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Diffraction Patterns Observed in VHF Signal Propagation

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Quasi-periodic fading of TV signal in the fringe region of reception has been reported. The amplitude patterns observed in this case show some similarities with narrow Fresnel type patterns usually observed in orbiting satellite signals passing through ionosphere. Characterization and seasonal variations of the observed patterns are discussed.

1 Introduction

The transhorizon propagation characteristics critically depend on frequency, antenna heights, location and meteorological conditions. Results on propagation can be obtained by monitoring the existing TV stations[1] and such results are useful for the designers to establish tropospheric communication circuits. With this in mind, a collaborative programme was initiated in Calcutta among Indian Statistical Institute, Institute of Radio Physics and Electronics and Bengal Engineering College, each separated from one another by a distance of about 8 km. All these stations are recording simultaneously the TV signals at 189 MHz from Satkhira (Bangladesh) situated at a distance of 75 km from Calcutta. Periodic amplitude variation is often noticed during the passage of an aircraft across the propagation path. These variations originate presumably from the obstruction or reflection of successive Fresnel half period zones involved, resulting in a diffraction type pattern. Similar interference/diffraction patterns are observed even when there is no aircraft in the propagation path. Such patterns are presumed to originate from some moving tropospheric structures in the propagation path.

Attempts have been made earlier by several workers[2,3] to simulate some of the observed quasi-periodic fluctuations of satellite signals by postulating a drifting diffraction pattern generated by a simple Gaussian irregularity or irregularities[4]. Observations at a sub-auroral zone site of transmission from certain geostationary satellites have revealed an unusual regular type of fading apparently due to diffraction from moving ionospheric deformations. The fading patterns observed in transionospheric propagation have been explained by earlier workers[5,6] in terms of interference of two signals. Some investigators consider the plasma lenses in the F-region[5] while others suggest that these are caused by sporadic-E patches[4]. Titheridge[6] has used the Kirchoff integral to calculate the diffraction pattern on the ground, caused by the lenses which produce Gaussian distribution of phase across the wavefront.

Gjessing[7] has shown in the analysis of diffraction phenomena that a terrain obstacle within the line-of-sight (LOS) of a ground-based radio duct gives rise to a well defined beam of diffracted power behind the obstacle. Knowing the propagation path, obstacle location, obstacle geometry and the properties of duct, the diffracted power spectrum can be deduced. The spectral characteristics of the observed patterns of TV signals received at Calcutta have already been reported earlier[8].

In this paper we present the results of characterization of the observed quasi-periodic fading patterns of TV signals recorded during one year. These patterns show variations and are similar to Fresnel type[2] and last, sometimes, for 60 s. Moreover, these patterns, though look different, have some ordering as discussed later.

2 Observations

When a radio wave propagates through the earth's atmosphere it passes through a medium whose intrinsic properties are not always constant. The variation of pressure, temperature and water vapour content changes the direction and velocity of the waves. The surface of the earth acts as a curved boundary from which radio waves are reflected and diffracted.

According to the simple ray theory, the effect of an isolated irregularity causes slight change in the direction of incident rays. For weak irregularities this amounts to a smooth variation in amplitude across the ground, as the downcoming waves are spread out in some places and bunched up in the others. As the density of the irregularities increases, the refraction of the rays increases until it reaches a point where different rays overlap producing interference effects. The ground pattern then shows large and rapid fluctuations in amplitude and phase. The mean signal level, recorded at the Indian Statistical Institute (ISI), Calcutta, was found to vary over a range less than 0.1V to about a mean level of 1.8V. The amplitude variations of the diffraction patterns lie between 5 mV and 50 mV. The diffraction patterns recorded at three different stations around Calcutta are normally uncorrelated, but on certain occasions, these are observed at two or three stations with a characteristic time delay between the stations as shown in Fig. 1. Such patterns usually occur in pairs.

The observed patterns, in general, can be classified as 'strips' or 'edges', but there is a large variety in the actual shapes. These patterns show extensive ringing and vary from event to event. When a series of patterns occur, they are often of equal amplitudes and shapes as shown in Fig. 2. The separation gaps between the successive patterns are approximately constant while the periodicity varies from event to event. Elkins and Slack[2] have obtained similar scintillation patterns having periodicity of 10-15 min, originating from F-region irregularities.

Titheridge's work[6] on diffraction by isolated irregularities can be used as a basis which produces Fresnel diffraction pattern on the ground. For diffraction of a wave with wavelength, λ, by a one-dimensional phase fluctuation $\phi(x)$, the field observed at a point on the ground may be described by a component, A, in phase with the undisturbed wave and a component, B, in quadrature with it. The expressions for A and B are given as

$$A = 1 - 2\int \sin(p+\phi/2)\sin(\phi/2)\,\mathrm{d}x/\sqrt{r\lambda} \qquad \ldots (1)$$

$$B = 2\int \cos(p+\phi/2)\sin(\phi/2)\,\mathrm{d}x/\sqrt{r\lambda} \qquad \ldots (2)$$

and

$$p = \frac{2\pi}{\lambda}(r-h) - \pi/4 \qquad \ldots (3)$$

where h is the height of the irregularity and r the distance between the element $\mathrm{d}x$ and the receiver. The integrals are taken only over the irregularity. The concept of opaque strips may be acceptable at 20-40 MHz, but it is likely that opacity dominates even at frequencies as high as 189 MHz. A better approach is to treat the irregularity in terms of a phase screen.

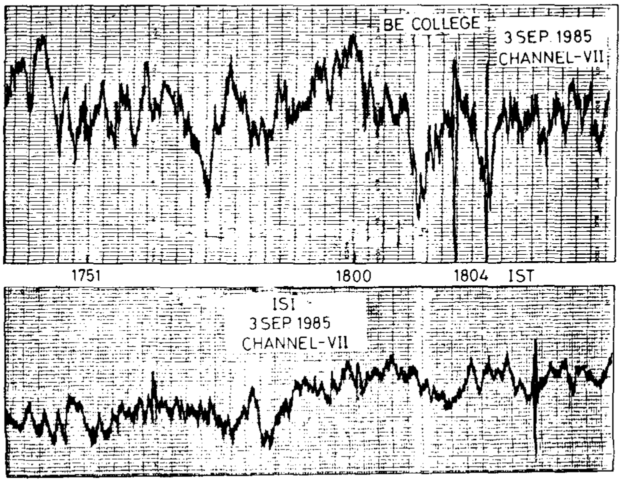

Fig. 1—Diffraction pattern observed at ISI and BE College

The cylindrical lens model might give a better interpretation of the diffraction pattern at higher frequencies. It provides the required modulation of the diffraction pattern provided the maximum phase shift is sufficiently large and the width of the lens (σ) is sufficiently small. The cylindrical lens model can give a Gaussian distribution of phase, ϕ, across the emergent wavefront, i.e.

$$\phi = \phi_0 \exp\left\{-\frac{(d-d_0)}{2\sigma^2}\right\} \qquad \ldots (4)$$

where d_0 is the distance of the lens measured along the line perpendicular from receiving point to the incident wavefront and σ, the scale size of the lens. The parameters σ, d and d_0 are measured in terms of first Fresnel zone. Both symmetrical and asymmetrical patterns could be produced by cylindrical lenses with a symmetrical or unsymmetrical cross-section.

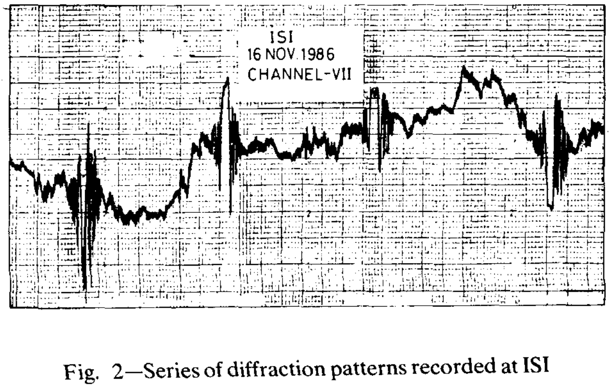

Fig. 2—Series of diffraction patterns recorded at ISI

Alternatively, these may be the result of temporal changes, e.g. the expansion of lens.

However, analytical approach to this problem has been confined to various limiting cases. The statistical properties of the resulting diffraction pattern can be evaluated readily when the r.m.s. phase derivation, ϕ, imposed on the screen is small. The problem is considerably more complex when, ϕ, is of the order of 1 radian. However, no analytical solution or approximation is available.

3 Characterization of Diffraction Patterns

The various types of fading patterns obtained at different stations around Calcutta show some similarities and dissimilarities. The amplitude of the patterns observed in BE College station is usually larger. The gain of the recording system is kept constant in all the stations. In order to find the order of patterns and to characterize the patterns we have selected four patterns of different dates at ISI as shown in Fig. 3. Though these patterns appear to be very different from one another, still there are some orders as shown in Fig. 4. The periodicity falls off gradually as we move away from the middle of the patterns. The periodicity of patterns are found to vary from 0.6 to 6 s.

These patterns can be represented by a set of polynomials for amplitude and period as

$$y = 2.6906 - 0.6442x + 0.0636x^2 - 0.00206x^3 \quad \text{(for right half of period)} \qquad \ldots (5)$$

$$y = 2.5229 - 0.5824x + 0.0552x^2 - 0.00122x^3 \quad \text{(for left half of period)} \qquad \ldots (6)$$

$$y = 2.1302 - 0.4495x + 0.0396x^2 - 0.00122x^3 \quad \text{(for right half of amplitude)} \qquad \ldots (7)$$

$$y = 1.4171 - 0.1284x + 0.0031x^2 + 0.000025x^3 \quad \text{(for left half of amplitude)} \qquad \ldots (8)$$

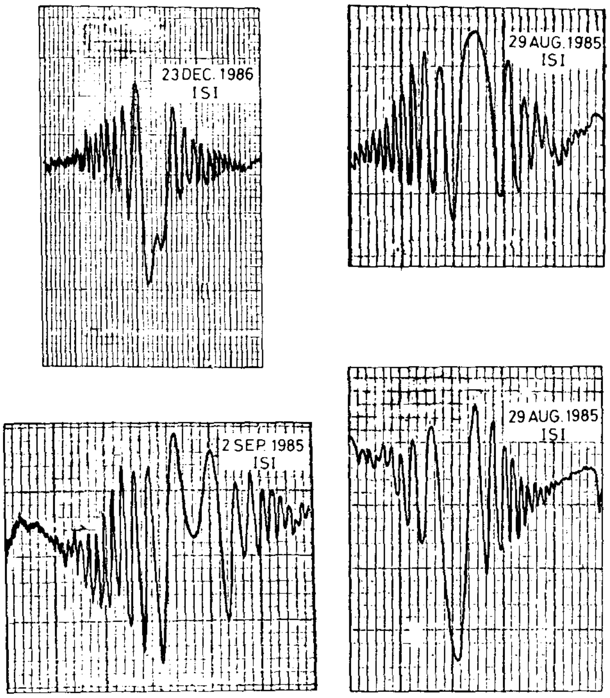

Fig. 3—Different types of patterns recorded on various dates

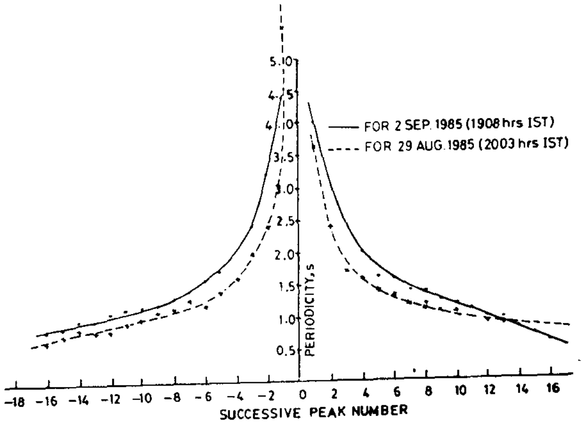

Fig. 4—Plot of periodicity of different patterns

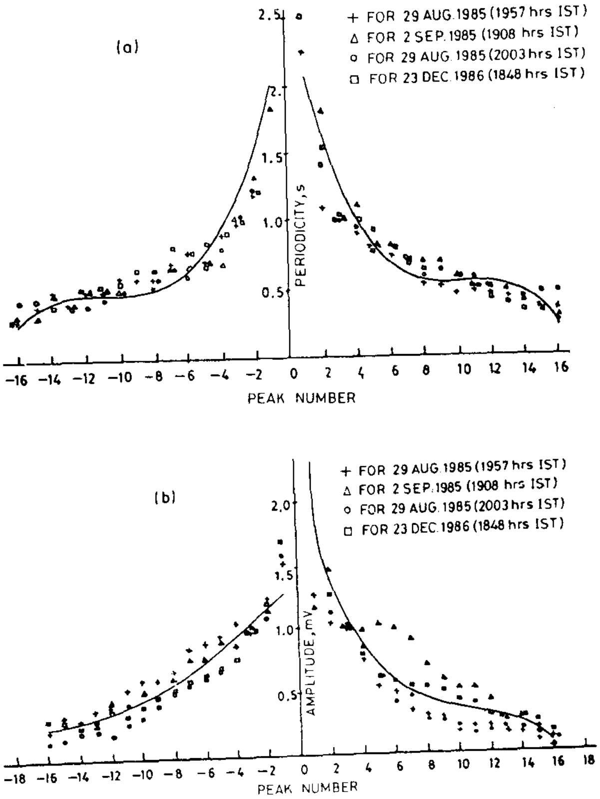

Fig. 5—Plot of polynomials showing scattering among the different patterns for (a) periodicity and (b) amplitude

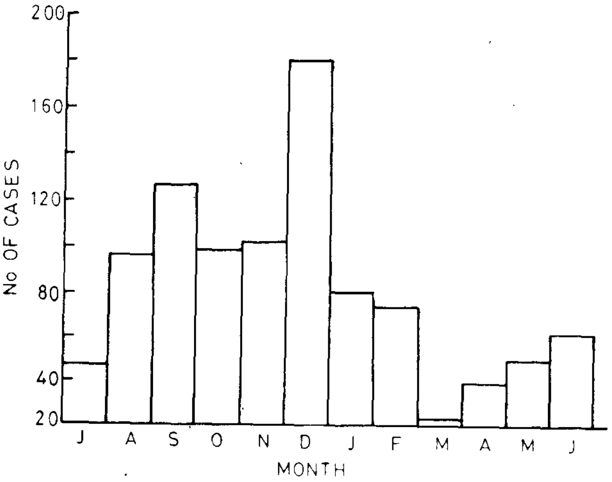

Fig. 6—Seasonal characteristics of the patterns

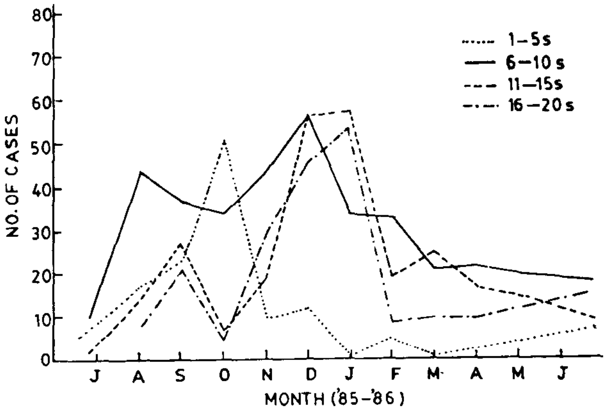

Fig. 7—Plot of duration of the various patterns

The third order equations [Eqs (5)-(8)] are sufficient to represent the behaviour of these patterns. These polynomials are plotted and the data values for diffraction patterns are inserted to observe the scattering amongst the various patterns observed on different dates [Fig. 5 {(a), (b)}]. From the curve it is clear that since the scattering is small, the different patterns can be represented by third order polynomials [Eqs (5)-(8)]. This means that the patterns, though looking different in shape, are generated by the same principle, i.e. by a moving object intercepting the normal propagation path of the VHF signal. This moving object acts as a phase changing screen similar to orbiting satellite system and produces the diffraction patterns of VHF signal. The time differences of the diffraction patterns observed between ISI and BE College can be explained if one assumes different obstacles in the propagation path. The dimension and horizontal extent of these elevated layers or obstacles can be estimated by standard drift experiment method.

The seasonal variations of these patterns recorded at ISI are shown in Fig. 6. The frequency of the patterns is maximum in winter and minimum in summer. The duration of occurrences is also different and varies from 1 to 60 s. The duration plot of the patterns is shown in Fig. 7. Usually the patterns occur in pair which is obvious as the radio ray enters the phase changing screen and then leaves the screen. Such fading patterns probably occur when an elevated layer crosses the propagation path at its maximum height (for Bangladesh and Calcutta TV signal, the maximum height of the propagation path attained is usually of the order of ~ 500 m above the ground). We have tried to find the similar patterns during the same period in the microwave link operation at Calcutta, but completely failed. The height of the microwave tower is about 75 m above the ground and the microwave LOS signal propagates within 100 m above the surface. While, for the VHF signal that we are receiving by 11 element Yagi antenna, the propagation takes place well above 200 m. It is also seen from the sodar studies at ISI that elevated layers in this region occurred at a height ranging from 250 to 350 m. Such moving layers are involved in producing the diffraction phenomena at VHF at these stations.

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