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Propagation Power Loss Analysis and Evaluation under Variant Atmospheric Conditions

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Abstract - The effect of propagation factors on high rate transmission services at microwave range is observed to be very high. The variant nature of atmospheric conditions places a major part in the distortion of original signal. Among various factors observed in signal degradation, power loss is observed to be a dominant factor. The loss in power strength degrades the receiving signal strength resulting in very low estimation efficiency. The power losses are observed basically with the variation in transmission frequency. As frequency increases, there is a crucial change to link power margins in the communication system. In addition to the free space losses, there are other losses due to atmospheric absorption, clouds, fog and precipitation, as well as multipath at low elevation angles. All of these losses due to the atmosphere at microwave range is been evaluated.

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PROPAGATION POWER LOSS ANALYSIS AND EVALUATION UNDER VARIANT ATMOSPHERIC CONDITIONS

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Propagation Power Loss Analysis and Evaluation under Variant Atmospheric Conditions

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Abstract - The effect of propagation factors on high rate transmission services at microwave range is observed to be very high. The variant nature of atmospheric conditions places a major part in the distortion of original signal. Among various factors observed in signal degradation, power loss is observed to be a dominant factor. The loss in power strength degrades the receiving signal strength resulting in very low estimation efficiency. The power losses are observed basically with the variation in transmission frequency. As frequency increases, there is a crucial change to link power margins in the communication system. In addition to the free space losses, there are other losses due to atmospheric absorption, clouds, fog and precipitation, as well as multipath at low elevation angles. All of these losses due to the atmosphere at microwave range is been evaluated.

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I. Introduction

As with the increase in demanded service quality and data rate the conventional approach of the data transmission is getting upgraded. To achieve the demanded service compatibility various high ranges have emerged in recent past. Therefore modified approaches of microwave system are in developing process. The most important advantages of Modifies microwave system are the availability of antennas with high directive gain and large bandwidth. At such high frequencies, for example 1% bandwidth at 600 MHz is 6 MHz (the bandwidth of the single television channel) and at 60 GHz, 1% bandwidth is 600 MHz (100 television channels). But, on the other hand, at frequencies about above 10 GHz, the electromagnetic radiation starts interacting with neutral atmosphere and also with various meteorological parameters, in particular, precipitation, producing absorption of energy, and thus attenuation of signal levels. Implicit in these predictions of losses is a detailed knowledge of the physical mechanism of the various meteorological parameters and their interactions with electromagnetic radiation.

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The adverse weather causes microwave signal degradations mostly due to rain and suspended particles like fog and water vapor. Atmospheric gases cause signal attenuation through molecular absorption in certain characteristic frequency bands (Zvanovec *et al.,* 2007). A very large number of gases exhibit resonant absorption features. But, only a few have a major impact on signal propagation through the earth's atmosphere in the wavelength range of interest. Molecular oxygen and water vapor at millimeter & sub millimeter wavelengths are the most important constituents. In order to increase transmission bandwidth, the current systems of operations are upgrading their operating frequency. Microwave signals in the new frequency band are expected to have higher propagation losses than in the 1.4–2.4 GHz (L and S bands) band due to atmospheric attenuation and terrain interference (Suen *et al.,* 2008). The impact on microwave power link margin due to the frequency increase is been evaluated in this paper.

II. Atmospheric Attenuation

The effects of atmospheric and weather are more significant on 3–30 GHz frequency band and are not negligible as at the 1.4–2.4 GHz frequency band which the military is using now. There are mainly two types of attenuations that will affect the power margin at higher frequencies (Federici et al., 2005). One is the atmospheric gaseous absorption, while another is the rain attenuation when microwave signals pass through the rain. Additional environmental phenomena, such as, cloud, fog, ice, snow, aerosol, dust, etc., can also cause severe signals impairment as increasing operating frequency (Johnson *et al.,* 2008). Several anomalous propagation modes (such as ducting and tropospheric scatter) also play major roles in trans-horizon interference for a very small percent time. At low elevation angle, the atmospheric scintillation and multipath fading become significant. Atmospheric absorption, clouds, fog, precipitation, and scintillation incur losses in a transmitted signal (Fiorino *et al.,* 2009). Previously, these losses were deemed negligible at the lower frequencies. As the frequency increases, this method is not acceptable. It is necessary to identify all the propagation mechanisms and estimate attenuation that might arise in the new frequency band.

III. Propagation Modeling

The models of the atmospheric gaseous absorption and rain attenuation for various rainfall rates were studied to modeled the propagation effect at 3–30 GHz. Atmospheric absorption and rain attenuation mainly occur at low altitudes, an area called as the troposphere. There are several models for the atmospheric attenuation calculation. They are mostly regional dependence.

The principal interaction mechanism between radio waves and gaseous constituents is molecular absorption from molecular oxygen and water vapor in the atmosphere (Zvanovec *et al.,* 2007). The oxygen volume ratio in the gases is quite stable, while the water vapor density varies a lot, with strong regional and seasonal dependence. Within the studied frequency band, there was an absorption line at 22.235 GHz (Koshelev *et al.,* 2007). The following equations are used to plot the attenuation of oxygen and water vapor for the horizontal path, the vertical path, and different elevation angles over a specified frequency range.

For oxygen, specific attenuation in the horizontal dependence is given as:

$$\gamma_0 = \left[7.19\times10^{-3} + \frac{6.09}{f^2+0.227} + \frac{4.81}{(f-57)^2+1.50}\right] f^2\times10^{-3}\ dB \qquad (1)$$

Where f is frequency in GHz.

For water vapor, specific attenuation in the horizontal dependence is given as

$$\gamma_w \left[0.067 + \frac{3}{(f-22.3)^2+7.3}\ \frac{9}{(f-183.3)^2+6}\ \frac{4.3}{(f-323.8)^2+10}\right] f^2\rho 10^{-4} \qquad (2)$$

in dB/km where f is frequency in GHz and ρ is the water vapor density in g/m^3. In this study we have selected a maximum value of 12 g/m^3 and an average value of 7.5 g/m^3.

$$\gamma_a = \gamma_0 + \gamma_w \qquad dB/km \qquad (3)$$

The oxygen and water vapor equivalent heights are given as:

$$h_0 = 6 \qquad (4)$$

$$h_w = 2.2 + \frac{3}{(f-22.3)^2+3} + \frac{1}{(f-183.3)^2+1} + \frac{1}{(f-323.8)^2+1} \quad km \qquad (5)$$

The dependence on elevation angle is then taken into account.

$$A_a = \frac{h_0\gamma_0 + h_w\gamma_w}{sin\theta} \qquad dB \qquad (6)$$

Using the ITU gaseous absorption model, we have calculated attenuations due to both compositions along horizontal and vertical paths. Total zenith losses and its elevation angle dependence also are calculated and plotted. The losses at 3, 6, 12, and 24 GHz are estimated respectively. Rain and other hydrometeors, such as hail, ice, and snow, can cause severe attenuation for higher frequency signals. Water drops will absorb and scatter energy from incident waves. This absorption and scattering causes the attenuation to increase exponentially as the frequency increases (kim *et al.,* 2004). The attenuation coefficient is also strongly dependent on rainfall rate. ITU models on "Attenuation by Hydrometeors, in Particular Precipitation, and Other Atmospheric Particles" were used to plot the attenuation of rain different elevation angles and different rainfall rates over the specified frequency range. This model shows that total specific attenuation rate, γ_R, is a function of rain fall rate, R, as

$$\gamma_R = kR^\alpha \quad in\ dB/km \qquad (7)$$

Where two coefficients α and k are functions of signal's frequency and elevation angle and have been experimentally determined in the model.

Clouds and fog can be described as collections of smaller rain droplets. Different interactions from rain as the water droplet size in fog and clouds are smaller than the wavelength at 3–30 GHz (Kim et al., 2003). Attenuation is dependent on frequency, temperature (refractive index), and elevation angle (Podobedov *et al.,* 2004). It can be expressed in terms of the total water content per unit volume based on Rayleigh Approximation:

$$\gamma_c = k_l M \qquad dB/km \qquad (8)$$

Where:

γ_c: specific attenuation (dB/km) within the cloud

K_l: specific attenuation coefficient [(dB/km)/(g/m^3)]

M: liquid water density in the cloud or fog (g/m^3)

To obtain the attenuation due to clouds for a given probability value, the statistics of the total columnar content of liquid water L (kg/m^2), which is an integration of liquid water density, M, in kg/m^3 along a column with a cross section of 1 m^2 from the surface to the top of clouds, or, equivalently, mm of perceptible water for a given site must be known yielding:

$$A = LK_l/sin\theta,\ dB for\ 90^\circ \geq \theta \geq 5^\circ \qquad (9)$$

Where θ is the elevation angle.

In additional to the line of sight propagation, the radio wave can propagate trans horizontally through several anomalous models. Anomalous modes propagation mechanisms depend on climate, radio frequency, time percentage of interest, distance, and path topography (Hils *et al.,* 2008). At any one time a single mechanism (or more than one) may be present.

The path loss during the signal propagation is defined by the Friis Equation used to estimate distance realated loss for free space or an atmospheric medium but at lower frequency (generally < 3 GHz).

$$P_r = \frac{P_t G_t}{4\pi d} A_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 = \frac{P_t G_t G_r}{L_{FS}} \qquad (10)$$

Where: P_r: power received; P_t: power transmitted

G_t: transmitter antenna gain; G_r: receiver antenna gain

A_r: effective area of receiver antenna ($\lambda^2 G_r/4\pi$)

L_{FS}: free space loss $(4\pi d/\lambda)^2$;

d: distance between transmitter and receiver

λ: wavelength of radio wave

When representing the Friis Equation in decibels (dB), we have

$$Pr = Pt + Gt + Gr - LFS \text{ in dB} \qquad (1)$$

or

$$Pr = EIRP + Gr - LFS \text{ in dB} \qquad (2)$$

Where EIRP is effective isotropically radiated power in dBW; and,

$$LFS = 92.45 + 20\log f + 20\log d \text{ in dB} \qquad (3)$$

Where frequency, f, in GHz, distance, d, in km.

The effect of propagation for the developed approach is evaluated the observation obtained for the value of attenuation at different frequency of transmission is evaluated.

IV. Observations

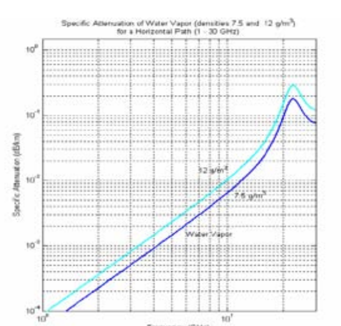

Figure 1: Specific attenuation of water vapor (densities 7.5 and 12 g/m³) for horizontal path (1-30GHz)

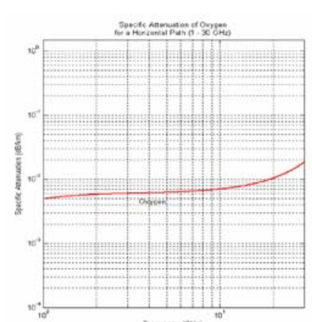

Figure 2 : Specific attenuation of oxygen for a horizontal path (1-30GHz)

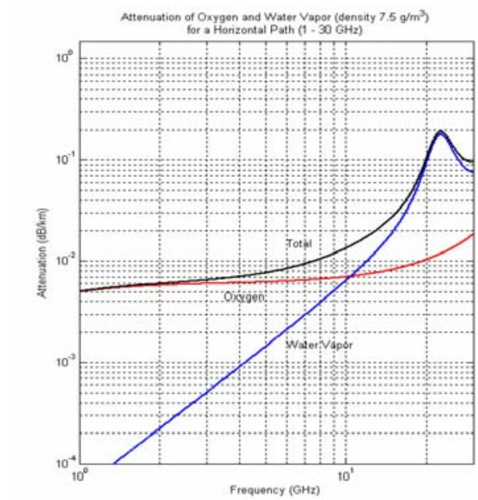

Figure 3 : Attenuation of oxygen and water vapor (density 7.5 g/m³) for horizontal path (1-30GHz)

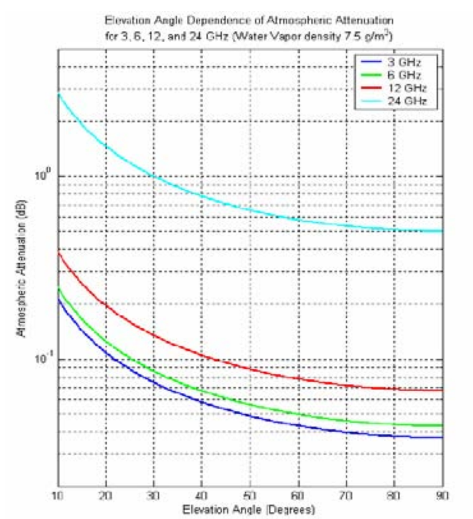

Figure 4 : Elevation angle dependance of atmospheric attenuation for 3,6,12 & 24GHz(water vapor density 7.5 g/m³)

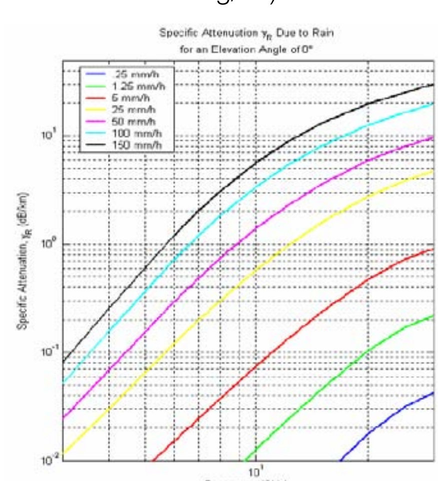

Figure 5 : Specific attenuation due to rain for an elevation angle of 0^0

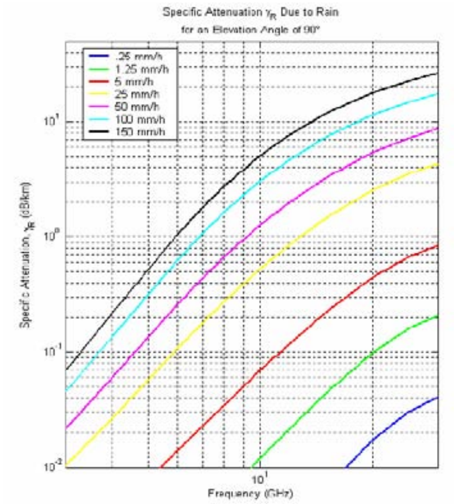

Figure 6 : Specific attenuation due to rain for an elevation angle of 90^0

V. Conclusion

The results show that for a rainfall rate of 50 mm/hour, rain attenuation at 30 GHz is about 10 dB/km, while it is only 1 dB/km at 9 GHz. Thus, the rain attenuation is the main problem at higher frequency for heavier rain.

VI. Acknoweledgement

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