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A Study of VHF TV Signal Propagation Far Beyond the Primary Service Zone

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Television signals from Jullunder and Mussorie stations operating in band-III are recorded at National Physical Laboratory. An attempt is made to identify the propagation mechanism with the help of path loss predictions under different conditions. It is found that the Jullunder signal propagates by means of scattering and reflection, and Mussorie signal through line-of-sight mode. The cumulative distribution of median signal levels of both the transmissions are presented and the structure parameter (C_n^2) values deduced from Delhi-Jullunder path are found to be low during day time and high during nighttime.

1 Introduction

With the phenomenal increase of TV stations, the frequency allocation in the already crowded VHF band is going to be extremely critical. The future frequency allocation has to be based on various transhorizon propagation phenomena like sporadic-E, freak F-layer reflections, turbulent scatter, rain scatter, reflection from elevated layers ducting etc. The interest in the transhorizon propagation in the early part of the century was in terms of low-level signal statistics and service reliability. With the advent of satellite communications, the interest in the transhorizon propagation has declined. Recently the interest in this field is renewed because of the concern over its interference potential between different systems operating in the same frequency band. In fact, the switching of the transmission to Band-IV of UHF increases the probability of interference, as even smaller ducts can trap these signals. So a complete understanding of the medium on TV signal propagation is essential for future allocations. The propagation characteristics derived from the monitoring of the existing TV stations can provide valuable inputs to the frequency planners.

2 Experimental Details and Observations

The sound carriers of TV signals originating from Jullunder and Mussorie stations are recorded from June 1983 to May 1984 at National Physical Laboratory (NPL), New Delhi. The data were collected depending on the availability of TV transmissions. During June-August, the data were collected from 1500 to 2230 hrs, whereas in the post monsoon months and during winter season, the signals were recorded even during daytime. But the main drawback of the study is the non-availability of transmission between post-midnight and early morning hours in any of the months. From the Ayanagar observatory of India Meteorological Department, the radiosonde data of the same period are also obtained. The system consists of a high gain Yagi antenna, an on-mast front end amplifier, a VHF field intensity meter and a strip chart recorder.

The details of the transmitting stations are given in Table 1.

2.1 Terrain Profiles

The terrain profiles of Delhi-Jullunder and Delhi-Mussorie are shown in Figs 1 and 2, respectively. In the case of Delhi-Jullunder path the transmitting antenna at Jullunder is located at an elevation of 455 m above mean sea level. The terrain consisting of open grass, shrubs, agricultural farms and Sutlez river with a width of 1 km crosses the path at 50 km from the transmitting antenna. The path is not obstructed by any mountains or hills.

In the case of Delhi-Mussorie path the transmitting antenna is situated at Mussorie on a hill at a height of 2223 m and the receiving antenna at NPL, New Delhi. The line-of-sight (LOS) path is not obstructed by any hilly structure. The path crosses dense shrubs, a reserved forest, a fairly dense mixed jungle and some

Table 1—Details of Transmitting Stations

Station	Freq. MHz	Transmitted power kW	Distance from Delhi km	Antenna height m	Path loss dB
Jullunder	208.75	10	360	200	197
Mussorie	215.75	10	216	91	173

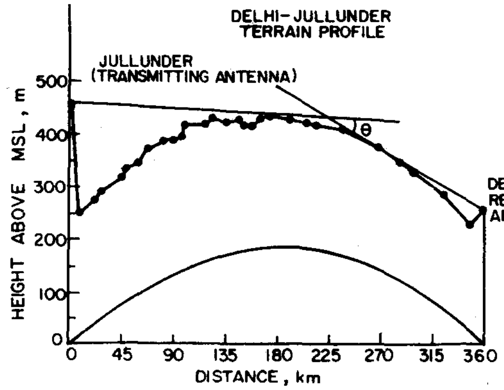

Fig. 1—Terrain profile of Delhi-Jullunder

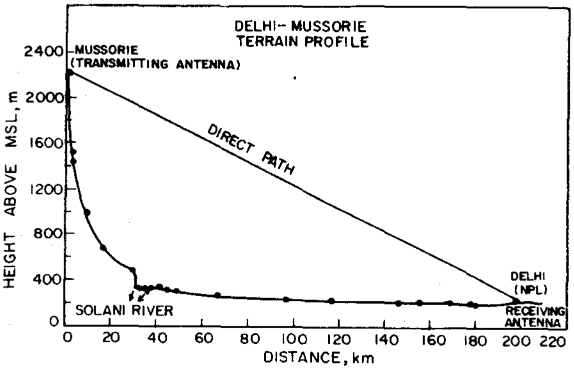

Fig. 2—Terrain profile of Delhi-Mussorie

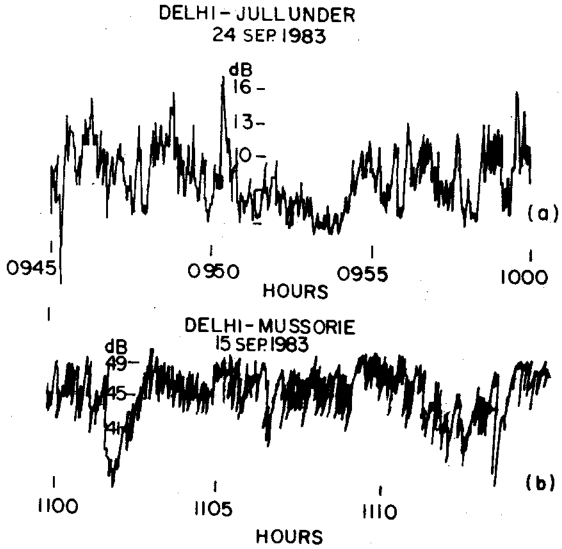

Fig. 3—Typical records of Jullunder and Mussorie signals

rocky cliffs but these are not effective enough to obstruct the path.

2.2 Typical Records

Typical daytime records of Jullunder and Mussorie signals are shown in Fig. 3 [(a) and (b)]. The records reveal that Jullunder TV signal propagates in scatter mode. The signal exhibits small amplitude rapid fluctuations of the order of 2-4 dB up to 1900 hrs and afterwards the signal starts increasing exhibiting slow and deep fades of the order of 5-10 dB. The increase in signal strength and the formation of slow and deep fades may be due to the reflections of the signal from the layer structures of the atmosphere. The Mussorie signal propagates in LOS mode. The signal increases up to 1900 hrs and decreases thereafter till 2030 hrs. After this time the signal shows an increasing tendency till 2100 hrs and remains stable thereafter. The average Mussorie signal is found to be of the order of 30-35 dB above 1 μV.

2.3 Identification of the Propagation Mechanism

As the frequencies of both the signals are above 200 MHz, ionospheric propagation is completely ruled out. The possible tropospheric propagation modes are LOS diffraction scatter and ducting; of course, all the above modes will give extended coverage if super-refraction conditions are associated. Here we will first investigate the Jullunder signal.

The LOS range (r_0) is given by

$$r_0 = \sqrt{2a'}\,(\sqrt{h_1} + \sqrt{h_2}) \qquad \ldots (1)$$

where a' is the effective earth radius, h_1 and h_2 are the heights of transmitting and receiving antennae. Substituting the values of h_1, h_2, r_0 we get $a' = 46{,}580$ km or $K = 7.31$ (K is known as effective earth radius factor and is given by $K = a'/a$, a being the earth radius). The corresponding refractivity gradient is found to be -136 N/km (N is the refractivity). So when a gradient of this value exists, then only Jullunder signal propagates in LOS mode. As the observed gradients are much lower than this value, LOS as well as ducting mechanisms are eliminated.

2.4 Calculation of Path Loss under Diffraction Conditions

Here the CCIR method[1] has been utilized for calculating the received field strength. According to this method, we have

$$20 \log \left(\frac{\varepsilon}{\varepsilon_0}\right) = F(d) + H(h_1) + H(h_2) \qquad \ldots (2)$$

where ε is the received field strength, ε_0 the field strength in free space at the same distance, d the distance of the path and h_1 and h_2 are heights of antennas.

The function F (influence of distance) and H (height-gain) are calculated from the nomograms. For an observed gradient of -40 N/km corresponding to monsoon season, the diffracted field is -76 dB above 1

μV or the path loss amounts to 287 dB. As this value is much higher than the experimentally observed value, it can be concluded that the signal cannot propagate through diffraction mechanism.

2.5 Scatter

The third possibility is the scattering of radio energy from the refractive index irregularities. The forward scattered power depends on the spatial distribution of irregularities and the radio wavelength. It is difficult to predict the magnitude of scattered power because of the variability of refractive index with time and position, and the variability of wave number spectrum with local meteorological conditions. The prominent prediction techniques are: NBS-101 method, NPL method, French Administration method, CCIR method and Collin's method. Among these NBS-101 is a widely accepted one.

2.6 NBS-101 Method

This method, for the calculation of transhorizon forward scatter loss, is documented in NBS-101(Ref.2) and computer code (Ref.3). The four essential parameters are radiofrequency, surface refractivity, terrain characteristics and antenna heights. According to this technique, the reference value L of long-term median basic transmission loss due to forward scatter is given by

$$L = 30 \log f - 20 \log d + F(\theta, d) - F_0 + H_0 - A_a \quad \ldots (3)$$

where f is frequency in MHz, d the distance in km, $F(\theta,d)$ the attenuation function, θ the angular distance in rad, F_0 the scattering efficiency correction term, H_0 is frequency gain function and A_a is atmospheric attenuation.

At lower frequencies A_a is completely negligible and F_0, which allows for reduction in scattering efficiency rarely exceeds 2 dB. For $\frac{h_{te}}{\lambda}$ and $\frac{h_{re}}{\lambda} > \frac{4a}{d}$, H_0 is negligible. In the present case $h_{te}/\lambda = 315.97$, $4a/d = 70.78$, and $h_{re}/\lambda = 177.08$. Here h_{te} and h_{re} are the heights of transmitting and receiving antennae, respectively.

Neglecting the last 3 terms and substituting the value of $F(\theta,d)$ for a surface refractivity of 330 in Eq.(3), we get $L = 186$ dB. So NBS method underestimates the path loss by as much as 11 dB. The non-suitability of NBS method was even illustrated earlier by Majumdar[4] and Sarkar[5], while examining the transhorizon propagation characteristics over Northern India.

2.7 NPL Method

This prediction technique developed by Majumdar[6] is based on the Eklund-Wickerts model[7] which assumes that layer reflection and scattering from the common volume intercepted by the antennae exist simultaneously, with layer reflection being more frequent when wide beam antennae and lower frequencies are used. The reflecting facets caused by either thermal convection or reduced vertical exchange are characterized by high refractivity gradients. The field strength is given by

$$A = \frac{P_s}{P_{Fs}} + \frac{P_d}{P_{FS}} \quad \ldots (4)$$

The first and second term of R.H.S. of Eq. (4) represent, respectively, the scattered power[8] and the power received due to reflection, and are given by

$$\frac{P_S}{P_{FS}} = 0.76 \times 10^{28} C_n^2 \left(\frac{dM}{dh} \right)^{-14/3} \times d^{-11/3} \lambda^{-1/3} \alpha^3 \quad \ldots (5)$$

and

$$\frac{P_d}{P_{FS}} = \frac{4}{\pi d^2} \int_V n A_e dV \quad \ldots (6)$$

where n is the number density of reflecting facets per m^3, A_e the bistatic radar reflection area of each facet, dV the elemental volume, M the refractivity modulus and α the beam width of the antenna. The path loss calculated by summing up the scattered and received powers is found to be 193 dB. The path loss from the signal measurements can be obtained as follows.

$$\text{Path loss} = P_t - P_r + G_t + G_r + A_r$$

where A_r is the gain of front-end amplifier. Substituting the values of P_t, P_r, G_t, G_r, A_r we get path loss as 197 dB.

The value obtained through NPL technique is much closer to the observed value than NBS and even other propagation mechanisms. Therefore, it can be concluded that Jullunder signal propagates through scattering and reflection.

2.8 Delhi-Mussorie Path

The expected free-space field strength (ε_0) was computed by $\varepsilon_0 = (30PG)^{1/2}/r$. The value of ε_0 was compared with the measured field strength ε_m (from records). Thus, we have $P = 20 \log \left(\frac{\varepsilon_0}{\varepsilon_m} \right)$ and the free space attenuation, $Q = 20 \log \left(\frac{4\pi d}{\lambda} \right)$. So the total path loss becomes $L = P + Q = 48 + 125 = 173$ dB. As the transmitting end is situated on a hill, the receiving point comes within the LOS distance.

3 Results and Discussion

The cumulative distributions of median signal levels for Jullunder and Mussorie stations are shown in Figs 4 and 5, respectively. The Jullunder signal exceeds 9 dB for 80 % of time and a level of 25 dB exceeds for less than 2 % of the time, in both monsoon and post monsoon seasons. In monsoon season the signal exceeds 11 dB for 50 % of time whereas in the post monsoon season the signal exceeds 13 dB for 50 % of time. The seasonal variation is prominent between 40 and 75 % of times. Mussorie signal exhibits seasonal variation more vividly. A signal level of 56 dB is exceeded for 2.5 % of time in both the seasons. In monsoon season, the median level exceeds 23 dB for 50% of time, whereas in the post monsoon season the signal level exceeds 36 dB for 50% of the time. For 80% of time the signal exceeds 13 dB in monsoon season,

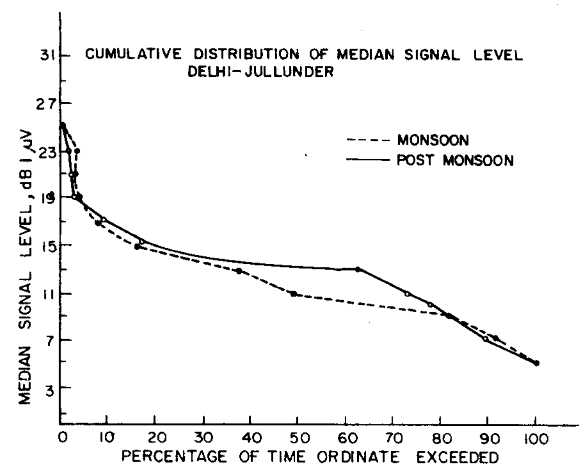

Fig. 4—Cumulative distribution of median signal level for Delhi-Jullunder path

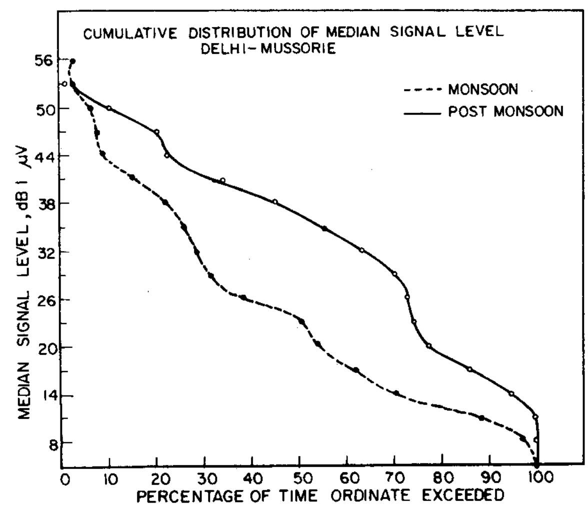

Fig. 5—Cumulative distribution of median signal level for Delhi-Mussorie path

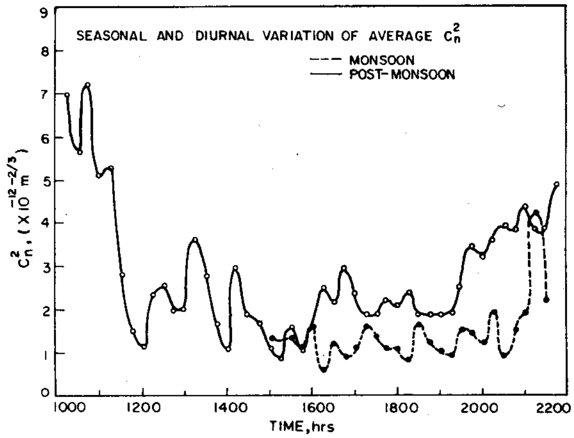

Fig. 6—Seasonal and diurnal variation of average C_n^2

whereas post monsoon values exceed 19 dB for 80% of time.

Fig. 6 depicts the variation of C_n^2 values as a function of time. These values are deduced from the Jullunder signal, as these will be more representative of refractive index fluctuations because of its scatter propagation. The C_n^2 is of the order of $7 \times 10^{-12} m^{-2/3}$ at 1000 hrs and starts decreasing at 1200 hrs. It remains more or less steady at the value 2×10^{-12}, starts increasing at 1800 hrs and approaches a value of 5×10^{-12} at 2200 hrs. In the monsoon season, daytime values are of the order of 1×10^{-12}, and the nighttime values around 3×10^{-12}. Overall post-monsoon values are higher than the monsoon values. Tatarskii[9] evaluated C_n^2 at 1.5 km which was found to be in the range 1.4×10^{-13} to $4.4. \times 10^{-16} m^{-2/3}$. Majumdar[6] quoted the value of C_n^2 as10^{-13}-10^{-14}in his transmission loss data.Dutta *et al.*[10] reported a value of $3.18 \times 10^{-12} m^{-2/3}$ for C_n^2 from Delhi-Sonepat LOSS link data.

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