CHAPTER IV

MICROWAVE PROPAGATION CHARACTERIZATION IN THE COASTAL AND INLAND ZONE IN TROPICAL INDIA
4.1 INTRODUCTION:

In the previous chapters various meteorological parameters and their effect on microwave propagation have been discussed. In this chapter propagation characteristics observed over a line-of-sight microwave link of 115 km hop length are presented. The long-hop microwave link is situated between Gooty and Penukonda (inland region) and for the first time an attempt has been made to study systematically the propagation characteristics observed over this microwave link. For this link, seasonwise fading statistics have been computed and the association of field strength with various meteorological parameters are also discussed. Propagation characteristics over microwave links situated in the coastal zone differ from those of propagation characteristics prevailing over inland zone, because of high humidity and high occurrence percentage of super refraction/ducting.

4.2 OBJECTIVE:

With the above philosophy in mind, this chapter presents the study of the propagation characteristics namely median signal level, basic transmission loss, fade rate, fade depth, scintillation index and structure intensity parameter observed over Gooty-Penukonda microwave link. A few protection methods are studied and some remedial methods are suggested. Geoclimatic factors are determined and path inclination effect on fading of microwave signal is studied using the data of Puducherry-Madras, Chittadu-Nellore, Tiruttani-Tirupati, Pallavaram-Tirumala, Elagiri-Tirumala and Gooty-Penukonda microwave links situated in Southern India. A brief survey of the earlier work carried out by researchers on the microwave propagation is presented in the next section.
4.3 PREVIOUS INVESTIGATIONS:

The transmission performance of a line-of-sight microwave link is affected by the intervening medium and the terrain characteristics. The intervening medium, because of its ever changing dynamics, both spatial and temporal (Bullington, 1957; Wait, 1962; Livingston, 1970) causes changes in the received signal and also results in fading phenomena (Dougherty, 1968; Bullington, 1971; Lin, 1971). This can be studied by monitoring the propagation characteristics such as hourly median signal level, basic transmission loss, fade rate, average fade depth and average fade-outs per hour and their average and seasonal variations.

The diurnal variation of fading on terrestrial line-of-sight radio paths have been previously studied by several groups all over the world (Morita and Kakita, 1958; Turner et al., 1966; Livingston, 1970; Barnett, 1972; Simpson, 1975; Christensen and Mogensen, 1982; Schiavone, 1982 and 1983; Nandini, 1985; Prasad, 1989, Rao et al., 1991a, 1991b, 1991c, 1992 and 1993; Reddy, 1993; Tang, 1993; Al Nuami, 1993; Dungey, 1993; Tawfic, 1993; Rao, 1994). In general, field strengths were higher in summer than in winter and diurnal changes are more pronounced in summer (Longley et al., 1971). Fading activity was found to be higher during the warmer periods of the year (Vigants, 1975). Autumn conditions characterized by a static or slow moving high pressure system have been identified as causing propagation problems on line-of-sight links in Central Europe (Samson et al., 1970) and in Germany (Farrow and Skerjanee, 1979).
In India fading characteristics of line-of-sight paths around 7 GHz were studied by a number of researchers (Sarkar, 1978; Nandini et al., 1983; Rao, 1984; Reddy, 1986; Prasad, 1989; Bhaskara Rao, 1990, Krishna Reddy, 1991, Rao et al., 1993). In Northern India, Sarkar (1978) made investigations on fading characteristics over flat terrains with 7.6 GHz link between Delhi and Sonepat. Prasad (1989) made an attempt to explain multipath fading on Delhi-Meerut troposcatter link operating at 2.2 GHz and also suggested remedial measure to overcome multipath fading (Prasad et al., 1990). In Southern India, Rao (1984) made detailed investigations on radioclimatology over Southern India using radiosonde data, and also the propagation characteristics of Tiruttani-Tirupati microwave link operating at 7.6 GHz. Propagation characteristics of microwave links situated over coastal and inland region in Southern India have been studied by Reddy (1986). Bhaskara Rao (1990) studied the propagation characteristics of two microwave links operating around 7 GHz with long hops. In Southern India, investigations to explore possible remedial measures to overcome severe fading of the microwave links situated over inland are very few.

4.4 TERRAIN CHARACTERISTICS:

The line-of-sight microwave link of Indian Railways lies in the inland zone and is situated between Gooty (Lat. 15°7'N; Log. 77°38'E) and Penukonda (Lat. 14°4'N; Log. 77°35'E) with a path length of 115 km operating at 7.3 GHz. The field strength measurements have been made at Penukonda (receiving station). The important feature of this microwave link is that it is a long hop and also surrounded by hills.
The transmitting antenna at Gooty is at a height of 457 meters whereas the elevation being 537 meters above mean sea level (msl). The receiving antenna at Penukonda is situated on a hill of 917 meters height and the antenna height being 8 meters, giving the effective antenna height of 925 meters above msl. The terrain profile of the microwave link is shown in figure 4.1. From the figure it can be seen that the rays reaching the receiver are having sufficient Fresnel zone clearance as there are no obstacles in between the ray path. The ray path is drawn using the effective earth’s radius factor 4/3. The system characteristics of the microwave link are given in Table 4.1.

It is important to note that the Gooty-Penukonda link is a commercial link and there were severe fading occurrences particularly in the late night and early morning hours in the premonsoon and winter seasons. This link was chosen with the idea of understanding the fading phenomena and suggesting some remedial measures to improve the performance of the link.

4.5 DATA BASE:

The amplitude measurements of the received signal strength are recorded on twenty four hour basis from July 1989 to June 1990. These observations are recorded using an omniscribe strip chart recorder with a time constant of 100 msec. During the observational period i.e., July 1989 to June 1990, the link is operated for 5,957 hours spread over 329 days. The non-operational periods are mainly due to power failure, and also some times malfunctioning of the recorder. The microwave link data is quite representative for all the seasons of the period under study.
FIG. 4.1: TERRAIN PROFILE OF THE MICROWAVE LINK BETWEEN GOOTY AND PENUKONDA

- **PENUKONDA**
  - Elevation: 917 m
  - Antenna height: 8 m

- **GOOTY**
  - Elevation: 457 m
  - Antenna height: 80 m
The field strength has been studied for both diurnal and seasonal behaviour. The seasons have been classified as premonsoon (March to May), monsoon (June to September), postmonsoon (October and November) and winter (December to February).

Tropospheric radioclimatological features deduced from the radiosonde data obtained from Bangalore are taken to correlate the observed fading. Monthly distribution of refractivity gradients between surface to 900 mb level are shown in table 4.2. The location of microwave link and near by radiosonde stations is given in figure 4.1(a), from which it can be seen that Madras, Hyderabad and Bangalore radiosonde stations are 310 km, 390 km, and 130 km away from the receiving terminal. The radiosonde data of Bangalore is taken as it is the nearest radiosonde station available from the transmitter and receiver. According to meteorologists, radiosonde data is generally valid upto a distance of about 300 kms. Hence the data can be used to study the observed fading over Gooty-Penukonda microwave link. Obviously, in making this assumption, it is not expected that there exists one-to-one correspondence between the refractive profiles observed over Bangalore and received signal behavior on this link, but only to indicate trends in the type and intensity of gradients and their probable occurrence and their diurnal and seasonal patterns.

4.5.1 Calibration of the microwave link

The tropospheric fluctuations of the signal over the Gooty-Penukonda microwave path are recorded by connecting an omniscribe strip chart recorder (with a time constant of 100 msec) at the AGC point of
TABLE 4.1: SYSTEM CHARACTERISTICS OF GOOTY-PENUKONDA LOS MICROWAVE LINK

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>7.338 GHz</td>
</tr>
<tr>
<td>Transmitting station</td>
<td>Gooty</td>
</tr>
<tr>
<td>Receiving station</td>
<td>Penukonda</td>
</tr>
<tr>
<td>Transmitting antenna</td>
<td>Parabolic dish with horn feed</td>
</tr>
<tr>
<td>Height of the transmitting antenna</td>
<td>925 meters, m.s.l.</td>
</tr>
<tr>
<td>Gain of the transmitting antenna</td>
<td>43 dB</td>
</tr>
<tr>
<td>Receiving antenna</td>
<td>Parabolic dish with horn feed</td>
</tr>
<tr>
<td>Height of the receiving antenna</td>
<td>537 Meters, m.s.l.</td>
</tr>
<tr>
<td>Gain of the receiving antenna</td>
<td>43 dB</td>
</tr>
<tr>
<td>Transmitted power</td>
<td>1 watt</td>
</tr>
<tr>
<td>Recorder time constant</td>
<td>100 msec</td>
</tr>
<tr>
<td>Data reported</td>
<td>July 1989 - June 1990</td>
</tr>
<tr>
<td>Observed free space loss</td>
<td>151 dB</td>
</tr>
<tr>
<td>Observed loss during daytime</td>
<td>202 dB</td>
</tr>
</tbody>
</table>
### TABLE 4.2: MONTHLY DISTRIBUTION OF REFRACTIVITY GRADIENTS BETWEEN SURFACE TO 900 mb LEVEL AT 0000 GMT AND AT 1200 GMT

<table>
<thead>
<tr>
<th>Months</th>
<th>B</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>December</td>
<td>-52 (-45)</td>
<td>-50 (-45)</td>
</tr>
<tr>
<td>January</td>
<td>-60 (-55)</td>
<td>-58 (-45)</td>
</tr>
<tr>
<td>February</td>
<td>-65 (-55)</td>
<td>-65 (-55)</td>
</tr>
<tr>
<td>March</td>
<td>-60 (-60)</td>
<td>-75 (-55)</td>
</tr>
<tr>
<td>April</td>
<td>-55 (-60)</td>
<td>-80 (-60)</td>
</tr>
<tr>
<td>May</td>
<td>-55 (-50)</td>
<td>-90 (-65)</td>
</tr>
<tr>
<td>June</td>
<td>-51 (-40)</td>
<td>-70 (-50)</td>
</tr>
<tr>
<td>July</td>
<td>-62 (-45)</td>
<td>-62 (-50)</td>
</tr>
<tr>
<td>August</td>
<td>-65 (-40)</td>
<td>-65 (-55)</td>
</tr>
<tr>
<td>September</td>
<td>-61 (-45)</td>
<td>-70 (-50)</td>
</tr>
<tr>
<td>October</td>
<td>-72 (-45)</td>
<td>-55 (-50)</td>
</tr>
<tr>
<td>November</td>
<td>-51 (-40)</td>
<td>-60 (-50)</td>
</tr>
</tbody>
</table>

B - Bangalore  
M - Madras

The numbers within brackets indicate the refractivity gradients at 1200 GMT.
FIG. 4.1(a): LOCATION OF MICROWAVE STATION AND NEARBY RADIOSONDE STATIONS
The receiver at Penukonda. Calibration is made using microwave attenuator (Analyzer) and a steady signal source. The accuracy of measurement has been found to be ± 0.5 dB and hence the observed signal levels have been rounded off to the nearest integer value.

4.6 PROPAGATION CHARACTERISTICS OF THE MICROWAVE LINK

4.6.1 Median signal level

The rate of change of signal can be measured as a change in signal level in a specified small interval of time (CCIR Rep. 338-6, 1990). The signal strength is expressed in terms of median signal level which is computed for every 10 minute interval. The median signal level is defined as that which is exceeded during a half of the reception time. The median signal level has been expressed in units of dBm which denotes the signal strength with respect to 1 milli Watt of received power.

Diurnal variation of hourly median signal level for all the seasons is shown in figure 4.2. The figure shows that the signal level has a clear diurnal variation in all the seasons, which can be explained on the basis of general radioclimatology in this region. The thermal convection during the day time provides a natural vertical mixing, thereby the irregularities cannot have high gradients. The thermals mix up the humidity vertically, thereby forming the gradients around -40 N/km (Lane and Partridge, 1968; Wickerts, 1970; Majumdar et al., 1977; Schiavone, 1981; Webster, 1983). Under these circumstances, the direct ray alone reaches the receiver resulting in a steady (no fading) maximum signal in all the seasons in the day time.
Fig. 4.2 Diurnal variation of Median signal level observed during all seasons.
The interesting feature in this link is the minimum signal strength observed between 0800-1000 hours IST. This may be due to the surface based inversion formed at night, which moves upward in the form of a rising inversion (Ball, 1960; Anfossi et al., 1974; Mitra et al., 1977). The rising inversion is caused by the movement of the surface based inversion under the influence of the solar heating of the earth's surface (Mc Allister et al., 1969; Sarkar, 1978; Dutta et al., 1984), thereby resulting in a typical elevated layer which moves up. This movement causes many changes in the refractivity profile (Bean et al., 1966; Dougherty, 1968; Samson, 1975; Morita, 1980; Sylvain et al., 1983; Gossard et al., 1984). Unfortunately, we have no system [such as instrumented towers, tethered balloons or kytoons, Airborne systems] to measure the vertical profile of refractivity after the sunrise except for the radiosonde profiles in the morning hours. Thus complete explanation of the observed diurnal variation of the field strength, could not be given. However, it will be important to study the cumulative distribution of the basic transmission loss given in the next section.

4.6.2 Basic transmission loss

The transmission loss of a radio link is defined as the ratio of the radio frequency (r.f.) power radiated from the transmitting antenna to the resultant r.f. signal power that would be available from the receiving antenna if there were no circuit losses other than those associated with radiation resistance (CCIR-rep. 341, 1978). The basic transmission loss, \( L \) sometimes called the path loss, is defined as the transmission loss expected between ideal, loss-free isotropic
transmitting and receiving antennae (Lustgarten and Madison, 1977; CCIR-

In day time the path loss is given by,

$$L = L_m^f + L_g$$  \hspace{1cm} \ldots (4.1)$$

$L_f$ = Free space loss = $32.4 + 20 \log f + 20 \log d$

$L_g$ = Path attenuation

During night time,

$$L = L_m^f + L_g + L_r$$  \hspace{1cm} \ldots (4.2)$$

$L_r$ = Loss due to layer reflection which is applicable only when layers occur i.e., generally during night time

Cumulative distribution of basic transmission loss observed in all the seasons is shown in figure 4.3. It can be seen from the figure that during all the seasons the basic transmission loss varies from 161 to 190 dB. At 10 percent probability level, in premonsoon it exceeds 182 dB, in winter it exceeds 173 dB, in monsoon it exceeds 174 dB and in postmonsoon it exceeds 164 dB. At 1 percent probability level, in premonsoon it exceeds 192 dB, in winter it exceeds 183 dB, in monsoon it exceeds 177 dB and in postmonsoon it exceeds 196 dB. Similarly at 0.5 percent probability level, in premonsoon it exceeds 195 dB, in winter it exceeds 192 dB, in monsoon it exceeds 184 dB and in postmonsoon season it exceeds 182 dB, respectively.

4.6.3 Fade rate characteristics

Fade rate can be defined as the number of fades in a particular time interval and is usually expressed as fades per hour. It is determined by counting the intersections of the median signal level in a
Fig. 4.3 Cumulative distribution of Basic transmission loss observed during all seasons.
specified time interval. In the absence of multipath fading, it is related to the size and drift of the atmospheric irregularities (Herbstreit and Thompson, 1955; Norton et al., 1955; Bullington, 1971). As a practical application, it limits the digital data transmission rate (Sasaki and Akiyama, 1979; Greenstein and Prabhu, 1979). Thus fade rate is an important parameter which decides the quality of transmission in Line-of-Sight microwave links and especially important in error free digital data transmissions. Higher fade rates degrade the quality of voice and data transmissions.

Diurnal variation of fade rate characteristics of this microwave link is presented in figure 4.4. The maximum fade rate for the microwave link is observed during transition hours (i.e. 0700-1000 IST) in all the seasons, 124 fades per hour in premonsoon season, 60 fades per hour in winter, 49 fades per hour in monsoon and 27 fades per hour in postmonsoon season, respectively. Similarly minimum fade rate is observed in the daytime (from 1200 to 1600 hours). The minimum fade rate in premonsoon is 9 fades per hour, in winter 3 fades per hour and in monsoon and postmonsoon seasons the fade rate is zero. The fade rate is basically decided by two distinct atmospheric phenomena. One is related to scattering caused by the atmospheric irregularities which are of the order of 2 of the link operational frequency. In this case the fading is severe and higher fade rates are observed. The slow fading which is the second distinct atmospheric phenomenon is caused by the changes in the refractive properties of the medium or can be caused by the multipath from the elevated layers. Thus the period of low fade rate represents essentially the presence of layers in the atmosphere and the
Fig. 4.4 Diurnal variation of fade rate observed during all seasons.
period of high fade rates relates to the prevalence of small-scale irregularities in the atmosphere.

Our observations show that the daytime is characterized by the presence of small-scale weak irregularities due to thermal convection which give rise to very weak fades and therefore the fade rate for fades greater than 1 dB in amplitude is either absent or extremely low. In the nighttime formation of inversions results in the low fade rates.

The diurnal variation is most pronounced in premonsoon season due to the severe convection in daytime and the formation of well-defined inversions in the night which also results in the formation of a well-defined rising layer in the morning transition hours. It is during this period that this region depicts high-refractive gradients resulting in the highest fade rates observed over this link. Similarly, this is followed by winter in which the daytime irregularities are less frequent (compared to premonsoon) so as to cause high fade rates but the inversions in winter will have the highest static stability due to the availability of maximum time for the radiative cooling resulting in lower fade rates. In the post monsoon season, the daytime has dull convection and nighttime inversions are also shallow in the thermal gradients or the gradients associated with these inversions are low. Monsoon season, of course has large water vapor in the atmosphere, resulting in the homogeneous conditions.

Cumulative distribution of fade rate for the entire period of observations is presented in figure 4.5. At 50% probability level, the fade rate exceeds 41 fades per hour for the premonsoon season and it
Fig. 4.5 Cumulative distribution of fade rate observed during all seasons
exceeds 20 fades per hour for winter months while for monsoon and postmonsoon periods the fade rate exceeds 8 fades per hour and 6 fades per hour respectively. At 10% probability level, the fade rate is exceeding 90 fades per hour and it exceeds 38 fades per hour for the winter months while in monsoon it exceeds 18 fades per hour and for postmonsoon months the fade rate exceeds 13 fades per hour. At 1 percent probability level, it exceeds 110 fades per hour in premonsoon, 55 fades per hour in winter, 30 fades per hour in monsoon months and 20 fades per hour in postmonsoon months.

The irregularities and the layers responsible for the fading phenomena present another important aspect of fading defined as fade depth and is discussed in the next section.

4.6.4 Fade depth

Usually fading is expressed in terms of fade depth. Fade depth is defined as the difference between the maximum and minimum signal strength over a very small interval of time (Dolukhanov, 1971; Rao, 1984). In our case, the depth of fading has been taken across at least one fade, irrespective of its duration and then averaged over one hour interval. Also, fade depths less than 1 dB have not been taken into account and the signal is considered as stationary.

Figure 4.6 illustrates hourly average fade depth (dB) as a function of local time (diurnal variation) for different seasons. The fade depth values of the whole season are averaged and decimal values are rounded upto its nearest integer. The maximum average fade depth of 12 dB in
Fig. 4.6 Diurnal variation of fade depth observed during all seasons.
premonsoon, 9 dB in winter, 4 dB in monsoon and 3 dB in postmonsoon are observed. Minimum fade depth is observed between 1200 to 1600 hours during all the seasons. However, fade depth as large as 35 dB has been observed on several occasions during transition hours especially in Premonsoon and Winter months. A typical record of large fade depth observed on 23-3-1990 is shown in figure 4.7.

The diurnal variation of fade depth is similar to the fade rate variation indicating that the fast fading is associated with large fade depths. In daytime when both fade rate and fade depths are low, it indicates the absence of sharp irregularities which cause fading. During night time, slow fading is associated with high fade depth indicating this to be caused by multipath effects. Over Penukonda, the night time is characterized by the presence of both surface based and elevated inversions or layers. These layers have slow changes in terms of their refractive gradients both temporal and spatial.

It is observed that soon after sunrise, the fading decreases in all the links situated either over northern India or over southern India (Reddy, 1986; Prasad, 1989; Ravi, 1989; Bhaskara Rao, 1990; Sarkar et al., 1991). It is important to note that in the study of average fade depth, the extreme values of fade depths are smoothened and can be studied through the cumulative distribution of fade depths in all the seasons.

The cumulative distribution of fade depth for different seasons is shown in figure 4.8. From the figure it can be observed that at 10
FIG. 4.7: TYPICAL RECORDS OF FADE DEPTHS OBSERVED ON 23-3-1990
Gooty-Penukonda
(July 1989–June 1990)

Fig. 4.8 Cumulative distribution of fade depth observed during all seasons
percent probability level, the fade depth exceeds 12 dB in premonsoon, 6 dB in winter, 3 dB in monsoon and 2 dB in post monsoon seasons. Similarly, at 1 percent probability level in premonsoon season the fade depth exceeds 21 dB while for winter months it exceeds 9 dB and in monsoon season 8 dB and in postmonsoon season it exceeds 6 dB.

4.6.5 Scintillation Index

Rapid variations in tropospheric signal intensity, usually referred to as scintillations, are caused when it is scattered by refractive index fluctuations owing to atmospheric irregularities along the path of propagation (Karasawa et al., 1988). The intensity fluctuations are measured by a well known index, normally, the scintillation index (S.I) (Whitney, 1969). The fluctuations, are in general, nonstationary, but of short periods, lasting from minutes to hours.

Several studies on tropospheric scintillations have been carried out both theoretically and experimentally (Tatarskii, 1961; Yokoi et al., 1970; Thompson et al., 1975; Crane, 1976; Strickland et al., 1977; Cole et al., 1978; Haddon et al., 1980; Moulsey and Vilar, 1982; Schiavone, 1983; Vilar and Haddon, 1984; Banjo and Vilar, 1986; Tatarskii, 1987; CCIR report 1990). Theoretical models describing scintillations have been verified by optical, short hop line-of-sight propagation studies (Strohbehn, 1973; Strohbehn et al., 1975). Several researchers extended theoretical models to scintillation phenomena at microwave frequencies (Staras and Strohbehn, 1952; Lee and Harp, 1969; Clifford and Strohbehn, 1970). Scintillation Index is defined as,
where $P_{max}$ is the power of the third peak down from the maximum excursion of the signal strength and $P_{min}$ corresponds to the power of the third peak upwards from the minimum excursion of the signal strength.

Fluctuations in the amplitude of the received signal are caused by scattering from small scale refractive index irregularities generated by turbulence or reflection/refraction from atmospheric layers which give rise to multipath propagation. If scattering is a predominant process, the received signal exhibits rapid variations in the signal amplitude over its median values (Cole, 1978). If reflection/refraction from atmospheric layers is to be a dominant mechanism, received signal may fade deeply and also cause the median signal level change considerably from the normal value. The fluctuations may be fast or slow depending upon the actual path conditions. However, for most of the time on land paths, both the mechanisms are found to work simultaneously during nighttime while in the day time, weak scattering from refractive inhomogeneities generated by convective cells is predominantly observed.

The diurnal variation of the scintillation index observed during different seasons is illustrated in figure 4.9. For all the seasons, scintillations occur around the clock with the maximum occurrence during nighttime and transition hours (0700 to 1100 hours). Scintillation index varies from 20 to 35 percent for all the seasons.
Fig. 4.9 Diurnal variation of Scintillation Index observed during all seasons.
In premonsoon season, the maximum scintillation index varies from 5 to 35 percent. In the day time at 1500 hours the minimum scintillation index having a value of 5 percent is observed. During premonsoon season daytime convective conditions last for longer time, and formation of the ground based inversions starts late in the night around 1900 hours and keep on increasing till morning. The day time convective condition shows a minimum value of scintillation index.

During monsoon season in the transition hours the scintillation index is about 15 percent and from 1200 to 1900 hours the scintillation index is zero. From 2000 to 0600 hours the scintillation index is around 12 percent.

During the postmonsoon period the maximum scintillation index observed is 6 percent from 0800-0900 hours and there is not much variation in the scintillation index in the day time and night time.

During winter season it is observed that the scintillation index is varying from 2 to 30 percent. During the transition hours the scintillation index is about 54 percent and from 1100 hours the scintillation index falls rapidly. The scintillation activity starts early in the evening hours as the earth cools early in the day because of the low temperature in the day time in these seasons. From 1900 hours the scintillation index increases gradually and is around 30 percent throughout the night.

From the figure it can also be seen that, in general, for all seasons scintillation index is maximum at night and minimum during the noon hours. High values of scintillation index are observed during
premonsoon followed by winter. Similarly low values of scintillation index are observed during postmonsoon and monsoon seasons. From the figure it can also be observed that, during the period of sunrise and post-sunset, high scintillation index values are observed for this microwave link.

The cumulative distribution of scintillation index for all the seasons is shown in figure 4.10. In premonsoon months at 90% probability level the scintillation index exceeds 20 percent and at 10% probability level it exceeds 53 percent. In the winter months at 90% probability level it exceeds 5 percent and at 10% probability level it exceeds 45 percent. During postmonsoon and monsoon seasons scintillation index exceeds zero percent.

The scintillation is caused by the scattering of signals from the atmospheric irregularities. These irregularities are caused or formed by a number of atmospheric phenomena (Tatarskii, 1967 and 1971; Ishimaru, 1978; Strohbehn, 1978; Mon et al., 1980; Blomquist et al., 1980; Webster, 1987) but, the irregularities can persist for longer periods under static/inversion conditions. It is for these reasons that the scintillations are predominantly associated with the atmospheric inversion conditions as the inversion provides a conducive environment for the development of the intense irregularities.

4.6.5.1 Structure intensity parameter, $C_n^2$

Structure intensity parameter, $C_n^2$, is a measure of the variability of the refractive index fluctuations and a knowledge of $C_n^2$, will help in optimizing system design. The small scale refractivity
Fig. 4.10 Cumulative distribution of Scintillation Index observed during all seasons.
irregularities also scatter radio energy. Hence the morphology of $C_n$ is essential for designing forward scatter tropo systems and sensitive radars that use back-scattered energy. It can also be a cause of concern, sometimes, even for line-of-sight microwave systems, scattering from strong turbulent regions can produce rapid and deep fading (Livingston, 1970).

Tatarskii (1967) treated refractive index as a random function with stationary first increments and describes its statistical properties in terms of a structure function.

$$Q(k) = 0.033 C_n^2 k^{-11/3}$$  \( \ldots (4.4) \)

Where $Q(k)$ is the power spectral density, $n$ is the wave number and is given by $k=2\pi l/\lambda$, $l$ is the scale size and $C_n^2$ is the refractivity structure parameter.

This description assumes that the turbulent fluctuations are isotropic and $l$ is in the inertial subrange.

Unlike the case at optical wavelengths, $C_n^2$ is highly dependent on humidity for wavelengths in the microwave band.

Tatarskii (1961) derived the following equation for $C_n$ at microwave frequencies.

$$C_n^2 = a L M^{4/3}$$  \( \ldots (4.5) \)

where

- $a = 2.4$
- $L$ is the outer scale of turbulence and
- $M$
\[ M = -79 \times 10^{-6} \left( \frac{P}{T} \right) \left[ \frac{1 + 15500q/T}{1 + 15500q/T} \right] \frac{dT}{dr} \frac{r}{t} - \frac{7800 - 7800}{1 + 15500q/T} \frac{dq}{dz} \] ...

\( P \)  Barometric pressure (mb)
\( T \)  Absolute temperature (K)
\( q \)  Specific humidity (dimensionless)
\( z \)  Altitude (km)
\( a \)  Adiabatic temperature gradient, 9.8 K/Km

Sirkis (1971) evaluated the variation of

\[ 2 2 \frac{2}{4/3} \]
\[ M = \frac{C}{a} L \]
\[ n \]

... (4.7)

It may be noted that even for a small change in the amount of water vapor, there is a large increase in the value of structure intensity parameter, \( C_n \). Hence, in hot and humid climates the values of \( C_n \) are larger, thereby requiring due consideration.

4.6.5.2 Determination of structure intensity parameter, \( C_n \) from scintillation analysis

The structure intensity parameter, \( C_n \) has considerable importance in the tropospheric propagation as it is directly related to the refractive index fluctuations (Ishimaru, 1969; Bean et al., 1971; Ishimaru, 1972; Ochs and Lawrence, 1972; Gossard, 1977; Ishimaru, 1978; Basili et al., 1988).

The structure intensity parameter, \( C_n \) can be computed from scintillation index obtained from the line-of-sight records (Dutta et al., 1984; Rao et al., 1985) by the following relationships.
The variance of the logarithm of the intensity is given as

$$\sigma_{\ln}^2 = (\ln \frac{I}{I_o} - \langle \ln \frac{I}{I_o} \rangle)^2 = 4 \sigma_X^2 \quad \ldots (4.8)$$

where \( \sigma_{\ln} \) is the variance of the observed scintillations. This is related to the random amplitude modulation depth, \( m = \frac{I}{I_o} \langle I \rangle \) by the expression (Andreyov et al., 1978)

$$\sigma_{\ln}^2 = 4 \sigma_X^2 \ln (1 + m^2) \quad \ldots (4.9)$$

Now \( m \) is equivalent to the scintillation index \( S_4 \), so the above relation can be written as,

$$\sigma_{\ln}^2 = \ln (1 + S_4^2) \quad \ldots (4.10)$$

There is another well known relationship (Tatarskii, 1971) connecting the variance with the structure intensity parameter \( C_n \), wave number \( K \) and path length \( L \) by

$$\sigma_{\ln}^2 = 0.31 C_n^2 K^{7/6} L^{11/6} \quad \ldots (4.11)$$

Combining equations (4.10) and (4.11) \( C_n \) has been computed.

\( C_n \) is computed from the observed \( P \) and \( P \) during a time interval of 5 minutes and then the average is calculated for one hour. These average values of a particular hour are further averaged to obtain diurnal variation in each season.
Figure 4.11 gives a diurnal and seasonal plot of $C_n^2$. Structure intensity parameter, $C_n^2$, which is observed to be high in premonsoon followed by winter and monsoon registering minimum in postmonsoon months. The variation in $C_n^2$ is maximum in the night and early hours of the day. The minimum $C_n^2$ value observed are in the afternoon hours. During the early morning and evening hours of premonsoon season, high $C_n^2$ values are observed. In postmonsoon and monsoon seasons low $C_n^2$ values are seen.

Cumulative distribution of structure intensity parameter, $C_n^2$ observed during all the seasons is shown in figure 4.12, from which it can be seen that for different percentage of probability level $C_n^2$ is observed to be highest in premonsoon followed by winter and monsoon registers minimum in post monsoon months. The structure constant is a function of altitude and local meteorological conditions, in the boundary layer, it is a function of terrain as well (Brown, 1977).

During the day, when the atmosphere is fully convective, the refractivity gradients are small and $C_n^2$ values are small. But in the evening, as the ground cools down, the stability in the lower levels of boundary layer will increase due to heat loss to ground layer and large refractivity gradients are produced. Though on a lower scale, turbulence still continues and this coupled with large refractivity gradients cause higher $C_n^2$.

4.6.5.3 Comparison of results with early work:

Several studies have been made to estimate $C_n^2$ at radio frequencies using different experimental techniques and it was found to vary between
Fig. 4.11 Diurnal variation of Structure Intensity parameter observed during all seasons
Fig. 4.12 Cumulative distribution of Structure Intensity parameter observed during all seasons.
10 to 10 m (CCIR Rep-563, 1986). Rao (1984) reported $C_n$ at 1 km height to be $4 \times 10^{-2/3} m$ at 0000 GMT and $1 \times 10^{-2/3} m$ at 1200 GMT over Madras. Reddy (1986) reported a value of $10^{-11}$ to $10^{-12}$ m over coastal and inland regions. Bhaskara Rao (1990) has reported the refractive index structure parameter, $C_n^2$ which deduced from the scintillation studies of 7.6 GHz LOS links varies from $10^{-13}$ to $10^{-15}$ in Southern India.

The values of $C_n^2$ estimated from the amplitude scintillation measurements on Gooty–Penukonda line-of-sight microwave link have been studied. The diurnal and seasonal variation of $C_n^2$ in different seasons has also been discussed. The results have been compared with those reported earlier. The values observed ($10^{-10}$ to $10^{-15}$ m) are in good agreement with the values given by the researchers.

4.7 CORRELATION OF PROPAGATION CHARACTERISTICS WITH METEOROLOGICAL PARAMETERS

In the past many workers have predicted path loss on the basis of surface refractivity and tried to correlate signal levels and fade depths with surface refractivity (Majumdar, 1967; Sarkar, 1978). But over the Indian subcontinent it is found to have better correlation with signal parameters (Dutta et al., 1984; Rao et al., 1986; Prasad, 1989; Bhaskara Rao, 1990; Sarkar et al., 1991). For the present study radiosonde data obtained from the Bangalore observatory is utilized for computing the refractivity gradients.

It has been observed from the propagation characteristics of Gooty–Penukonda microwave link that the late night and early hours of the day
are prone to have high order of irregularities and are related to high fading. Inversions also frequently contain strong gradients of humidity and can therefore seriously affect radiowave propagation (Ruthroff, 1971; Majumdar et al., 1976; Mitra et al., 1977; Nilsson, 1979; Mon, 1981; Schiavone, 1982; Sylvain, 1983). Figure 4.13 represents a typical sharp fall in $N$ values near the surface observed over Bangalore on 26-3-1990 at 0000 GMT. Corresponding signal amplitude variations can also be seen in figure 4.14 on the same day. Figures 4.15 and figure 4.16 illustrate the hourly median field strength and fade depth against refractivity gradient (between surface to 950 mb). The scatter diagrams depict a good correlation between the signal parameter and the refractivity gradients. It can be seen that large (more negative) refractivity gradients are associated with more loss of signal strength while small refractivity gradients are related to steady signal level. The correlation coefficient of the median signal level and refractivity gradient is 0.353.

Correlation of initial refractivity gradient with fade depth is studied and is shown in figure 4.16. The figure illustrates correlation of fade depth with initial refractivity gradients. The correlation coefficient observed in this case is 0.326. It can be seen from the figure that large refractivity gradients are associated with large fade depth while low order refractivity gradients are related to lower fade depth. The figures 4.15 and 4.16 depict a good correlation between the signal parameters and the refractivity gradients.

Higher signal losses and large fade depths observed in premonsoon season are due to the large refractivity gradients prevailing in this
Fig. 4.13 Refractivity profile observed over Bangalore on 26.3.1990 at 0000 GMT
FIG. 4.14: TYPICAL RECORDS OF SIGNAL ON SAME DAY (26.3.1990)
GOOTY - PENUKONDA
JULY 1989 - JUNE 1990

MEDIAN FIELD STRENGTH, dB

Y = 0.294X - 36.3
Correlation coefficient = 0.85

Fig. 4.15 Correlation of Median signal level against Refractivity gradient between surface to 900 mb level
Fig. 4.16 Correlation between Fade Depth and Refractivity gradient between surface to 900 mb level

\[ Y = -0.142 \times -7.07 \]

Correlation coefficient = 0.926
period over this microwave link. This is followed by winter season and monsoon period while postmonsoon season accounts for the lowest values. The average refractivity gradient observed over Bangalore in premonsoon season is -81 N/km, in winter -74 N/km, monsoon -67 N/km and Postmonsoon season -65 N/km. As the refractivity gradients become more negative, signal loss and fade depth increase. The strong signal strength and smaller fade depths during afternoon hours are due to the convective conditions prevailing. With the sunset, the convective conditions give way to stable layered structures in the atmosphere. These layers are formed due to the radiative cooling of the earth’s surface and reflect the signal thus accounting for the increase in signal level in nighttime.

4.8 PERFORMANCE OF PROTECTION METHODS FOR LOS MICROWAVE LINK

Based on the above studies an attempt is made to suggest certain remedial measures so as to improve the performance during the severe fading conditions. For this purpose it is worthwhile to examine the existing diversity methods that are usually employed and to suggest remedial measures from the communication point of view which could be incorporated for the improvement of the microwave link.

The standard techniques to improve the performance of any microwave link are:

1. Frequency Diversity
2. Space Diversity
3. Estimation of Fade Margin
4. Tilting the antenna
In order to calculate the maximum frequency separation required for the frequency diversity system one should calculate the path length difference between the two rays and distance of the ground reflection point in terms of the effective earth's radius factor.

The path length difference between the direct ray and ground reflected ray is important for the phase difference it produces between the two components at the receiving antenna. It is given by Dzik et al., (1983)

\[
S = \frac{2}{h} \left\{ \frac{1}{d} - \frac{2}{2KRh} \right\} \left\{ \frac{1}{d} - \frac{2}{2KRh} \right\} \ldots (4.12)
\]

\( h \) = Height of the transmitting antenna above mean sea level
\( t \) = Height of the receiving antenna above mean sea level
\( r \) = Distance from the transmitter to the reflection point
\( t \) = Distance from the receiver to the reflection point
\( d \) = Effective earth's radius factor
\( R \) = Radius of the earth
\( d \) = Path length

For calculating \( d_t \), \( d_r \) the reflection point is to be calculated.

4.8.1 Reflection point:

Calculation of the reflection point involves the solution of a cubic equation of the form (Norton, 1965; Hall, 1979).

\[
2d^3 - 3dd^2 + (d - 2KR(h + h) d) + 2KRd = 0 \ldots (4.13)
\]

By solving equation (4.13) one can calculate \( d_t \) as a function of \( K_t \) factor or initial refractivity gradient. By substituting \( d_t \) and \( d_r \) values for different atmospheric conditions the path difference between
the 2 rays is calculated. Figure 4.17 shows the path difference as a function of initial refractivity gradient.

4.8.2 Diversity studies:

In the present line-of-sight link, two separate frequencies with a separation of 70 MHz are transmitted using the same antenna and the simultaneous recordings of both the frequencies show that there is a high degree of correlation between both the signals. As frequency and space diversity are well known techniques to alleviate multipath fading, an attempt is made here to calculate the frequency and space separations theoretically for Gooty - Penukonda link and examine the possibility of optimum separations to improve the performance of this link.

When designing a line-of-sight system one must always take care that the received signal is higher than a certain minimum value for a suitable percentage of time. If the signal, due to the fading, becomes lower than this minimum value, communication will get disrupted.

4.8.2.1 Frequency diversity:

In this technique two or more frequencies are transmitted with the same information under the assumption that both the frequencies do not suffer fading at the same time. If the correlation between the channels is above 0.6, diversity gain decreases. So a correlation coefficient of 0.6 may be used as a threshold for diversity applications (Norton et al., 1965; Hall, 1979).

The phase difference between the direct and reflected rays of the first frequency is \((2\pi/\lambda) \Delta S\) and for the second frequency, it is
Fig. 4.17 Variation of path length difference against Refractivity gradient between surface to 900 mb level
(2\pi/\lambda) \Delta S; \Delta S is the same for both the signals. If f > f we have 
2
1
2

\[(2\pi/\lambda) \Delta S\] - \[(2\pi/\lambda) \Delta S\] = (2n - 1)\pi \quad (4.14)

The basic aim of the diversity is that both the signals should fade independent of each other. We know that \(f_1 \lambda = f_2 \lambda = C\), where 
1 \qquad 1 \qquad 2 \qquad 2 
C is the velocity of electromagnetic wave. Then

\[f_1 - f_2 = \Delta f = \frac{(2n - 1)c}{2 \Delta S} \quad (4.15)\]

Here \(\Delta f\) is the frequency difference between the two channels and \(\Delta S\) has been already calculated for different \(K\) (or gradient) values. So the minimum frequency separation is

\[\Delta f = \frac{c}{2 \Delta S} \quad (4.16)\]

Figure 4.18 shows the frequency separation as a function of initial refractivity gradient for Gooty - Penukonda link. It is observed that a minimum of 55 MHz is required for the frequency diversity reception.

The existing frequency diversity has a frequency separation of 57 MHz for Gooty - Penukonda link. This separation is close to the expected separation. Hence it may be concluded that the frequency diversity needs no change.

4.8.2.2 Space diversity:

In line-of-sight propagation the received signal is a function of height of the receiving antenna. If \(h\) is varied, receiving signal \(r\) also varies. If the signal is maximum at \(h_{1}\) and minimum at \(h_{2}\) then,

\[r_{1} \quad r_{2}\]
Fig. 4.18 Variation of Frequency separation against Refractivity gradient between surface to 900 mb level.
\[ \Delta S - \Delta S = \frac{(2n - 1) \lambda}{2} \quad \ldots \quad (4.17) \]

where \( \Delta S \) and \( \Delta S \) are path differences corresponding to the two receiving antennae. For practical considerations antenna spacing should be a minimum. Taking the equation (4.12) of path difference, we get

\[ \frac{(\Delta S - \Delta S)}{\Delta h} = \left[ \frac{2h}{d} \right] \left( 1 - \frac{d}{2KRh} \right) \quad \ldots \quad (4.18) \]

where \( h \) is the separation between receiving antennae.

Figure 4.19 shows antenna separation as a function of initial refractivity gradient observed over this microwave link. For normal atmospheric conditions (\( K=4/3 \)), a minimum separation of 6m is required, most of the refractivity gradients which are more negative a separation of 5.5 m is ideal.

4.8.3 Fade margin estimations:

The maximum allowable fade margin for a specified annual system availability can be obtained by solving the Barnett-Vignat reliability equation. The following equation indicates the solution for an unprotected diversity system (Feher, 1981).

\[ \text{Undp} = 2.5 \times 10^{-6} \left( \frac{F}{10} \right) \quad \ldots \quad (4.19) \]

Where,

\[ \text{Undp} \] be the non diversity annual outage probability

\[ a = \text{Roughness factor}, \]

which is 4 for very smooth terrain including over water; 1, for average terrain with same roughness; 1/4, for mountainous very rough terrain
Fig. 4.19 Variation of Space diversity against Refractivity gradient between surface to 900 mb level
\( b = \) Factor to convert worst month probability to annual probability; 
1/2, for hot, humid area; 1/4, for average inland areas; 1/8, for 
mountainous or very dry areas

\( F = \) Fade margin (dB)

\( D = \) Distance (statute miles)

\( f = \) Frequency (GHz)

For 99.99% reliability, the Fade margin for Gooty - Penukonda link 
is found to be 36 dB. The microwave link at present is having 36 dB 
fade margin, which is sufficient even in worst month basis.

### 4.8.4 Tilting of the antennas:

Tilting of the antennae is preferred over other techniques though 
it can offset the median signal level by 2 to 3 dB. It is important to 
note that the aim is to reduce the depth of fading, therefore a 
reduction of 2 to 3 dB in the median signal level does not affect the 
performance of the link. Sasaki (1989) proposed a tilted beam diversity 
reception system to reduce line-of-sight microwave fading. By tilting 
the antennas Prasad et al., (1991) obtained good results over Delhi-
Meerut microwave link.

For any LOS link, the daytime signal is a combination of direct and 
ground reflected rays, whereas the nighttime signal is a combination of 
direct, ground reflected and layer reflected rays. This can be reduced by 
minimizing or eliminating the amount of radio frequency energy 
reflected via layer. This can be achieved by slight repositioning of 
the antenna. Generally layers can be classified into ground based and 
elevated. If the layers are occurring below the transmitter and
receiver terminals, the upward tilting of the antenna will reduce the layer reflected energy, and if the layers occurring above the transmitter and receiver heights are responsible for fading, then downward tilting helps to minimize the fading occurring at the receiver.

4.9 MICROWAVE PROPAGATION CHARACTERISTICS OVER COASTAL ZONE

Many investigators have studied the propagation characteristics of the LOS microwave links situated over coastal zone in India (Nandini, 1983, Reddy, 1986, Reddy, 1991). Though all the studies made are on the basis of the propagation characteristics namely median signal level, fade rate, fade depth and scintillation index, an information about the path inclination effect on microwave propagation is not dealt with. Hence in the present study propagation characteristics are studied for an understanding of path inclination effect in microwave links. For these microwave links with known system and terrain characteristics, Geoclimatic factors which are useful for finding the fade depth for different probability levels are also determined.

As in the case of inland zone the diurnal variation of the propagation characteristics of the LOS microwave links can be explained on the basis of the diurnal variation of the atmospheric conditions prevailing in the coast of India. In the coastal zones of India, the atmospheric conditions are greatly dominated by both the sea and land breeze (Ramanathan and Subbaramaiah, 1965; Dekate, 1968; Narayan, 1976). The sea breeze phenomenon persists due to the high temperature over the land mass during the daytime leading to the formation of sea-breeze before mid-day (Kelkar, et al., 1989). Sea breeze is a peculiar
phenomenon over coastal and island regions. This is due to thermally driven mesoscale atmospheric circulation and differential heating is the essential requisite for this. A direct thermally driven circulation such as the sea/land breeze occurs more frequently and with more regularity in the tropics than in the middle and high latitudes. Since a moist air mass moves over land, during sea breeze, a change in temperature and humidity takes place and windflow direction is from sea to land. Study of air motion either in mesoscale or any other scale circulation forms an integral part of meteorology. Sea breeze occurrence is an important event in environmental monitoring though it is a pure local phenomenon. The surface meteorological data (such as temperature, humidity and wind) obtained by India Meteorological Department is used to study the occurrence of sea breeze phenomena.

In the Southern India, the earlier work carried out by Roy (1940) is important for discussion wherein the investigators (Rao, 1955; Ramakrishnan and Jambunadhan, 1958; Atlas, 1960; Eastwood and Rider, 1961; Simpson, 1967) have shown that the sea breeze effect is predominant during the pre-monsoon period due to the most intense heating during this season. Similarly, the work on radar propagation conditions over Madras coast has shown that the maximum superrefractive echoes are observed during premonsoon season (Bhaskara Rao et al., 1984). The sea breeze flows close to the ground near the coast and as it penetrates inland, it is pushed upwards due to the convection and is weakened (Pielke, 1973). Acoustic sounders are also capable of identifying the signature of the atmospheric dynamics. The acoustic sounder situated over this coast at Vishakapatnam has shown that the
depth of sea breeze close to the coast can be 250 m (Purnachandra Rao et al., 1986) with a clear seasonal variation. In the case of present study, the link is situated close to the coast, therefore the large refractivity changes associated with the sea breeze flow keep the link submerged resulting in deep and fast fading during early morning and late night of the day. It is a typical coastal phenomenon observed over many other links operating in the east coast (Reddy, 1986). The time of formation of sea breeze, its flow pattern and the associated changes in the radio refractivity profiles depend on many factors including the terrain features (Craig, et al., 1945; Gill, 1968). Similarly, in the evening hours, the formation of land breeze starts due to the radiative cooling of the earth's surface (Readings et al., 1973; Smith, 1974). This cooling results in the development of surface based inversions which results in the formation of superrefractive/subrefractive gradients.

Madras radiosonde data, and the data from a nearby coastal station show that the inversions are maximum during premonsoon, winter and minimum during the monsoon and postmonsoon seasons (Venkiteshwaran and Narayan, 1970; 1972; Rao, 1984; Reddy, 1986; Bhaskara Rao, 1990). In fact, the rains during monsoon and afterwards in the post monsoon period break the formation of well defined sea breeze as the coastal fields are full of water, resulting in the paddy cultivation. The water over the land then does not allow a severe convective activity resulting the suppression of the formation of sea breeze. It is due to these factors that the day time signal is steady only in the afternoon, the time when convection is most severe resulting in a homogeneous atmosphere in the
lower regions. But as the conditions change to either super refractive or subrefractive, the received energy comes in many ways resulting in the decrease of the median signal level at night. The maximum diurnal variation in pre-monsoon is due to the maximum diurnal variability in the atmospheric conditions and minimum during the post monsoon season.

4.10 DETERMINATION OF GEOCLIMATIC FACTOR FROM MICROWAVE LINK DATA

Based on the method given in CCIR report no. 338-6 (1990) geoclimatic factors are evaluated for six microwave links between Chittedu-Nellore, Puducherry-Madras, Elagiri-Tirumala and Tiruttani-Tirupati, Pallavaram-Tirumala and Gooty-Penukonda. The path profiles of the microwave links are as shown in figures 4.20 and 4.1. The inputs used are the fading data of the microwave links. Since the worst month for these links is March, cumulative distribution of fade depths for the month of March is utilized and are shown in figure 4.21.

The geoclimatic factor is given by

$$P = 0.93 -1.1 -1.2 -\frac{A}{10}$$

$$P = Kd f \left(1+|\epsilon|\right) \phi 10^{(\%)}$$

Where,

- $P$ = Percentage of time ordinate exceeded for fade depths
- $|\epsilon|$ = Path inclination (milliradians)
- $\phi$ = Grazing angle (milliradians)
- $K$ = Geoclimatic factor
- $f$ = Frequency (GHz)
- $d$ = Path length (km)

The above equation is applicable to narrow band systems. They are considered valid for fade depths greater than about 15 dB or the value exceeded for 0.1% of the worst month, whichever is greater.
FIG. 4.20: PATH PROFILE OF MICROWAVE LINKS SITUATED IN COASTAL ZONE
Fig. 4.21 Cumulative distribution of fade depths observed in worst month for different microwave links.
Table 4.3 shows the geoclimatic factors for different probability levels of fade depths and are found to vary between $0.05 \times 10^{-3}$ and $0.9 \times 10^{-3}$. In Brazil (Dhein, 1987), fade depth occurrence was measured on several line-of-sight links (6 GHz) in tropical and equatorial regions. The climate factor determined from experimental data was found to be $0.04 \times 10^{-3}$ and $0.9 \times 10^{-3}$ in these regions. The observed geoclimatic factors over the region in which the microwave links are situated show a fairly good agreement with the observed data ($0.47 \times 10^{-3}$) in Brazil.

The importance of geoclimatic factor lies in its dependence on the system characteristics, terrain characteristics and also the meteorological conditions prevailing in the region. Once it is determined the fade depths for different percentages of probability level can be predicted, and the system characteristics can be optimized in such a way to get the required value for the geoclimatic factor so as to achieve the predetermined threshold values of fade depths for required percentages of probability level. Thus geoclimatic factor is very much useful in system engineering.

4.11 PATH INCLINATION EFFECT ON MICROWAVE LINKS

The transmission performance of a line-of-sight microwave link is affected by the intervening medium and the terrain characteristics (Schiavone, 1982). The intervening medium, because of its ever changing dynamics, both spatial and temporal (Beckmann and Spizzichino, 1963; Livingston, 1970) causes changes in the received signal and also results in fading phenomena (Dougherty, 1968; Lin, 1988). This can be
<table>
<thead>
<tr>
<th>Probability level (%)</th>
<th>Fade depth (dB)</th>
<th>Geoclimatic factor (X10⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Name of the link: Chittedu-Nellore</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>3</td>
<td>.571</td>
</tr>
<tr>
<td>71</td>
<td>5</td>
<td>.655</td>
</tr>
<tr>
<td>64</td>
<td>5.5</td>
<td>.663</td>
</tr>
<tr>
<td>51</td>
<td>6</td>
<td>.593</td>
</tr>
<tr>
<td>48</td>
<td>6.5</td>
<td>.626</td>
</tr>
<tr>
<td>32</td>
<td>7</td>
<td>.568</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>.596</td>
</tr>
<tr>
<td>.4</td>
<td>30</td>
<td>.580</td>
</tr>
<tr>
<td><strong>Name of the link: Elagiri-Tirumala</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>2.5</td>
<td>.049</td>
</tr>
<tr>
<td>88</td>
<td>4</td>
<td>.051</td>
</tr>
<tr>
<td>71</td>
<td>4.5</td>
<td>.049</td>
</tr>
<tr>
<td>64</td>
<td>5</td>
<td>.054</td>
</tr>
<tr>
<td>51</td>
<td>5.5</td>
<td>.046</td>
</tr>
<tr>
<td>48</td>
<td>6</td>
<td>.047</td>
</tr>
<tr>
<td>32</td>
<td>6.5</td>
<td>.042</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>.05</td>
</tr>
<tr>
<td>.8</td>
<td>15</td>
<td>.06</td>
</tr>
<tr>
<td>.4</td>
<td>25</td>
<td>.045</td>
</tr>
<tr>
<td><strong>Name of the link: Puducherry Madras</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>1</td>
<td>.616</td>
</tr>
<tr>
<td>51</td>
<td>2</td>
<td>.618</td>
</tr>
<tr>
<td>48</td>
<td>2.5</td>
<td>.652</td>
</tr>
<tr>
<td>32</td>
<td>4</td>
<td>.614</td>
</tr>
<tr>
<td>20</td>
<td>7</td>
<td>.766</td>
</tr>
<tr>
<td>15</td>
<td>8</td>
<td>.723</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>.609</td>
</tr>
<tr>
<td>.4</td>
<td>23</td>
<td>.61</td>
</tr>
</tbody>
</table>

Contd.
<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of the link : Tiruttani-Tirupati</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>0</td>
<td>.21</td>
</tr>
<tr>
<td>85</td>
<td>.7</td>
<td>.892</td>
</tr>
<tr>
<td>45</td>
<td>.8</td>
<td>.901</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>.98</td>
</tr>
<tr>
<td>5</td>
<td>2.4</td>
<td>.892</td>
</tr>
<tr>
<td>2.5</td>
<td>5.5</td>
<td>.911</td>
</tr>
<tr>
<td>1</td>
<td>9.4</td>
<td>.894</td>
</tr>
<tr>
<td>.5</td>
<td>12.4</td>
<td>.892</td>
</tr>
<tr>
<td>.4</td>
<td>13.4</td>
<td>.899</td>
</tr>
<tr>
<td><strong>Name of the link : Gooty-Penukonda</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>.2</td>
<td>.197</td>
</tr>
<tr>
<td>87</td>
<td>.8</td>
<td>.197</td>
</tr>
<tr>
<td>76</td>
<td>1.5</td>
<td>.189</td>
</tr>
<tr>
<td>69</td>
<td>1.8</td>
<td>.198</td>
</tr>
<tr>
<td>61</td>
<td>2.4</td>
<td>.195</td>
</tr>
<tr>
<td>53</td>
<td>2.93</td>
<td>.198</td>
</tr>
<tr>
<td>41</td>
<td>4</td>
<td>.195</td>
</tr>
<tr>
<td>30</td>
<td>5.4</td>
<td>.198</td>
</tr>
<tr>
<td>24</td>
<td>6.4</td>
<td>.199</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>.191</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>.190</td>
</tr>
<tr>
<td><strong>Name of the link : Pallavaram-Tirumala</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>.2</td>
<td>.409</td>
</tr>
<tr>
<td>87</td>
<td>.75</td>
<td>.408</td>
</tr>
<tr>
<td>76</td>
<td>.8</td>
<td>360</td>
</tr>
<tr>
<td>56</td>
<td>1.4</td>
<td>.323</td>
</tr>
<tr>
<td>45</td>
<td>2.3</td>
<td>.310</td>
</tr>
<tr>
<td>36</td>
<td>3.2</td>
<td>.297</td>
</tr>
<tr>
<td>25</td>
<td>4.8</td>
<td>.298</td>
</tr>
<tr>
<td>13</td>
<td>7.7</td>
<td>.302</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>.298</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>.298</td>
</tr>
</tbody>
</table>

P = Probability level (%)  
A = Fade depth (dB)  
K = Geoclimatic factor
studied by monitoring the propagation characteristics such as fade depth. There is evidence to suggest that the deep fadings observed on LOS links due to super-refractive/sub-refractive layers decrease with increasing path inclination (Netto, and Dhein, 1985; CCIR Report 563-4, 1990). This is the first time that these types of results have been presented from this region with the occurrence of very high temperatures and high humidity gradients (Rao et al., 1991b).

4.11.1 Terrain characteristics and Data base

The LOS microwave links between Pallavaram-Tirumala (PLM-TML), Tiruttani-Tirupati (TRT-TPT), Elagiri-Tirumala, (ELI-TML), Puducherry-Madras (PDY-MDS) and Chittedu-Nellore (CHD-NLR) are situated in hilly region. Figure 4.20 shows the path profiles of above five LOS microwave links. The field strength data for these LOS links were recorded using an Ominiscribe recorder with a time constant of 100 msec. The microwave amplitude measurements were made at the receiving end of the microwave links i.e., at Tirumala, Tirupati, Tirumala, Madras and Nellore for one year. The details of the system characteristics of the microwave links are shown in Table 4.4. Though the data is not for the same year, since climatological changes will not be very high from year to year, an attempt is made to investigate qualitatively the effect of path inclination on the performance of LOS microwave links. These links taken for study having different path inclinations are located in similar radioclimatological zone.

4.11.2 Radioclimatology observed over Madras region

Radiosonde data, collected from the India Meteorological Department Observatories at Madras at 0000 GMT and 1200 GMT, has been also
## Table 4.4: Details of Various Link Parameters

<table>
<thead>
<tr>
<th>Link Name</th>
<th>Frequency (GHz)</th>
<th>Transmitted power (dBm)</th>
<th>Transmitting antenna gain (dB)</th>
<th>Receiving antenna gain (dB)</th>
<th>Path length (km)</th>
<th>Path inclination (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLM-TML</td>
<td>7.394</td>
<td>30</td>
<td>46</td>
<td>46</td>
<td>117.5</td>
<td>920</td>
</tr>
<tr>
<td>TRT-TPT</td>
<td>7.659</td>
<td>30</td>
<td>40</td>
<td>40</td>
<td>60</td>
<td>840</td>
</tr>
<tr>
<td>ELI-TML</td>
<td>7.394</td>
<td>30</td>
<td>46</td>
<td>46</td>
<td>142</td>
<td>15</td>
</tr>
<tr>
<td>PDY-MDS</td>
<td>11</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>31.2</td>
<td>6</td>
</tr>
<tr>
<td>CHD-NLR</td>
<td>6</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>44</td>
<td>2</td>
</tr>
</tbody>
</table>

PLM-TML: Pallavaram-Tirumala; TRT-TPT: Tiruttani-Tirupati; ELI-TML: Elagiri-Tirumala; PDY-MDS: Puducherry-Madras and CHD-NLR: Chittedu-Nellore
utilised to study these microwave link performance. Occurrence percentage of Radio refractivity gradients observed over Madras at 0000 GMT & 1200 GMT is shown in Figure 4.22. The climate over Madras region is characterised by hot, humid summers and the terrain consists of rolling plains with cultivated lands. In the premonsoon period it is observed that for 50% of time the refractivity gradient is less than -70 N/km and for 10% of the time the gradient is less than -157 N/km in the plains where the links are monitored. This shows that the percentage occurrence of layers and ducts in this region is high and deep fades observed in these links are due to layers and duct only.

4.11.3 Study on the performance of links

Usually fading is expressed in terms of fade depth and depth is defined as the difference between the maximum and minimum signal strength over a very small interval of time (Dolukhanov, 1971). The data collected from the above five links were analysed for different fade depths. In analogue microwave system, fade depth is a good indicator of link performance (Prasad et al., 1990) and the cumulative distribution of fade depth gives an idea about the performance and reliability of the link. The cumulative distribution of fade depth for these links is shown in figure 4.23. From this figure it is observed that as the path inclination increases, fading due to super-refractive/subrefraction layers decrease. This is also observed by Hautefeuille et al (1980) in Senegal, where they have noticed that the horizontal path suffers deep and long duration fading compared with the inclined path. These are the most severe and well documented
Fig. 4.22 Occurrence percentage of Super refraction, Subrefraction and Ducting observed over Madras at 0000 GMT.
Fig. 4.23 Cumulative distribution of Fade depths observed over different microwave links in the coastal zone.
observations of multipath fading in tropical countries. Webster (1983) while investigating the multipath effects observed that the worst height for the receiver is the same height as that of transmitter. Netto and Dhein (1985) observed in Brazil that greater path inclination and space diversity can result in considerable improvement in links where ducts and layers occur very frequently.

4.11.4 Fading observed on LOS microwave links

Hourly fading distribution for all five LOS microwave link situated at different locations have been measured. It is instructive to compare the different distributions since the comparison can provide information on the dependence of the meteorological mechanisms contributing to fading. The hourly fading distributions for five locations are compared with each other. Frequencies range between 6, 7 and 11 GHz; frequency is not expected to influence diurnal distribution shapes significantly. Path geometries are reasonably similar. The diurnal fading depth distributions for various locations is shown in figure 4.24.

For all five distributions that are compiled from 12 months data base, there appears to be a correlation between the distribution width and latitude. The widths measured here are for the central 90% of the distribution, and they are presented in Table 4.5 along with latitudes. From the study it can be seen that in the nocturnal hours the distribution width decrease as the latitude increases.
Fig. 4.24 Diurnal variation of Fade depths observed over different microwave links in the coastal zone.
<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude (°N)</th>
<th>Diurnal Distribution width (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elagiri-Tirumala</td>
<td>12°55'</td>
<td>11</td>
</tr>
<tr>
<td>Puducherry-Madras</td>
<td>13°06'</td>
<td>12</td>
</tr>
<tr>
<td>Pallavaram-Tirumala</td>
<td>13°20'</td>
<td>15</td>
</tr>
<tr>
<td>Tirupati-Tiruttani</td>
<td>13°25'</td>
<td>20</td>
</tr>
<tr>
<td>Chittedu-Nellore</td>
<td>14°14'</td>
<td>23</td>
</tr>
<tr>
<td>Penukonda-Gooty</td>
<td>14°35'</td>
<td>27</td>
</tr>
</tbody>
</table>
4.12 DISCUSSION:

The propagation characteristics in humid tropical regions are significantly different from those in temperate climates. However, most of the data available on propagation is related to continental temperate climate (The U.S. and Germany) and maritime temperate climate (The U.K. and Japan). The data on other climates is sparse (Longley and Hufford, 1979). This calls for detailed studies in tropical zone over a number of years for interpreting and alleviating existing propagation anomalies. The field strength data of Gooty - penukonda microwave link is studied for both diurnal and seasonal variations, and also a comparison is made with other climates in India.

From this study it is noticed that there is a striking contrast in the propagation characteristics over various paths in India, even after taking care of the differences in terrain features, depending on the geographical region and maritime influence (Majumdar, 1977; Sarkar, 1978; Rao, 1984; Reddy, 1986; Nandini, 1985; Sarkar et al., 1987; Rao et al., 1987; Sen et al., 1987; Rao et al., 1989; Prasad, 1989; Ravi, 1989; Bhaskara Rao, 1990; Rao et al., 1991a; Prasad et al., 1991; Sarkar et al., 1991). However, there are certain common features. There is a definite diurnal and seasonal variation in the type and level of received signal and fading patterns. In general, in Southern India the period between 1900 hours and 0900 hours of IST is considered to be prone to signal degradation, fading and frequent communication outages on various links (Rao, 1984; Reddy, 1986; Ravi, 1989; Bhaskara Rao, 1990; Rao et al., 1991b), which may be attributed to steep anomalous
refractive gradients that often develop under stratified atmospheric structure formed due to nocturnal radiative cooling of the earth's surface. In contrast, during the daytime, because of solar heating, convective mixing is active in the boundary layer and steep gradients could not form and the refractive gradients are near normal i.e., around -40 to -75 N-units/km and consequently the propagation is normal and the signal levels are near free space level and remain constant but for small and rapid amplitude scintillations owing to turbulent fluctuations in the radio refractive index along the ray trajectories.

All over the world, some remedial measures were suggested by several workers (Dougherty, 1968; Vigants, 1975; Fehlaber, and Giloi, 1976; Hartman and Smith, 1977; Hautefeuille et al., 1980; Vigants, 1981; Garcia-Iopez, 1982; Webster, 1983; Netto and Dhein, 1985; Lin, 1988) to overcome severe fading of the microwave links, depending on terrain geometry, local climate and geographical location of the link path. In northern India on Delhi and Meerut microwave link, Prasad et al., (1991) have experimented antenna tilting technique. The antennae were tilted under convective conditions for a signal loss of 3 dB. The study showed that tilting of antennae has decreased the fade depths, and an improvement in the performance of the link is obtained. To overcome the obstruction fading, Vigants (1981) suggested to raise the antennae to minimize severe fading (Schiavone, 1981; CCIR Rep. 338-6, 1990).

It is observed from the investigations made on Gooty-Penukonda microwave link that super refraction gradients and the existence of layer structures in the ray path contribute significantly for the
fading. In order to suggest some remedial measures such as frequency diversity, space diversity, and fade margin estimations are studied. It is suggested that tilting the antenna upwards will reduce the observed fading and this will not have any financial commitment. Apart from this study a systematic comparison is made on geoclimatic factors. From the findings of the path inclination effect it can be concluded that fading is more on non-inclined paths compared to that of inclined paths.

The study carried in this chapter will significantly contribute to the characterization of several microwave links situated in different parts of tropical India.