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A Study on Environmental Factors that Adversely Affect the Propagation of Very High Frequency Electromagnetic Waves in Space Communication Systems

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Abstract: This paper deals with the propagation factors that are of immense use for the design and development of centimeter and millimeter space communication systems. It is a known fact that several other applications of space research encounter millimeter wave propagation problems, such as radio meteorology, radio navigation and radio ranging of satellites, etc. Transmission of an e.m. wave through the ionosphere and the atmosphere is subject to variety of impairments whose importance depends upon carrier frequency, angle of elevation, atmospheric and ionospheric condition and the solar activity. Rain attenuation is the most important phenomenon that is required to be study in details. The objective of this paper is to present and discuss some of the factors concerning the theoretical study of the problems of propagation at 20 GHz and 30 GHz frequency bands and also the parameters that adversely affect the propagation of these waves. The future objective of this study will be to obtain models for propagation loss, rain depolarization and carry other signal impairment introduced by the model of propagation of millimeter waves on earth space communication links.

Keywords: Propagation impairment, precipitation, attenuation, atmospheric effects, satellite communication.

1. INTRODUCTION

There has been a growing demand for bandwidth for the communications of various kinds and this has led to the exploitation of ever higher frequencies much above 10 Ghz to satisfy the demand. The design and developments of communication systems using frequency above 10 Ghz is strongly influenced by the propagation medium. As atmospheric influences, rain attenuation, scintillation and depolarization become more severe with increasing frequency in ku- and ka- bands; therefore the availability of precise information on the effects of propagation is a necessary prerequisite requirement for the design of communication system at these higher frequency bands. Precipitation, especially rain, causes absorption and scattering of an electromagnetic wave. Although all frequencies are subject to these effects, the attenuation is of special importance for the frequencies above 10 Ghz. [1-8]. The effects of the earth's atmosphere on radio waves propagation between earth and space platforms has been a matter of constant concern in the design, development and performance of space communication systems. In case of systems operating at 20/30 Ghz frequency bands the problem becomes more acute because at these frequencies communication links can be adversely affected by precipitation, atmospheric gases, clouds, fog and scintillation. The successful execution of space program also depends on proper evaluation of the hostile natural space environment. Apart from radiations, the environment includes atomic oxygen, various types of plasma environments meteoroids, debris, ultraviolet radiations and thermal environment. In this paper, we have presented some important factors that affect the propagation of higher frequencies that are used in communication systems. Efforts will also be made for the estimate of these parameters theoretically which is the most fundamental obstacle encountered in the design of communication systems. Efforts will also be made for the estimate of these parameters theoretically which is the most fundamental obstacle encountered in the design of communication systems at the frequencies above 10 Ghz. Some consideration will be given to the problem of design considerations and systems specifications that are required for conducting the propagation experiments at higher frequency bands.

2. ATMOSPHERIC ATTENUATION

The effects of atmospheric gases, clouds and precipitation on millimeter waves have been examined for a homogeneous medium. Those results can be applied to a horizontally stratified atmosphere and used to estimate total atmospheric attenuation as a function of metrological conditions and location of space terminal. The models of standard atmosphere and an atmosphere with precipitation have been studied. It is found that the total atmospheric attenuation, which is relatively low at angles near zenith, increase monotonically with zenith angles and becomes very large near the horizon. Atmospheric gases and precipitation in addition to absorbing also emit electromagnetic energy; this emission is often referred to as sky noise. For a uniform medium in thermodynamic equilibrium, the theory of blackbody radiation states that a good absorber is also a good emitter. The rain affects the transmission of electromagnetic waves in three ways.

- it attenuates the signals,
- it increases the system noise temperature and
- it also changes the polarization of the electromagnetic wave.

3. FADING PHENOMENON

Fading in microwave radio systems is generally related to atmospheric changes and becomes more of a problem as the transmission frequency increases. While fading phenomenon is by its very nature a random event, certain conditions cause this phenomenon to become more disruptive. Fading tends to be greater during clear, quiet periods rather than during inclement weather. Fluctuations in the field strength are larger during the night than in the daytime. Winter is more stable time; fading is generally more frequent during warm weather.

4. IONOSPHERIC SCINTILLATION

Ionospheric scintillations refer to amplitude and phase variations of high frequency electromagnetic waves transmitted through the ionosphere from outside the earth. Two common sources are cosmic noise from outer space and signals from artificial satellites. In considering the transmission of signals between two or more communication terminals via satellite, ionosphere scintillations present a problem in pulsed systems where information is contained in a coded pulse train and the presence or absence of a pulse in a particular train may change the entire context of the message. Such a problem exits in satellite communication systems using digital schemes as a modulation method.

5. RAIN ATTENUATION

It is well known that precipitation, especially rain causes absorption and scattering of an electromagnetic wave. These effects combine to produce attenuation. Although all frequencies are subject to these effects, attenuation is of special importance for frequencies above 10GHz. Also the rain and cloud act as the source of noise radiation and attribute to the increase in the antenna noise temperature. The link margin required to combat the effects of intense precipitation is a function of performance criteria and the associated link availability factor. Rain is the main factor for the absorption and scattering of millimeter waves which is responsible for the attenuation. The attenuation increases with rain fall rate with frequency and with decreasing elevation angle. It has been observed that the effect of clouds is small as compared with that of rain for frequencies upto about 30 GHz [9-16]. In order to predict attenuation due to precipitation along the earth station-satellite link it is necessary to obtain information on their distribution in space and time and in their specific attenuation in dB per km.

6. ATTENUATION MODEL

Several theoretical and experimental studies have shown [9-16] that the rain attenuation A_r can be modeled adequately by the expression

$$\alpha = aR_p^{\,b}$$

$$A_r = \alpha\, L,$$

Where α is the specific attenuation (dB/km)

R_p is the point rain rate (mm/hr)

and L is path length in km.

The values of a and b are calculable theoretically from the considerations of electromagnetic wave propagation in spherical rain drops. These results can be obtained from several CCTR reports.

The prediction of rain attenuation ($A_{0.01}$ in dB) exceeded for a specific percentage of time (0.01 per cent yearly) is given by a standard relation

$$A = LR_{0.01}$$

Where $R_{0.01}$ is the reduction factor for the specific percentage of time (0.01 per cent).

Attenuation exceeding for any percentage of time can be computed with the knowledge of the conversion factor. The method of prediction of rain attenuation is given in CCTR Report 564 based upon the above mentioned method rain attenuation values can be calculated by developing a suitable computer software.

7. PROPAGATION AT LOW ELEVATION ANGLE

The propagation of electromagnetic waves from ground to satellite and back at low elevation angle suffer degradation of the signal from atmospheric effects, scintillation as well as due to rain fall. The mechanism covering scintillation in clear weather and in presence of precipitation are yet to be characterized. The possibility of combating such fading by using short baseline diversity techniques should also be considered. The problems associated with propagation to mid-latitude or equatorial should also be characterized for 20-30GHz frequency bands which have got immense applications when the requirements for more bandwidth are needed.

8. CONCLUSION

It is quite important that, the design of the space communication systems in 20GHz and 30 GHz frequency bands should take into account, the rain attenuation for a specific percentage of time required and also the increase in system noise temperature due to precipitation and system performance for specified small percentage of time. Statistical data on attenuation, depolarization, back scatter and precipitation etc. are quite essential for the optimum design of satellite communication systems operating at millimeter frequency bands. The research work utilizing new methods for modeling slant paths or describing novel techniques for obtaining experimental data may be of further interest.

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