

Calculation of the variability of the window channel frequency near 90 GHz for four Indian stations

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सार – भिन्न जलवायविक परिस्थितियों वाले चार भारतीय केन्द्रों में मिलिमीटर तरंग विंडो आवृत्तियों में विचलन के कारण जलवाष्प सांद्रण में परिवर्तन से संचरण के क्षैतिज मोड का पता चला है। 94 GHz पर न्यूनतम और अधिकतम आर्द्रता में विशिष्ट क्षीणन का भिन्नता का और उनके अनुरूप विंडो आवृत्तियों का भी इस शोध पत्र में सूक्ष्मता से परीक्षण किया गया है।

ABSTRACT. The shift of millimeter wave window frequencies owing to changes of water vapour concentration for four Indian stations having different climatic behaviours have estimated for horizontal mode of propagation. Difference in specific attenuation at minimum and maximum humidity for 94 GHz and corresponding window frequencies are also analysed.

Key words – Water vapour, Propagation, Specific attenuation.

1. Introduction

At the millimeter wave windows and absorption bands originating from the oxygen and water vapour molecules of the atmosphere attenuation of radio waves are controlled by the meteorological parameters of the atmosphere (Mondal *et al.*, 1996). The windows between two consecutive absorption bands are dominated by water vapour concentration, in general. This is, however, not always true between 60 and 118 GHz where oxygen absorption continues to be significant. For very dry atmospheres oxygen absorption can exceed water vapour absorption even at 90 GHz. The amount of oxygen absorption is very sensitive to the line complying assumptions. The water vapour absorption is influenced by two factors : (i) resonant absorption and (ii) non-resonant absorption; which shows a rising trend with increasing frequency. The higher the concentration of water vapour the higher is the rate of increase of the non-resonant absorption with frequency. As a result the window frequency is subject to change with varying water vapour concentration. We have estimated the shift of millimeter wave window frequencies due to changes of water vapour concentration for four Indian stations situated at the four corners of the country. This paper

considers the attenuation in the 70 - 100 GHz region, which is a broad window region between the oxygen lines around 50 - 60 GHz and the line at 118 GHz. However, this window region has residual transmission loss due to water vapour absorption, the physical mechanism for which is still the subject of debate but is widely believed to be due to inadequate treatment of the far wings of distant lines.

2. Estimation technique and sources of data

For a clear sky condition, $\alpha_T(f)$, total atmospheric absorption coefficient is the sum of absorption coefficients due to water vapour and oxygen, *i.e.*,

$$\alpha_T(f) = \alpha_{\text{H}_2\text{O}}(f) + \alpha_{\text{O}_2}(f) \text{ dB/km}$$

where $\alpha_{\text{H}_2\text{O}}(f)$ and $\alpha_{\text{O}_2}(f)$ are the attenuation coefficients due to water vapour and oxygen molecules.

The oxygen absorption coefficient may be given by,

$$\alpha_{\text{O}_2}(f) = 1.61 \times 10^{-2} f(P/1013)(300/T)^2 F' \text{ dB/km} \quad (1)$$

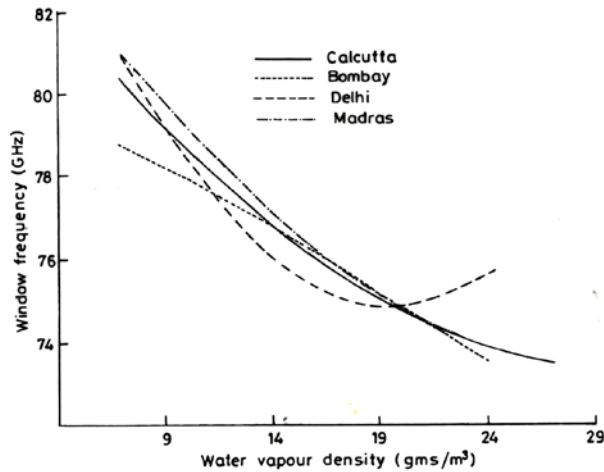


Fig. 1. Millimetre wave window variation for four Indian stations

where F' is a function which incorporates the line strengths and determines the shape of absorption spectrum with factor f^2 .

Below 45 GHz, the contribution of 118.75 GHz absorption line may be neglected and therefore Eqn. (1) could be reduced to

$$\alpha_{O_2}(f) = 1.61 \times 10^{-2} f^2 \left(\frac{P}{1013} \right) \left(\frac{300}{T} \right)^2 \times \gamma \left(\frac{1}{(f - f_0)^2 + \gamma^2} + \frac{1}{f^2 + \gamma^2} \right) \text{dB/km} \quad (2)$$

where P , T and f are pressure (hPa), temperature (κ) and frequency (GHz) respectively. Here γ is the line width parameter given by Meeks & Lilley (1963).

The water vapour absorption coefficient in 1-300 GHz region was given by making use of Van Vleck Weisskopf line shape function as,

$$\alpha_{H_2O}(f) = 2f^2 \rho \left(\frac{300}{T} \right)^{5/2} \sum_{i=1}^{10} A_i e^{-\varepsilon_i/T} \left(\frac{\gamma_i}{(f_i^2 - f^2)^2 + 4f^2 \gamma_i^2} \right) \text{dB/km} \quad (3)$$

Where

$$\gamma_i = \gamma_{i0} \left(\frac{p}{1013} \right) \left(\frac{300}{T} \right)^x \left(1 + 0.01 a_i \frac{\rho T}{p} \right) \text{GHz}$$

f_i 's are water vapour resonance frequencies upto 448 GHz and ε'_i , A_i , γ_{i0} , a_i and x are obtained from the tables given by Waters (1976).

A computer program has been developed using the above expressions for oxygen and water vapour absorption coefficients to estimate total absorption coefficient, $\alpha_T(f)$ in 1-300 GHz range. This program includes pressure, temperature and dew-point temperature as input and computers for the oxygen absorption co-efficient, water absorption coefficient and total absorption coefficient at a frequency of interest.

Radio meteorological monthly data collected by NOAA, USA for the locations of Calcutta, Bombay, Delhi and Madras, *i.e.*, at four stations over the Indian subcontinent for a 3-year period are utilized for the estimation.

3. Millimeter wave windows and shift of window frequency

The estimated range of variation of the window frequencies for four Indian stations having different climatic behaviours are shown in Fig. 1 for horizontal mode of propagation.

The lowest window frequency over a year was found to lie between 74 to 75 GHz for all the four stations but the highest window frequency was found to vary from one place to another. The variation of window frequency near 94 GHz over different stations for horizontal mode of propagation at surface are estimated. Monthly averaged data for three years were taken to calculate the variation of window frequencies. On considering a linear temperature dependence on the attenuation due to water vapour in window regions temperature dependence of -0.6% per $^\circ\text{C}$ for water vapour remains valid between -20°C to 40°C (Gibbins, 1986). So, the dependence of window frequency with corresponding surface temperature, dew point temperature may be represented as the dependence of window frequency with water vapour density in order to establish regression line as shown in Fig. 1, where a wide variation was noticed in the so called 94 GHz window. The best fit second degree polynomial for various locations are obtained as:

$$\text{Calcutta} : f = 84.96 - 0.75\rho + 0.013\rho^2$$

$$\text{Bombay} : f = 80.40 - 0.22\rho - 0.002\rho^2$$

$$\text{Delhi} : f = 89.29 - 1.48\rho + 0.38\rho^2$$

$$\text{Madras} : f = 86.04 - 0.83\rho + 0.04\rho^2$$

TABLE 1

Differences in specific attenuation at minimum and maximum humidity for 94 GHz and corresponding window frequencies for the four Indian locations

Locations	Window range (GHz)	For 94 GHz window	
		Specific attenuation difference (dB/km) At min. humidity	At max. humidity
Calcutta	74-78	0.11	0.34
Bombay	74-77	0.14	0.31
Delhi	74-82	0.04	0.30
Madras	74-76	0.18	0.36

where ρ and f stands for water vapour density (gm/m^3) and frequency (GHz) respectively. The water vapour density is related to dew point temperature and partial pressure of water vapour by the equation

$$e = 6.1078 \exp \left[5396 \left(\frac{1}{273} - \frac{1}{T_D} \right) \right]$$

$$\rho = \frac{e \times 18 \times 10^2}{8.31 \times T_D}$$

where e is the partial pressure of water vapour in hPa, T_D is the dew point temperature in Kelvin and ρ is the water vapour density is gm/m^3 .

A program has been developed by incorporating the regression equations to calculate actual surface window frequency for a particular location. The program can display the actual surface window frequency when the meteorological parameters, *e.g.*, temperature, relative humidity, dew point temperature are given as input. Some interesting results are :

(i) There is a common window zone around 75 GHz existing for a water vapour density about 20 gm/m^3 independent of surface temperature.

(ii) For lower water vapour densities, the window frequency shift is small. The deviations are, then, due to variation in surface temperature at the different locations.

(iii) Water vapour densities above 20 gm/m^3 the window frequency deviation from one location to another is much pronounced due to the surface temperature dependence at such high water vapour densities.

The differences in specific attenuations for 94 GHz and corresponding window frequencies have presented in Table 1. The table shows that the difference in specific attenuation is much in higher humidity situation.

The 94 GHz window being the best compromise frequency for achieving high angular resolution consistent with tolerable rain attenuation, the results obtained from the study of the shift of window frequency would appropriate to play a vital role in choosing the operating frequency for most of the high resolution radar and radiometric applications like, anti-aircraft and antitank weapon systems and missile seeker (Liebe, 1989).

4. Conclusions

We have attempted to study the variability of the point where the window channel is 'cleanest' (*i.e.*, great transmission) as a function of temperature and humidity. We find that as the water vapour density increases the window frequency falls but that the variability of the window frequency with temperature is only significant at very high water vapour densities. The paper also highlights the transmission loss at 94 GHz compared to the point of lowest transmission loss and then concludes about the appropriateness or otherwise of the choice of 94 GHz for monitoring precipitation and military applications.

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