6

SHIFT OF MILLIMETERWAVE WINDOW FREQUENCIES AT DIFFERENT INDIAN LOCATIONS

6.1. Introduction :

Radio communication at mm-wave band is primarily affected by two atmospheric gases, viz. water vapour and oxygen because they have strong absorption lines in the band. Abundance of these gases in the atmosphere results in severe attenuation to the mm-wave signal particularly around their resonance lines. Interestingly, the attenuation is non-linear over the band and there are some frequency zones at which mm-wave signal suffers low attenuation. These low attenuation regions are exploited for communication and known as communication 'window'. Prediction of attenuation at 'window' regions are critical because,

- absorption is a function of signal frequency, atmospheric temperature, pressure and humidity which varies with time and location.
- net absorption is dependent on hundreds of wings of absorption lines for which line shapes are not precisely known
- meteorological parameters are difficult to know along the path of propagation (especially for slant path)

Oxygen concentration remains almost same irrespective of time and location, therefore, it is easy to predict. On the contrary, water vapour is a highly variable quantity which varies considerably with time and location. In general, the water vapour attenuation is controlled by two factors : (a) resonant absorption and (b) non-resonant absorption. Besides being dependent on the meteorological parameters, both of these terms increase with water vapour concentration in the atmosphere. At higher water vapour concentration, window frequency is found to be shifted from its actual value. In order to have an idea of how much shift takes place with change in water vapour and related parameters, an attempt was made to study the window frequency variation at different climatic conditions. This study was conducted with NOAA data during the period 1980-82.

Estimation of attenuation were done previously by *Crane* [1980], *Liebe* [1981, 1983], *Allen* [1983b], *Gibbins* [1986a]. *Liebe* [1985, 1989] proposed a modified model which takes account of contributions from hundred of absorption lines and have shown better correlation with the experimental results. *Waters* [1976] proposed a propagation model from the theory of microscopic interactions of atmospheric molecules and electromag-netic wave through spectral line equations. In clear weather condition, the *Water*'s model holds good, particularly for frequencies below 100 GHz and is closely in agreement with that obtained by *Liebe* [1985, 1989]. For simplicity, therefore, this study has been done on the basis of *Water*'s [1981] model and described in the following sections.

6.2. Theoretical considerations :

Electromagnetic wave in the mm-wave band is influenced by atmospheric water vapour and oxygen. Water vapour molecules are having electric dipole moment and oxygen molecules have magnetic dipole moment. In mm-wave communication, atmospheric water vapour and oxygen molecules absorb energy from the propagating signal and go to higher energy levels of quantum state. In thermal equilibrium, soon they start dissipating the absorbed energy in all directions and fall back to their initial energy states. As the process is continued, some energy from the transmitted signal loses direction and effectively gets attenuated in the preferred direction of propagation. Water vapour and oxygen have been identified to be major contributors to the attenuation since they have strong absorption lines in the millimeter band, while for other minor constituent gases, viz. O_3, CO, N_2O, NO_2, CH_2O absorption lines are too weak to absorb significant energy. Therefore, the total attenuation,

$$\alpha_{TOTAL}(f,k) = \alpha_{H_2O}(f,k) + \alpha_{O_2}(f,k) \quad \text{dB/km}$$

$$\text{where } k = f(P, T, \rho)$$

$\alpha_{H_2O}(f,k)$ and $\alpha_{O_2}(f,k)$ are the water vapour and oxygen attenuation coefficients at frequency f and they are also functions of P, T, ρ which stands for atmospheric pressure, temperature and water vapour density respectively.

6.2.1. Oxygen absorption :

Oxygen molecules, due to their inherent rotational dipole moments centered around frequencies 60 GHz and 118.75 GHz exhibit absorption lines. For computing oxygen absorption, the approach taken by *Meeks & Lilley* [1963], *Tolbert and Straiton* [1961], *Carter* [1968], *Zhevakin & Naumov* [1965] using *Van Vleck Weisskopf* [1945] and *Gross* [1955] line shape factor contains unwanted linewidth dependence on pressure. This problem was resolved by *Rosenkranz* [1975]. Besides this, a complex set of line intensities, linewidths and interference coefficients are generated due to overlapping and interference of spectral lines at tropospheric pressures (between 250-1000 mbar). The interference coefficients for overlapping oxygen are further considered by *Rosenkranz* [1988] and arrived at relation,

$$\alpha_{O_2}(f) = 1.61 \times 10^{-2} f^2 \left(\frac{P}{1013}\right)\left(\frac{300}{T}\right)^2 F' \quad \text{dB/km} \qquad (6.1)$$

F' is a function that takes account of line strength 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.(6.1) may be written as,

$$\alpha_{O_2}(f) = 0.011 f^2 \gamma \left(\frac{P}{1013}\right)\left(\frac{300}{T}\right)^2 \left[\frac{1}{(f-f_o)^2+\gamma^2} + \frac{1}{f^2+\gamma^2}\right] \text{dB/km} \qquad (6.2)$$

here, γ is the line width parameter given by *Meeks & Lilley* [1963].

5.2.2. Water vapour Absorption :

Water vapour molecule, due to its inherent electric dipole moment exhibits absorption due to rotational transition at 22.235 GHz and 183.31 GHz. This absorption is further influenced by far wing contributions from strong infrared lines. For computing water vapour absorption, two models are available, one is *Water*'s model [1976] and the other is *Liebe*'s model [1989]. *Liebe* model accounts for contributions from all H_2O lines below 1000 GHz and also dimmer contributions. For better result, a 'continuum' term was added in the calculation to consider influence of lines above 1000 GHz. Whereas Water's model is based on kinetic liner shape model *of Zhevakin-Naumov-Gross* [1963,1965] to fit the 22.235 GHz absorption lines and an empirical term was added to consider the wings absorption. The line shape function was later modified by *Reifenstein III* [1971] and is given by,

$$\alpha_{H_2O}(f) = 2f^2\rho\left(\frac{300}{T}\right)^{\frac{5}{2}}\sum_{i=1}^{10} A_i e^{-\frac{\xi_i'}{T}}\left[\frac{\gamma_i}{\left(f_i^2 - f^2\right) + 4f^2\gamma_i^2}\right] \tag{6.4}$$

where, $$\gamma_i = \gamma_{io}\left(\frac{P}{1013}\right)\left(\frac{300}{T}\right)^{\chi}\left[1 + 0.01a_i\frac{\rho T}{P}\right]$$

f_i's are water vapour resonance frequencies up to 448 GHz and ξ_i', A_i, γ_{io}, a_i and χ are obtained from the table given by *Waters* [1976]. *Water*'s model is well suited for frequencies below 100 GHz as asserted by *Westwater* [1990].

6.2.3. Computer program 1 :

Taking the above expressions for oxygen absorption and water vapour absorption coefficients, a computer program has been developed to estimate total absorption coefficient in the range of 1-300 GHz. This program takes pressure, temperature and dew point temperature values as input data and computes separately oxygen absorption coefficient and water vapour coefficient and then total absorption coefficient at a frequency of interest. The software is written in BASIC language and the program listing is given at the end of this chapter.

5.3. Estimate of mm-wave attenuation for various Indian locations :

Theoretical estimates of millimeterwave attenuation were computed with the above software program for a range of locations with widely varying climatic conditions in India. For this purpose, data over a period of 3 years from NOAA, USA were used. First of all, we considered horizontal mode of propagation. Fig.6.1 shows frequency (GHz) vs. attenuation (dB/km) curves for some locations viz., Calcutta, Guwahati, Bombay and Srinagar. Here, Calcutta and Guwahati show similar trend of variation in attenuation while Bombay and Srinagar show higher attenuation except near oxygen absorption bands around 60 and 118.75 GHz. In Fig.6.1, it is important to note that 94 GHz as window frequency is no longer valid. For Calcutta, it has been shifted to 76 GHz and for Guwahati it is shifted to 75 GHz and for Bombay and Srinagar it is around 74 GHz. It is also observed that for higher window frequencies of around 140 GHz and 220 GHz, the shift is small and not

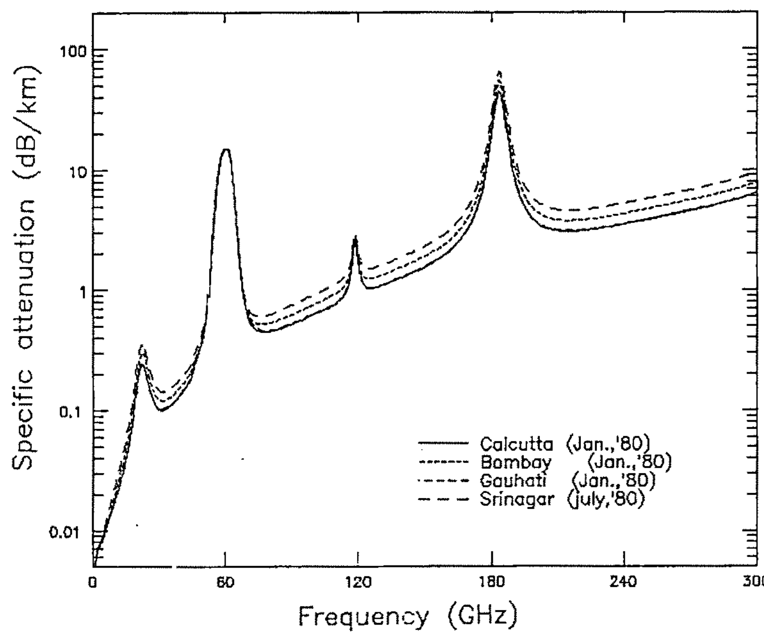

Fig.6.1 Theoretical estimate of attenuation coefficient (dB) for 1-300 Ghz due to atmospheric water vapour and oxygen for few Indian locations.

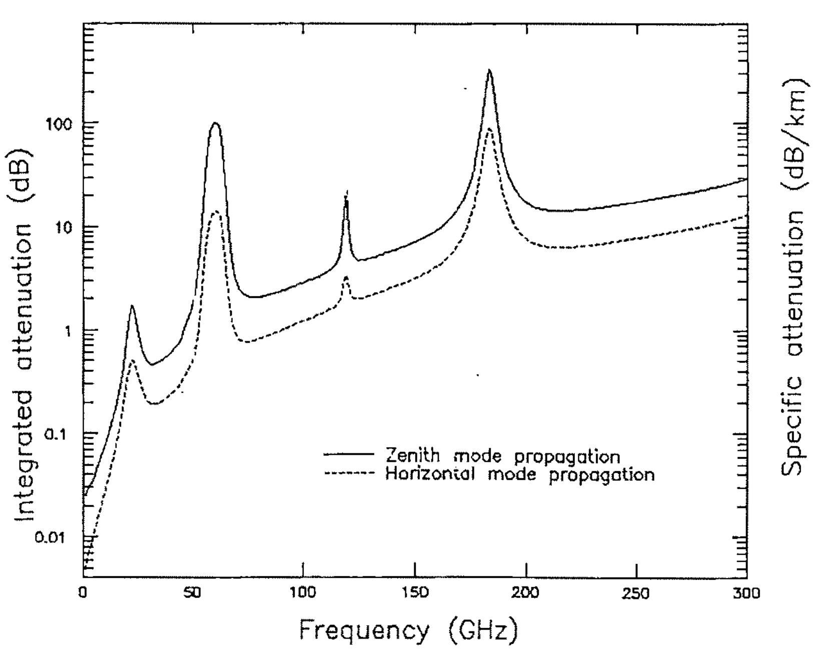

Fig.6.2 Estimated values of net zenith attenuation (dB) and surface attenuation coefficient (dB/km) for Digha between 1-300 GHz.

much predominant although there are some spatial and temporal changes from time to time. In the lower window frequency of around 35 GHz, there is also some changes though it is much less than 94 GHz window. Further, it has been found that the regions with higher surface water vapour density are prone to much more shift in window frequency. For Calcutta, the 35 GHz window is shifted to 31 GHz while the shift is small for Bombay and Srinagar. The variation of different window frequencies are studied with varying climatic conditions. Table 6.1 shows the range of variation for 18 locations in India. A similar trend of shift in window frequencies is observed when propagation mode is changed from horizontal to vertical. The integrated zenith attenuation in the range 1-300 GHz has been calculated taking 10 metre of slabs of the atmosphere and summing up the results over a 10 km vertical path. Beyond this height, water vapour attenuation is negligible. In this estimation, meteorological parameters viz., temperature, pressure and humidity are assumed to be constant within each 10 metre of slabs. A plot is shown in Fig.6.2 for Digha (87°40′E, 21°41′N) located in the eastern coastal region of India. The figure demonstrates that none of the Windows lie in the conventional window bands of 35, 94, 140 & 220 GHz and the window frequencies are not even same for vertical and horizontal mode of propagation. For instance, in Digha, the 94 GHz window has been shifted to 74 GHz for horizontal mode of propagation and the same is shifted to 78 GHz for vertical mode of propagation.

Table 6.1 Millimeterwave window variations in different Indian locations

Place \ Window	Freq. (GHz)	Freq. (GHz)	Freq. (GHz)	Freq. (GHz)
Ahmedabad (23.03N; 72.4E)	31-32	74-80	124-125	214-215
Bhubaneswar (20.15N;85.52E)	31-32	74-79	124-126	214-215
Bombay (18.55N; 72.54E)	32	74-77	124-125	214-215
Calcutta (22.34N; 88.24E)	31-32	74-78	124-126	214-215
Cochin (09.58N; 76.17E)	31-32	74-80	124-125	214-215
Guwahati (26.11N; 91.47E)	31-32	74-79	124-125	214-215
Hyderabad (17.20N; 78.30E)	31-32	75-79	124-126	214-215
Goa/Panjim (15.30N; 73.55E)	31-32	75-77	124-125	214-215
Jodhpur (26.18N; 73.04E)	31-32	75-81	124-127	214-215
Lucknow (26.55N; 80.59E)	31-32	74-80	124-126	214-215
Madras (13.04N; 80.17E)	32	74-76	124	214-215
Minicoy (08.10N; 73.00E)	31-32	74-77	124-125	214-215
Nagpur (21.09N; 79.09E)	31-32	75-80	124-126	214-215
New Delhi (28.38N; 77.12E)	31-32	74-82	124-127	214-215
Port Blair (11.41N; 92.43E)	32	74-76	124	215
Srinagar (34.06N; 74.51E)	31-32	76-83	125-127	214-215
Trivandrum (08.29N; 76.59E)	31-32	74-77	124-125	214-215
Vishakhapatnam(17.4N;83.2E)	31-32	74-78	124-126	214-215

Fig.6.2 also reveals that the integrated water vapour content for the vertical path is less than that for a horizontal path of same length around window regions. MONEX (Monsoon experiment) radiosonde data collected by India Meteorological Department, during June-July 1979 were used for estimation of specific attenuation and integrated attenuation for Digha.

6.4. Critical observations on 94 GHz window :

Because 94 GHz window is much more in use for many applications and the amount of shift is maximum as compared to other windows, a detailed study of the 94 GHz window shift becomes more important. Estimation of 94 GHz window shift with change in time and location have revealed some interesting results. As evident from Table 6.1, the 94 GHz window can go down to a minimum level of 74/75 GHz at particular times of the year while the largest value of window frequency is different from place to place. To understand this more clearly, we have identified 6 locations, viz., Calcutta, Guwahati, Madras, Bombay, Nagpur and New Delhi, having widely varying climatic conditions over the year. For horizontal mode of propagation study, monthly averaged data for three years between 1980-1982 were taken to calculate the variation of window frequencies precisely with respect to water vapour density. It has been found that the window frequency is largely controlled by water vapour density rather than by temperature. The temperature dependence of attenuation for a particular water vapour concentration, in general, exhibits complex pattern especially around absorption peaks. But, considering a linear temperature dependence on the attenuation due to water vapour in window regions temperature dependence of -0.60 per °C for water vapour remains valid between -20°C to 40°C [*Gibbins*, 1986a]. So the dependence of window frequency on corresponding surface temperature, dew point temperature may be represented as the dependence of window frequency on water vapour density in order to establish regression line as shown in Fig.6.3, where a wide variation was observed in the conventional 94 GHz window. The best fit second order polynomial for various locations are :

Bombay	:	$f = 80.40 - 0.22\rho - 0.002\rho^2$
Calcutta	:	$f = 84.86 - 0.75\rho + 0.013\rho^2$
Guwahati	:	$f = 86.20 - 0.88\rho + 0.015\rho^2$
Madras	:	$f = 86.04 - 0.83\rho + 0.014\rho^2$
Nagpur	:	$f = 86.10 - 1.02\rho + 0.024\rho^2$
New Delhi	:	$f = 89.29 - 1.48\rho + 0.038\rho^2$

Atmospheric water vapour density is related to the dew point temperature and partial pressure of water vapour by the following relation,

$$e = 6.1078\,exp\left[5396\left(\frac{1}{273} - \frac{1}{T_D}\right)\right] \qquad (6.5)$$

and

$$\rho = \frac{e \times 18 \times 10^{-2}}{8.31 \times T_D} \qquad (6.6)$$

where e is the partial pressure of water vapour in millibar, T_D is the dew point temperature in K.

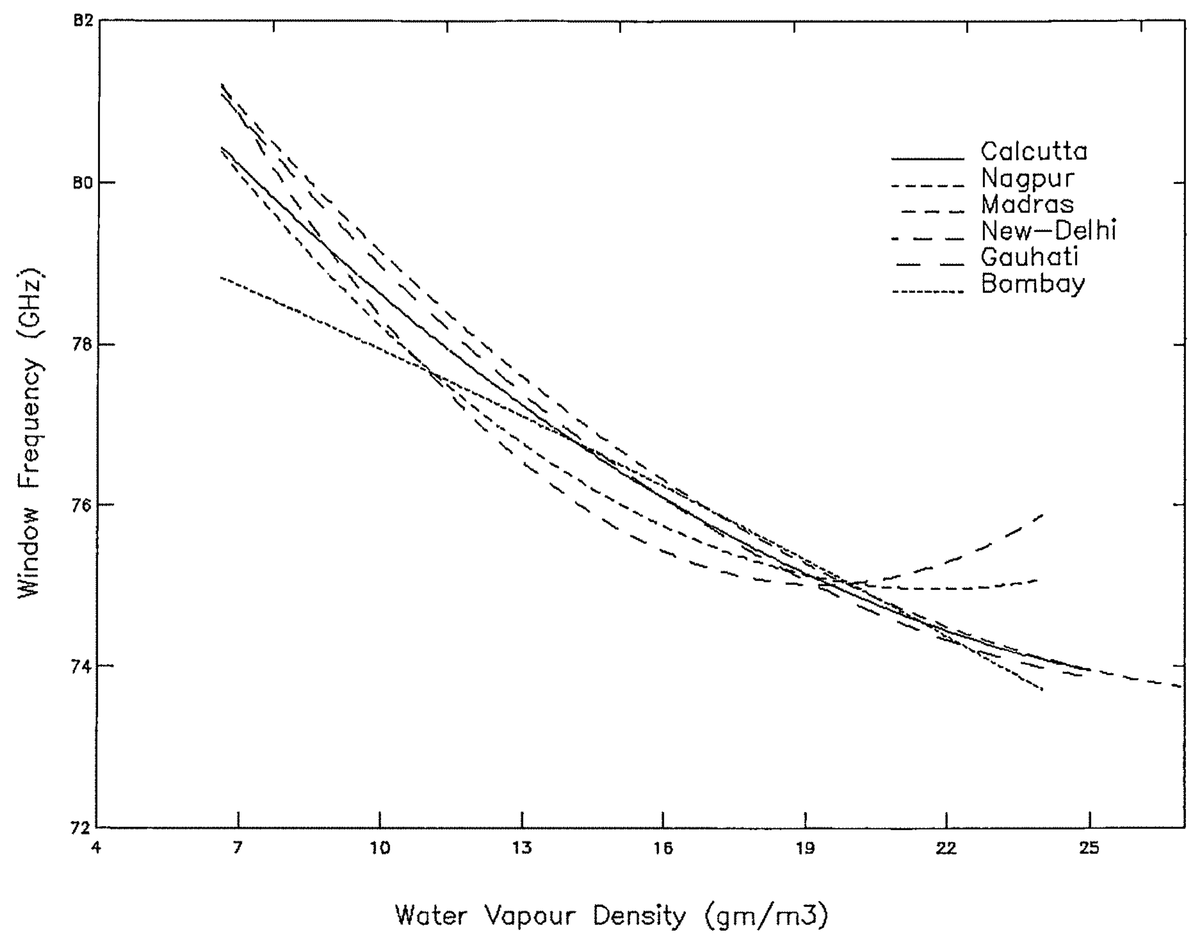

Fig.6.3 Variation of window frequency with water vapour density for six Indian loactions as obtained from regression equation.

6.4.1. Computer program 2 :

A second computer program was developed incorporating the regression equations to calculate actual surface window frequency for a particular location (here, 6 locations). The program can prescribe accurate surface window frequency when the surface temperature, relative humidity or dew point temperature values are given as input. It may be mentioned here that the surface window frequency estimate is useful for LOS link design. The list of the software program is given at the end of this chapter.

6.4.2. Window regression line analysis :

Radiosonde data for surface water vapour density and the true window frequency as estimated through computer program 2 when plotted in Fig.6.3 for different places in India, give rise to some interesting facts. These may be summarized as,

- There is a common window zone around 75 GHz existing for a water vapour density of about 20 gm/m^3, independent of surface temperature.
- For lower water vapour densities, the window frequency shift is small. The deviations are due to variations in surface temperature at different locations.
- For water vapour densities above 20 gm/m^3, the window frequency deviation from place to place is much pronounced due to the surface temperature dependence at similar higher water vapour densities.

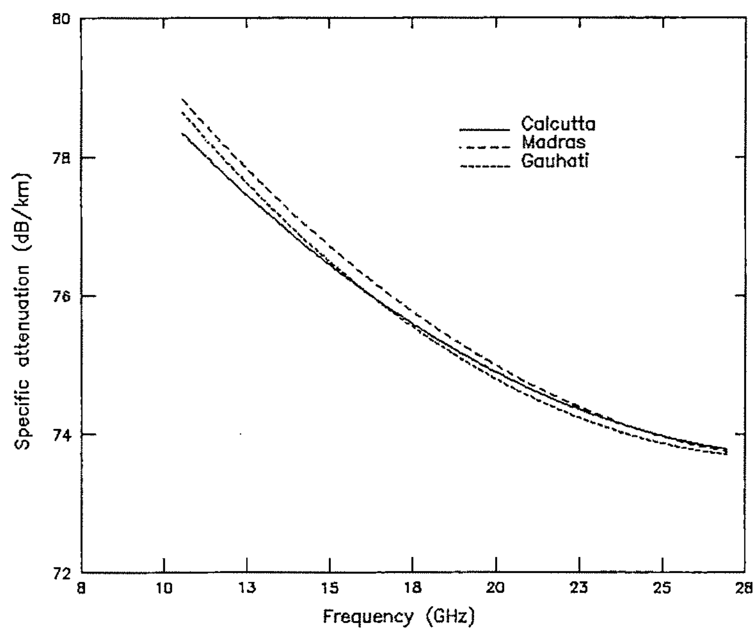

Fig.6.4 Non-linear window variation for a group of wet regions as plotted from regression equation.

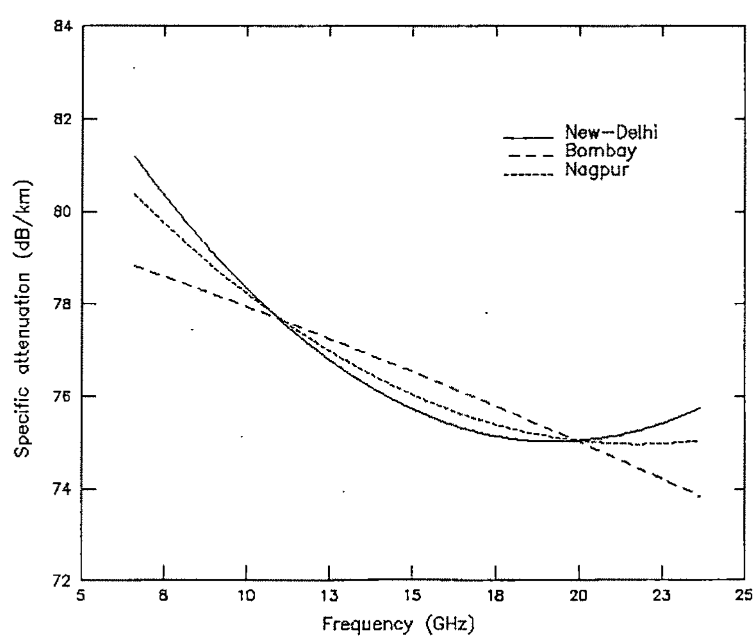

Fig.6.5 For dry regions, non-linearity in window frequency variation increases with atmospheric water vapour density.

A significant trend of increasing nonlinearity in the curves has been observed for dry climatic zone as depicted in Fig.6.4 and Fig.6.5 with the exception of Bombay for which the usual 94 GHz window varies more or less linearly with absolute humidity.

6.5. Estimation of minimum attenuation window :

Estimate of minimum window attenuation for different locations are presented in Fig.6.6 where 94 GHz window attenuations are plotted against respective window attenuations for varying humidity conditions. The differences in specific attenuations for 94 GHz and corresponding window frequencies have been furnished in Table 6.2. It is evident from the table that the difference in specific attenuations is more significant in higher humidity situations. For example, in Fig.6.6(a), at Calcutta, the difference between the 94 GHz attenuation and minimum window attenuation varies from 0.34 dB/km to 0.12 dB/km for water vapour densities of 25 gms/m^3 and 11 gms/m^3. For a 15 Km LOS link, as high as 5.1 dB may be lost due to shift in window frequency which is considerably high. Similar estimation for Bombay, as shown in Fig.6.6(d), exhibits a much more spectacular difference between the 94 GHz attenuation and minimum window attenuation. The estimates for Nagpur, Guwahati, New Delhi and Madras are shown in Figs.6.6(b), 6.6(c), 6.6(e) and 6.6(f).

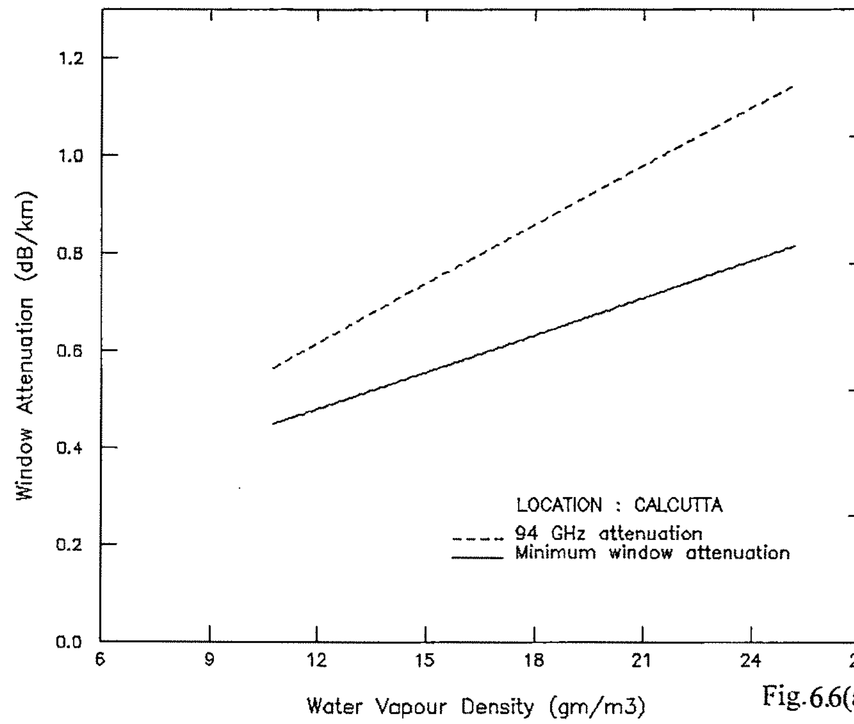

Fig.6.6(a)

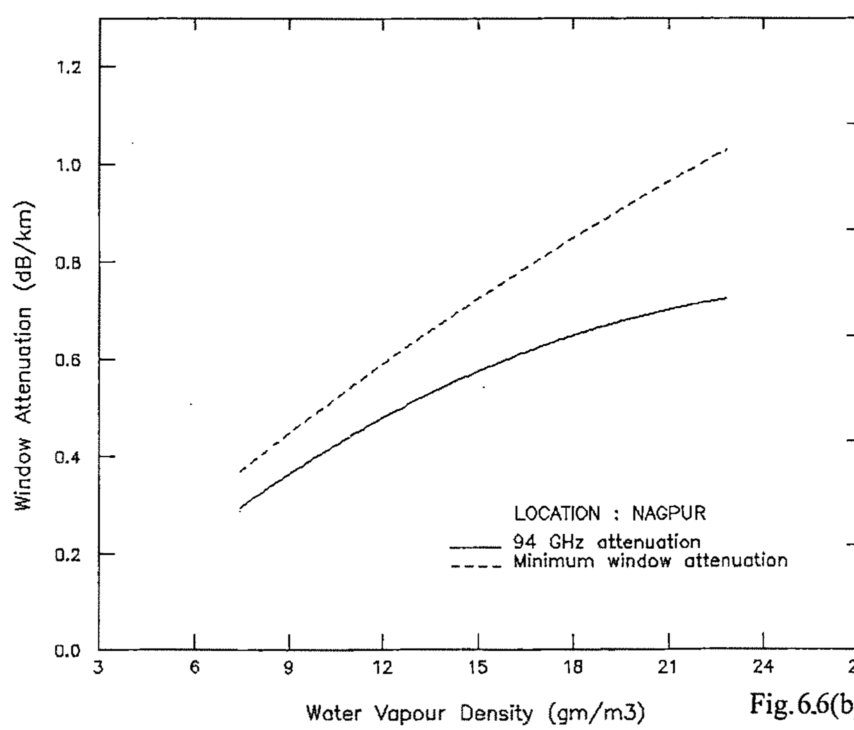

Fig.6.6(b)

Difference in window attenuation for conventional 94 GHz window and at minimum window frequency for maximum and minimum humidity

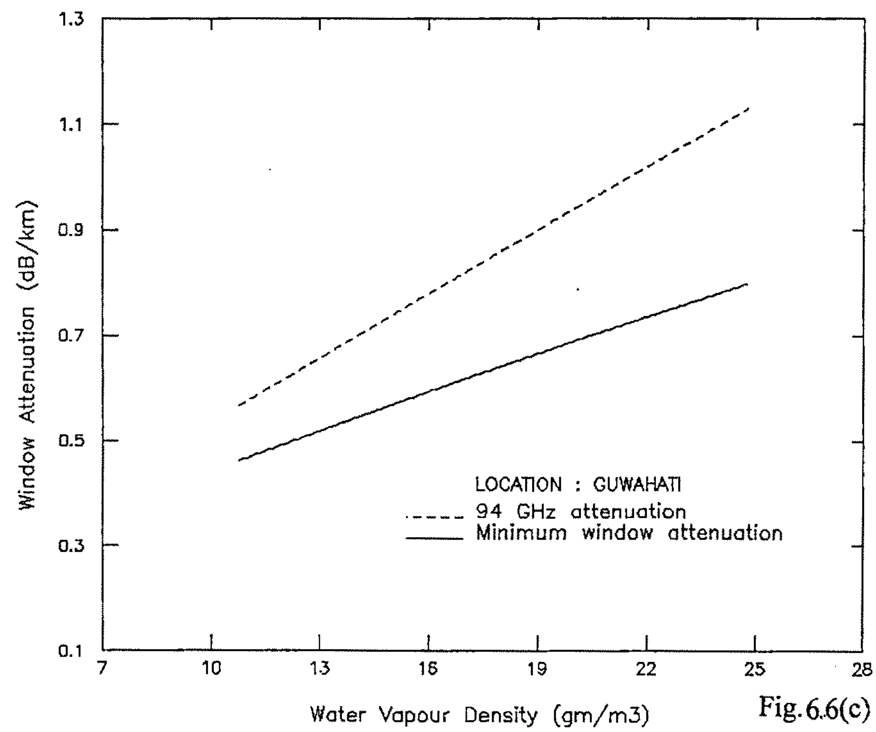

Fig.6.6(c)

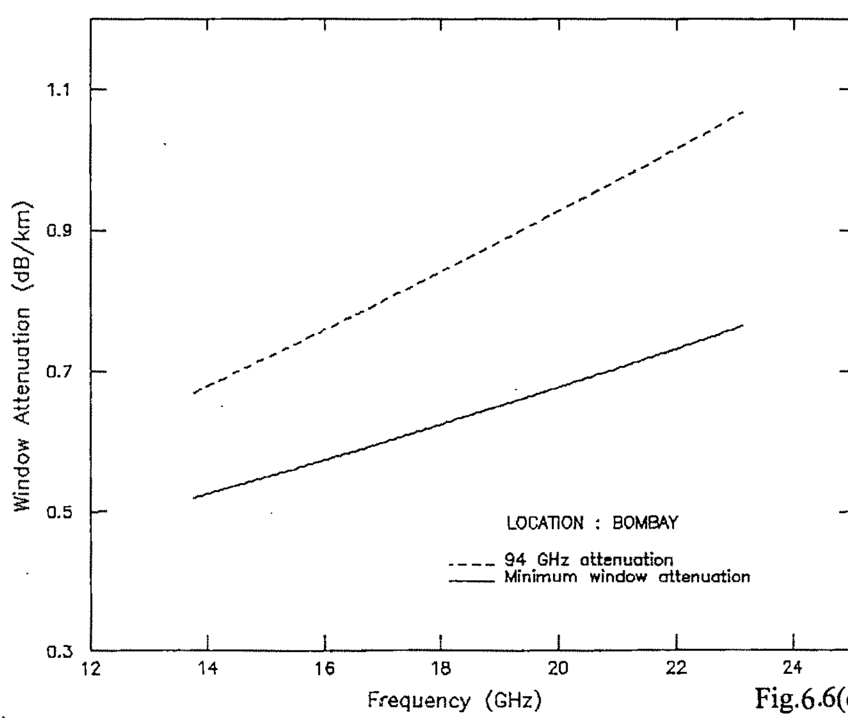

Fig.6.6(d)

Difference in window attenuation for conventional 94 GHz window and at minimum window frequency for maximum and minimum humidity

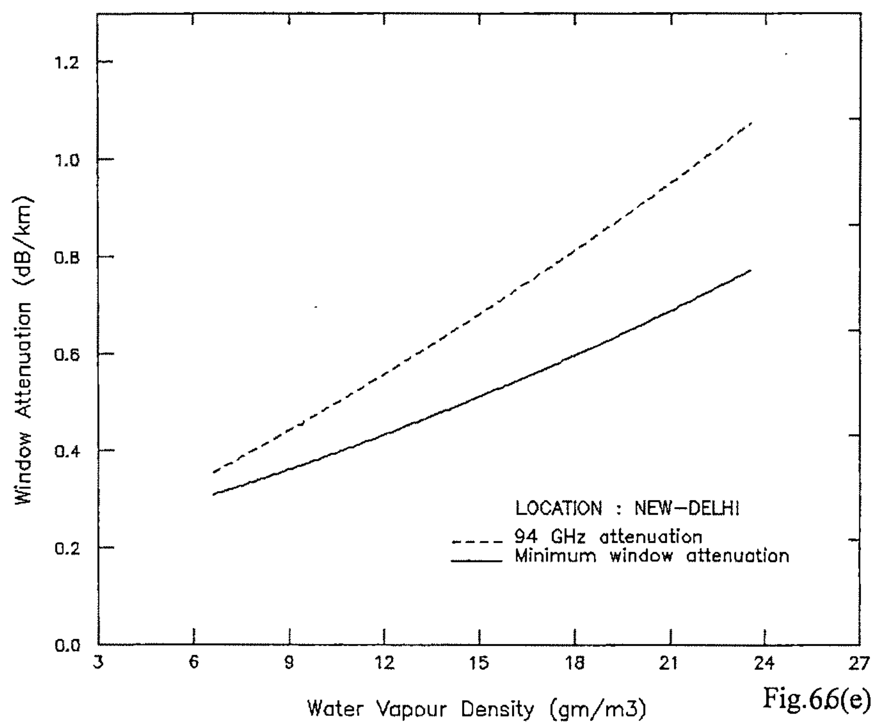

Fig.6.6(e)

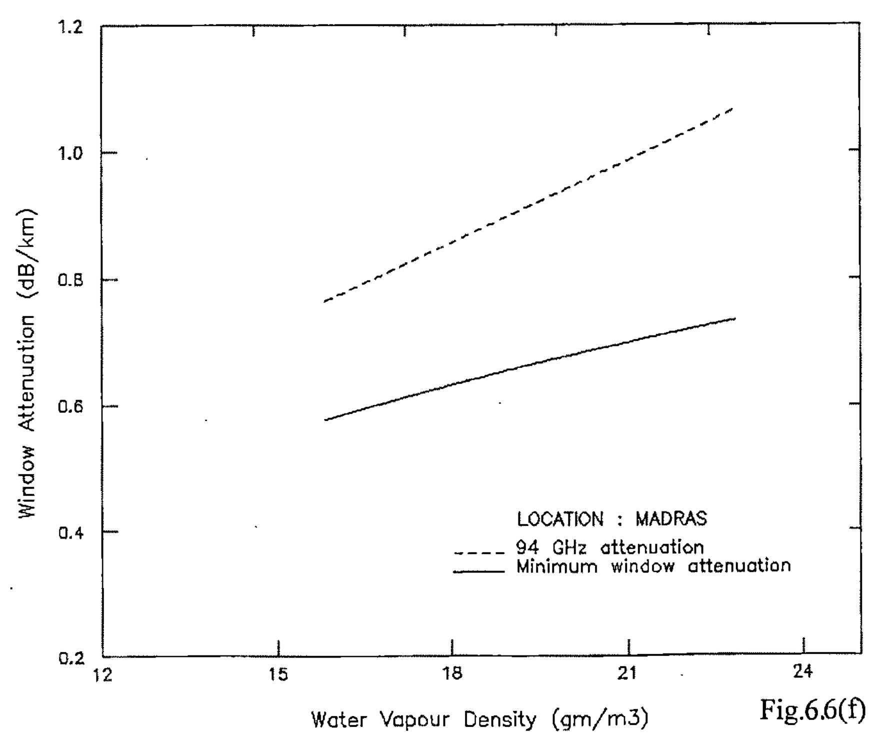

Fig.6.6(f)

Difference in window attenuation for conventional 94 GHz window and at minimum window frequency for maximum and minimum humidity

Table - 6.2

Difference in specific attenuation at minimum and maximum humidity for 94 GHz window

Locations	Window range (GHz)	For 94 GHz window Specific attenuation diff. (dB/km)	
		at min. humidity	at max. humidity
Bombay	74-77	0.11	0.34
Calcutta	74-78	0.11	0.34
Guwahati	74-79	0.10	0.33
Madras	74-76	0.18	0.35
Nagpur	75-80	0.06	0.27
New Delhi	74-82	0.04	0.30

6.6. Discussion and Conclusion :

It is interesting to note that the estimates of atmospheric opacity by *Smith* [1982] and that of downward brightness temperature by *Liebe* [1989] over the millimeter wave band also exhibit a shift of window for varying water vapour density. All the literature uptil now mentioned the fixed values of window frequencies at 35, 94, 140 and 220 GHz and the first paper indicating the window shift was made from our group [*Sen et al.* 1994]. The shift is largest for the window near 94 GHz and that is marginal at 220 GHz. As early as in 1988, *Altshular*[1988] observed that theoretical estimation of attenuation sharply differs from experimental values except at resonance lines in millimeter wave band and that this deviation is often 2 to 3 times larger than the theoretically estimated values. He suggested that such deviations may be due to the fact that the line shape function does not predict the absorption around the wings of resonance lines and there may be some other sources of absorption which are yet to be identified. The present estimate based on the Water's model, which is useful upto 100 GHz, agrees well with experimental window frequencies.

Amongst various windows, the 94 GHz window is 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 appropriately play a vital role in choosing correct operating frequency for most of the high resolution radar and radiometric applications like, anti aircraft and anti tank weapon systems and missile seekers. The selection of proper shifted window helps in enhancing the signal and reducing the noise to obtain a higher signal to noise ratio of the millimeter wave receivers, which is very important, in view of the scarcity of high power millimeter wave sources. Also, as the conventional 94 GHz window is shifted to the lower frequency end by about 20 GHz, receiver front end with comparatively lower noise figure will be available at the shifted window frequency to improve signal to noise ratio a step further.

Computer Program : 1

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10 '****** WATER'S MODEL  : OXYZEN+WATER VAPOUR ABSORPTION :  *******
20 '
30 KEY OFF :COLOR 10,12,11:CLS
40 DEFINT I-L,N
50 DEFSNG B-F,G-H,P-Z,M
60 DIM GNP(20),GNM(20),DNM(20),DNP(20),PHI(20),YNP(20),YNM(20),PO2(350),E(50),
PTOT(350),Z(350)
70 PRINT "              ********************************************"
80 PRINT "              *                                          *"
90 INPUT "              *    YEAR               : ",YE
100 PRINT "             *                                          *"
110 INPUT "             *    MONTH              : ",B$
120 PRINT "             *                                          *"
130 INPUT "             *    STATION            : ",A$
140 PRINT "             *                                          *"
150 INPUT "             *    SURFACE ALTITUDE (mt)   : ",HHT
160 PRINT "             *                                          *"
170 INPUT "             *    LAYER THICKNESS (mt)    : ",INC
180 PRINT "             *                                          *"
190 INPUT "             *    ENDING LATITUDE (mt)  :";ENDING
200 PRINT "             *    -------------------------------      *"
210 PRINT "             *                                          *"
220 INPUT "             *    STARTING FREQUENCY(GHz) :",F1
230 PRINT "             *                                          *"
240 INPUT "             *    ENDING FREQUENCY(GHZ)   :",F2
250 PRINT "             *                                          *"
260 INPUT "             *    INCREMENT IN FREQ(GHz)  :",M
270 PRINT "             *                                          *"
280 PRINT "             ********************************************"
290 CLS : KEY OFF
300 X=0 :S1=0 :S2=0: HT=HHT
310 PRINT "YEAR                : ";YE,"        MONTH  :";B$
320 PRINT "STATION             : " ;" ";A$
330 PRINT "STARTING ALTITUDE    : " ; HT; "(mt.)"
340 PRINT "INCREMENT            : " ; INC; "(mt.)"
350 '
360 OPEN "O",#1,"INTEG.DAT"
370       FOR I= 1 TO 10
380          READ GAIO(I),A(I),X(I),BF(I),EB(I),AA(I)
390       NEXT I
400 PRINT STRING$(80,61);
410 PRINT "Frequency           Integrated           Noise"
420 PRINT "  (GHz)           Absorption(dB)        Temperature(k)"
430 PRINT STRING$(80,61);
440 IF F1>45 THEN 720
450 IF F2=<45 THEN F3=F2 ELSE F3=45
460 FOR F=F1 TO F3  STEP M
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```
470 HT = HHT
480 S3=0
490 BEEP : FOR XX=1 TO 5000 : NEXT
500 FOR II= HT TO ENDING STEP INC  : ' 10000 mt : heighest level considered
510 GOSUB 1690
520 IF P>=333 THEN GAMMAO= .59 :GOTO 550
530 IF P<=25 THEN  GAMMAO= 1.18 :GOTO 550
540    GAMMAO = .59*(1+.0031*(333-P))
550       GAMMA = GAMMAO*P/1013*((300/T)^.85)
560         V = 1/((F-60)^2+GAMMA^2)+1/(F^2+GAMMA^2)
570       PO2(F)= .011*F^2*P/1013*(300/T)^2*GAMMA*V
580 GOSUB 1320
590 'PRINT "ZZ(F)=";Z(F)
600  PTOT(F)=PO2(F)+Z(F):   'GOSUB 1790
610 PTOT(F)=PTOT(F)*4.343
620 S3= S3+PTOT(F)*INC/1000 : PRINT "Alpha (dB/km) :";PTOT(F);"sum=";S3
630 PRINT "rov =";ROV
640 T = T-273 : TD = TD-273
650 PRINT #1, HT;T;ROV;PTOT(F);S3
660 HT = HT+INC
670 NEXT II
680 S4= (290*10^(S3/10))-290 : S4 = S4/10^(S3/10)
690 PRINT USING "###.##";F;:PRINT TAB(24);S3;TAB(50);S4
700 PRINT #1, HT;T;ROV;PTOT(F);S3
710 NEXT F : CLOSE #1 : END
720    FOR N=1 TO 20
730       READ GNP(N)
740    NEXT
750    FOR I= 1 TO 20
760       READ GNM(I)
770    NEXT I
780    FOR I= 1 TO 20
790       READ YNP(I)
800    NEXT I
810    FOR I= 1 TO 20
820       READ YNM(I)
830    NEXT I
840 IF F1>45 THEN F3=F1  ELSE F3=45 + M
850 FOR F=F3 TO F2 STEP M
860 HT = 10
870 S3 = 0
880 BEEP
890 FOR II = HT TO 10000 STEP INC
900 GOSUB 1690
910          GAMMAB= .49*(P/1013)*(300/T)^.89
920          GAMMAN= 1.18*(P/1013)*(300/T)^.85
930   Q=0
940            FOR N= 1 TO 39 STEP 2
950               X1= 2*N^2+3*N        : Y1= 2*N^2+N
960                     J=(N+1)/2
970               DNP(J)= (X1/(X1+1))^.5 : DNM(J)= ((Y1-1)/Y1)^.5
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```
980 '
990 '************* CALCULATION OF PHI(N) ************
1000 '
1010          Z1=-.00689*N*(N+1)*(300/T)
1020        PHI(J)=.0046*(2*N+1)*(300/T)*EXP(Z1)
1030    U=(GAMMAN*DNP(J)^2+P*(F-GNP(J))*YNP(J))/((F-GNP(J))^2+GAMMAN^2)
1040   IF F<0 THEN 1060
1050     A= U   :  GOTO 1070
1060     B= U
1070    S=(GAMMAN*DNM(J)^2+P*(F-GNM(J))*YNM(J))/((F-GNM(J))^2+GAMMAN^2)
1080          IF F<0 THEN 1100
1090            C= S : GOTO 1110
1100            D= S : F=-F   :GOTO 1120
1110            F=-F        :GOTO 1030
1120          E(J)= PHI(J)*(A+B+C+D)
1130       Q= Q+E(J)
1140     NEXT N
1150   DASH= .7*GAMMAB/(F^2+GAMMAB^2)+Q
1160   PO2(F)= .0161*F^2*(P/1013)*DASH*(90000!/T^2)
1170 GOSUB 1320
1180 PTOT(F)=PO2(F)+Z(F): 'GOSUB 1790
1190 GOTO 1200
1200 S3 = S3 +PTOT(F)*INC/1000
1210 HT = HT+INC
1220 T = T-273 : TD = TD-273
1230 NEXT II
1240 S4= (290*10^(S3/10))-290 : S4 = S4/10^(S3/10)
1250 PRINT USING "###.##";F;:PRINT TAB(24);S3;TAB(50);S4
1260 LPRINT USING "###.##";F;:LPRINT TAB(24);S3;TAB(50);S4
1270    NEXT F
1280          PRINT :PRINT :PRINT :PRINT
1290 CLOSE #1
1300 END
1310 '
1320 '***** WATER ABSORPTION BETWEEN 1-99 GHz ********
1330 '
1340 E=6.1078*EXP(5369*((1/273)-(1/TD)))
1350 ROV=E*18*100/(8.310001*TD)
1360 '
1370 '******* WATER ABSORPTION BETWEEN 1-300 GHz *******
1380 '
1390 Y1=0
1400 FOR I= 1 TO 10
1410    GAI = GAIO(I)*P/1013*((300/T)^X(I))*(1+.01*A(I)*ROV*T/P)
1420      Y=(BF(I)^2-F^2)^2+4*F^2*GAI^2
1430         Y=AA(I)*EXP(-EB(I)/T)*GAI/Y
1440    Y1=Y1+Y
1450 NEXT I
1460 WAB=2*F^2*ROV*((300/T)^2.5)*Y1
1470 DELK=4.69E-06*ROV*((300/T)^2.1)*(P/1000)*F^2
1480 Z(F)=WAB+DELK
```

```
1490 RETURN
1500 '
1510 '     ****** DATA BANK : WATER VAPOUR ABSORPTION  ******
1520 '
1530 DATA 2.85,1.75,.626,22.23515,644,1.0,2.68,2.03,.649,183.31012,196,41.9
1540 DATA 2.30,1.95,.42,323,1850,334.4,3.3,1.85,.619,325.1538,454,115.7
1550 DATA 3.19,1.82,.63,380.1968,306,651.8,2.11,2.03,.33,390,2199,127
1560 DATA 1.5,1.97,.29,436,1507,191.4,1.94,2.01,.36,438,1070,697.6
1570 DATA 1.51,2.02,.332,442,1507,590.2,2.47,2.19,.51,448.0008,412,973.1
1580 '
1590 '     ******* DATA BANK : OXYGEN ABSORPTION  *******
1600 '
1610 DATA
56.2648,58.4466,59.5910,60.4348,61.1506,61.8002,62.4112,62.9980,63.5685,64.1278,64.6789,65.2241,6
5.7647,66.3020,66.8367,67.3694,67.9007,68.4308,68.9601,69.4887
1620 DATA
118.7503,62.4863,60.3061,59.1642,58.3239,57.6125,56.9682,56.3634,55.7838,55.2214,54.6711,54.1300,
53.5957,53.0668,52.5422,52.0212,51.5030,50.9873,50.4736,49.9618
1630 DATA 4.51E-4,4.94E-4,3.52E-4,1.86E-4,3.3E-5,-1.03E-4,-2.23E-4,-3.32E-4,-4.32E-4,-5.26E-4,-
6.13E-4,-6.99E-4,-7.74E-4,-8.61E-4,-9.11E-4,-1.03E-3,-9.87E-4,-1.32E-3,-7.07E-4,-2.58E-3
1640 DATA -2.14E-5,-3.78E-4,-3.92E-4,-2.68E -4,-1.13E-4,3.44E-5,1.65E-4,2.84E-4,3.91E-4,4.93E-
4,5.84E-4,6.76E-4,7.55E-4,8.47E-4,9.01E-4,1.03E-3,9.86E-4,1.33E-3,7.01E-4,2.64E-3
1650 '
1660 PRINT USING "###.###";F;:PRINT TAB(14):PRINT USING "##.####";PO2(F),
1670 PRINT TAB(34):PRINT USING "##.####";Z(F);
1680 PRINT TAB(54):PRINT USING "##.####";PTOT(F):RETURN
1690 '**************   SUBROUTINE FOR REGRESSION   ************
1700 '
1710 PRINT
1720 PRINT "              HEIGHT              :";HT;"METRES"
1730 P = EXP(-1.33311E-04*HT)*983.396
1740 T = -2.03587 - .0136194*HT + 3.40837E-06*HT^2-5.20946E-10*HT^3
1750 TD = -19.723 - .0041416*HT + 8.95729E-07*HT^2-3.27643E-10*HT^3
1760 PRINT "              PRESSURE            :";P;" mb"
1770 T = 29.0708-5.89463E-03*HT+1.6137E-07*HT*HT-7.83469E-11*HT*HT*HT+1.66647E-
14*HT*HT*HT*HT-1.14291E-18*HT*HT*HT*HT*HT
1780 PRINT "              TEMPERATURE         :";T;" c"
1790 TD = -6.18492E-03*HT + 25.5677
1800 PRINT "              DEW POINT TEMPERATURE  :";TD;" c"
1810 PRINT
1820 T=T+273 :TD=TD+273
1830 RETURN
1840 E=6.1078*EXP(5369*((1/273)-(1/TD)))
1850 ROV=E*18*100/(8.310001*TD)
1860 GA1=2.85*(P/1013)*(1+.018*ROV*T/P)*(300/T)^.626 : PRINT "GA1=";GA1
1870 PRINT "ROV,T,F";ROV,T,F
1880 Z(F)=2*F*F*ROV*((300/T)^1.5)*GA1*((300/T)*EXP(-644/T)*1/((494.4-
F^2)^2+4*F^2*GA1^2)+.0000012) : PRINT "Z(F)=";Z(F)
1890 RETURN
```

Computer Program : 2

```
10 CLS : KEY OFF
20 '============= WINDOW FREQUENCY DETERMINATION ===========
30 '
40 PRINT "            TO FIND ACCURATE WINDOW FREQUENCY NEAR 94 GHz"
50 PRINT "                 FOR THE FOLLOWING LOACTIONS"
60 PRINT STRING$(80,45);
70 PRINT TAB(31);"BOMBAY     : 1 "
80 PRINT TAB(31);"CALCUTTA   : 2"
90 PRINT TAB(31);"GUWAHATI   : 3"
100 PRINT TAB(31);"MADRAS     : 4"
110 PRINT TAB(31);"NAGPUR     : 5"
120 PRINT TAB(31);"NEW DELHI  : 6"
130 PRINT STRING$(80,45);
140 LOCATE 11,1
150 INPUT "                    YOUR CHOICE : ";I
180 INPUT "             ENTER SURFACE WATER VAPOUR DENSITY (gm/m3): ",ROH
190 PRINT
200 PRINT STRING$(80,61);
210 ON I GOTO 220,250,280,310,340,370
220 '----- REGRESSION EQUATION FOR BOMBAY -------
230 F=80.4-.22*ROH-.002*ROH^2
240 GOTO 400
250 '----- REGRESSION EQUATION FOR CALCUTTA ------
260 F=84.86-.75*ROH+.013*ROH^2
270 GOTO 400
280 '----- REGRESSION EQUATION FOR GUWAHATI ------
290 F=86.2-.88*ROH+O.O15*ROH^2
300 GOTO 400
310 '----- REGRESSION EQUATION FOR MADRAS ------
320 F=86.04-.83*ROH+.014*ROH^2
330 GOTO 400
340 '----- REGRESSION EQUATION FOR NAGPUR ------
350 F=86.1-1.02*ROH+.024*ROH^2
360 GOTO 400
370 '----- REGRESSION EQUATION FOR NEW DELHI ------
380 F=89.29-1.48*ROH+.038*ROH^2
390 '-------------- RESULT ----------------
400 PRINT "             THE IDEAL WINDOW FREQUENCY IS     : ";F;" GHz"
410 PRINT STRING$(80,61);
420 END
```