NON-TYPICAL SERIES OF QUASI-PERIODIC VLF EMISSIONS

J. Manninen¹, N. Kleimenova², O. Kozyreva²

¹ Sodankylä Geophysical Observatory, Finland, e-mail: jyrki.manninen@sgo.fi; ² Institute of Physics of the Earth RAS, Moscow, Russia

Abstract. New types of the series of quasi-periodic (QP) VLF (very low frequency) emissions in frequency range of 1-5 kHz, not associated with geomagnetic pulsations, has been discovered at auroral latitudes (L=5.3) during the Finnish VLF campaign (held in December 2011). Several unusually spectacular events with duration of several hours have been observed in the night-time under conditions of quiet geomagnetic activity (Kp=0-1), while the usual QPs occurrence is the daytime. Contrary to the typical daytime QP emissions, the spectral structure of the reported QP events represented an extended complicated sequence of the combination of repeated discrete mostly rising diffuse VLF signals with the repetition periods ranged from ~several tens of seconds up to ~10 min. Four of such non-typical events are reported in this paper. The fine structure of the separated QP elements may represent a mixture of the different frequency bands signals, which seem to have independent origins. The VLF signals can come from different directions. Most of them have right-hand polarization indicating the location of the ionosphere VLF wave exit points being almost above the ground receiver. However, some events show the left-hand polarization, which can be interpreted as the wave arriving from ionospheric exit points far from the receiver, after propagation in the Earth-ionosphere waveguide. We suppose that these considered QP emissions can be attributed to auto-oscillations of the cyclotron instability of the Earth’s radiation belts [Bespalov, 1982; Bespalov and Trakhtengerts, 1986]. However, there is no complete theory, which could adequately explain the revealed type of QP emissions and their generation mechanism is not yet understood.

Introduction

The typical quasi-periodic emissions (QP) represented a sequence of repeated noise bursts of ~20-50 s duration, in which each burst may consist of a number of discrete events or periodic emissions [Helliwell, 1965]. The period between bursts is typically measured in tens of seconds. These emissions are understood to be whistler mode waves of magnetospheric origin that have propagated through the ionosphere to the ground. There are two types of QP emissions: associated and non-associated with geomagnetic pulsations. The first type of QP is more widely referred in the literature [e.g., Kitamura, 1974; Sato and Fukunishi, 1981; Bespalov and Kleimenova, 1989; Sazhin and Hayakawa, 1994; Manninen et al., 2012]. However, there was only a few papers analyzed the second type of QP emissions, i.e. non-associated with geomagnetic pulsations [e.g., Smith et al., 1998; Engebretson et al., 2004]. Based on Antarctic data these authors claimed that QP bursts have been observed more frequently during daytime in summer.

The series of non-typical quasi-periodic (QP) 1-5 kHz VLF emissions, not described previously in the literature, have been observed during the recent VLF campaign in December 2011 in Northern Finland near obs. Sodankylä Geophysical Observatory (L~5.3). These QP emissions were not associated with geomagnetic pulsations. At least five unusually spectacular events with duration of several hours have been observed in the night-time under conditions of quiet geomagnetic activity (Kp=0-1), and only one event was recorded in the late morning, while the usual QPs occurrence is the daytime. The description of some revealed events is the object of this paper.

Observations

The Finnish winter VLF campaign applying the very high-sensitivity VLF receiver with the threshold of the order of 10⁻⁶ nT has been carried out in Northern Finland (at the temporary station Kannuslehto: φ=67.74° N, λ=26.27° E; L=5.3), located about 40 km to the North-West from Sodankylä Geophysical Observatory. It was the first time when VLF observations have been carried out in the midwinter solstice under very quiet geomagnetic activity, and for the first time there was revealed a number of events of unknown types of QP emissions.

The geomagnetic (Dst and AE indices), solar wind, and IMF data for 15-25 December 2011 are given in Fig. 1. It is seen that during this VLF campaign, the magnetic activity was very low.
Here we present four QP events on 16, 17, 19, and 24 December, which were never published before. Only one event (17 December) was observed during late morning (03-07 UT, 05-09 MLT), other events were recorded during the night time. Below we show the temporal dynamics of the spectral structure of the considered events (Fig. 2-5): the intensity of the total (T), right-hand (R) and left-hand (L) polarized waves and the arriving angle ($\phi$) at different frequencies. The angles were determined as the direction of the minor axes of the polarization ellipses, which makes it possible to determine only the direction, but not the vector of arrival of the waves. This means that it can be argued that the waves came, for example, from the north–south direction, but it remains unknown whether the waves came from the north or from the south.

The strong horizontal lines in Fig. 2-5 are due to power line harmonic radiation (PLHR), which are multiplied of 50 Hz.

**Fig.1.** Dst and AE indices and solar wind and IMF data.

**Fig.2.** The QP event on 16 December

1. The spectrograms of the QP event on 16 December are shown in Fig. 2 as the 3-min plots of the signals in the frequency range of 1-4 kHz. The signals look like the composition of two kinds of QP emissions - lower and higher around 3 kHz. It is seen, that the (~2-4) kHz rising tone signals with the repetition period at about 30 s, are characterized by strong left-handed polarization. That indicates that the wave arrived from an ionospheric exit points far from the receiver, after propagation in the Earth-ionosphere waveguide. All signals arrive from the NW-SE direction, i.e. from the night side or from day side of the Earth.
2. The spectrograms of the morning (05-09 MLT) QP emissions on 17 December are presented in Fig. 3a, b. The left panels (a) show ~4 hours lasting event as an ensemble of the simultaneous occurrence of two different VLF types: the narrow-band (1.5-2.5 kHz) hiss and ~3-4 kHz complicated QP emissions. Both VLF types were characterized by the right-hand polarization indicating that the ionospheric exit points of the wave was located not far from the receiver station. But the arrival angles ($\phi$) of the VLF hiss and QP emissions were different: hiss came approximately from E-W direction and QP – from N-S direction.

The right panel (b) of Fig.3 presents the 3-min VLF spectrograms in different time intervals. The QP emissions look like separate discrete diffuse bursts consisting of some series of very short periodic signals coming mostly from N-S direction at ~03-05 UT and later on at ~06-07 UT – from NE-SW direction. The hiss was observed in very narrow frequency band (~1.6-1.8 kHz) in the beginning of the event (03.44-03.47 UT) coming mostly from N-S direction. Later on (05.10-05.13 UT) the frequency band of the hiss became wider (1.8-2.4 kHz) and the wave arrival changed to E-W direction. The QP emissions and hiss are seen to be of different independent origins, but why they occur simultaneously?

3. Two 30-min spectrograms of the rising QP event on 19 December are given in Fig. 4 in frequency range of 1-5 kHz (upper panels) and three 3-min interval of total signal power – in bottom ones. The repetition period of QP increased with time from ~1.5 min to ~2.0 min, the signals were mostly left-hand polarized indicating their arrival from ionospheric exit points located far from the receiver.
In the beginning of this event there was hiss emission at the frequency of about 2-3 kHz, while the QP signals were observed at the higher frequency (~2-5 kHz) as it was a rather similar to the 17 December event.

![Spectrogram](image)

**Fig. 4.** The spectrograms of the QP event on 19 December

4. The spectacular QP event on **24 December** is presented in Fig. 5a as three 30 min intervals and in Fig. 5b as six 3 min plots of the detailed signals from ~18 UT to ~21.30 UT in the frequency range of. The event started with a series of the quasi-regular diffuse rising bursts in the frequency range of ~1.7-2.4 kHz with the repetition periods of ~1.0-1.5 min. Later on, the upper QP frequencies increase up to 5 kHz and then decrease down to ~ 2 kHz in the end of the event. The detailed temporal frequency dynamics are shown in Fig. 5b. The separated signals look like as a superposition of two different signals: one lower and the
second higher than ~2.5 kHz with different frequency-time dispersion. The signals with lower frequency appear to trigger the strong dispersive upper frequency signals. A relatively similar frequency temporal dynamic of the QP event was observed on 18 December (this event does not present here).

The considered QP emissions were pure right-hand polarized.

Fig. 5. The spectrograms of the QP event on 24 December, (a) – three 30 min intervals, (b) – six 3 min intervals.
Discussion

There is no complete theory, which could adequately explain the observed QP emissions generation. However, according to [Bespalov, 1982; Bespalov and Trakhtengerts, 1986; Trakhtengerts and Rycroft, 2008] we suppose that the considered QP emissions can be attributed to auto-oscillations of the cyclotron instability of the Earth’s radiation belts.

Summary

Non-typical long lasting series of quasi-periodic VLF emissions have been relived under very quiet geomagnetic activity (Kp=0) near the midwinter solstice at a ground station at L~ 5.3. Contrary to the typical daytime QP emissions, this unusual series of QP event were mostly observed in the night time.

The considered QP events represented an extended complicated sequence of the combination of repeated discrete rising diffuse VLF signals with the repetition periods ranged from ~several tens of seconds to ~10 min. Four of such non-typical events have been reported in this paper.

The fine structure of the separated QP elements may represent a mixture of the different frequency bands signals, which seem to have independent origins. More of them had mostly the right-hand polarization. The VLF signals can come from different directions.

This finding is very important for future theoretical investigations because the generation mechanism of the revealed type of QP emissions is not yet understood.

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References


