In band A, the long-wave band, transmission by ground wave is stable and reliable for distances up to about 1,500 km, as shown in Figs. 14.5 and 14.6. For very long distances the wave propagates between the two concentric spheres formed by the earth and the lower surface of the ionosphere as described on p.449 and in this case the field strength varies with the distance d as $(1/d)\varepsilon^{-kd\lambda^{-1/2}}$ —the Austin-Cohen formula—in which the constant k has the value over water of $4{\cdot}7 \times 10^{-5}$. This property is used in the provision of a limited number of high-grade transoceanic telegraph channels, which are free from service interruptions except during severe magnetic storms.

Band B covers the range of broadcast frequencies, used mainly to provide a high-quality service within a limited area. A station of moderate power has a service radius of the order of 100 km, the field being provided by the ground wave in accordance with Figs. 14.5 and 14.6. Beyond this comes a zone in which fading occurs, and these stations are not normally receivable in daylight beyond a distance of perhaps 250 km over land or 1,000 km over water. In this frequency range the ionospheric wave is strongly absorbed in the ionosphere during the daytime, as discussed in Appendix 14.4. During darkness, however, when ionization is low, the ionospheric wave is only slightly attenuated, and reception by this means is possible up to thousands of kilometres. Such reception is generally unreliable and is particularly subject to selective fading.

The short-wave region covered by band C is that used for the great majority of long-distance communications. The ionospheric wave is used, and frequencies are selected for each particular requirement by means of the m.u.f. predictions and charts discussed earlier in the chapter. The region of the band between 1·5 and 3 Mc/s is erratic and unsatisfactory for distant communication because of absorption effects in the neighbourhood of the gyro-frequency, as discussed in Appendix 14.4. The region between 3 and 6 Mc/s is in use mainly for communications within the limits of a continent, while the remaining part between 6 and 30 Mc/s is used, by reason of the longer skip-distances involved, for long-distance intercontinental services.

Within band C short distances inside the skip distance are covered by the ground wave, with field strengths given by Figs. 14.5 and 14.6. The use is mainly for mobile land communications and ship-to-shore services.

For frequencies above 30 Mc/s it has been shown that the ionospheric wave is not regularly returned, and the surface wave is rapidly attenuated. Thus in range D communication is by the space wave within or somewhat beyond the optical horizon, the variation of field with distance being of the form shown in Fig. 14.28. There is sufficient diffraction round obstacles at these frequencies to allow short-range reception within built-up areas. For frequencies up to about 60 Mc/s reception of signals of limited bandwidth by ionospheric scatter propagation is possible up to distances of the order of 2,000 km.

Range E is useful mainly for line-of-sight distances, usually between fixed stations. Here also the field strength is calculated from the space wave, but wide variations may occur under sub-refracting and super-refracting conditions. From about 500 Mc/s upwards tropospheric scatter provides a limited degree of reception at ranges up to about 300–600 km.

APPENDIX 14.1

Surface-Wave Propagation

The mathematical analysis of wave propagation over an imperfectly-conducting earth gives results in a form where long calculations are needed. These have been reduced to a standard procedure, which the following outline illustrates in the simple case where the distance between transmitter and receiver is so small that the earth's curvature can be neglected.

For a transmitter and receiver placed at ground level the constant A in equation (14.5) is found through two auxiliary parameters, p (the *numerical distance*) and b, defined by the relations:

$$\left.\begin{aligned} b &= \tan^{-1}\left(\frac{\epsilon_r + 1}{x}\right) \\ p &= \frac{\pi}{x}\frac{d}{\lambda}\cos b \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (14.26)$$

where $x = \sigma/(\omega\kappa_0) = 18 \times 10^9\sigma/f$, λ is the wavelength, ϵ_r and σ are the relative permittivity and conductivity of the earth and ϵ_0 is the permittivity of free space. The value of A is then determined from the curves of Fig. 14.41.

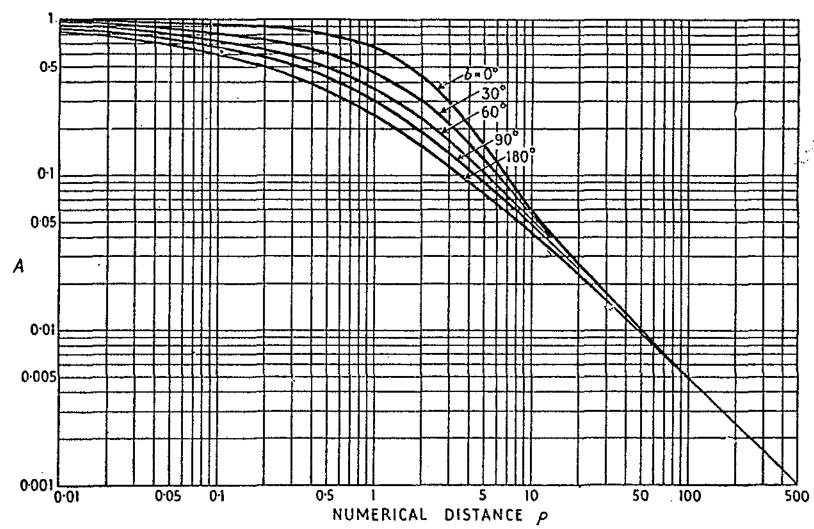

Fig. 14.41. Curves determining the factor *A* in equation (14.5).

The above expressions are for vertically-polarized radiation. The same curves can be used for horizontal polarization if b and p are defined by :

$$\left.\begin{aligned} b' &= \tan^{-1}\left(\frac{\kappa_r - 1}{x}\right) \\ b &= 180^\circ - b' \\ p &= \frac{\pi d}{\lambda}\frac{x}{\cos b'} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (14.27)$$

The distance up to which the assumption of a plane earth holds good is about $d = 10^4/f^{1/3}$ km.

Example: Let us find the field at a distance of 60 km from a transmitter of frequency 2 Mc/s radiating 200 W from a vertical half-wave aerial over earth with $\kappa_r = 12$ and $\sigma = 5 \times 10^{-3}$ mho/m.

From equations (14.26):

$$b = \tan^{-1}(13/45) = 16° \, 7'$$

$$p = \frac{\pi}{45}\,\frac{60{,}000}{150}\cos 16° \, 7' = 26{\cdot}8$$

Hence, from Fig. 14.41,

$$A = 0{\cdot}02$$

Substitution in equation (14.5) gives for the standard field of a 1-kW transmitter:

$$E = \frac{300 \times 0{\cdot}02}{60{,}000} \text{ volts per metre}$$

As the power gain of a half-wave aerial over a short dipole is 1·09, and the radiated power is 200 W, the required value of the field is:

$$\frac{300 \times 0{\cdot}02}{60{,}000}\left(1{\cdot}09 \times \frac{200}{1{,}000}\right)^{1/2} \times 10^6 = 47 \text{ microvolts per metre}$$

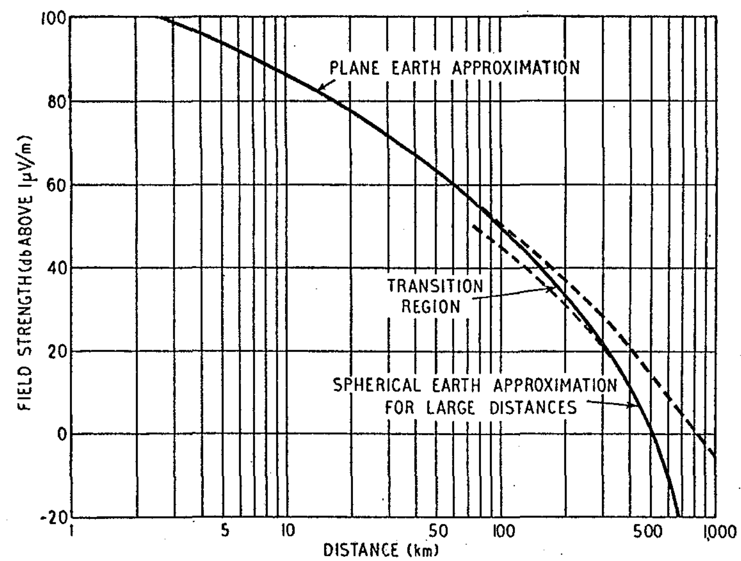

Fig. 14.42. Approximations to surface wave over earth with $\kappa_r = 15$, $\sigma = 10^{-2}$ mho/m. (1 kW transmitted power at 1 Mc/s.)

From Fig. 14.41 it is evident that, where the distance is large ($p > 10$), the factor A is inversely proportional to the numerical distance p, which itself is proportional to d; hence under these conditions the field strength is inversely proportional to the square of the distance.

When the distance exceeds that for which the assumption of a plane earth suffices the procedure becomes much more complex, and several other auxiliary curves and parameters are necessary. These will not be dealt with here, but Fig. 14.42 will illustrate the nature of the difference. It can be seen that the approximations for plane earth and spherical earth do not overlap, and an interpolated curve has to be drawn to join them in the transition region.

APPENDIX 14.2

Height–Gain Factors

When the transmitting and receiving dipoles are elevated at heights h_1 and h_2 above the earth's surface the received field is given by equation (14.5) multiplied by the height–gain factors $f(h_1)$ and $f(h_2)$, so that the field in this case becomes:

$$E = \frac{300}{d} A f(h_1) f(h_2) \qquad (14.28)$$

It is convenient to express aerial heights in terms of a *numerical height*, q, defined by the relations:

$$q = \frac{2\pi h}{\lambda}\left(\frac{\cos b}{x}\right)^{1/2}, \quad \text{for vertical polarization} \qquad (14.29)$$

$$q = \frac{2\pi h}{\lambda}\left(\frac{x}{\cos b'}\right)^{1/2}, \quad \text{for horizontal polarization} \qquad (14.30)$$

where x, b and b' have the meanings used in Appendix 14.1. The height–gain factor $f(h)$ is now found in terms of the calculated value of q by means of the curves of Fig. 14.43. These curves are not of universal application, and indeed

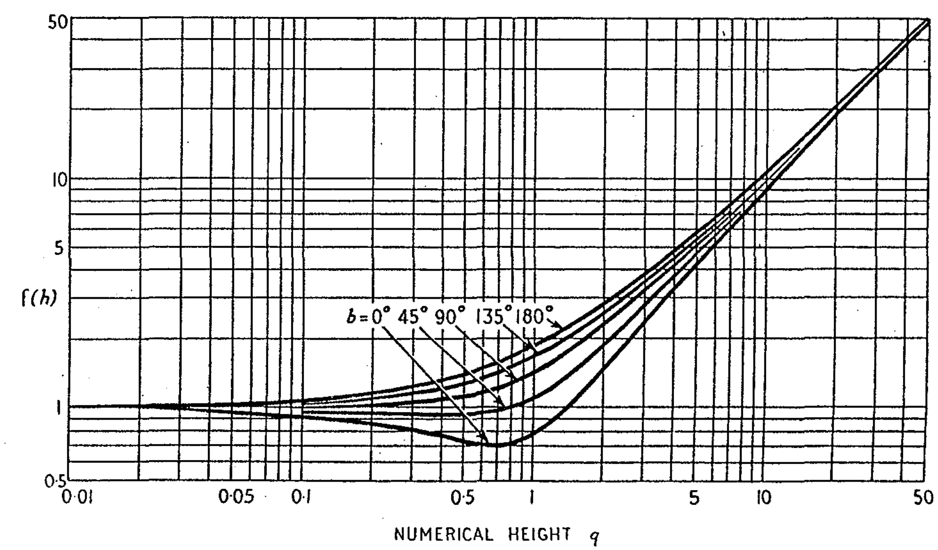

Fig. 14.43. Curves for calculation of height–gain factor $f(h)$.