A Study of Television Signal Propagation between Lucknow & Allahabad

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The feasibility of TV signal propagation between Lucknow (26° 39.9'N; 80° 54'E) and Allahabad (25° 27'N; 81° 44'E) has been studied. The electric field strengths due to diffraction and troposcattering have been calculated to be of the order of 1 and 10 μV/m, respectively. The seasonal variation of signal strength has been explained considering the effect of seasonal variation of dN/dh in the troposcattering link. The possibilities of duct propagation, very high refraction, meteorite scattering and reflection from sporadic-E have been ruled out. Though troposcatter signal strength is of very low order than the required value, as in the present case, it appears to be the only mechanism responsible for television signal propagation at distances of the order of 120 miles.

1 Introduction

On 27 Nov. 1975 a TV station was commissioned at Lucknow (26° 39.9'N; 80° 54'E). This station uses channel 4, the frequency range for which lies between 61 and 68 MHz. With a transmitting antenna height of about 85 m sufficiently large signals were obtained even at places like Allahabad (25° 27'N; 81° 44'E) situated at a distance of about 200 km. For the given antenna height Allahabad ordinarily lies in the shadow zone of the transmitter. The most significant observation is the persistent feature of the signal which is obtained for a period of 2-3 months during winter every year. The radio wave propagation for frequencies above 30 MHz beyond radio horizon is caused by a large number of factors, namely, (a) diffraction along the earth surface, (b) refraction and scattering in the troposphere, (c) scattering by meteors and (d) reflection from sporadic-E layer of the ionosphere. These phenomena have been extensively discussed in the works of Bullington1,2, Booker and Gordon3, Feinstein4,5, Carroll6, Villars and Weisskopf7, Norton8, Reed and Russel9, Dolukhanov10, Terman11 and Bowles12. In this paper we have analyzed the feasibility of each of these different types of radio wave propagation contributing to the TV signal at Allahabad considering tropospheric characteristics and electrical properties of the earth between Lucknow and Allahabad and have calculated the electric field due to diffraction and troposcattering.

2 Signal Strength due to Diffraction

Beyond the line-of-sight the surface wave that reaches the receiving point is due entirely to diffraction around the surface of the earth until some process other than diffraction becomes paramount in the turbulent region beyond. Signal strength in the diffraction region has been extensively studied by Sommerfeld13, Norton8, Reed and Russel9. Here we shall calculate the field strength due to diffraction based on the work of the above authors. The main parameters of the television transmitter at Lucknow are given in Table 1. The electric field strength due to elevated antennas over a spherical earth surface is given by

\[ E_{\text{diff.}} = E_{\text{su}} \times f(q_1) \times f(q_2) \]  

(1)

where \( E_{\text{su}} \) is the spherical earth surface wave field strength and \( f(q_1) \) and \( f(q_2) \) are the height gain functions of the receiving and transmitting antennas. Using the parameters given in Table 1 the field strength due to spherical earth surface wave has been obtained and is plotted in Fig. 1. For a distance of 200 km, Fig. 1 gives \( E_{\text{su}} \) equal to \( 1.6 \times 10^{-5} \) μV/m. The height gain

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture carrier frequency</td>
<td>62.25 MHz</td>
</tr>
<tr>
<td>Sound carrier frequency</td>
<td>67.75 MHz</td>
</tr>
<tr>
<td>Polarization</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Electrical ground constants (( \sigma ) and ( \epsilon_r ))</td>
<td></td>
</tr>
<tr>
<td>( \sigma )</td>
<td>( 5 \times 10^{-2} ) mho/m</td>
</tr>
<tr>
<td>( \epsilon_r )</td>
<td>13</td>
</tr>
<tr>
<td>Transmitter antenna height</td>
<td>85 m</td>
</tr>
<tr>
<td>Transmitter power</td>
<td>10 kW</td>
</tr>
<tr>
<td>Transmitter antenna gain</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Note: The receiving antenna height at Allahabad is approximately 30 m.
function, taking average values of ground conductivity ($\sigma$), relative dielectric constant ($\varepsilon_r$) and standard lapse rate of refractivity of troposphere ($dN/dh$) as

$$\sigma = 5.0 \times 10^{-2} \text{ mho/m}$$

$$\varepsilon_r = 13$$

$$\frac{dN}{dh} = -0.04 \text{ per metre}$$

has been calculated and is shown in Fig. 2. From Fig. 2 it is clear that for small antenna heights the height-gain function increases linearly; otherwise it has an exponential rise. For transmitting and receiving antenna height of the order of 280 feet and 75 feet, respectively, we obtain that $f(q_1) = 560$ and $f(q_2) = 126.5$.

Using these values of $f(q_1)$, $f(q_2)$ and $E_{\text{aw}}$, the diffraction field is obtained and is shown (broken line) in Fig. 1 which gives the electric field strength of the order of 1.2 $\mu$V at distances around 200 km.

### 3 Signal Strength by Troposcatter

It has been observed that in turbulent region that lies between approximately 30 miles beyond the radio horizon line and a total range of 400 miles from a high-power transmitter the troposcatter signal dominates the diffraction signal. In this region the average field strength decays at a rate of only about 1/7 dB per mile. The absolute value of the measured signal in the turbulent region is roughly 100 dB below the calculated free-space value at a total distance of 400 statute miles from the transmitter. The variation of signal strength with height appears to be very little for antenna heights up to 100 ft. Field strength in this case is calculated by a method given by Reed and Russell and is shown (turbulent field curve) in Fig. 1. The diffraction theory field strength curve is used up to the range where it meets 1/7 dB per mile curve. Beyond this point 1/7 dB per mile curve is used for greater ranges. For receiver separated by a distance of 120 statute miles from the transmitter the troposcatter yield is 7.2 $\mu$V/m. There is yet another analytical way of obtaining the troposcatter signal strength.

The troposcatter power density at the receiver is given by

$$P_r = \frac{P \cdot G}{4\pi d^2} F^2$$

where $P_r$ is transmitter power, $G$ is antenna gain and $F$ is the attenuation function which is given by

$$F = \frac{2}{d} \sqrt{\frac{\psi(\theta)}{\pi}} V$$

$\psi(\theta)$ is the effective scattering cross-section per unit volume, $\theta$ is the angle between transmitting and receiving antenna beams, $d$ is the distance of communication along the earth's surface and $V$ is the entire scattering volume.

A plot of the median values of attenuation function plotted against distance for winter is given by Dolukhanov and is shown in Fig. 3. From Fig. 3 we find that for a distance of 120 statute miles...
Table 2—Vertical Gradient of Radio Refractivity ($-dN/dh$) at Allahabad (25° 27'N; 81° 44'E)

<table>
<thead>
<tr>
<th>Month</th>
<th>I (per 1000 ft)</th>
<th>II (per 1000 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Feb.</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>Mar.</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Apr.</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>May</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>June</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>July</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Aug.</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>Sep.</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>Oct.</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Nov.</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>Dec.</td>
<td>17</td>
<td>10</td>
</tr>
</tbody>
</table>

Note:
I—Values between ground surface and 5000 ft.
II—Values between 5000 and 10,000 ft.

Table 3—Values of the Parameters $\sigma$, $\varepsilon$, and $-dN/dh$ between Lucknow and Allahabad during the Three Seasons

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Monsoon</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$ (mho/m)</td>
<td>$5 \times 10^{-2}$</td>
<td>$5 \times 10^{-4}$</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>13.0</td>
<td>9.0</td>
<td>5.0</td>
</tr>
<tr>
<td>$-dN/dh$ (per metre)</td>
<td>$5.25 \times 10^{-2}$</td>
<td>$5.57 \times 10^{-2}$</td>
<td>$2.94 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

4 Discussion
In our previous calculation of signal strength due to diffraction we have assumed that the surrounding terrain is fairly level land of average conductivity and permittivity. The results obtained either by diffraction or by scattering are insufficient to produce the requisite signal strength for picture reproduction. As indicated in Fig. 1, the minimum field strength required for a city service area is 5000 $\mu$V/m, for a rural service area it is 500 $\mu$V/m while for a marginal service area it is 50 $\mu$V/m. Calculations have shown that the diffraction or the scattering mechanism is incapable of giving a field strength beyond 10 $\mu$V/m. Thus the diffraction or the scattering fails to provide sufficient signal for producing a clear picture on the television screen. Another important feature is the seasonal variation of signal strength. In order to obtain the seasonal variation of the signal strength we need permittivity, conductivity and lapse rate of refractivity at different intervals of the season. The lapse rate of refractivity at Allahabad has been reported by Kulshrestha and Chatterjee and is given in Table 2. The average seasonal variation of $dN/dh$ between Lucknow and Allahabad has been obtained by averaging $dN/dh$ as indicated in Table 2 during monsoon, winter and summer and is given in Table 3. In obtaining this average we have assumed that the response of the atmosphere at Lucknow is same as that of Allahabad during all the three seasons. In Table 3 we have also given the median values of conductivity and permittivity of the dry earth, wet earth and the earth surface covered by grass and crops.

The calculations show that the diffraction field which is obtained by multiplying the spherical earth surface wave field strength $E_{su}$ by the height gain functions $f(q_1)$ and $f(q_2)$ of the transmitting and receiving antenna, i.e.

$$E_{diff} = E_{su} \times f(q_1) \times f(q_2)$$

and as given below

- $2.16 \mu V/m$ during monsoon,
- $2.09 \mu V/m$ during winter, and
- $0.56 \mu V/m$ during summer

does not very clearly indicate any seasonal variation. This seems to contradict our experimental observation.

The seasonal variation in the troposcatter field strength between Lucknow and Allahabad can be explained as follows. From Table 2, we find that as the winter gives way to summer the gradient $dN/dh$ increases (the gradient is always negative, it is the absolute value that decreases). As a result the radius of
respectively, calculations show that a very high signal strength in the shadow zone provides a marked decrease in the scattered field. On the other hand, since \( \psi \) is proportional to the mean variation in refractive index, which always decreases on moving away from the earth surface, there is a further decrease in the signal strength. This agrees with our observation but contradicts the normal troposcatter behaviour (Dolukhanov\(^1\)) that stipulates a warm maritime climate to favour tropospheric scattering and a cold dry climate to weaken the scattering.

There are certain other mechanisms which may give very high signal strength in the shadow zone. These are (i) duct propagation, (ii) a very high refraction, (iii) meteorite scattering and (iv) reflection from sporadic-E.

For duct propagation to occur there are three essential conditions, namely, (a) \( dN/dh < -0.157 \text{ m}^{-1} \) (b) the wavelength supported by the duct should not exceed \( \lambda_c \), the cut-off length which is related to the height of the duct \( h_o \), as

\[
\lambda_c = 8.5 \times h_o^{0.3} \times 10^{-4} \quad \text{(4)}
\]

where both \( \lambda_c \) and \( h_o \) are expressed in m, and (c) both transmitting and receiving antennas must be trapped within the duct\(^1\). Calculations show that, even if there are pockets or regions where the first condition is satisfied, to support a wavelength of 4.82 m (corresponding to the picture carrier of 62.25 MHz) a duct of 685.5 m height is required which is rather impossible because the height of the duct ordinarily never exceeds 200 m.

The possibility of a very high refraction may be explained as follows.

With \( h_1 \) as the transmitting antenna height, \( h_2 \) as the receiving antenna height, the maximum distance up to which the space wave can propagate is\(^1\)

\[
d_{\text{max}} = \sqrt{2h_1} a' + \sqrt{2h_2} a' \quad \text{(5)}
\]

where \( a' \) is the effective earth’s radius given by

\[
a' = \frac{a}{1 + a \frac{dN}{dh} \times 10^{-6}} \quad \text{(6)}
\]

and \( a \) is the actual earth radius (\( = 20.9 \times 10^6 \text{ ft} \)) (Ref. 10).

From Eqs (5) and (6) substituting the value of \( d_{\text{max}} \) as 120 statute miles, \( h_1 \) and \( h_2 \) as 280 and 75 feet, respectively, calculations show that a very high refraction needs a value of 143 m\(^{-1} \) for \( dN/dh \). From Table 2 we see that the lapse rate of refractivity is much smaller as compared to the required values; therefore the possibility of a very high refraction to occur is also ruled out.

As regards meteor or sporadic-E scattering no precise statement can be made because of the non-availability of either of the meteor or the sporadic-E data. But since the television signal is received continuously during winter every year, meteor or sporadic-E scatterings have also remote possibilities.

5 Conclusion

From the above discussions we can easily conclude that the most apparent mechanism for supporting the TV signal propagation between Lucknow\((26^\circ 39.9'N; 80^\circ 54'E)\) and Allahabad\((25^\circ 26'N; 81^\circ 44'E)\) appears to be the scattering in the troposphere, because the normal diffraction in the shadow zone provides a signal strength much below the requisite level and the possibility of meteorite and sporadic activity being dominant during the winter season is also remote. However, the variations in the signal strength that is available due to the tropospheric scattering, as calculated in the text, are on the lower side and this might have been caused by two factors. Firstly, the troposphere radio links used for calculating troposcatter signal, as shown in Fig. 3, may not exactly fit in with the Indian weather conditions, especially between Lucknow and Allahabad. Secondly as the radio links are not available at 62.25 MHz the average values of attenuation which have been chosen might again be responsible for the further decrease of the signal strength. The experiments for recording the TV signal at Allahabad are continuing and on receiving further data, it is believed that our conclusion that proposed scattering is responsible for the requisite TV signal at Allahabad will be further supported.

References

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