POLARISATION OF NATURAL RESONANCE SIGNALS IN ULF-ELF BANDS

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ABSTRACT

We demonstrate the clarity of resonance phenomena when observed in the polarisation of horizontal magnetic field component of natural ELF–ULF radio signals. Dynamic spectra are compared of the polarisation and of the field amplitudes for two kinds of resonance: the global, or Schumann, and the Alfven ionospheric resonance. The first one occurs when ELF waves propagate through the atmosphere and circle the globe. The second corresponds to the hydromagnetic waves trapped between the lower edge of the ionosphere and the ionisation maximum. The ellipticity of polarisation of the horizontal magnetic field vector reveals the resonance phenomena in the clearest way.

INTRODUCTION

The report is based on experimental data that we compare with the model computations. Model treats the Schumann resonance in the Earth–ionosphere cavity with anisotropic plasma. Experimental data survey natural resonance observed in the polarisation of horizontal magnetic component of the radio signal in different frequency bands: Alfven resonance [1] (frequencies between 0.1 and 5 Hz), and Schumann resonance [2] (the band from 4 to 40 Hz). The Schumann and Alfven resonance is driven by the electromagnetic radiation from the thunderstorm activity.

Schumann resonance takes place when the electromagnetic wave propagates in the dielectric layer between the lower ionosphere and the Earth's surface. The plasma anisotropy may cause a peculiar behaviour of the resonance electromagnetic field. We present durable records of the polarisation of the Schumann resonance and compare these with the numerical model accounting for the Earth's magnetic field. The simplest 'hedgehog' description is used for the geomagnetic field, and the single compact equatorial thunderstorm centre is the source, which circles the planet during the day. The comparison demonstrates an exceptional consistency between the experimental and model results. Influence of ionospheric gyrotropy leads to the elliptic polarisation with positive sense corresponding to resonance peaks.

The Alfven resonance is observed at frequencies between 0.1 and 5 Hz in the ambient night conditions. The resonance occurs in the magnetised plasma being localised between the lower ionospheric boundary and the ionisation maximum. The waves are trapped between these two boundaries. They move in vertical direction and form a characteristic succession of peaks in the power spectrum of the horizontal magnetic field component, which are found below the basic Schumann resonance frequency. The Alfven resonance is detected at the middle latitude observatories with exceptionally low level of local interference. We show in the report that the resonance structure clearly manifests itself in the field polarisation.

COHERENCE MATRIX AND POLARISATION

The polarisation by its definition is a property of the monochromatic electromagnetic field. It describes the orientation and evolution of the electric field vector. A wave is linearly polarised when the electric field rests in the same plane and its tip represents a straight line in time. When the electric vector circumscribes a spiral in the course of propagation, we speak about circular polarisation. An intermediate situation is regarded as the elliptical polarisation.

The term ‘polarisation‘ is also used when classifying radio waves in the guiding structures. Waves in conventional waveguides propagate as the transverse magnetic (TM polarisation) also called the electric wave, or as the transverse electric (TE polarisation) called the magnetic wave. In the first case, the magnetic field is perpendicular to the direction of propagation; the electric field behaves similarly in the case of TE polarisation. Electromagnetic field of Schumann resonance is the TM or TEM wave. It has the non-zero vertical electric E_R and the horizontal magnetic field H_φ components at the surface of the Earth. For an arbitrary position of the source, or in the case of an anisotropic Earth-ionosphere cavity, the magnetic field is composed of H_X (west to east) and the H_Y (south to north) orthogonal components. We use term ‘polarisation’ to describe the behaviour of horizontal magnetic field. Such a term is more convenient than the term ‘evolution of the tip of the horizontal magnetic vector’. The magnetic polarisation is introduced similarly to the conventional polarisation, i.e., by using the coherence matrix:

$$J(\omega)=\begin{pmatrix} < H_X(\omega)H_X^*(\omega)> & < H_X(\omega)H_Y^*(\omega)> \\ < H_Y(\omega)H_X^*(\omega)> & < H_Y(\omega)H_Y^*(\omega)> \end{pmatrix} \tag{1}$$

The angular brackets denote statistical averaging over the ensemble of spectral components of the horizontal magnetic field. Individual components are of the following form:

$$H_X(\omega)=H_\varphi(\omega)=A_1\exp[i(\omega t+\phi_1)] \tag{2}$$

$$H_Y(\omega)=-H_\theta(\omega)=A_2\exp[i(\omega t+\phi_2)] \tag{3}$$

The sense of polarisation β describes the direction of rotation of the horizontal magnetic field vector. It is found from the following expression:

$$\sin(2\beta)=\frac{2\mathrm{Im}(J_{XY})}{\sqrt{(J_{XX}-J_{YY})^2+4J_{XY}J_{YX}}}=\frac{2A_1A_2}{A_1^2+A_2^2}\sin(\phi_2-\phi_1) \tag{4}$$

For the majority of problems the sense of polarisation β depends on the co-ordinates, although it may become a constant in special cases, e.g., for the uniform plane wave. The ellipticity or the polarisation is defined as:

$$P=\tan(\beta) \tag{5}$$

The clockwise rotation of magnetic field vector corresponds to the positive value of angle $\beta > 0$ (the ellipticity is also positive $P > 0$), and we speak about right hand polarisation (RHP). The sense of polarisation and the ellipticity become negative ($\beta < 0$, $P < 0$) when the tip of magnetic field rotates counter clockwise. This is the left hand polarisation (LHP). The ionosphere becomes an isotropic medium in absence of the geomagnetic field, and components H_X and H_Y vary in phase, $\beta = P = 0$, and the vector turns into linearly polarised one. Influence of the geomagnetic field converts the ionospheric plasma into anisotropic medium, and the waves travelling from east to west and from west to east attain different phase velocities and attenuation rates. Their interaction determines the rotation of horizontal magnetic field vector at a given frequency.

EXPERIMENTAL RESULTS AND MODEL DATA

The top panel in Fig. 1 depicts the results of computations. We model the dynamic spectra of ellipticity P for two successive days of monitoring. The abscissa shows the time (UT), the ordinate depicts the frequency, and the polarisation is shown by the colour in the map. Resonance data were collected at observatory Lehta, Karelia, 64^0N and 34^0E and Karymshino, Kamchatka, 53^0N and 158^0E. The measurements of two orthogonal horizontal magnetic field components allowed us to obtain the coherence matrix and establish the ellipticity of the field plotted in the middle and bottom maps of Fig. 1. The bottom map depicts the raw data from the Lehta observatory, and middle map shows the same data smoothed. We clearly observe the Schumann resonance pattern as the horizontal dark blue strips.

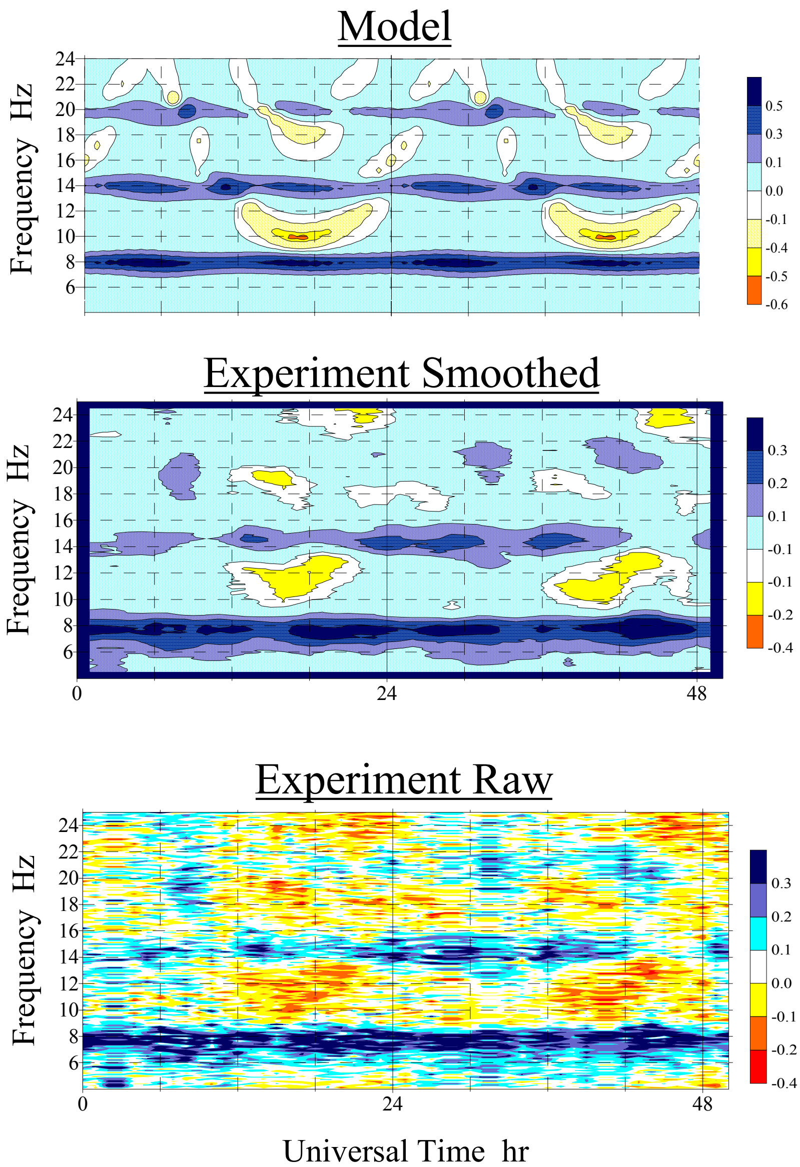

Fig. 1. Comparison between the experimental polarisation data (Lehta) and the computed results.

The top frame in Fig. 1 shows results of original computations of the dynamic spectra of ellipticity in the Schumann resonance band. The simplest, 'hedgehog', model [3] was used for the geomagnetic field. Such a field is purely radial, its amplitude is independent of the angular co-ordinates, and its sign abruptly changes when crossing the equator. The observer was placed in Europe at 0^0E meridian (Greenwich) and 40^0 N latitude. The compact equatorial vertical electric dipole was the field source positioned at the point with the 17 hr local time. The dipole circles the globe during a day giving rise to variations in the source-observer geometry (distance and arrival azimuth), which result in the regular pattern we show in the top of Fig. 1. One may see that smoothed experimental data presented in the middle frame are in a good agreement with the model computations. An optimist will discover the coincidence even in the characteristic details of two maps.

The Schumann resonance and the Alfven ionospheric resonance data (frequencies below 5 Hz) were also collected at Kamchatka. These demonstrate a remarkable recurrence when observed by using the wave polarisation. The Alfven ionospheric resonance is a local phenomenon, which takes place in the ionosphere at night [1]. It is observed after the sunset as a series of peaks in the horizontal magnetic field component at the ground. The peak frequencies undergo a characteristic change during the night caused by variations in the thickness of ionospheric slab. Weaker traces of Alfven resonance could be found also in the amplitude spectra and in the coherence measure.

DISCUSSION AND CONCLUSION

We compare computed results with the experimental spectra accumulated in the Schumann resonance band at two different field sites. The observatories have a low level of local noise and demonstrate similar behaviour of the dynamic spectra of polarisation. The sense of ellipticity tends to show a resonance pattern: we have the right hand polarisation (RHP) around the spectral maxima shown by the dark blue strip in the plots of Fig. 1. It is also reproduced in the vicinity of the second and third resonance peaks. The signal around spectral minima may have the left hand polarisation. The top map in Fig. 1 presents the model data, which have much in common with the experiment. Similarity allows us to conclude that the anisotropy of the ionospheric plasma is the cause of elliptical polarisation observed the horizontal magnetic field. The right hand polarisation is permanently present around the resonance peak frequencies for all the positions of equatorial source and an observer positioned in the middle latitudes. The ellipticity varies from 0.5 (when the source and observer occupy the same meridian) to 0.35 (when their longitudes differ by 90^0).

The polarisation results agree with the published numerical data on the spatial distribution of the electric field in the gyrotropic Earth–ionosphere cavity [2, 3]. Splitting of resonance lines supports a regime when the waves travelling from the west to east prevail in the vicinity of the Schumann resonance. Such a regime in conditioned by inequality of the wave attenuation pertinent to the side bands with the positive ($m > 0$) and negative ($m < 0$) zonal indices [2, 3]. As a result, the sub–levels with the negative *m* acquire higher amplitudes, and the resonant radio wave tends to propagate from west to east causing the magnetic polarisation shown in Fig. 1.

Summarising, we make the following conclusions.

- The Schumann and Alfven resonance provide remarkable polarisation effects even though these have different nature and take place in different media. Accuracy and sensitivity of polarisation measurements are comparable with those of the phase measurements of the man–made radio signals.
- Signals at resonance peak frequencies tend to have the same polarisation sense.
- The basic mode of Schumann resonance is clearly seen in the sense of polarisation all through the day, whilst the Alfven resonance pattern is observed only in the night.
- Some 'violations' may occur in the Schumann resonance polarisation at higher frequencies in the afternoon hours.
- The elliptical polarization is conditioned by the anisotropy of the ionospheric plasma.

References

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