

## CHAPTER I

INTRODUCTION AND SCOPE OF THE WORK1.1 Introduction

The radio link between two points has been considered in recent days as the most reliable means for communication, effective equally under normal condition as well as in time of emergency. But the transmitting and the receiving stations located on the earth's surface are subject to the threat of being destroyed by natural hazards like cyclones, tornadoes etc. or man-made hazards like bombing, particularly nuclear bombardment. It is desirable to protect the transmitting and receiving systems (including the antennas) from any such hazards. This gives the idea of submerging the entire transmitting and receiving systems, including the antennas, inside the earth. Thus, an excellent survival against all these hazards may be achieved.

The subsurface communication i.e. the communication between two submerged points employs the electromagnetic signals for communicating the information and in this respect it is similar to the normal above surface radio communication. But in the subsurface system, as the entire system will be located inside the earth, there will be an exponential attenuation of the electromagnetic energy in its path of propagation through the medium (earth) because of its inherent electrical conductivity. This type of attenuation is not present in

ordinary radio communication between above surface points. This exponential attenuation will normally make the communication impossible over a long range. In all possible modes of subsurface communication, as discussed later, the conductivity of the earth plays an important part. The radio communication between two distant subsurface points will be facilitated if the conductivity of that part of the earth, through which the propagation will take place, is very small.

It appears, therefore, that a knowledge of the electrical properties of the earth is needed before a successful subsurface communication system may be set up. Here the difficulty arises due to inhomogeneity of earth in its electrical properties in both horizontal and vertical directions<sup>1</sup>. The surface structure of the earth may be roughly sketched as follows. The top earth layer is sedimentary and may be covered with a thin film of soil<sup>2</sup> - the layer of sedimentary rock is extending a few kilometers<sup>3</sup>. Below this layer, there is a fractured granite layer which may be 2 or 3 kilometers in thickness and having at its bottom a layer of unfractured granite extending down to a depth of 10 or 20 kilometers<sup>2</sup>. The electrolytic solutions and the semiconducting minerals render the high electrical conductivity of the sedimentary rocks and the fractured granite layer. It has been assumed that the pressures at depths of several kilometers may reduce the pore spaces where water may exist and thus lower the electrical conductivity at these depths. At still greater depths, once again the conductivity is expected to have high value - this time may be because of increased

temperature in the deep basement rocks. This layer of high conductivity due to its high temperature had been described by Wheeler<sup>4</sup> as 'thermal ionosphere'.

Now, on the basis of the above mentioned picture of the electrical conductivity of earth with depth, there may be four possible modes for the propagation of the electromagnetic signals between two distant subsurface points. These are as follows :

### 1. The Direct Mode

In this mode the electromagnetic energy travels between the subsurface transmitting and receiving antennas in a direct path through earth. In such a situation the attenuation suffered by the electromagnetic signal increases exponentially with distance and the range is very much limited. Here the antennas (both transmitting and receiving) are located in the highly conducting upper layer. It thus becomes impossible to communicate over a long range (more than several skin depths) in this mode unless one uses a prohibitively large transmitted power.

### 2. The Up-Over and Down Mode<sup>2,5</sup>

A part of the energy radiated by the submerged radiator located in the upper conducting layer will also travel towards the interface between earth and air. This component of the primary wave on reaching the interface will set up secondary waves, due to the discontinuity

of the electrical constants of the two media involved. These secondary waves can then propagate as surface wave along the interface and continuously leak into the earth's surface. Some of this leak energy may be intercepted by the sub-surface receiving antenna. This mode of propagation is known as 'up-over and down' (U.O.D.) mode of propagation. Here, it is possible to have propagation over a reasonably large distance, provided the antenna depths are less than the skin depth in the medium.

### 3. The Interface-wave Mode<sup>2,5</sup>

In this mode antennas (both the transmitting and the receiving) are placed in the comparatively low conducting region below the upper highly conducting layer. The electromagnetic wave from the transmitting end, which will reach the receiving end, is comprised of a 'direct wave', a 'reflected wave' due to reflections from the upper conducting layer and an 'interface surface wave' travelling along the boundary between the layer of small conductivity and the layer of high conductivity. Communication over a range of several kilometers may be possible in this mode of propagation.

### 4. The Duct Mode<sup>2,4,5</sup>

This mode of propagation is based on the possibility of existence of a layer of basement rock of low conductivity (granite layer), trapped in between a layer

of highly conducting sedimentary rock on top and the highly conducting hot basement rock at its bottom. This is equivalent to a waveguide. The communication through this low loss subterranean waveguide at very low frequencies may be feasible over a considerable range provided the electrical conductivity of the dielectric of the waveguide is not more than  $10^{-6}$  mhos/m. Wheeler<sup>4</sup> estimated that with the conductivity around  $10^{-8}$  mhos/m and dielectric constant 6, transmission over a distance of 1500 km might be expected at the frequency of 1.5 KHz. But this granite region is at a depth of several kilometers and it is somewhat difficult to bury large antenna systems at that depth.

Out of the four modes of propagation just described, the radio signal in the first and third mode experiences large attenuation even if the frequency of operation is low (100 KHz)<sup>1</sup> giving a very limited range of propagation. In the waveguide mode, the attenuation will be smaller and atmospheric radio noise will be negligible at this large depth of the waveguide. But the major trouble is the antenna layout at this depth. Also, the electrical properties of earth at such large depths are not known quantitatively<sup>4</sup>. The boundaries of this waveguide may not be regular and well defined, these will then introduce some attenuation<sup>6</sup>. The only useful and practical propagation mode for subsurface communication is therefore the U.O.D. mode. The total attenuation suffered by the energy in its path of propagation in this mode will be the exponential attenuation in the paths from the transmitting antenna to the surface and from the surface to the receiving antenna together

with the attenuation suffered by the normal surface wave as it propagates along the interface.

The exponential part of the attenuation can be kept at a smaller value if the depths of the antennas are small compared to the skin depth of the medium. Again the basic need to have a subsurface system is the survival of the system from any kind of hazard and from that point of view the installations should be at somewhat larger depths. The problem arising out of these two conflicting situations can be solved by using low radio frequencies for transmission. Under this circumstance even if the depth of installation is not physically small, it may be smaller than the skin depth, hence that part of the attenuation which is exponential in nature can be kept at a low value. For a typical earth with conductivity of  $10^{-3}$  mhos/m and relative dielectric constant of 15, the skin depth at a frequency of 100 KHz is approximately 50 meters. Lowering the frequency will increase this value of skin depth further. Again, in the U.O.D mode of propagation, the electromagnetic energy travels along the interface as a surface wave after reaching the interface. The attenuation of the surface wave will be very large at high and very high frequencies<sup>7</sup>. Thus it appears that for a communication system submerged inside earth, the frequencies must not be high, a practical upper limit of one MHz had been suggested<sup>8</sup>.

At the low radio frequency of operation, the antenna construction poses one of the major problems associated with

the subsurface communication. The performances of the subsurface antennas are greatly influenced by the surrounding lossy medium and are found to differ in great extent from that of the antennas in free space. So studies on subsurface antennas are essential for any successful communication system. The above surface antennas at low radio frequencies are having very big structures. It is impractical to have similar type of structures inside the earth. Even if the structure is simple, its large dimension will involve a large cost of installation. Naturally, the problem boils down in having a subsurface antenna which will be reasonably efficient at the low frequencies of operation, yet not very large in size and easy to install. This requires that the frequency of operation should not be very low. Whereas, it has been pointed earlier that the frequency should be kept low for keeping the attenuation small. Considering these facts, the frequency range chosen for the present study is from 100 KHz to 300 KHz. In this range of frequency, the attenuation of the electromagnetic wave will be tolerable and the antenna size will not be unreasonably large. The present work is mainly concerned with the studies of subsurface antennas for radio communication in this frequency range.

## 1.2 Scope of the work

As the first phase of the present study, a review of different works regarding the antennas in a lossy medium had been made. A review paper<sup>B</sup> on this subject had also been published. The information content of this paper has been made

up-to-date as far as possible and is covered in Chapter II. The lossy medium may be either the conducting earth or sea water or an ionised medium such as plasma. Since the main interest of the present study centres around the antennas located inside the earth, the antennas in other lossy medium have not been given much stress. The effect of the surrounding lossy environment on the performance of the antennas has been discussed. Three types of antenna : (1) loop and (2) dipole in insulating radome and (3) an insulated long wire with end electrodes are compared among themselves on the basis of the system merit factors. A good cross-section of the large number of available literature on the electric dipole and the long wire antenna as well as on the magnetic dipole placed inside a lossy medium has been summarised in respect of their terminal and radiating properties. The experimental procedure as also the results of the experiments have been discussed. The experiments described were performed either in actual environment or they might have been conducted under controlled conditions in the laboratories as model experiments. The different considerations regarding the array of subsurface antennas are also mentioned. The antenna structures suggested for the subsurface propagation in the waveguide mode have been mentioned in brief.

In Chapter III, the terminal and the radiating properties of a long wire antenna insulated throughout its length from the surrounding medium are studied. A part of the contents of this chapter had already been published<sup>10</sup>. The antenna input

impedance and the current distribution along the antenna have been obtained using transmission line theory. The antenna with a layer of insulation on it and surrounded by the lossy medium is equivalently taken to be a co-axial line with its outershield being replaced by the surrounding medium. The axial propagation constant and the characteristic impedance of this equivalent line have also been evaluated. Since the radii of the antenna wire and its insulation are small compared to the wavelength, the symmetric TM wave will be the dominant wave. With this dominant TM wave on the line, the axial propagation constant can be determined by matching the radial impedances at the boundaries between the wire and the insulator and between the insulator and the medium. The characteristic impedance of the line is also obtained after evaluating the radial electric field inside the insulator. The proximity effect of the interface is considered by including a correction term introduced by Guy and Hasserjian<sup>11</sup>. In the next stage, the expressions for the far-zone electric and magnetic fields due to an electric dipole placed in the same location and in the same orientation as the long wire antenna have been obtained. The fields are obtained at the interface of earth and air. The vertically polarised electric field component has been found to dominate over the other electric field components. This electric field component ( $E_{zh}$ ) due to the submerged long wire antenna is then determined and compared with the corresponding field component ( $E_{zv}$ ) due to a vertical monopole above the interface. An 'efficiency'<sup>B</sup> is defined as the square of the absolute value

of these two field strengths at a distant point i.e.

$|E_{zh}/E_{zv}|^2$ . The 'input impedance' and the 'efficiency' have been computed for different sets of the electrical constants of the earth for the frequencies ranging from 100 KHz to 500 KHz. All the calculations have been done for a teflon-insulated wire antenna of length 91.5 meters located at a depth of 3 meters in I.I.T. Campus and are presented in Chapter III.

A closely wound helical antenna insulated all through its length and buried inside earth is next studied<sup>12,13</sup> and are described in Chapter IV. The far-zone electromagnetic fields of this type of helical antenna are obtained. The total length of the wire used in the helix is small compared to the wavelength. In this situation, the low frequency approximation of the helix can be made so that each turn of the helix is replaced by a linear combination of an electric dipole and a loop. As has been mentioned already, the far-zone electromagnetic fields due to the electric dipole along the axis of the helix will be obtained in Chapter III. The electromagnetic fields due to the loop antenna are determined in this chapter. The field due to a single turn of the helix can thus be determined. In finding the field due to the entire helical antenna (end fed), two cases have been considered. In the first case the antenna is taken to be a shorted-end one, where as its length is taken to be small compared to wavelength the current along the antenna has been assumed to be uniform both in amplitude and phase. The far-zone fields may then be

evaluated just by multiplying the field due to a single turn by the number of turns. In the second case, the antenna is taken to be an open-ended one. In this case, because of small electrical length of the antenna, the current variation may be assumed to be linear becoming zero at the open-end. This linear current variation is approximated as a discrete variation i.e. it has been assumed that the current will remain uniform over any turn of the helix, but changes its value only when the next turn comes. This assumption may be justified if the number of turns over a given length is large and if at the same time the diameter of the turns is small. Although the number of turns has been increased, the diameter of the turns has been kept smaller, so that the total length of wire used in the antenna remains smaller than the wavelength.

Measurements made on the different types of antennas are described in Chapter V. The measurements had been taken for the input impedance of an open-ended linear antenna of 91.5 meters long and buried in the soil of I.I.T., Kharegpur at a depth of 3 meters, for different frequencies from 60 KHz to 500 KHz. Using this antenna as a radiator, the field strengths in the neighbouring areas had been measured. The input impedance of an open-ended helical antenna over the frequency range from 50 KHz to 250 KHz were also measured. The helical antenna was of length one meter, placed at a depth of 0.5 meter and closely wound with a wire of diameter 1 mm. Each turn of the helix was having a diameter of 10 cm. The input impedance of a model linear antenna ( 5 cm long ) was also

measured (in the laboratory) after submerging it in a solution of NaCl at a depth of 1 cm. The scaled frequencies for this laboratory measurement were ranging from 150 MHz to 350 MHz. The conductivities and the dielectric constants of a number of coal-dust samples from various coal fields of eastern India were measured in the laboratory at different frequencies (from 10 KHz to 300 KHz). Some observations had also been taken inside a coal mine. The results of all these measurements have been summed up in Chapter V.