hf Communication Problems at Low Latitudes due to Steep Spatial & Temporal Electron Density Gradients

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Very frequent degradation in ionosphere-supported communication occurs at low latitudes due to large temporal and spatial electron density gradients in the ionosphere. The dynamic situation during early morning hours and the horizontal gradients in F-region electron density associated with equatorial anomaly cause unusual difficulties in the choice of right operational frequencies. Data from the topside sounder satellite Alouette-2 have been analyzed to derive horizontal gradients in the peak electron density of the F-region. Horizontal gradients in electron density as large as 3000 to 4000 electrons/cm²/km have been observed very often and an effect of such large gradients is to render the ionosphere as a non-mirror-like reflecting layer. The magnitude and the morphology of these problems are discussed to keep the prediction users aware of the conditions.

1. Introduction

The tropospheric and ionospheric communication group at the National Physical Laboratory has been responsible for issuing predictions of the radio environment as well as for rendering advisory services for radio communication organizations in India for more than 15 years. During this period, several problems related to hf communications which are particularly serious at low latitudes, had come up. The limited scope of this paper is to describe the origin of these problems and to suggest possible reasons and remedies.

Two most serious problems are caused by (a) large local time variations of foF2 critical frequencies especially during sunrise hours and (b) large horizontal latitudinal gradients in the F-region electron densities associated with geomagnetic anomaly. Similar problems may arise with respect to the gradients in the midlatitude trough region at night; however, no discussion on this aspect is included here since this paper is restricted to low latitude issues.

2. Steep Temporal Gradient Problems Particularly during Dawn

The local time gradients during sunrise hours are known to plague hf communications particularly at low latitudes. This problem is extremely important in countries where the main stay of point-to-point communications continues to be the hf band supported by ionosphere. Specific mention may be made of the following points in this connection.

(i) The hf link operators are expected to get their frequencies cleared from the appropriate governmental authority well in advance and it is usual practice to fix one frequency for the daytime and another for the nighttime. The use of the night frequency during sunrise will require much more power than is normally permitted while the frequency allocated for the daytime will be higher than the MUF during the transient period.

(ii) Point-to-point links normally use inexpensive tuned directional antennas and frequent change of operational frequency is deleterious from the point of view of antenna efficiency.

(iii) In case of long distance circuits in the east-west direction involving multi-hop F-region propagation, the problem of the sunrise period will extend to a large number of hours, because the different F-region reflection points will fall in the transient location at different periods.

Fig. 1 shows the diurnal variation in foF2 for Kodaikanal and Ahmedabad for winter during low solar activity period. The normalized hourly percentage changes in foF2 are shown in the lower portion of Fig. 1. The significance of the percentage changes is important because even assuming that changes in the link frequency are permitted antenna design considerations restrict such changes. The normalized percentage changes are calculated using the following relation:

\[ \text{Normalized percentage change in } \frac{(foF2)_{\text{hour } x}}{(foF2)_{\text{hour } x+1}} = \frac{(foF2)_{\text{hour } x} - (foF2)_{\text{hour } x+1}}{(foF2)_{\text{hour } x}} \times 100 \]

The most important feature of Fig. 1 is the extremely steep percentage increase in foF2 which is
Fig. 1 — Diurnal variation of $f_0F2$ and the corresponding normalized hourly percentage changes in $f_0F2$ for Kodaikanal and Ahmedabad (Remarkably large percentage increase of 230% in $f_0F2$ for Kodaikanal at 0500 hrs LT is an important feature to be noticed.)

Fig. 2 — Spectacularly large values of percentage increase in $f_0F2$ for Kodaikanal during medium and low activity periods (The latitudinal dependence of dawn time $f_0F2$ changes can be appreciated by comparing Kodaikanal and Brisbane.)
as high as 230% at 0500 hrs for Kodaikanal. Of course, the very low nighttime minimum values in \( f_0F_2 \) at low latitudes are essentially responsible for these abnormally high percentage increases. It may also be noticed from Fig. 1 that the dusk changes are not so spectacular especially when the percentage changes are considered.

Fig. 2 shows variation of normalized percentage changes in \( f_0F_2 \) at dawn for Kodaikanal and Brisbane during the years 1957-67. The solar activity variations modulated by seasonal variations as the running average sunspot number decreased from about 200 to 10, are very obvious. The magnitude of variations at Brisbane (geomag. lat., 35.7°S) during the dawn are only marginal and show very little solar activity dependence. For Kodaikanal (geomag. lat., 0.8°N), however, the percentage changes are spectacularly large and the variation with solar activity is very significant. A very interesting feature is that during high solar activity period the percentage values are larger at Brisbane, whereas at Kodaikanal the changes are insignificant. Fig. 2 convincingly demonstrates the seriousness of this problem at low latitudes for medium and low solar activities. The incidence of this problem at various stations combining seasonal and solar activity variations is depicted in Fig. 3. The data employed for this study pertain to the year 1958 representing high solar activity and the year 1965 representing low solar activity. The salient features that can be observed from these histograms are the following.

(i) Percentage changes in \( f_0F_2 \) are dependent on
solar activity especially at low geomagnetic latitudes. (ii) The spectacularly large changes can be observed only at Kodaikanal which is almost on the geomagnetic equator. The changes gradually decrease with increasing geomagnetic latitude reaching very marginal values at latitudes around 30° and above.

It may be repeated again that the main contribution for these apparently spectacular large percentage changes at very low geomagnetic latitudes is the very low nighttime electron densities in the F-region. However, as soon as the sun strikes the F1-layer level at dawn, the low latitude F2-region builds up much more rapidly than at middle latitude. This is further accentuated by the fact that at low geomagnetic latitudes there is a steep decrease in $f_0F2$ even beyond midnight bringing down $f_0F2$ to a very low value at 0400 hrs local time. This problem is less serious during the dusk hours as may be seen from Fig. 1. However, at middle and higher latitudes, gradients during dusk hours may be as large as those during dawn hours partly because of an evening enhancement in $f_0F2$ followed by a sudden decrease after sunset.\(^8\)

3. Large Spatial Gradient Problems in Equatorial Anomaly Region

The equatorial zone of approximately 30° width centered at the geomagnetic equator exhibits several peculiar ionospheric properties, one of which is the large spatial gradient that affect ionospheric radio propagation in a number of ways. The phenomenon of transequatorial propagation, whereby frequencies as high as 100 MHz can be reflected by the ionosphere in transequatorial paths, has been studied in detail.\(^3-9\) Several suggestions were made about the possible mode of this propagation like ionosphere to ionosphere reflection such as $F2$ propagation, exospheric field guided propagation, etc. However, the problem discussed here does not concern transequatorial propagation, but propagation within one hemisphere itself where anomalous communication is possible, because of large horizontal latitudinal gradients. For example, if we consider the anomaly peak in the northern hemisphere to be at 15°N geomag. lat. and if a north-south hf circuit is operating such that the reflection point is on either side of the peak and if the frequency of the link is very close to the MUF, a peculiar situation arises. If the point of reflection is equatorward of this anomaly peak, the radio waves incident on the ionosphere for the northern circuit will continuously come across increasing levels of electron density on two counts, viz. (a) due to the vertical gradient as the radiowave penetrates higher into ionosphere and (b) due to the horizontal gradient as the wave progresses in the direction of increasing electron density. On the other hand, for the same link in the return direction, the horizontal gradient is reversed. Thus the real MUF values for the two opposite directions in the same circuit can vary by a large margin depending on the angle of incidence and on the magnitude of the horizontal gradient. In fact, rather frequently, especially when the operating frequency is close to the MUF (calculated ignoring horizontal gradients), only one-way communication would be possible. This has been one of the unusual complaints in the Indian sub-continent. To understand the magnitude of this problem we have used the Alouette-II data ($f_4F2$), so that spatial resolution of the data can be high compared to ground-based data. Assuming simple parabolic distribution, vertical electron density profiles are derived in the F2-region and the latitudinal gradients at fixed heights are computed. These horizontal gradients along the ray path are compounded with the vertical gradients to calculate the change in the real MUF for varying magnitudes of horizontal gradients.\(^10-12\)

Fig. 4 shows some sample results of the change in MUF for different gradients for three angles of incidence. As expected, the shift in the MUF increases with increasing angles of incidence (at the ionosphere). It has been observed that gradients between 3 and 4 electrons per cubic centimeter per
Fig. 4 is given only to illustrate the problem, and results from more rigorous three-
dimensional ray tracing methods which only confirm this are beyond the scope of this paper. However, the point to be noted is that even for modest angles of incidence such as 50° and electron density gradients of 3.5/cm³/m, the shift in actual MUF is from 15 to 18 MHz while in the opposite direction the effective MUF will fall to 13 MHz. Thus, employing a frequency higher than 13 MHz will result only in one-way communication.

4. Conclusion

Very obviously, the solution for both the problems discussed in this paper is to take these situations into account while predicting the link frequencies. It has been found practical to get a third frequency assigned for the dawn hours and use an antenna system with appropriate bandwidth. Predictions of operational frequencies for north-south two-way links at low latitudes should take the anomalous gradients into account and a frequency lesser than the reduced MUF must be used.

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References