ISSN : 2248-9622, Vol. 5, Issue 4, (Part -1) April 2015, pp.20-23

RESEARCH ARTICLE OPEN ACCESS

Estimation of Water Vapour Attenuation And Rain Attenuation

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Abstract
Attenuation due to and water vapour and rain can severely degrade the radio wave propagation at centimeter or millimeter wavelengths. It restricts the path length of radio communication systems and limits the use of higher frequencies for line-of-sight microwave links and satellite communications. The attenuation will pose a greater problem to communication as the frequency of occurrence of heavy rain increases.In a tropical region, like Malaysia, where excessive rainfall is a common phenomenon throughout the year, the knowledge of the rain attenuation at the frequency of operation is extremely required for the design of a reliable terrestrial and earth space communication link at a particular location.

I. ITU-R MODEL OF WATER VAPOUR ATTENUATION:

The specific attenuation due to water vapor [dB/Km] at ground level (pressure equal to 1013hpa) and at temperature 15^0 C can be approximatedthe following equation for frequencies below 350 HZ.

$$\gamma_w = \left[3.27\cdot 10^{-2}\cdot r_t + 1.67\cdot 10^{-3}\frac{r_t{}^7\rho_v}{r_p} + 7.7\cdot 10^{-4}\cdot\sqrt{f} + \frac{3.79}{(f-22.235)^2+9.81\cdot r_p{}^2\cdot r_t} + \frac{11.73\cdot r_t}{(f-183.31)^2+11.85\cdot r_p{}^2\cdot r_t} + \frac{4.01\cdot r_t}{(f-325.153)^2+10.44\cdot r_p{}^2\cdot r_t}\right] f^2\cdot\rho_v\cdot r_t\cdot r_p\cdot 10^{-4}$$

[1.1]

Where:

f = frequency, (GHz).

ρ_v = water vapour density (g/m^3)

P = total air pressure (hPa)

r_p = p/1013

T = temperature (C)

r_t = 288/(T+273) = reciprocal temperature (K^{-1})

The water vapour value may not exceed the saturation value at the temperature considered in the equation 1.1, at a temperature of 15◦C the saturation value is 12 g/m^3. For highervapour densities the equation (1.1) must be corrected for higher temperatures necessary to sustain such densities.

Equation (1.1) applies to the pressure range of 1013±50hpa with an accuracy of 15% over a temperature range of -20◦C to 40◦C and a water vapour density range from 0 to 50 gm/m^3.

As an approximation to Zenith path attenuation (at sea level) may be obtained by multiplying the specific attenuation given by the equation (1.1) by the equivalent heights of water vapour given by (below frequencies 350GHz).

$$h_w = h_{w0}\left[1 + \frac{3.0}{(f-22.2)^2+5} + \frac{5.0}{(f-183.3)^2+6} + \frac{2.5}{(f-325.4)^2+4}\right] \text{ (km) [1.2]}$$

Where h_{w0} = Water Vapour equivalent height in the window regions.

Equal to 1.6 km (clear weather) and 2.1 km (rain conditions).

For a ground temperature different from 15◦C the equivalent height of water vapour can be corrected by 0.1 %(clear weather) or 1 %(rain) per◦C.

The water vapour Zenith attenuation is then:

$$A_w = \gamma_w h_w \text{(dB)} \quad [1.3]$$

For elevation angles between 10◦and 90◦, the path attenuation is obtained by using the cosecant law:

$$A_w = \frac{\gamma_w h_w}{sin\theta}\text{(dB)} \quad [1.4]$$

Where:

Θ =elevation angle.

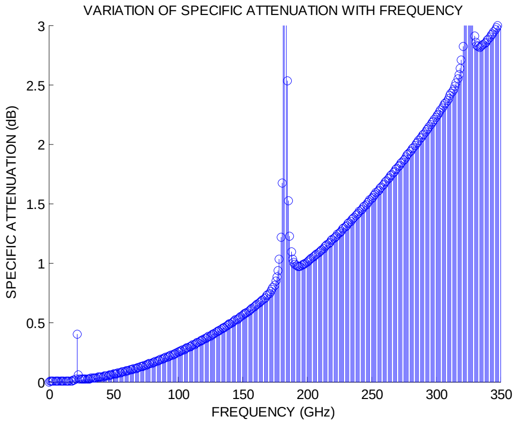
For elevation angles between 0◦ and 10◦ a more accurate formula must be used, modeling the real length of the atmospheric path.

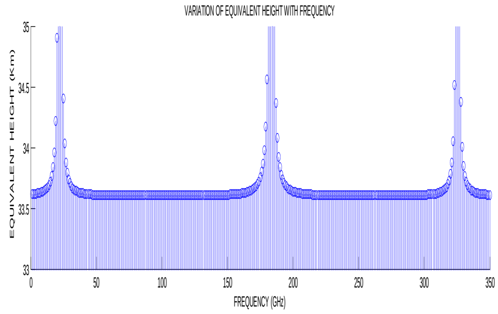
The ITU-R model was compared to an exact, but computationally intensive, model like the MPM .The data set used for this test contained 24 stations, selected according to the criteria of geographical coverage, data quality and availability, and covering 10 years of observations.

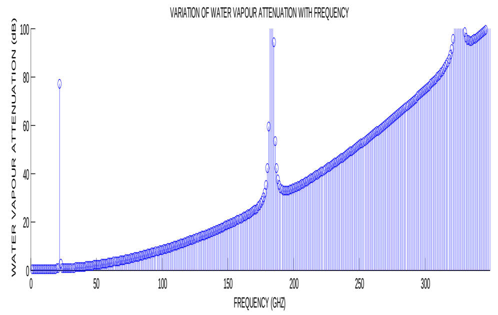
The MPM93 and ITU models have been used to calculate the total attenuation in the absence of liquid water, using the data from radio soundings and from meteorological measurements .The relative error of the gaseous attenuation calculated using the ITU-R model, $A_{ITU,}$ with respect to the attenuation calculated using Liebe’s model and local radiosonde data, A_{MPM} , has been defined as:

$$\varepsilon = \frac{A_{MPM} - A_{ITU}}{A_{MPM}}\cdot 100(\%) \quad [1.5]$$

II. Results of water vapour attenuation







III. Calculation of rain attenuation and variation of rain attenuation with elevation angle and probability of period of reference by using Itu-r model:

Above about 10 GHz, rain attenuation becomes the dominant impairment to wave propagation through the troposphere. Extensive efforts have been undertaken to measure and model long-term rain attenuation statistics to aid communication system design. Measured data is necessarily restricted to specific locations and link parameters. For this reason, models are most often used to predict the rain attenuation expected for a given system specification. In this section, two rain attenuation models are presented that have performed well for many diverse.regions and types of rain: the ITU-R Rain Attenuation Model, and the DAH model. The models are semi-empirical in nature, and they are based on the relationship relating the specific attenuationγ $(dB/km)$to the rain rate R (mm/hr) through the parameters a and b. The models differ in the methods used to convert the specific attenuation to total attenuation over the path of the rain.

The ITU-R rain attenuation model is the most widely accepted international method for the prediction of rain effects on communications systems. The model was first approved by the ITU in 1982 and is continuously updated, as rain attenuation modeling is better understood and additional information becomes available from global sources. The ITU-R model has, since 1999, been based on the DAH rain attenuation model, named for its authors (Dissanayake, Allnutt, and Haidara). The DAH model has been shown to be the best in overall performance when compared with other models in validation studies. The ITU-R states that the modeling procedure estimates annual statistics of path attenuation at a given location for frequencies up to 55 GHz.

2)Steps for determining the expected attenuation exceeded on a given slant-path using itu-r (p.618-5) are as follows

The input parameters required for the ITU-R Rain Model are:

- Latitude of the earth station – ϕ (deg)
- Altitude of the earth station above mean sea-level – h_s (km)
- Point rainfall rate for 0.01% of an average year - $R_{0.01}$ (mm/h)
- Percentage exceedance probability for which attenuation is to be calculated – p
- Elevation angle – θ $(\deg)$
- Frequency – f (GHz)

Step 1:Determine the rain rate for 0.01% of an average year, $\boldsymbol{R_{0.01}}(mm/h)$.

The rainfall intensity $R_{0.01}$ corresponding to the geographical area corresponding to coordinates of our receiving station is must be found. 0.01% corresponds to a signal availability of 99.99% of the year, which means for 0.01% of the year the service will be interrupted. This value is obtained from *ITU-R P.837 Recommendation* paper.

Step 2:Determine the rain height at the ground station of interest, $\boldsymbol{h_r}$.

Determination of the rain height, which according to the *ITU-R P.839* referenceis given by:

h_r=4-0.075(Ø-36) km (2.1)

Step 3:Calculate the slant-path length, L_s.

The slant path length , L_s, in the rain is:

Ls=(h_r-h_s)/sinθ (2.2)

where h_s is the height above mean sea-level of the earth station (km).

Step 4: Compute the path reduction factor,$r_{0.01}$.

The path adjustment factor is given by:

r0.01=1/(1+($L_s$cosθ/L0)) (2.3)

Where

L0=35eˆ(-0.015/R0.01)km (2.4)

$\theta = elevation\ angle\ (degrees)$

Step 5: Calculate the effective path length in the rain, L_e.

The effective path length in the rain is given by:

Le=L_s r0.01 km (2.5)

Step 6:Calculate the specific attenuation, $\gamma\ (\ dB/km)$

Calculate the specific attenuation

$\gamma\ (\ dB/km)$using frequency and polarization dependent coefficients k and $\alpha$and the rainfall rate $R_{0.01}\ (mm/h)$, determined from *step 1*, by using:

γ=k(R0.01)ˆα dB/km (2.6)

Step 7: The attenuation exceeded for 0.01% of an average year,$A_{0.01}$, is obtained from:

A0.01 = γ Le dB (2.7)

Step 8:The estimated attenuation to be exceeded for other percentages of an average year,A_p, in the range 0.001% to 1.0%, is determined from the attenuation to be exceeded for 0.01% for an average year:

$$A_p = A_{0.01} \times 0.12 p^{-(0.546+0.043\log p)}\ dB \ldots \quad (3.18)$$

(2.8)

Note: The attenuation due to rain does not only deteriorate the quality of the signal, it also increases the atmospheric noise collected by the ground station antenna, which is given by the equation:

$$T_{rain} = T_m\left(1 - 10^{-L_{rain}/10}\right)\ldots \quad (3.19)$$

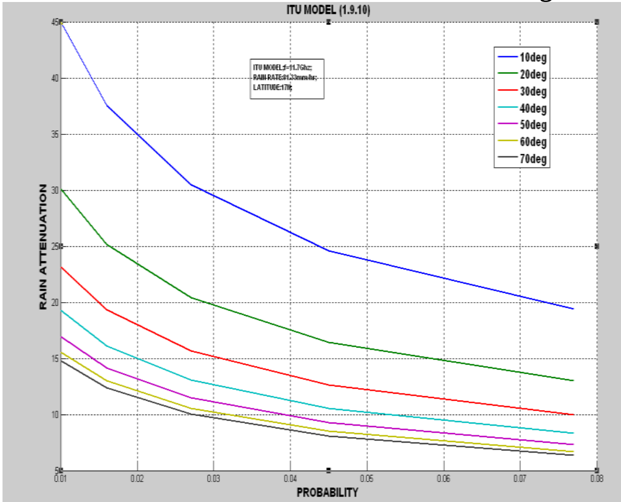
(2.9)

Where:

L_{rain} = total attenuation due to rain (dB)

T_m = effective temperature of the medium = $\begin{cases} 280K & for\ clouds \\ 260K & for\ rain \end{cases}$

Variation of rain attenuation with elevation angle



Tabular Form Showing Variation Of Rain Attenuation With Elevation Angle And Probability Of Period Of Reference On 01.09.2010 :

θ / prob%	0.0100	0.0160	0.0270	0.0450	0.0770
θ = 10°	44.9819	37.5756	30.4584	24.5691	19.3954
θ = 20°	30.0976	25.1419	20.3798	16.4393	12.9775
θ = 30°	23.1429	19.3324	15.6706	12.6406	9.9788
θ = 40°	19.2747	16.1011	13.0514	10.5278	8.3109
θ = 50°	16.9558	14.1640	11.4812	9.2613	7.3110
θ = 60°	15.5569	12.9954	10.5340	8.4972	6.7079
θ = 70°	14.7863	12.3517	10.0122	8.0763	6.3756

IV. Conclusion

Radio wave propagation through the earth's atmosphere will experience reduction in signal level due to the water vapour and rain parameter present in the transmission path. Accurate estimation of radio waves propagation impairments that affect link quality and availability and determination of the signal performance are essential to design a reliable satellite or terrestrial communication systems and earth terminals networks.

Thus the rain fading variation with changes in the elevation angle has been carried out and is observed to be decreased with increase in the elevation angle. Thus the control of rain attenuationthrough variation in angle of elevation has been achieved.

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