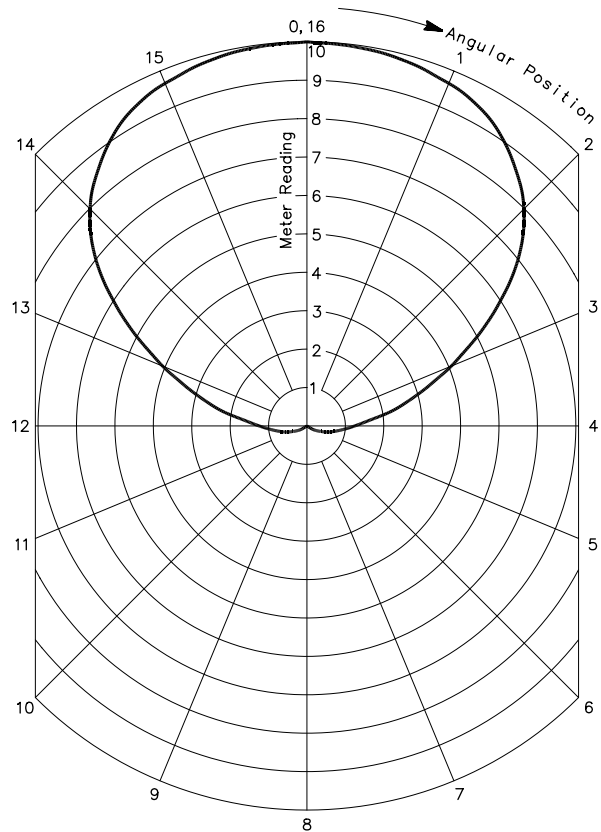

Fig 10—The radiation pattern of the flashlight in Fig 9. The measured values are plotted and connected with a smooth curve.

or inductive in nature. The reactive near field is sometimes called the "induction field," meaning that the magnetic field usually is predominant over the electric field in this region. The antenna acts as though it were a rather large, lumped-constant inductor or capacitor, storing energy in the reactive near field rather than propagating it into space.

For simple wire antennas, the reactive near field is considered to be within about a half wavelength from an antenna's radiating center. Later on, in the chapters dealing with Yagi and quad antennas, you will find that mutual coupling between elements can be put to good use to purposely shape the radiated pattern. For making pattern measurements, however, we do not want to be too close to the antenna being measured.

The strength of the reactive near field decreases in a complicated fashion as you increase the distance from the antenna. Beyond the reactive near field, the antenna's radiated field is divided into two other regions: the *radiating near field* and the *radiating far field.* Historically, the terms *Fresnel* and *Fraunhöfer* fields have been used for the radiating near and far fields, but these terms have been largely supplanted by the more descriptive terminology used here. Even inside the reactive near-field
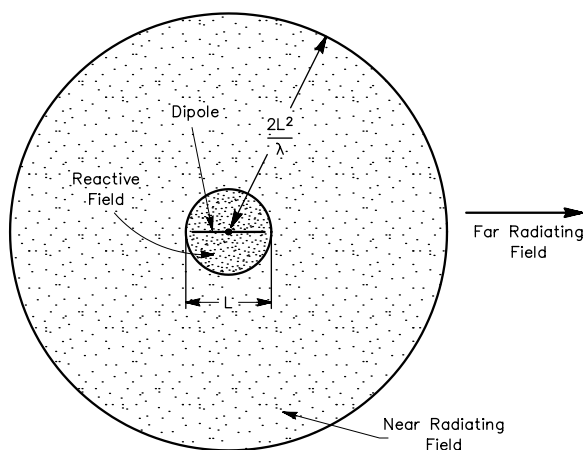
Fig 11—The fields around a radiating antenna. Very close to the antenna, the reactive field dominates. Within this area mutual impedances are observed between antenna and any other antennas used to measure response. Outside of the reactive field, the near radiating field dominates, up to a distance approximately equal to 2L²/λ, where L is the length of the largest dimension of the antenna. Beyond the near/far field boundary lies the far radiating field, where power density varies as the inverse square of radial distance.

region, both radiating and reactive fields coexist, although the reactive field predominates very close to the antenna.

Because the boundary between the fields is rather fuzzy, experts debate where one field begins and another leaves off, but the boundary between the radiating near and far fields is generally accepted as:

$$D \approx \frac{2L^2}{\lambda} \qquad \text{(Eq 4)}$$

where L is the largest dimension of the physical antenna, expressed in the same units of measurement as the wavelength λ. Remember, many specialized antennas do not follow the rule of thumb in Eq 4 exactly. **Fig 11** depicts the three fields in front of a simple wire antenna.

Throughout the rest of this book we will discuss mainly the radiating far-fields, those forming the traveling electromagnetic waves. Far-field radiation is distinguished by the fact that the intensity is inversely proportional to the distance, and that the electric and magnetic components, although perpendicular to each other in the wave front, are in time phase. The total energy is equally divided between the electric and magnetic fields. Beyond several wavelengths from the antenna, these are the only fields we need to consider. For accurate measurement of radiation patterns, we must place our measuring instrumentation at least several wavelengths away from the antenna under test.

Pattern Planes

Patterns obtained above represent the antenna radiation in just one plane. In the example of the flashlight, the plane of measurement was at one height above the floor. Actually, the pattern for any antenna is three dimensional, and therefore cannot be represented in a single-plane drawing. The *solid* radiation pattern of an antenna in free space would be found by measuring the field strength at every point on the surface of an imaginary sphere having the antenna at its center. The information so obtained would then be used to construct a solid figure, where the distance from a fixed point (representing the antenna) to the surface of the figure is proportional to the field strength from the antenna in any given direction. **Fig 12B** shows a three-dimensional wire-grid representation of the radiation pattern of a half-wave dipole.

For amateur work, *relative* values of field strength (rather than absolute) are quite adequate in pattern plotting. In other words, it is not necessary to know how many microvolts per meter a particular antenna will produce at a distance of 1 mile when excited with a specified power level. (This is the kind of specifications that AM broadcast stations must meet to certify their antenna systems to the FCC.)

For whatever data is collected (or calculated from theoretical equations), it is common to normalize the plotted values so the field strength in the direction of maximum radiation coincides with the outer edge of the chart. On a given system of polar coordinate scales, the *shape* of the pattern is not altered by proper normalization, only its size.

E and H-Plane Patterns

The solid 3-D pattern of an antenna in free space cannot adequately be shown with field-strength data on a flat sheet of paper. Cartographers making maps of a round Earth on flat pieces of paper face much the same kind of problem. As we discussed above, cross-sectional or plane diagrams are very useful for this purpose. Two such diagrams, one in the plane containing the straight wire of a dipole and one in the plane perpendicular to the wire, can convey a great deal of information. The pattern in the plane containing the axis of the antenna is called the *E-plane pattern*, and the one in the plane perpendicular to the axis is called the *H-plane pattern*. These designations are used because they represent the planes in which the electric (symbol E), and the magnetic (symbol H) lines of force lie, respectively.

The E lines represent the *polarization* of the antenna. Polarization will be covered in more detail later in this chapter. As an example, the electromagnetic field pictured in Fig 1 of Chapter 23, Radio Wave Propagation, is the field that would be radiated from a vertically polarized antenna; that is, an antenna in which the conductor is mounted perpendicular to the earth.

When a radiation pattern is shown for an antenna mounted over ground rather than in free space, we automatically gain two frames of reference—an *azimuth angle* and an *elevation angle*. The azimuth angle is usually ref-