# Propagation of Radio Waves

B. CHATTERJEE, Ph.D.

*Department of Electronics and Electrical Communication Engineering, Indian Institute of Technology, Kharagpur*



ASIA PUBLISHING HOUSE

BOMBAY • CALCUTTA • NEW DELHI • MADRAS
LUCKNOW • LONDON • NEW YORK

PRINTED IN INDIA
BY LOYAL ART PRESS PRIVATE LTD., 164, DHARAMTALA STREET, CALCUTTA-13 AND PUBLISHED BY P. S. JAYASINGHE, ASIA PUBLISHING HOUSE, BOMBAY.

ASIA MONOGRAPHS 3

# PROPAGATION OF RADIO WAVES

OTHER ASIA MONOGRAPHS

*Radiology of Tuberculosis of Bones and Joints with Special Reference to Tropical Countries* by P. K. Ganguli

*Transient Analysis of Single Phase Motors* by P. Venkatarao

*The Lead Accumulator—A Review of the Latest Developments* by I. A. Aguf and M. A. Dasoyan (translated by S. Sathyanarayana)

*Pollen Morphology of Western Himalayan Plants* by P. K. K. Nair

*National Accounts and the Input-Output Accounts of India* by D. V. Ramana

*Bundelkhand Granites and Associated Rocks* by M. N. Saxena

*The Many-Electron Problems* by K. S. Viswanathan

*Pulse Circuits* by B. Chatterjee

# *Preface*

This small book is rather a concise presentation of the lectures delivered to post-graduate students in Electrical Communication Engineering of this Institute. With the starting of post-graduate courses in different engineering institutes in India, the need of such a treatise was urgently felt by students, and the author's humble attempt will be considered fruitful if it can somewhat satisfy their need.

The post-graduate students should have more informations in the subject than available in the standard under-graduate text books like "Electro-magnetic Waves & Radiating Systems" by Prof. E. C. Jordan. On the other hand, the authoritative treatises like "The Upper Atmosphere" by Prof. S. K. Mitra are too costly and too elaborate for a student for Master's degree. Also, being specialised books, they usually deal in great details only about a single aspect of radio wave propagation, and they are actually meant for research workers and specialists in the field.

In this book, attempts have been made to discuss different aspects of propagation in a clear and concise manner, so as to be useful for students.

For people interested in further studies and research, references have been given at the end of each chapter. It is hoped that the book will be useful for under-graduate students as well, who may read the same, omitting some of the mathematical details.

B. CHATTERJEE

# *Contents*

CHAPTER ONE

# *Basic Considerations in Radio Wave Propagation*

## 1·1 *Introduction*

To have an efficient radio linkage between two points we should have a knowledge of the propagation characteristics and the mode or modes of propagation of waves concerned as well as the structure and properties of the propagating media. Broadly speaking, radio waves mean that band of electromagnetic energy which covers the frequency range from a few *Kc/s* (Very Low Frequencies or Very Long Waves) to a few *KMc/s* (Super High Frequencies or Microwaves). Propagation modes and propagation characteristics vary considerably for different frequencies and design procedures for efficient communication must be changed accordingly.

As practical radio communication (for speech and music) takes place in the frequency band of 300 *Kc/s* to about 30 *Mc/s*, propagation of these waves will be considered in greater detail. In the next section, we shall consider briefly the propagation characteristics in different frequency ranges.

Propagation of radio waves from the transmitting to the receiving antenna may take place in one or more of the following ways:

(*i*) *Ground wave* or *surface wave*[1] propagation, in which the wave energy glides over the earth's surface, (as shown in path 1 of Fig. 1.1), more or less in the same manner as a guided wire wave travels on the wire. This mode of propagation is useful only for lower radio frequencies, viz. medium waves, long waves and very long waves. As earth's attenuation increases with frequency, this mode of propagation is of no use for short waves or higher frequency signals.

[1] Sometimes the term 'ground wave' is used to mean both 'surface wave' and 'space wave' together.

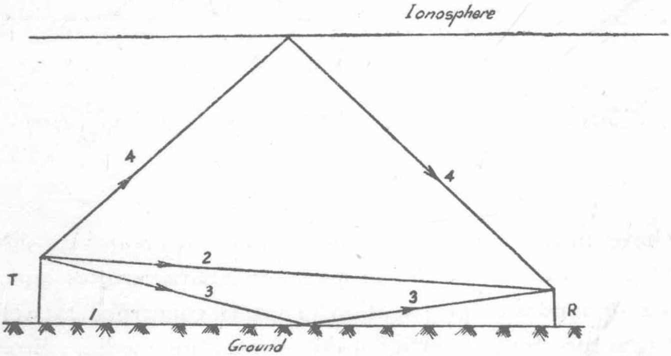


FIG. 1.1

A schematic diagram ( not to scale ) depicting different possible propagation paths from transmitter to receiver. The path 1 is the surface wave path and paths 2 and 3 are the space wave paths. Path 2 is the direct wave path and path 3 is for the ground-reflected wave. Path 4 shows the sky wave path.

(*ii*) *Space wave* propagation, in which the wave energy travels from transmitting to receiving antenna either straight through air (or space) or being reflected at ground, as shown by paths 2 and 3 respectively in Fig. 1.1. This mode of propagation is quite analogous to that of light and is the primary mode for propagation of higher radio frequencies like V.H.F., U.H.F. and microwave. Although, space wave propagation also takes place for lower frequencies but surface wave and sky wave modes give the major contributions at these frequencies.

(*iii*) *Sky wave* propagation, in which the wave is reflected back to earth from ionized regions in the upper atmosphere (ionosphere) as shown in path 4 of Fig. 1.1. Such a propagation takes place mainly for medium waves and short waves and is the only mode for establishing long-distance radio linkage round the globe.

Besides these, propagation is also possible by forward scatter from ionospheric or tropospheric irregularities. These different modes of propagation will be discussed in more details in the subsequent chapters.

## 1·2 *Propagation characteristics of radio waves in different frequency ranges*

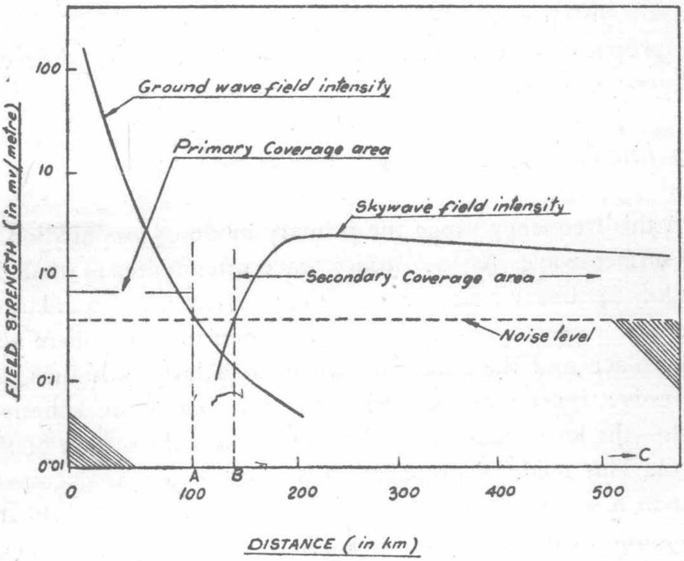


FIG. 1.2

Variation of field strength with distance for different modes of propagation. Primary coverage (due to ground wave) is up to a distance A, while the secondary coverage (due to sky wave) is from B to C. The region AB is the skip-region where no signal is received.

In order to have good reception, field strength of the desired signal should be above the noise level at the receiving site in the frequency range of interest. Unless it is so, no increase in receiver sensitivity will be able to improve the quality of reception. The noise level differs from place to place and is also dependent on the frequency range. Usually, urban areas are more noisy than rural areas. Also, noise is less prominent for the higher frequency ranges. For a given transmitter, the distance up to which the ground wave, (i.e. space and surface waves together) field strength is above the noise level is known as the primary coverage area. This is shown as distance *OA* in Fig. 1.2. Similarly, the region over which the field strength of sky wave is above the noise level, is known as the secondary coverage area. Region *BC* in Fig. 1.2 shows the secondary coverage area for sky wave propagation. Region *AB* over which both the field strengths are below noise level is called the skip distance. In the next few paragraphs, we shall discuss the propagation characteristic of radio waves at different frequency ranges.

*Very Low Frequency* (a few *Kc/s* to 100 *Kc./*s) :

In this frequency range the primary mode of propagation is the surface wave. As the surface wave attenuation is small in this low frequency range, the surface wave can travel to a larger distance. Reflection from the lower edge of the ionosphere also takes place and the wave can travel to a large distance by successive reflections between the two conducting spherical shells—the lower edge of the ionosphere and the surface of the earth. This mode of propagation is more or less analogous to that in a wave guide and can be treated accordingly. As the attenuation caused by the reflection at the ionosphere depend on its ionization density, the received field strength shows some diurnal, seasonal and sun-spot cycle variation. But this variation becomes smaller in the lower frequency end; and near 10 *Kc/s*, the sky-wave field intensity remains practically independent of time of the day or season of the year. The gre atest difficulty of having radio communication in this frequency range is its prohibitively large antenna size and the unwieldy antenna height necessary.

*Low-Frequency* (100 *Kc/s* to 500 *Kc/s*) :

Propagation characteristics of these waves resemble those of the lower frequency range with some differences. As the frequency is higher, there is increased ground wave attenuation and long distance communication becomes entirely dependent on sky waves. Also, attenuation at the lower edge of the ionosphere increases and the sky wave field intensity shows appreciable variation with hour of the day and season of the year.

In general, long distance communication is not possible in the day time, particularly in summer.

*Medium waves or Broadcast frequencies* (500 *Kc/s* to 2 *Mc/s*) :

The surface wave attenuation is further increased due to increased frequency and the ground wave (primary) coverage area does not exceed 100 to 150 *Km*. Sky wave field intensity is very low during day-light hours, as the wave suffers high attenuation in the *D*-region of the ionosphere. Thus, reception is limited to the primary coverage area during day time and these frequencies are almost solely used for local broadcasting. At night, when the *D*-region is absent, it is possible to have appreciable field intensity for the sky wave and hence long distance communication. The region *PQ* (in Fig. 1.3), over which the sky wave field intensity is comparable with that of

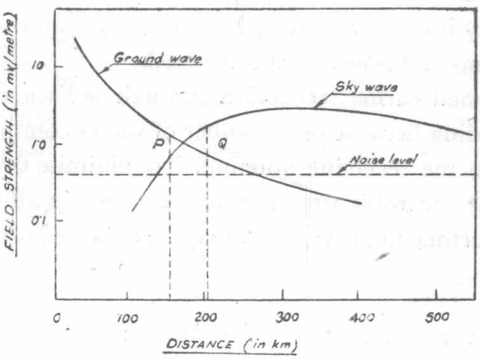


FIG. 1.3

Variation of field strength with distance for the case where the primary and secondary coverage areas overlap over certain regions. The region PQ over which the ground wave and sky wave field intensities are of almost equal magnitude is the region of 'selective fading'.

the ground wave (at night), increased distortion occurs as the carrier and the individual side-bands fade in and out more or less independently. This type of fading ( due to interaction between ground wave and sky wave) is known as selective fading. At distances where only the sky wave is prominent, there is also some fading and distortion as a result of two or more sky waves following different paths in travelling to the receiver. But this is much less severe than the previous case.

*Short Waves or High Frequency* (2 *Mc/s* to 30 *Mc/s*) :

Due to high surface wave attenuation for short waves, the primary coverage area is reduced to a very small distance. Such frequencies are usually used for long distance communication or broadcasting through sky wave transmission. In this frequency range the waves are reflected back from the *E* and *F* regions of the ionosphere and suffer very little attenuation in the reflection process. Some attenuation is suffered in the *D*-region during day times which is higher for lower frequencies. Thus, transmission is always carried out at the highest possible frequency—slightly below the Maximum Usuable Frequency value. If, however, the frequency is further increased, the wave penetrates the ionospheric regions and is never reflected back.

As mentioned earlier, reception through sky wave is always subject to fading because of a number of waves coming by different paths to the receiving antenna. To minimise fading, automatic volume control is almost exclusively used in all short wave receivers. Further improvements may be obtained with diversity reception.

*Very High Frequency* (30 *Mc/s* to 300 *Mc/s*) :

Space wave or line-of-sight propagation is practically the only mode of propagation in this frequency range and laws of geometrical optics can be conveniently applied. The actual service area is slightly larger than the line-of-sight distance due to refraction in the earth's atmosphere. Propagation to a long distance through ionospheric scatter (usually in the *E*-region) is quite often possible in the lower frequency end of the V.H.F. band.

*Ultra High Frequency and Microwaves* (above 300 *Mc/s*) :

Only space wave propagation takes place as in the previous case. There is no possibility of ionospheric scatter, but tropospheric scatter sometimes takes place in the U.H.F. band. Depending on the condition of the lower atmosphere there may be formation of 'inversion layers' and propagation to a larger distance is possible at times. This is known as 'duct propagation'. Appreciable absorption takes place in the lower atmosphere for microwave frequencies of 30 *K Mc/s* and above (wavelength 1 cm or less).

## REFERENCES

1. F. E. Terman, *Electronic & Radio Engineering* (1955)
2. E. C. Jordon, *Electromagnetic Waves and Radiating Systems* (1953)

CHAPTER TWO

# *Surface Wave Propagation*

## 2·1 *Introduction*

The general problem of radiation from a linear vertical antenna above a plane earth of finite conductivity was solved first by Sommerfeld [1]. Then Norton [2,3] simplified the complex expression of Sommerfeld into a practical form. Their result shows that the field at a point consists of two types of expression—one is dependent only on the distance and the transmitted power but the other depends on the earth's constants as well. The former is known as the space wave and the latter the surface wave.

In general, the field intensity at a point is a combination of the space wave and surface wave as also of the sky wave, where ionospheric reflection takes place. As in this and the following chapter we are not going to consider the sky wave, let us neglect its effects (if any) for the time being. Of the space and surface waves, which one will be predominant at a given point depends on the transmitter frequency, ground characteristics and distance and height of the receiving point. The curvature of the earth gives an advantage to the surface wave for long distances where line-of-sight propagation of space wave is not possible (except very slightly due to diffraction). Surface waves can bend round the curvature of the earth just as an electromagnetic wave in a wire can bend round its curvature. At a given location, the space wave field intensity increases with antenna height.

The term 'surface wave', however, does not mean that most of the wave energy is confined to the earth's surface. Rather, a greater part of the energy is in the air above the surface. But, in this particular form of propagation, the wave is guided along the surface of the earth and around its bends and curvatures in a manner analogous to that in a guided wire wave.

## 2·2 *Surface wave field intensity due to an elemental vertical dipole antenna*

In the cylindrical co-ordinate (as used for a linear antenna), the axial component of the electric field for an elemental dipole antenna of length *dl* and carrying a current *I*, is given by [2,5]

$$E_z = j\,30\,\beta I dl \left[ \cos^2\psi \left( \frac{\epsilon^{-j\beta R_1}}{R_1} + \Gamma \frac{\epsilon^{-j\beta R_2}}{R_2} \right) + (1-\Gamma)\,(1-u^2-u^4\cos^2\psi).\,F.\,\frac{\epsilon^{-j\beta R_2}}{R_2} \right] \tag{2-1}$$

and the radial component,

$$E_\rho = -j\,30\,\beta\,I\,dl \left[ \text{Sin}\,\psi\,\cos\psi \left( \frac{\epsilon^{-j\beta R_1}}{R_1} + \Gamma \frac{\epsilon^{-j\beta R_2}}{R_2} \right) - \cos\psi\,(1-\Gamma)\,u\sqrt{1-u^2\cos^2\psi}\;\;F.\,\frac{\epsilon^{-j\beta R_2}}{R_2} \left( 1+\sin\frac{^2\psi}{2} \right) \right] \tag{2-2}$$

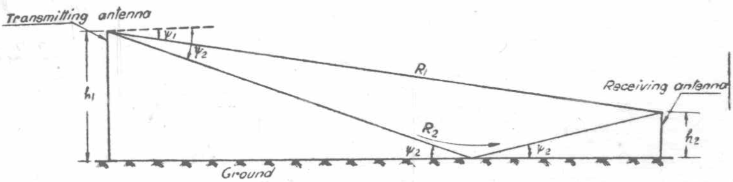


FIG. 2.1

Illustrates different parameters in ground wave propagation. $R_1$ is the direct wave path length and $R_2$ is the path length for the ground-reflected wave. $\psi_1$ and $\psi_2$ are the corresponding angles made with the horizon.

where, $\beta = 2\pi/\lambda$, $\lambda$ being the wavelength of the transmitted signal.

$R_1$ = distance between the receiving and transmitting points by the direct wave path (Fig. 2.1)

$R_2$ = distance between the receiving and transmitting points by the ground reflected wave path.

$\Gamma$ = Reflection coefficient of the ground.

$\psi$=Angle made with the horizon, with which the wave leaves the transmitting antenna.

$F$=Attenuation factor that depends on earth's constants.

$u^2 = \dfrac{1}{k+jx}$ where $k$=relative dielectric constant of earth.

and $x=\dfrac{\sigma}{\omega\, k}$, $\sigma$ being earth's conductivity and

$\omega$ being the angular frequency of radiation.

If the height of the receiving antenna is very small compared to its distance from the transmitting antenna, then $\psi_1 \simeq \psi_2 = \psi$. From Eqs. (2-1) and (2-2), it is seen that the first term within third bracket in each of the equation is independent of the ground attenuation factor $F$ and is known as the 'space wave'. Whereas the second term depends on $F$ and is the 'surface wave'.

Separating these two types of waves and adding the radial and axial components (vectorially) gives,

$$E_{space} = j\,30\,\beta I\,dl\,\cos\psi\left(\frac{\epsilon^{-i\beta R_1}}{R_1} + \Gamma\frac{\epsilon^{-i\beta R_2}}{R_2}\right) \tag{2-3}$$

$$E_{surface} = \frac{j30\,\beta I\,dl\,(1-\Gamma).F.\dfrac{\epsilon^{-j\beta R_2}}{R_2}}{\sqrt{1-2u^2+(\cos^2\psi)u^2\left(1+\text{Sin}^2\dfrac{\psi}{2}\right)}} \tag{2-4}$$

[ neglecting terms containing $u^4$ ]

In this chapter, we shall concentrate our attention on the surface wave[1] component [as given by Eq. (2-4)] only.

For transmission over large distances (much greater than $\lambda$), $R_1 \simeq R_2 = R$ and the expression for the surface wave field may be written as [from Eqs. (2-1) and (2-2)],

[1] As mentioned earlier, surface wave is sometimes referred as 'ground wave'.