Field Strength Measurements at 4.6 GHz in Line-of-sight, Diffraction & Scatter Modes of Propagation over Delhi-Pilani Link

S K SARKAR, M RAMAKRISHNA, H N DUTTA & B M REDDY
Radio Science Division, National Physical Laboratory, New Delhi 110012

Received 31 August 1981; accepted 26 June 1982

Results of microwave field strength measurements at 4.6 GHz in three different modes of propagation are presented. Measurements were conducted in the month of Nov. 1979 when the installation of a microwave troposcatter link between Indian Institute of Technology, Delhi, and Central Electronics Engineering Research Institute, Pilani, was done. In the line-of-sight mode the field level was measured up to a distance of 15 km. The microwave field was received in diffraction mode at a distance around 50 km. The Pilani/Delhi link starts functioning in tropo mode beyond 80 km.

1 Introduction
Tropospheric microwave communication is strongly dependent on different modes of propagation. The three well known modes of propagation are: (i) line-of-sight (LOS) (ii) diffraction and (iii) troposcatter. The LOS propagation is always within the horizon while the diffraction and troposcatter are beyond the horizon. The dominant mechanism in LOS propagation can be explained on the basis of two-ray-optics theory. The LOS received signal is a combination of direct ray and ground reflection with a possible contribution from scatter, etc. In the case of diffraction propagation one receives the signal diffracted from the physical object\(^2\). Far beyond the horizon, i.e. in case of troposcatter mode, the received power is a combination of scattered power and reflected power\(^2,3\). Scattering is due to the irregularities\(^4\) and reflection is due to the glints\(^2\) present in the scattering volume.

In this paper, the results observed in three different modes of propagation are presented. Measurements at 4.6 GHz were conducted in the month of Nov. 1979. The occasion was the installation of a microwave troposcatter link between Indian Institute of Technology (IIT), Delhi, and Central Electronics Engineering Research Institute, Pilani. A mobile field intensity meter (frequency range 1-10 GHz) with parabolic dish of 1.5 ft diameter with horn feed was installed in a jeep. In LOS mode, field strength was recorded up to 15 km. At a distance of about 50 km, the field strength was measured in the diffraction mode. It was observed that over the diffraction region, the signal level decreased very sharply. Tropscatter experiment was performed at a place called Jazzhar, 120 km away from Pilani. The field strength was of the order of 32 dB with respect to 1 \(\mu\)V. Fading period was very low (15-30 sec). The observed field was of typical scattered type showing that scattering was the dominant propagation mechanism.

The terrain profile features of Pilani/Delhi path (path distance = 160 km) are given in Table 1.

2 Meteorological Conditions over Delhi/Pilani Propagation Path
The meteorological parameters for the month of November for Delhi/Pilani path were determined on the basis of three years radiosonde data. The radiosonde measurements of Delhi and Jodhpur were considered for this troposcatter path. The following results were obtained.

| Effective earth’s radius factor for morning | 1.7 (0000 GMT, i.e. 0530 hrs IST) |
| Effective earth’s radius for morning | 10829 km |
| Effective earth’s radius factor for evening | 1.4 (1200 GMT, i.e. 1730 hrs IST) |
| Effective earth’s radius for evening | 8918 km |
| Average number of surface ducting 2 gradients in the morning per month | 2 |
| Average number of surface ducting 0 gradients in evening per month | 0 |
| Typical morning ducting gradient | -160 N/km |
| Typical evening ducting gradient | Nil |
| Observed duct thickness | 250 m |

Table 1—Details of Path Geometry

<table>
<thead>
<tr>
<th>Station</th>
<th>Elevation m</th>
<th>Obstacle elevation m</th>
<th>Obstacle distance km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilani</td>
<td>290</td>
<td>400</td>
<td>50</td>
</tr>
<tr>
<td>(Terminal 1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delhi</td>
<td>220</td>
<td>200</td>
<td>30</td>
</tr>
<tr>
<td>(Terminal 2)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 System Characteristics

The equipments which are in use for Pilani/Delhi troposcatter link have the following characteristics.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio frequency</td>
<td>4.6 GHz</td>
</tr>
<tr>
<td>Transmitting power</td>
<td>800 W</td>
</tr>
<tr>
<td>Receiver sensitivity</td>
<td>-90 dBm</td>
</tr>
<tr>
<td>Receiver antenna gain</td>
<td>25 dB</td>
</tr>
<tr>
<td>Transmitting antenna gain</td>
<td>45 dB</td>
</tr>
<tr>
<td>Type of transmitting antenna</td>
<td>Dish</td>
</tr>
<tr>
<td>Type of receiving antenna</td>
<td>Dish</td>
</tr>
</tbody>
</table>

4 Different Modes of Propagation

4.1 Line-of-sight (LOS) Propagation

In LOS mode, the transmitting and receiving aerials are within the horizon. When the transmitting and receiving aerials are only a short distance apart, it is safe to ignore the curvature of the earth’s surface and to think that radiowaves are propagated along a flat imperfectly conducting surface. Furthermore, it may be assumed that the surface is smooth and uniform along the entire length of the propagation path. This is a common occurrence in practice. In the case of LOS propagation, the received field power, \( E \), is a combination of direct ray and reflected ray from the ground. The resultant field \( E \) is expressed as

\[
E = E_1 + E_2
\]

where \( E_1 \) is the instantaneous field due to the direct ray and is given by

\[
E_1 = \frac{245}{r} \sqrt{P_1 G_1} \exp(i\omega t) \quad \text{(2)}
\]

and \( E_2 \) is the instantaneous field due to the ground reflected ray and is expressed as

\[
E_2 = \frac{245 P_1 G_1 G_2}{r} \exp \left( i \left( \omega t - \frac{2\pi}{\lambda} \Delta r \right) \right)
\]

where

- \( P_1 \) Transmitted power
- \( G_1 \) Gains of transmitted aerial
- \( G_2 \) Gains of receiving aerial
- \( \lambda \) Wavelength
- \( r \) Propagation path length
- \( \Delta r \) Path length difference between direct and reflected rays

From a comparison of Eqs. (2) and (3) it follows that the reflected ray differs from the direct one, both in amplitude and phase. The difference in amplitude is caused by the inevitable losses of energy in reflection. The difference in phase is due to two causes, namely, (i) the phase shift, \( \theta \), in reflection and (ii) retardation in phase due to difference in path lengths.

In all practical cases \( \Delta r \ll r \), so that \( \Delta r \) may be neglected in comparison with \( r \) in the denominator of Eq. (3). However, under no circumstances \( \Delta r \) can be neglected in comparison with \( r \) in the exponent.

In view of this, the rms value of \( E \) can be expressed in terms of attenuation function \( F \), where \( F \) is given as

\[
F = \left( 1 + 2R \cos \left( \theta + \frac{2\pi}{\lambda} \Delta r + R^2 \right) \right)^{1/2}
\]

where \( R \) is the reflection coefficient.

4.2 Knife-edge Diffraction

A propagation path with a common horizon for both terminals may be considered as having a single diffracting knife-edge. The common horizon may be a mountain ridge or similar obstacle and such paths are referred to as obstacle gain paths. In some cases, over a relatively smooth terrain or over the sea, the common horizon may be the bulge of the earth rather than an isolated ridge. This case is not covered under knife-edge diffraction. The diffraction attenuation due to a single knife-edge without ground reflections is given by

\[
A(V, 0) = 12.953 + 20 \log V
\]

while the parameter \( V \) is defined by

\[
V = \pm \left( \frac{2d \tan \alpha_0 \tan \beta_0}{\lambda} \right) \quad \text{(6)}
\]

where \( \lambda \) is the wavelength, \( \alpha_0 \) and \( \beta_0 \) are transmitting and receiving angles and \( d \) is the total path distance. In the case of LOS path, \( V \) is negative and for a transhorizon path \( V \) is positive.

4.3 Troposcatter Propagation

It is well established now that in troposcatter communication, turbulent scattering (homogeneous, isotropic scattering obeying \(-5/3\) spectral law) and reflection due to large number of reflection facets occur simultaneously. These facets caused by either thermal convection or reduced vertical exchange due to stability, are characterized by high refractivity gradients across the boundaries of these facets and are typically 3 m in thickness with a radius of curvature of the order of 1 km. A relationship is assumed between the change of refractive index, \( \Delta n \), through sharp boundaries and spectral intensity, \( C_n^2 \), of refractive index fluctuations, because the strong gradients are broken through the action of turbulence into a spectrum of fluctuations obeying \(-5/3\) spectral law. This relationship is expressed by

\[
\Delta n = 0.6 C_n^2 10^{1.6}
\]

The received power due to reflection by many facets is given by

\[
\frac{P_d}{P_{FS}} = \frac{4}{\pi d^2} \int \int N A_x \, dv
\]

... (8)
where

\[ P_d \] Power received due to reflection
\[ P_{FS} \] Power due to free space propagation
\[ d \] Path length
\[ N \] Number of reflecting facets per unit volume
\[ A_e \] Bistatic radar reflection area of facets

The resultant hourly median field strength due to both scattering and reflection due to these facets is given by

\[ A = \left( \frac{P_s}{P_{FS}} + \frac{P_d}{P_{FS}} \right) \] ... (9)

where \( P_s/P_{FS} \) is the power received due to scattering and is given by the relation \( 4 \)

\[ P_s/P_{FS} = 0.76 \times 10^{28} C_n^2 \left( \frac{dM}{dh} \right)^{-14/3} d^{-11/3} \lambda^{-1/3} a^3 \] ... (10)

where \( dM/dh \) is the modulus of refractivity, \( d \) the path length and \( a \) the antenna beam width.

5 Experiments and Results

The experiment was conducted in Nov. 1979 during early morning (0600 hrs IST) and was continued till late evening (1800 hrs IST). Field intensity meter of Singer (USA) make having 1.5 ft diameter parabolic dish with horn feed was installed in a jeep. In the initial stage of the experiment, the field intensity of the transmitted signal was recorded at every kilometre up to 15 km. Beyond 15 km, measurements were taken at an interval of 10 km up to around 50 km. Finally, measurements were done at a distance of 120 km from Pilani. Therefore, this experiment gives results of field strength for LOS diffraction and for troposcatter modes of propagation.

From Pilani end, the signal was received in LOS mode up to 15 km. Beyond 15 km, because of non-availability of greater height for installing the antenna, the measurements could not be done further in the LOS mode. The received field level at 15 km was of the order of 81 dB with respect to 1 \( \mu \)V. The basic free space transmission loss for 15 km propagation path at 4.6 GHz is 145 dB. The observed level was compared with the theoretical values and was found that observed level is 10 dB above the calculated signal level.

At about 50 km away from Pilani some hilly terrain, namely, Mahendergarh range is situated. Microwave amplitude measurements were conducted beyond Mahendergarh. The behaviour of signal level observed at this point shows that the field pattern is of the diffracted type. The order of signal level observed at distances of 52 and around 62 km is 62 and 47 dB, respectively, with respect to 1 \( \mu \)V. At this location the field levels were measured at every 2 km distance from this hilly point. It was found that the diffracted signal level decreased very sharply with distance. The position of the field intensity meter was also disturbed horizontally during the period of diffraction experiment. It was seen that the field strength decreased sharply in moving towards left as well as right of the central point. The field strength observed over both the sides are presented in Fig. 1. Fig. 1 reveals the angular spread through which the signal is spreading over the hill. Field strength measurements could not be performed around 70, 80, 90, 100 and 110 km distances because of non-availability of suitable locations where the measuring equipments could have been kept. In these positions, the receiving antenna was directed a few degrees off from the transmission line. However, at about 120 km from Pilani, a place called Jazzhar, field of scattered type was observed. The receiving antenna height was 2 km. The observed field level was of the order of 32 dB with respect to 1 \( \mu \)V. The predicted signal for Pilani/Delhi link is shown, in Fig. 2, for all the months by using two
methods. One is NPL method and the other is NBS 101 method. Fig. 2 shows that NBS 101 underestimates the field strength by about 10-15 dB. The fading depth was 30-40 dB, typical of the scattered type. The fading rate was very fast showing that the scattering mode was dominant. The fading period was 15-30 sec. The meteorological information deduced from the daily radiosonde observations obtained from the India Meteorological Department, New Delhi, suggests that during November, super refraction activity is less frequent over the Pilani/Delhi path. It may be mentioned here that in a tropo-link the scattered signal is caused because of atmospheric turbulence (refractivity gradient is of low order) while the reflected signal is because of superrefractive gradient.

The results obtained in all the three modes of propagation, viz. LOS, diffraction and troposcatter modes for Pilani/Delhi communication circuits are presented in Fig. 3 which shows that in LOS and troposcatter modes, the fall in signal level with distance is fairly steady, while in diffraction mode, there is sudden fall in signal intensity.

Acknowledgement
The authors are grateful to the Director General, India Meteorological Department, New Delhi, for providing the meteorological data for analysis. The cooperation extended by the team of CEERI, Pilani, and particularly the assistance of Dr M D Singh are gratefully acknowledged.

References
1 Beckman P & Spizzichino A, A scattering of e.m. waves from rough surfaces (Pergamon Press, London), 1962.
4 Tatarskii V I, The effects of the turbulence atmosphere on wave propagation (Moscow, Nauka), 1971.
5 Kirby R S, Dougherty H T & McQuate P L, Proc IRE (Australia), 43 (1965) 1467.