

## RECOMMENDATION ITU-R P.527-3\*

**ELECTRICAL CHARACTERISTICS OF THE SURFACE OF THE EARTH**

(1978-1982-1990-1992)

The ITU Radiocommunication Assembly,

*considering*

- a) that ground-wave propagation is mainly governed by the electrical characteristics of the ground, and the extent to which lower strata influence the effective values of the electrical characteristics of the Earth depends on the depth of penetration of the radio energy;
- b) that the electrical characteristics may be expressed by three parameters: the permeability  $\mu$ , the permittivity  $\epsilon$  and the conductivity  $\sigma$ ;
- c) that the permeability of the ground,  $\mu$ , can normally be regarded as equal to the permeability in a vacuum and that values of the relative permittivity and the conductivity are needed as a function of frequency for various types of surface;
- d) that information on the variation of the penetration depth with frequency is required,

*recommends*

that the information in Annex 1 be used in the calculation of ground-wave field strength at the frequencies concerned and under the conditions stated.

## ANNEX 1

**1. Introduction**

This Annex gives typical values of electrical characteristics for different types of surface of the Earth and discusses the physical factors upon which these characteristics depend.

**2. Permittivity and conductivity values**

In Fig. 1 typical values of conductivity and permittivity for different types of ground, as a function of frequency, are given. These values, frequently referred to as intrinsic values, refer to homogeneous sub-surface soil structures.

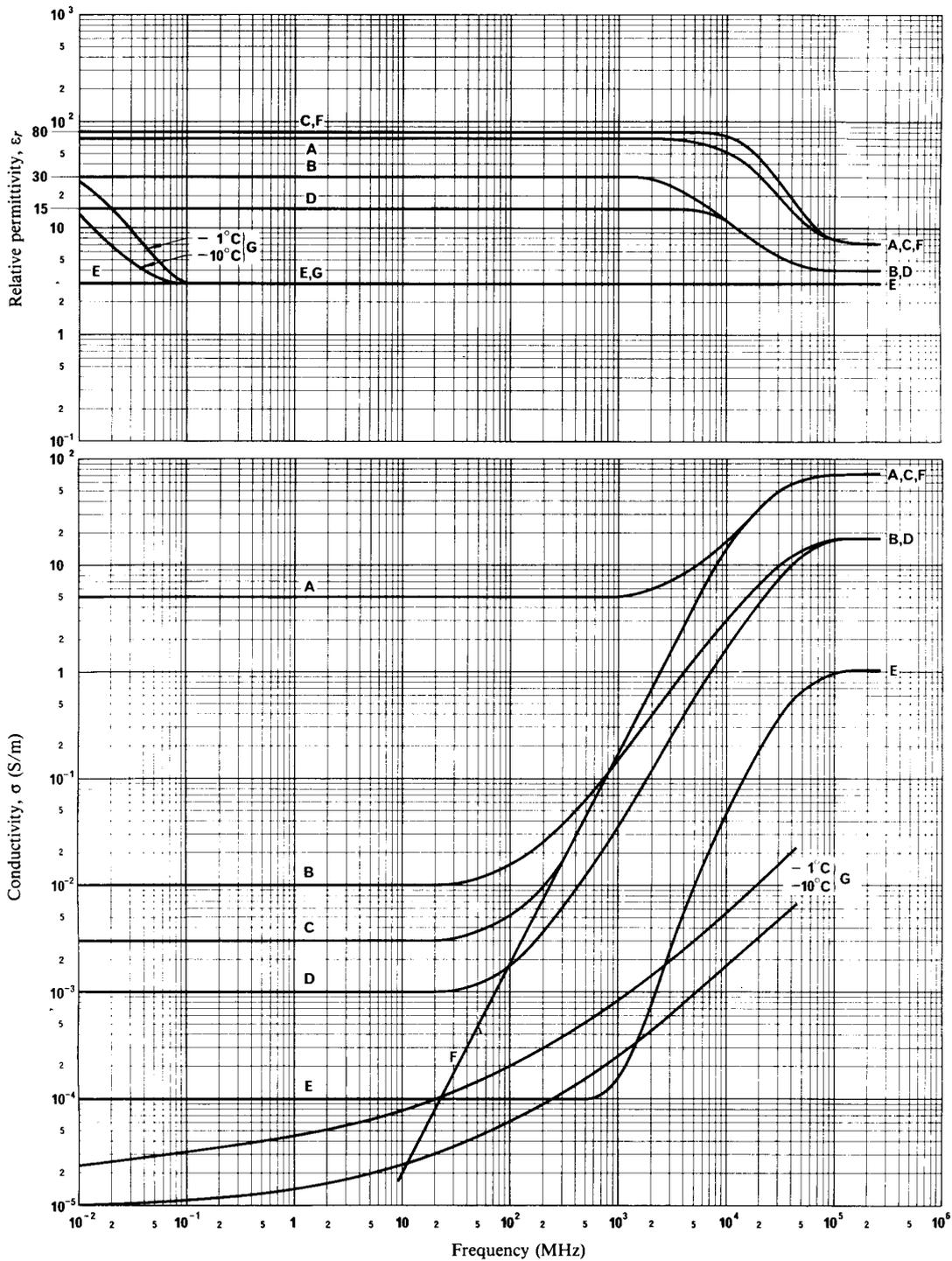
However, the sub-surface structure is rarely homogeneous, but rather consists of two or more layers of different thickness and different conductivities and permittivities. This fact must be taken into account and this could be done by introducing the concept of effective parameters. This concept of effective parameters allows the use of the homogeneous smooth earth ground-wave propagation curves of Recommendation ITU-R P.368, the inhomogeneous sub-surface soil being replaced by an equivalent homogeneous structure whose parameters are the effective conductivity and effective permittivity. These parameters can be determined if the values of the parameters of each layer are known.

The values of relative permittivity (dielectric constant) and conductivity in Fig. 1 for different types of ground indicate the approximate range of values which may be met under different conditions, but in extreme cases values outside this range may occur. In very wet fertile areas higher values of conductivity will be found, while in mountainous and arctic regions the conductivity at frequencies below 100 MHz may be as low as  $10^{-5}$  S/m. In cases of snow-covered ground, lower values of permittivity than shown in curve E of Fig. 1 may be encountered. The water in lakes and rivers has a conductivity that increases with the concentration of impurities.

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\* Radiocommunication Study Group 3 made editorial amendments to this Recommendation in 2000 in accordance with Resolution ITU-R 44.

FIGURE 1  
Relative permittivity,  $\epsilon_r$ , and conductivity,  $\sigma$ , as a function of frequency



- A: sea water (average salinity), 20° C
- B: wet ground
- C: fresh water, 20° C
- D: medium dry ground
- E: very dry ground
- F: pure water, 20° C
- G: ice (fresh water)

### 3. Penetration and spread of waves

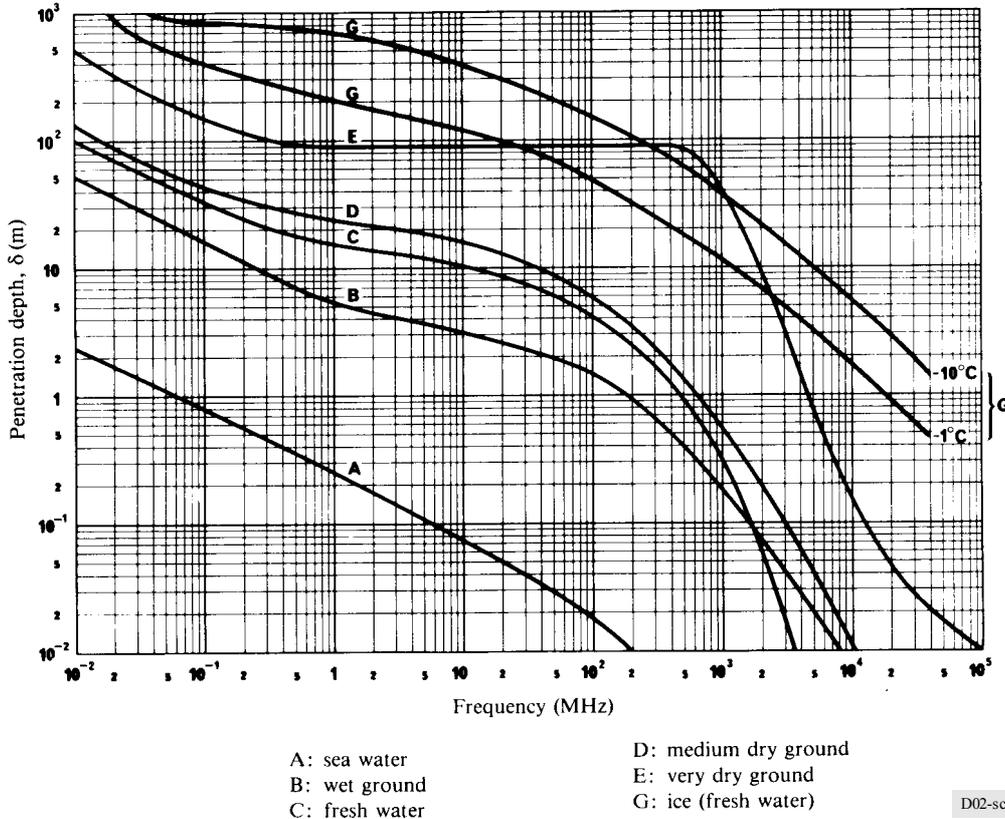
3.1 The extent to which the lower strata influence the effective electrical characteristics depends upon the depth of penetration of the radio energy,  $\delta$ , which is defined as that depth at which the wave has been attenuated to  $1/e$  (or 37%) of its value at the surface. The penetration depth as a function of frequency is shown in Fig. 2 for different types of ground and water.

3.2 If the penetration depth,  $\delta$ , is less than the thickness of the layer, the underlying strata have little influence. If  $\delta$  is much greater than the top layer thickness, propagation is determined by the electrical characteristics of the lower strata.

At low frequencies, except for sea water, strata down to a depth of 100 m or more must be taken into account as shown in Fig. 2. This is of particular importance when the upper strata are of lower conductivity and the energy can therefore penetrate more readily to lower levels. Such cases, for example, occur for ice-covered lakes and ocean areas.

3.3 The radio energy received at a point does not travel solely by the direct path from the transmitter, but also by a large number of indirect paths distributed on either side of it. It is necessary, therefore, to consider electrical characteristics not only along the path itself, but also over the area covered by the lateral spread of the wave paths. No definite limits can be put on this area, but it has been suggested that it is effectively the first Fresnel half-wave zone.

FIGURE 2  
Penetration depth  $\delta$  as a function of frequency



## 4. Sea

### 4.1 Sea water

The electrical conductivity of sea water is a function of the salt content (salinity) and temperature. At frequencies below 1 GHz its value is given by the expression:

$$\sigma = 0.18 C^{0.93} [1 + 0.02 (T - 20)] \quad \text{S/m} \quad (1)$$

where  $C$  is the salt content in parts per thousand and  $T$  is the temperature in degrees Celsius.

At 20 °C a value of 5 S/m is used as a world-wide average. In some areas of the Baltic Sea values of less than 1 S/m have been observed. In the Red Sea the conductivity may exceed 6 S/m.

The permittivity of sea water is also a function of salinity and temperature. A value of 80 has often been used for the relative permittivity of sea water at 20 °C although the actual low frequency value is about 70. However, at frequencies below about 100 MHz,  $\epsilon_r$  is much less than  $60 \lambda \sigma$ , and either value may be used to calculate ground-wave propagation factors over the sea with no measurable differences in the results.

### 4.2 Sea ice

Sea ice is a complex substance whose electrical characteristics vary over a large range as a function of the temperature and age of the ice. The range of values of these electrical characteristics and penetration depths is shown in Fig. 3 for frequencies between 0.1 and 30 MHz. Above about 30 MHz the electrical characteristics of sea ice asymptotically approach those of fresh water ice.

## 5. Factors determining the effective electrical characteristics

The effective values of the constants of the ground are determined, not only by the nature of the soil, but also by its moisture content and temperature, by the frequency, by the general geological structure of the ground and by the effective depth of penetration and lateral spread of the waves.

### 5.1 Nature of the soil

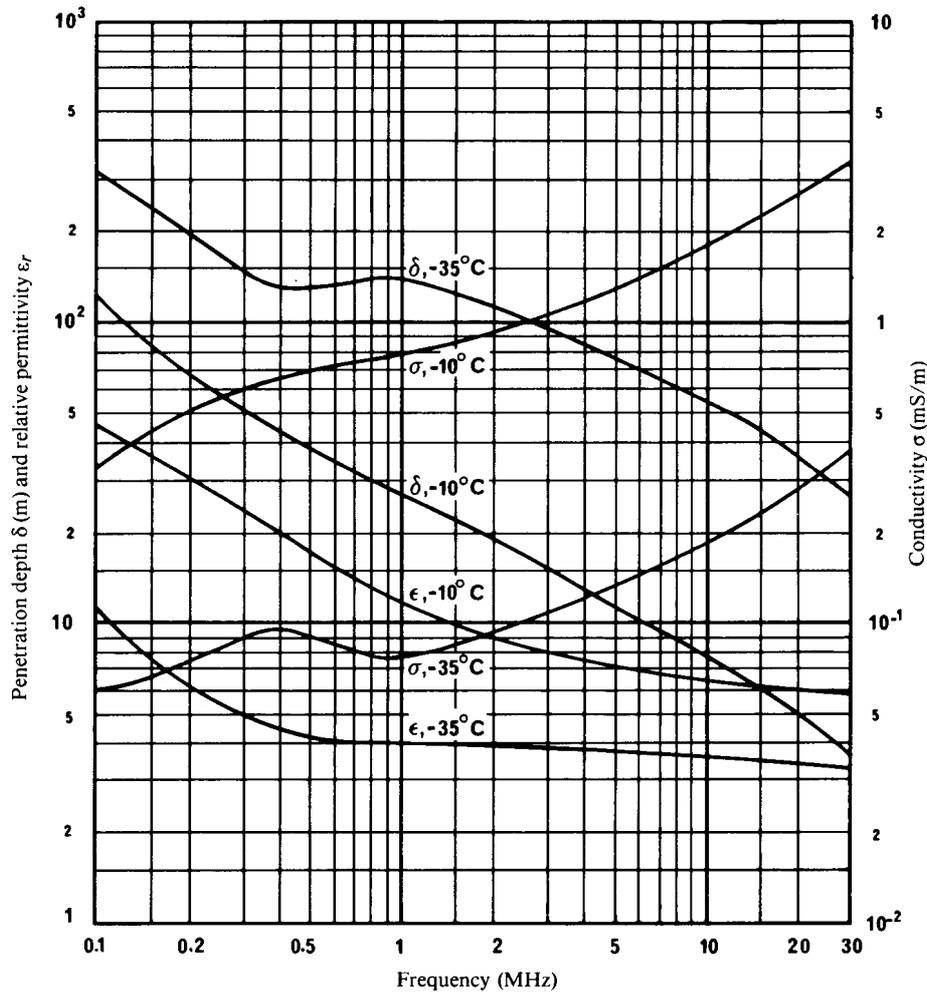
Although it has been established by numerous measurements that the values of the electrical characteristics vary with the nature of the soil, it seems probable that this variation may be due not so much to the chemical composition of the soil as to its ability to absorb and retain moisture. It has been shown that loam, which normally has a conductivity of the order of  $10^{-2}$  S/m can, when dried, have a conductivity as low as  $10^{-4}$  S/m, which is of the same order as that of granite.

### 5.2 Moisture content

The moisture content of the ground is probably the major factor determining its electrical constants. Laboratory measurements have shown that, as the moisture content is increased from a low value, the values increase, rapidly reaching their maximum as the moisture content approaches the values normally found in such soils on site. At depths of one metre or more, the wetness of the soil at a particular site seems to be substantially constant all the year round and, although it may increase during rain, the drainage of the soil and surface evaporation soon reduces it to its normal value after the rain has stopped.

The moisture content of a particular soil may, however, vary considerably from one site to another, due to differences in the general geological formation which provide better drainage in one case than another.

FIGURE 3  
 Range of values of the penetration depth  $\delta$ , relative permittivity  $\epsilon_r$ ,  
 and conductivity  $\sigma$  of sea ice



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### 5.3 Temperature

Laboratory measurements of the electrical characteristics of soil have shown that, at low frequencies, the temperature coefficient of conductivity is of the order of 3% per degree Celsius, while that of the permittivity is negligible. At freezing point, there is generally a large decrease in both permittivity and conductivity. Although these changes are appreciable, it must be borne in mind that the range of temperature variation during the year decreases rapidly with depth, so that temperature effects are likely to be important only at high frequencies where the penetration of the waves is small, or when the ground is frozen to a considerable depth.

### 5.4 Seasonal variation

The effect of seasonal variation on ground-wave propagation loss depends upon the ratio of the depth of the soil exhibiting seasonal changes to the penetration depth. Any such seasonal effects will be frequency dependent.

### 5.5 Energy absorption by surface objects

Although surface objects have no direct influence on the electrical characteristics of the ground itself, they can contribute appreciably to the attenuation of ground waves, and the effects of such energy losses may be taken into account by using appropriately modified values of the electrical characteristics in propagation calculations.