A CASE STUDY OF VLF PHASE AND AMPLITUDE VARIATION AT 12.1 kHz (ALDRA) IN ICELAND

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Abstract: The phase and the field strength of 12.1-kHz VLF signals propagating from Aldra, Norway have been continuously recorded at Tjörnes, Iceland using a phase-locked receiver with a loop antenna parallel to the great circle path between Norway and Iceland.

Nighttime records represent irregular phase and amplitude fluctuations and sometimes involve quasi-sinusoidal fluctuations. The phase and amplitude change associated with cosmic noise absorption (CNA) are observed on the VLF signals, for which the phase is advanced with the change of the electron number density distribution of lower ionosphere.

1. Introduction

1.1. Quasi-sinusoidal fluctuations

VLF stations distributed over the world usually transmit radio signals with a frequency stability of the order of 10^{-10} per day. If a frequency deviation greater than this value is observed at a receiving site, it might be a Doppler-shift caused by a time variation of the medium along the propagation path. The observation of quasi-sinusoidal fluctuations of VLF signals was made by GOSSARD (1967), GOSSARD and PAULSON (1968), in which the fluctuations have the period of 23, 6.25, 3.85, and 2.49 min, respectively.

They found that the fading records are often dominated by 'beating' between the one-path reflected signals and one or two off-path wave components. The results imply that drift alone cannot explain the complicated fading patterns and not inconsistent with a regime in which both drift and internal wave motion are presented.

1.2. VLF phase anomalies caused by substorm

The substorm-associated phase anomalies were observed by KIKUCHI (1981), KIKUCHI *et al.* (1983), KIKUCHI and EVANS (1983) on the transauroral propagation path for VLF signals, Omega Aldra (12.1 kHz), GBR (16.0 kHz), Omega N. Dakota (13.6 kHz) and NLK (18.6 kHz) received at Inubo, Japan. The phase anomalies are caused by energetic electrons injected from the magnetotail and/or the outer radiation belt. They estimated the energy of the precipitating electrons from the decrease in the reflection height for the VLF waves as >150 keV.

The precipitation of such high-energy electrons is observed at all local times, but is predominant at 0800, 1630 and 2230 LT. The nighttime precipitation commences almost simultaneously with the onset of the nightside magnetic bay, while the dayside precipitation is delayed by 10–100 min. They concluded that the magnetotail originated electrons with energy >150 keV are injected directly into the nightside auroral region and some of the injected electrons drift eastward and then precipitate into the morning and afternoon sectors. The drift speed deduced from the time delay of onset is 5°/min on the average. In this paper, we will describe the observational results such as quasi-sinusoidal fluctuations and significant phase anomalies associated with magnetic substorm. Some interpretations of the typical events for phase anomalies associted with magnetic substorm will be tried.

2. Observations and Interpretations

Continuous observations of the phase and the field strength of Omega–Aldra signals propagating in the earth-ionosphere wave-guide were started at Tjörnes, Husavik, Iceland, in September 1984 by using the phase-locked VLF receiver whose block diagram is shown in Fig. 1. Figure 2 shows the positions of the transmitter and the receiver, and the great circle path between Aldra and Tjörnes. The path length is about 1300 km. Geographic coordinates of Tjörnes and Aldra are (66.20°N, 17.12°W) and (66.42°N, 12.15°E), respectively. Figure 3 shows one example of the diurnal variations of the phase and the field strength of Aldra signals by setting the antenna parallel to the Aldra-Tjörnes path.

In this section, we will describe two typical examples which were observed at Iceland during our stay.

2.1. *Quasi-sinusoidal fluctuations*

The phase and the field strength are almost constant in the daytime, but in the nighttime they contain small fluctuations of a few to ten minutes period. Though the fluctuations are usually irregular, quasi-sinusoidal variations in phase and amplitude sometimes continue for 3 h or more, as shown in Fig. 4. The most frequent period of the quasi-sinusoidal fluctuations is about 3 min and the envelope of the signals is also modulated periodically with 20 min, as shown in Fig. 5. The VLF phase advance appears to be related with VLF amplitude decrease during the interval 2100 to 2110 LT and related with VLF amplitude increase during the interval 2110 to 2120 LT. It seems that these relations will be changed every 10 min. We examine the diurnal variation of Doppler beat signals at Tjörnes, Iceland. The data period is about a month from September 8 to 30, 1984. Figure 6 shows the occurrence probability of Doppler beat signal *vs.* local time. An occurrence peak of Doppler beat phenomena is noticeable at 2000 LT in this figure. The type of fluctuation, a typical example of which is shown in Fig. 5, suggests that in the nighttime there are more than two waves with slightly different frequencies. But these fluctuations were so complicated that we could not propose a good model for interpretation.

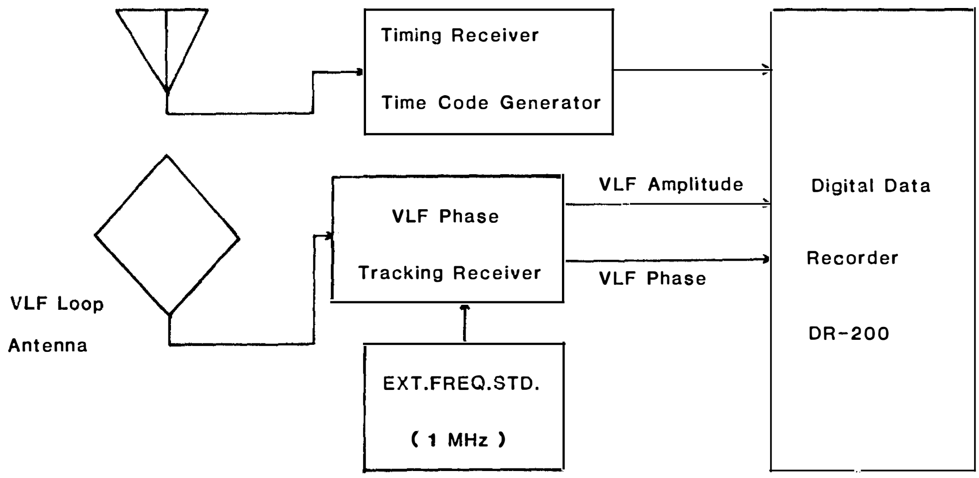

Fig. 1. Simplified diagram of VLF phase tracking receiver system.

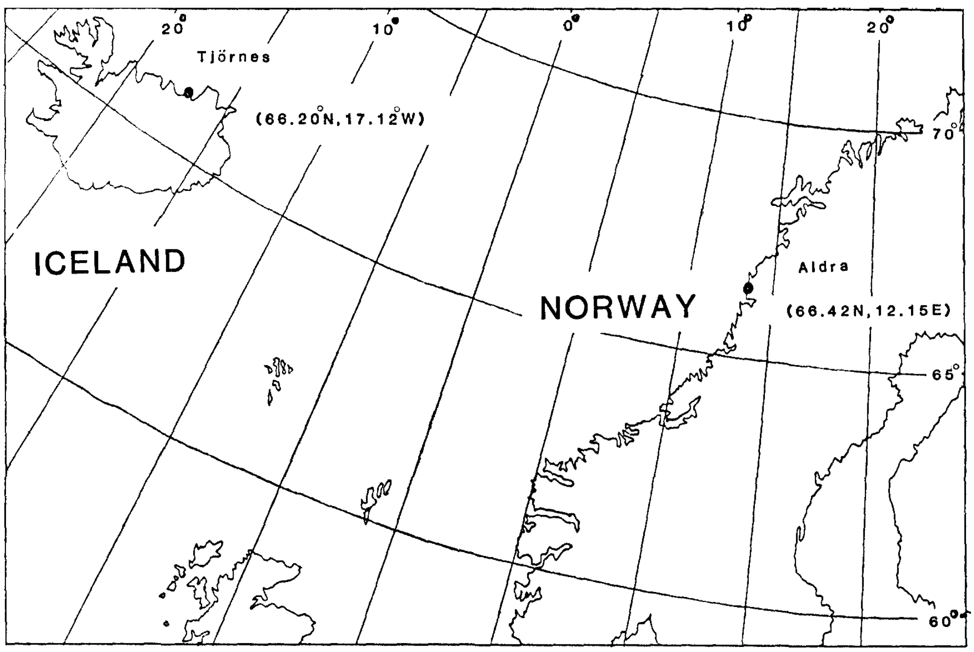

Fig. 2. Location of Tjörnes in Iceland and Aldra in Norway.

2.2. *VLF phase and amplitude anomalies caused by substorm*

It is shown in Fig. 7 that the phase of the Omega-Aldra signals (12.1 kHz) advances significantly in association with ionospheric absorptions. In correspondence to these disturbances, VLF amplitude is increased on the signal received at Tjörnes, Iceland. These events are quite different from normal absorption anomalies, in which the lower ionosphere was slightly ionized by the low-energy precipitated electrons and the apparent ionospheric height is decreased and the wave propagates in such an ionized region, so that the VLF field intensity is decreased by the absorption in the lower ionosphere.

The modal equation solved by YAMASHITA (1969), with use of the sharp-bounded and homogeneous ionospheric model, that the sudden enhancement of signal strength and the sudden phase anomaly are produced for critical frequencies greater than 15

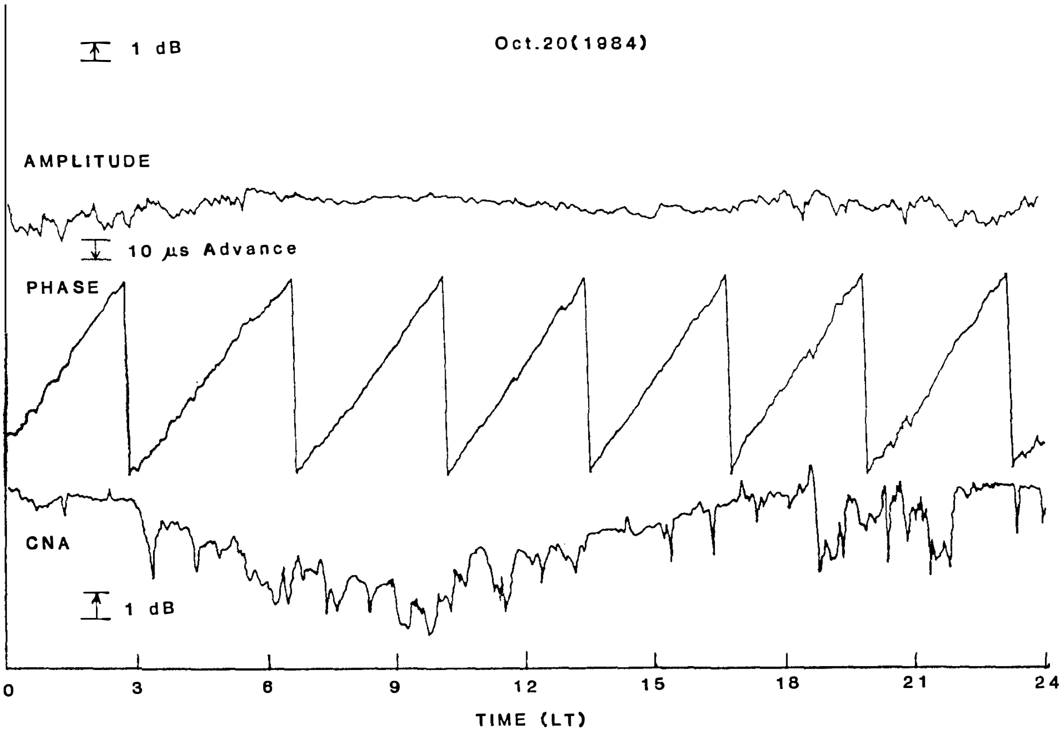

Fig. 3. Example of the data observed by VLF phase tracking receiver and riometer at Tjörnes.

kHz. Its results showed that the critical frequency will be shifted to higher frequency with increase of electron number density at the reflection height.

But, in our case of frequency below 15 kHz, the signal intensity must be decreased with sudden phase anomaly, according to the above result, which is inconsistent with our result; the phase advance and the amplitude increase with CNA. As shown in Fig. 8, because of the precipitated high-energy electrons >150 keV (KIKUCHI, 1981), the density gradient in the lower ionosphere becomes so steep that the signal intensity is increased, due to reflection at the sharp boundary.

3. Discussion

The phase (Φ) and the field strength (E) of frequency-stabilized VLF signals on 12.1 kHz from Aldra, Norway have been continuously recorded at Tjörnes, Iceland. The quasi-sinusoidal fluctuations with the period of 20 and 3 min were observed at Tjörnes, Iceland. These quasi-sinusoidal fluctuations were of the same period as Gossards observation (from 2 to 23 min). The phase advance and the amplitude increase associated with CNA were observed.

These anomalies may be interpreted that because of the precipitated high-energy electrons, the density gradient in the lower ionosphere becomes so steep that the signal intensity is increased due to reflection at the sharp boundary. In the future, a more precise computer calculation including the above-mentioned density gradient model will be necessary.

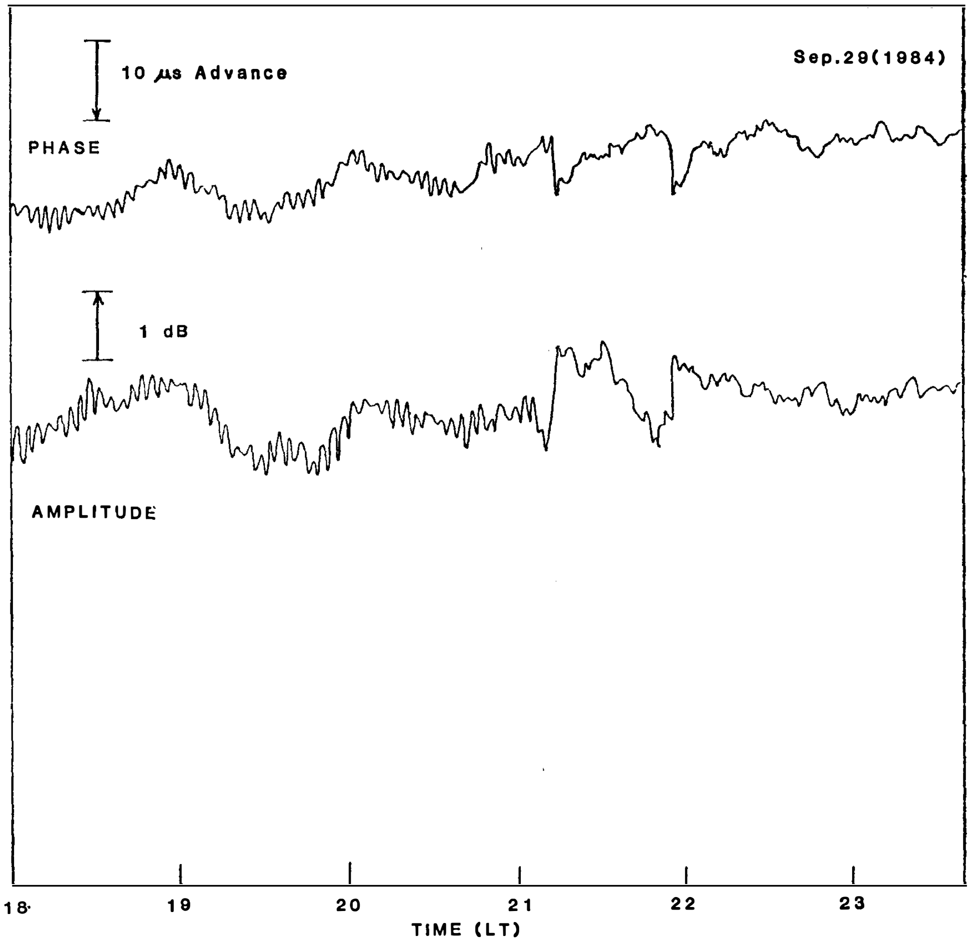

Fig. 4. Example of doppler beat signal and phase anomalies at Tjörnes.

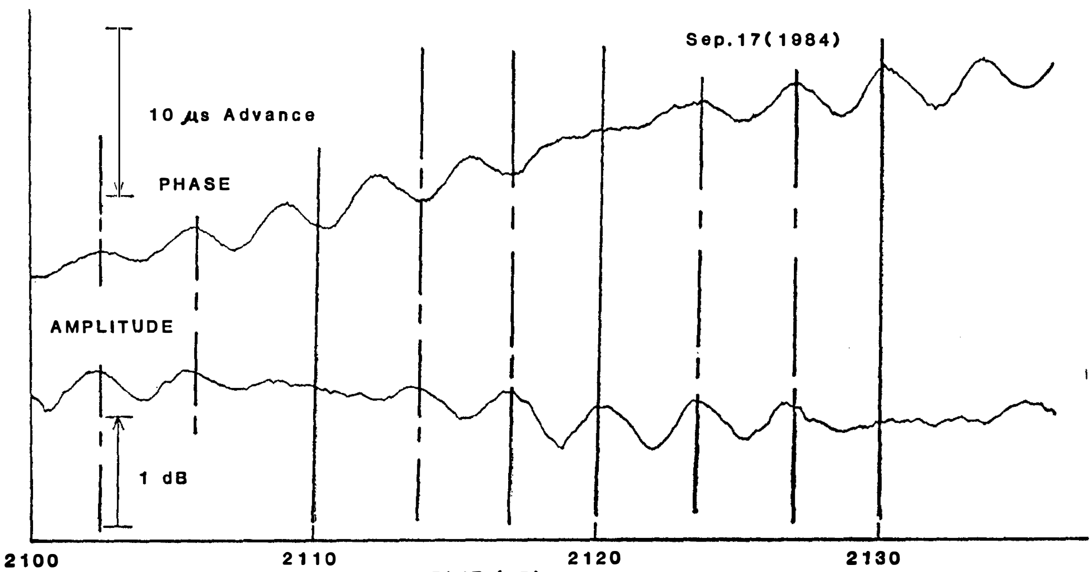

Fig. 5. Example of doppler beat signals at Tjörnes.

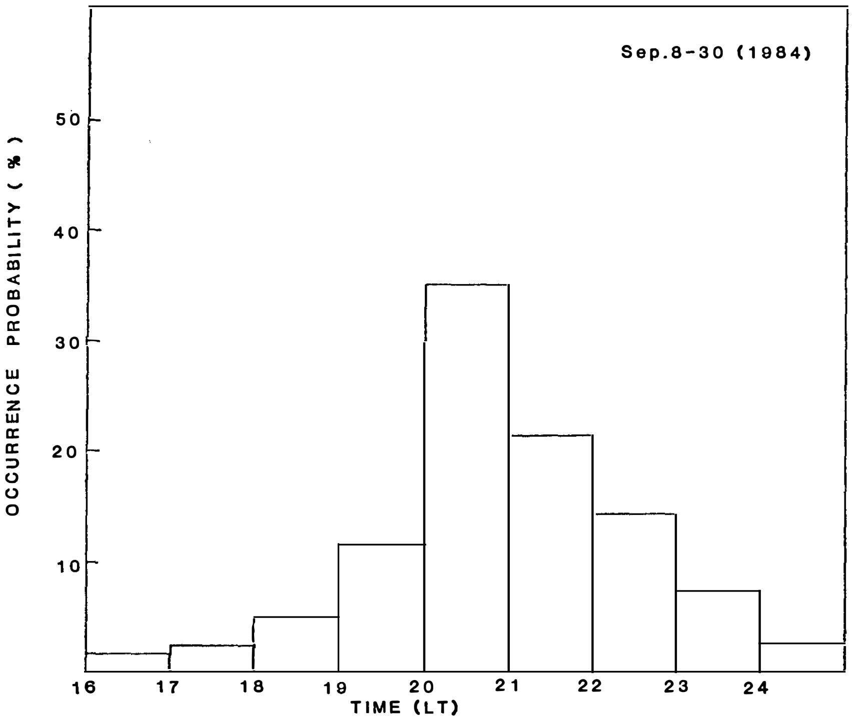

Fig. 6. Doppler beat occurrence number.

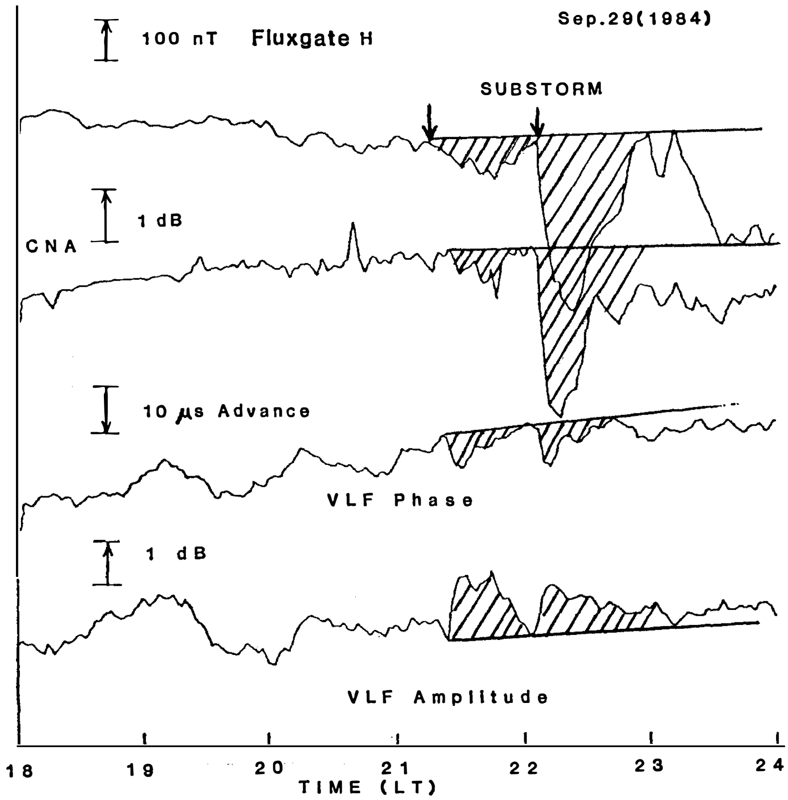

Fig. 7. Example of phase anomalies in the nighttime.

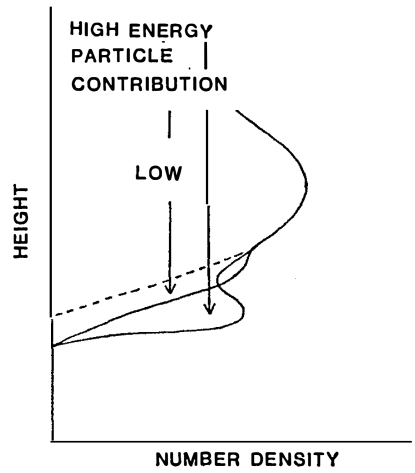

Fig. 8. A schematic illustration of electron density distribution with height.

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