Dynamics of the lower atmosphere through analysis of fade characteristics of microwave signals

Sanjay Sharma, K I Timothy*, M Devi & A K Barbara
Department of Physics, Gauhati University, Guwahati-781014

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Fade characteristics of 6/7 GHz signal collected over Milmilia, Maopet and Laopani line-of-sight (LOS) links of Assam valley have been analysed along with supporting meteorological parameters in relation to receive-system dynamics. Statistical analyses of fade rate such as probability of occurrence, cumulative distribution (at 50% probability level) etc. at different temporal situations have been made. The vertical velocity of the atmospheric irregularities leading to signal fluctuations has been calculated from fade durations. Using these velocity components, a model equation relating vertical velocity and fade rate has been framed. A few case studies on particular fade events over Laopani link have been carried out to derive irregularity parameters such as scale size, scattered component and refractivity structure constant \( C_n^2 \). Finally the fade analysis has been used as a tool for interpreting morning time fast fades due to the scattering of signal by high speed (0.3 m/s) small scale dense irregularities, and nocturnal fades through reflection of signal from relatively stable layers.

1 Introduction

When a radio wave propagates through a non-ionized atmosphere, it is distorted by factors like absorption, anomalous refraction and random scattering of signal. While anomalous refraction of signal results from steep changes in radio refractive index (RRI) gradient of the medium leading to development of layered structures, the random scattering is associated with the small scale fluctuations of RRI. As RRI is a function of temperature, pressure and humidity of the atmosphere, a close relationship is established between velocity fluctuation of air (i.e. atmospheric turbulence) and RRI. Significant progress has been made towards receiving scale size of turbulence through analysis of refractive index spectra. Field strength of a signal (at the receiving end) varies with the characteristics of the medium that can broadly be seen as long-term and short-term changes. The fluctuations of microwave signals in a turbulent atmosphere as well as in layered structures have been extensively studied in the past. In such studies fades are generally associated with coherent and incoherent scattering of signals from atmospheric irregularities.

It is known that field strength at the receiving site is a composition of direct and scattered components. The purpose of this analysis is to determine relative magnitudes of these two components in terms of \( S_K \), where \( S_K \) is the ratio in decibels of root mean square amplitudes of scattered component to the amplitude of the constant component. The \( S_K \) value is determined from fade range and the relationship is given by

\[
R(0.1) - R(0.9) = 22.2628 \times 10^k + 12.1880 \times 10^{k^3} \quad (1)
\]

and

\[
S_K = 20 \log_{10} k \quad (2)
\]

where \( R(0.1) - R(0.9) \) is a fading range.

The vertical velocity of the irregularities in a propagating medium can be described by the following relation

\[
V = E / 8 t (D \lambda / n)^{1/2} \quad (3)
\]

where \( V \) is the vertical velocity of the irregularities, \( D \) is the distance traveled by irregularity, \( \lambda \) the radio wavelength, \( t \) the fade duration, \( E \) the envelope voltage, and \( n \) the number of Fresnel zones.

The corresponding scale size of the irregularities is expressed by the following relation

\[
l_0 = \sqrt{3} V_n / N[r(0.5)] \quad (4)
\]

where \( V_n \) is the velocity of the irregularities across the propagation path and \( N[r(0.5)] \) is the fade rate at the median value.
2 Data Collection and Analysis

Fade data of 6/7 GHz signal collected over Milmi1ia, Maopet and Laopani links of Assam valley have been analysed along with supporting meteorological parameters like temperature, pressure and humidity to receive the growth and development conditions of irregularities of various scale sizes and their velocity components. Microwave links selected for this purpose are given below along with the longitudes and latitudes of the receiving stations.

<table>
<thead>
<tr>
<th>Link parameter</th>
<th>Milmi1ia-Durgasarovar link (long. 91.75°E, lat. 26.20°N)</th>
<th>Maopet-Durgasarovar link (long. 91.75°E, lat. 26.20°N)</th>
<th>Laopani-Habaipur link (long. 93.10°E, lat. 25.80°N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance, km</td>
<td>40.2</td>
<td>64.4</td>
<td>55.8</td>
</tr>
<tr>
<td>Frequency, GHz</td>
<td>6.4</td>
<td>6.0</td>
<td>7.13</td>
</tr>
<tr>
<td>Antenna height, m</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 50</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 70</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 80</td>
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<tr>
<td></td>
<td>R&lt;sub&gt;r&lt;/sub&gt;: 50</td>
<td>R&lt;sub&gt;r&lt;/sub&gt;: 70</td>
<td>R&lt;sub&gt;r&lt;/sub&gt;: 80</td>
</tr>
<tr>
<td>Antenna gain, dBm</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 43.3</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 44.8</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 39.5</td>
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<tr>
<td></td>
<td>R&lt;sub&gt;r&lt;/sub&gt;: 43.3</td>
<td>R&lt;sub&gt;r&lt;/sub&gt;: 44.8</td>
<td>R&lt;sub&gt;r&lt;/sub&gt;: 35.5</td>
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<tr>
<td>HASL</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 105</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 1660</td>
<td>80</td>
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<tr>
<td></td>
<td>R&lt;sub&gt;r&lt;/sub&gt;: 228</td>
<td>R&lt;sub&gt;r&lt;/sub&gt;: 228</td>
<td>80</td>
</tr>
<tr>
<td>Power*, dBm</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 40</td>
<td>T&lt;sub&gt;r&lt;/sub&gt;: 40</td>
<td>30</td>
</tr>
</tbody>
</table>

The technical information and terrain features of the above mentioned links are given in Table 1 (Ref. 14). The analysis given in this paper is primarily based on the data collected during the period of one year covering 1992-93.

To characterize fade features of microwave signal, the automatic gain control (AGC) outputs of the receivers were recorded on round the clock basis on a chart recorder. Fade rate was found out by counting the number of times the positive slope of the signal crossed the mean value. The data were analysed for 30-min durations. The analysis was made for each 5-min durations for fast fade signals. The fade depth was coded at intervals of 2 dB and the duration over which a particular signal level remained below a specified value was found out. The average fade duration at any fade depth was obtained from the ratio of total time at or below the fade depth level to the number of fades of this depth.

3 Types of Fades

Microwave fades over these three links were first grouped after examining the three basic parameters viz. fade rate, fade depth and fade duration of a signal, and based on this study the fade patterns were grouped into three basic types as slow and deep, fast and deep, and fast and shallow (scintillation type). The representative fade patterns of each type are shown in Fig. 1.

4 Fade Rate Characteristics

4.1 Milmi1ia-Durgasarovar Link

Figure 2(a) represents the probability of occurrence of fade rate of a particular fade rate level over Milmi1ia-Durgasarovar path. We note that fade rate varies with season and probability of occurrence is highest during winter months with 5 fades/h which is detected 34% of the total winter period. However, the maximum fade rate is observed in summer when 80 fades/h is noted with low occurrence of probability (0.1%). During pre-monsoon months too fade rates are fairly high (70 fades/h). The maximum fade rate for winter and post-monsoon season is limited at 40 fades/h. This picture is also obtained from cumulative distribution of fade rate which is shown in Fig. 2(b). It is also noted that fade rate is not uniform all throughout the day and signals that suffer fast fades are detected more often during morning to midday hours. Figure 2(c) gives the diurnal variation of average fade rate. It shows that the average fade rate (with 17 fades/h) is maximum during midday hours in summer months.

4.2 Maopet-Durgasarovar Link

The occurrence percentage of different fade rates for a complete season over this link [Fig. 3(a)] shows that though the probability of occurrence of 5-10 fades/h is maximum during winter, the fade rate as high as 120 fades/h has also been observed during summer with fairly low occurrence probability (0.5% only). The cumulative distribution of average fade rate also reflects this pattern [Fig. 3(b)]. Here we see that for 50% probability level, winter favours 5 fades/h while during summer it goes to 10 fades/h. Figure 3(c), which represents an average diurnal variations of fade rate, shows fade rate to reach maximum during daytime and minimum during night hours.
Fig. 1—Sample records of microwave fades [(a) Slow and deep, (b) Fast and deep, and (c) Fast and shallow (scintillation type)].

Fig. 2—Fade rate characteristics over Milmilía-Durgasarovar link [(a) Probability of occurrence of fade rate, (b) Cumulative distribution of fade rate, and (c) Diurnal variation of average fade rate].
The average fade rate is highest in summer months with 20 fades/h and is minimum during winter months with 8 fades/h. During pre-monsoon and post-monsoon periods, average fade rate varies between 15 and 10 fades/h respectively.

4.3 Laopani-Habaipur Link

The maximum fade rate over this link is observed during summer months as has been seen for other two links. Figure 4(a) shows the probability of occurrence of fade rates at different seasons of the year. The fade rate up to 160 fades/h is more often detected during summer and fast fades are very less during winter, while fade rate up to 140 fades/h is present during pre- and post-monsoon periods. This picture is also reflected in the cumulative distribution of fade rate [Fig. 4(b)]. The fade rate which is high during summer with 20 fades/h at 50% probability level goes down to 8 fades/h during winter. A clear preferential development time of fast fades is noted while examining the presence of diurnal variation of fade rate. The fast fades start developing after 3-4 h of local sunrise and fade rate increases till pre-noon hours [Fig. 4(c)]. The average fade rate goes up to 24 and 14 fades/h during summer and pre-monsoon pre-midday hours.

5 Fade Rate versus Vertical Velocity

The vertical velocity of irregularities generated in a medium can be computed through fade duration parameter [Eq. (3)]. However it would be of interest to examine the relationship between fade rate and vertical velocity of irregularities. In an attempt to find such a relation, fade rates of 7.13 GHz signal over Laopani-Habaipur link were analysed at median value (for periods of 5-min duration) for the same fade series used for calculating the vertical velocity through fade duration analysis. The representative fade patterns of the signal used for such analysis are shown in Fig. 1(a-c). The relation between fade rate and vertical velocities (calculated through fade duration parameter) for a large number of fade patterns involving both fast and slow variations is shown in Fig. 5. The best fit curve is represented by a solid line. It is clear that these two parameters are associated with a power law which can be fitted into an expression,

\[ V = (0.00099) N^{0.533} \]

6 Case Studies of Receive-System Dynamics

One of the important parameters through which the dynamics of the system can be realized is the \( S_K \) values. As this parameter gives the scattered
component of the signal, one can have a fairly good idea of scale size of the irregularities through examination of $S_K$ values. To study the scattered component at different fade situations, we studied a few cases and the $S_K$ values received for each case were averaged over 2-min time durations. For example, the scattered components received through fade depth data of fade pattern shown in Fig. 6(a) are found to vary between 5 and 20 dB (Fig. 7), while for fades of Fig. 6(b) the scattered component is negligible (i.e. $S_K$ is very small). It is to be noted that in the pattern of Fig. 6(a) fast fades are significant and the wide variation in $S_K$ as observed in this case is therefore expected. The signal undergoes slow variations (dominant component) in the fades of the type shown in Fig. 6(b).

The vertical velocity and the scale sizes of the irregularities were then calculated by using Eqs (3) and (4) and the results are presented in Fig. 8 for fast fades [of the type shown in Fig. 6(a)]. The corresponding parameters for slow fades are shown in Fig. 9. For fast fading, the vertical velocity of the irregularities varies from 0.20 m/s to 0.60 m/s while for slow fading the vertical velocity goes down to 0.01 m/s. The average scale size of the irregularities in both cases however lies within 20 to 140 cm. This is not unexpected because in type 1 fades [Fig. 6(a)], though scattering predominates (with $S_K$ going as high as 20 dB), slow deep fades modulate the signal all throughout. Similarly in type 2 signal, though it has suffered deep slow fades, there are relatively fast fluctuations with low $S_K$ values superimposed over slow fades. The spectral analysis technique was then adopted to compute velocity of irregularities. For this purpose, the fade series [of the
type shown in Fig. 6(a)] was sampled at 1-s interval and was first processed through autocorrelation technique to derive the correlation parameter, if any, before FFT was adopted. Figure 10 shows the typical autocorrelation parameter received from such fade pattern. The presence of undulation in autocorrelation parameters indicates development of wavelike structure in the atmosphere. As each lag corresponds to 10 s, the undulation structures presented in Fig. 10 has an average duration of one minute. After realizing the presence of the periodic structure in the atmosphere, the time series was processed for FFT analysis and the maximum powered frequency of $80 \times 10^{-3}$ Hz (for this case) was received from this spectral analysis (Fig. 11). The velocity of the irregularities was then calculated by using the relation$^{16}$, $f_m = \nu/(2\lambda z)^{1/2}$, where $\nu$ is the velocity of
the irregularities, $\lambda$ the radio wavelength, $f_m$ the maximum spectral density frequency, and $z$ the antenna height in our case. This technique gives the vertical velocity of the order of 24 cm/s, which is almost of the same magnitude as received through fade duration analysis.

One more important parameter through which system dynamics can be realized is $C_n^2$, the refractivity structure constant that gives a measure...
of intensity of fluctuation of refractive index. $C_n^2$ can be calculated by using the following formula:

$$\sigma^2 = 0.31 \ C_n^2 \ K^{7/6} \ L^{1.6}$$

where $K$ is the wave number and $L$ is the path length.

As the refractivity structure constant is associated with fast fadings, we calculate this parameter for the type of fading as shown in Fig. 6(a). The value of $C_n^2$ for this pattern is found out to be $1.8 \times 10^{-9} \text{ m}^{-2/3}$.

### 7 Discussion

Microwave signal undergoes fades due to varied intrinsic properties of the atmosphere. The three basic parameters of fades like fade depth, fade rate and fade duration can effectively be used to extract the dynamics of the system. The above analysis shows that the fade rate maintains a clear diurnal and seasonal pattern irrespective of terrain features and in all the cases fade rate reaches maximum during pre-noon hours. This high fade rate (scintillation type of fading) during this period is generally developed after a couple of hours of sunrise. Such fast fades may be expected during this period because due to ground heating, the ground-based inversion layer, when moves up, generates a turbulent condition in the atmosphere causing incoherent scattering of signal from small scale irregularities and in all the cases fade rate reaches maximum during pre-noon hours. This high fade rate (scintillation type of fading) during this period is generally developed after a couple of hours of sunrise. Such fast fades may be expected during this period because due to ground heating, the ground-based inversion layer, when moves up, generates a turbulent condition in the atmosphere causing incoherent scattering of signal from small scale irregularities (if developed in such a process), resulting in scintillation type of fading.

The sodar observation at the midpath of Milimilia-Durgasarvar link has also suggested this possibility. Increase in the number of fades during morning hours has been reported even from a near radio horizon measurements at 100 MHz (Ref. 20).

It would be of interest to examine the temporal changes of RRI gradient parameter in the above context. For this purpose RRI gradient was systematically monitored for a year at midpath over one of the links. Figure 12 shows that radio refractive index gradient ($dN/dH$) may go up to $-180 \text{ N/km}$ with 5% probability of occurrence during sunset hours, whereas this value goes down to $-140 \text{ N/km}$ (for the same probability of occurrence) during sunrise hours. It is also seen from Fig. 12 that the most probable value of $dN/dH$ in this period lies between $-60$ and $-80 \text{ N/km}$, a situation when atmosphere undergoes convective mixing. As this process inhibits the formation of stable layers, in such a situation one can only expect microwave signal to suffer scattering from small scale dense irregularities if developed in the mixing process. The development of fast fluctuations in microwave signal (with large $S_K$ values), leading to large fade rate during sunrise period (Fig. 1(c)), can therefore be associated with the scattering of signal from such irregularities. Fast fluctuations modulated over slow fades during pre-midnight hour (types of fades shown in Fig. 1(b)) are also expected as both reflection and scattering of signal are possible from relatively stable layered structures embedded with small scale dense irregularities. Similar observation has also been reported over a 42 km link path of a 7 GHz link. The fades detected from pre-midnight to pre-sunrise hours can very well be associated with the reflection of signal from stable structures in the atmosphere as recorded by sodar echogram at the midpath of the Durgasarvar-Milimilia link in Fig. 13. The vertical velocities that have been calculated through simple assumption (velocity to be same all through the
8 Conclusions
(1) Fade rate follows a distinct diurnal pattern irrespective of the terrain, and the maximum fade rate is seen during summer day hours.
(2) Nocturnal fadings are dominated by reflection phenomenon and the daytime fadings occur mainly due to scattering from relatively fast moving small scale dense irregularities.
(3) Fade rate and vertical velocity of the irregularities maintain a positive relation following a power law, \( V = (0.00099) N[r(0.5)]^{0.33} \).
(4) Scale sizes of the irregularities responsible for scattering 7 GHz signal are found to vary from 20 to 140 cm.
(5) The vertical velocities of irregularities are found to vary between 0.01 m/s and 0.6 m/s at 80 m height level (antenna height level).
(6) Refractivity structure constant is received as \( 1.8 \times 10^{-9} \) over one of the 55-km link paths.
(7) The nocturnal high RRI gradient up to \(-180 \text{ N/km}\) as observed over midpath of one of the links reflects development of stable layers, while the relatively low values of RRI gradient during sunrise hours suggest presence of a fairly active mixing process.

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References