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THE VLF WAVE MODULATION BY Pc1/2 PULSATIONS IN THE MAGNETOSPHERE AS A FUNCTION OF MAGNETOSPHERE PLASMA PARAMETERS

Marina Goncharova and W.Lyatsky *(Polar Geophysical Institute, Apatity, 184200 Russia)*

Abstract. A circularly polarised ion cyclotron wave (ICW) propagating in the dipole geomagnetic field along the flux tube wherein the VLF waves are amplified causes oscillations of the magnetic field in the flux tube reference frame. As a result, the variations in output intensity of the VLF wave ought to be observed. The efficiency of the interaction mechanism is studied as a function of magnetosphere plasma parameters: warm electron content α^{-1}, warm electron parallel beta $\beta_{\|}$, and electron anisotropy factor $D \equiv A+1=T_{\perp}/T_{\|}$. The ICW characteristics needed to modulate effectively are considered as well. It is shown that the proposed mechanism under the typical quiet magnetosphere conditions at L=5 for the Pc1-2 amplitude 5 nT and period 7s enables to get the VLF intensity variations of order of 50%.

1. Introduction

In the VLF range both intensity- and frequency-modulated emissions and/or auroral luminosity pulsations with the modulation period of Pc1-2 pulsations are often observed. The experimental results on both interacting waves being jointly detected are reported in *Arnoldy et al.*[1983], *Goncharova et al.*[1992]. An interaction mechanism considered here is based on the VLF growth rate response to the magnetic field increment in the flux tube radially displaced by the ICW. Pc1-2 pulsation peak-to-peak amplitudes measured in the magnetosphere are of order of 1-6 nT (*Inhester et al.*, 1984; *La Belle and Treumann*, 1992). The goal of the actual paper is to examine the efficiency of mechanism for VLF emission modulation by ion-cyclotron waves in the magnetosphere as a function of magnetosphere plasma parameters and perturbing wave properties.

2. Model

The circularly polarised ICW propagating in the dipole geomagnetic field displaces the thin magnetic flux tube inwards and outwards (Fig.1), what gives rise to the magnetic field variations inside the flux tube. If in this flux tube the VLF waves are generated their growth rate will response to the magnetic field oscillations at each point of the flux tube. As a result, the VLF amplification coefficient has to vary too that is the modulation of the VLF wave amplitude would occur.

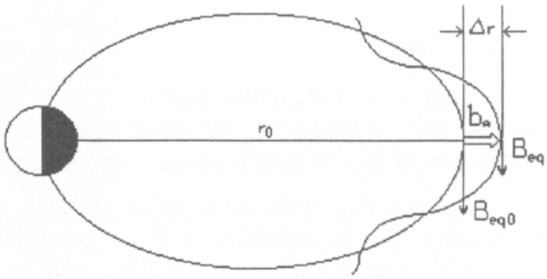

Fig.1. Geometry of the problem. Deviation of the thin magnetic flux tube, disturbed by an ion cyclotron wave, in the ambient dipole magnetic field. $r \equiv R_E L$, B_{eq} are the equatorial distance and magnetic field respectively, Δr is the radial displacement of the flux tube, b_a is the ICW amplitude.

The magnetic field increment in the magnetosphere equatorial plane is given by:

$$\Delta B_{eq} = -B_{eq0}\frac{3\Delta r}{r_0} = -\frac{3v_a}{R_E L\omega_a}b_a, \qquad (1)$$

where $r_0 \equiv R_E L$ and B_{0eq} are the undisturbed equatorial distance and magnetic field respectively, v_a is the Alfven velocity, ω_a and b_a are the ICW frequency and amplitude respectively. The local VLF growth rate equation in the form of *Cuperman and Landau* [1974] is used:

$$\gamma = \frac{1}{\alpha}\sqrt{\frac{\pi(1-x)}{2\alpha\beta_{\|}}}(D-\frac{1}{1-x})(1-x)^3\exp(-\frac{(1-x)^3}{2\alpha\beta_{\|}x}), \qquad (2)$$

where $\gamma = \mathrm{Im}\omega/\Omega_e$, $x = \mathrm{Re}\omega/\Omega_e$, ω is the VLF wave frequency, Ω_e is the electron gyrofrequency, $D=T_{\perp}/T_{\|} \equiv A+1$, the electron anisotropy factor, α is the total-to-warm electron content ratio, and $\beta_{\|}$ is the electron parallel beta.

The field-aligned inhomogeneity of the geomagnetic field and the temporal parameter variations due to the perturbation are accounted for when calculating the path integrated growth rate G:

$$G = \int \frac{\gamma(s)}{v_{VLF}} ds, \qquad (3)$$

where v_{VLF} is the whistler mode wave propagation velocity, s is the equatorial distance along the magnetic field line. The strictly field-aligned propagation of whistler mode waves is assumed. In our estimates the electron Alfven velocity has been substituted into (3) for v_{VLF}. In the frame of the gyrotropic model of the plasma density distribution along the magnetic field line this allows to factor the VLF propagation velocity out of integrating.

3. Results

When examining the modulation in the equatorial plane it was found that the increment of the maximum growth rate $\Delta\gamma$ in linear approximation can be given by:

$$\Delta\gamma=\gamma_0\, \varepsilon \cdot P(x_0, \alpha, \beta_{\parallel}, D), \qquad (4)$$

where γ_0 is the undisturbed VLF growth rate in the equatorial plane, ε is the relative magnetic field perturbation amplitude, P is a function of magnetosphere plasma parameters and VLF wave frequency. The $\Delta\gamma$ value as a function of total-to-warm electron content α and electron parallel beta $\beta_{\parallel}$ in Fig.2 is represented for equatorial normalised frequency x_0=0.25 and for electron anisotropy factor D=1.5 and 3. As seen the largest $\Delta\gamma$ values correspond to high warm plasma content ($\alpha \to 1$) and high electron $\beta_{\parallel}$. From (4) it is seen also the larger the undisturbed VLF growth rate, $\Delta\gamma$, and relative magnetic field perturbation, ε, are, the larger is the $\Delta\gamma$ value. Calculations were done for the typical quiet magnetosphere conditions in the equatorial plane at L=5: electron number density n_{eq}=1 cm^{-1}, B_{eq}=250 nT, Pc1-2 amplitude b_A=5nT and period τ_A=7c.

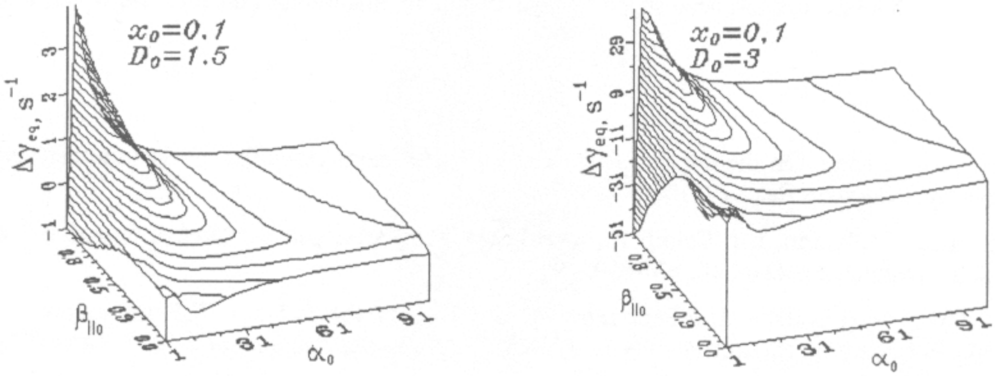

Fig.2 (a,b). The growth rate variation in the equatorial plane as a function of the undisturbed plasma parameters: total-to-warm electron content ratio $\alpha=n/n_{warm}$ and warm electron parallel beta $\beta_{\parallel}$. Calculations are done for L=5, $x_0=\omega/\Omega_{e(eq)}$=0.1, n_{eq}=1 cm^{-1}, Pc2 period is 7s, Pc2 amplitude is 5nT; electron anisotropy factor $D=T_{\perp}/T_{\parallel}$=1.5 (left) and 3 (right).

After integrating along the magnetic field line the emission intensity will be described by the path integrated growth rate (3) that is the VLF wave intensity logarithm. The variation of the G value is given by :

$$\Delta G = \frac{1}{v_{VLF}} \int \Delta\gamma(s) ds, \qquad (5)$$

where as v_{VLF} the electron Alfven velocity is assumed. Since change of the sign of $\Delta\gamma(s)$ is determined by the Pc1-2 wavelength it is evident that for high ICW frequencies and/or low Alfven velocity values the $\Delta\gamma(s)$ values of opposite sign compensate each other when summing along the field line. It is shown that by the typical quiet magnetosphere conditions at L=5 the compensation effects suppress completely the intensity modulation for Pc1-2 pulsations with period less than 3s (Fig.3). It is shown also that for pulsations with amplitude 5nT in the equatorial plane and period 7s under the same magnetosphere conditions for the electron anisotropy A=0.5 the intensity modulation at frequency $\omega=0.1\Omega_{e(eq)}$ would reach 50%.

4. Conclusions

1) The proposed mechanism of the modulation of VLF waves by Pc1-2 pulsations in the magnetosphere is effective under the quiet magnetosphere conditions for ICW with the period not less then 3s. Under the quiet magnetosphere conditions at L=5 by the Pc1-2 amplitude of order of a few nT in the equatorial plane and by the electron anisotropy A=0.5 the intensity modulation at frequency $\omega=0.1\Omega_{e(eq)}$ would reach 50%.

2) The important reason suppressing the modulation is the mutual compensation of the perturbations of the VLF growth rate since they change their sign along the magnetic field line. Therefore the Pc1-2 pulsations with period less than 3s are poorly effective for modulating under the typical quiet magnetosphere conditions.

3). The efficiency of the mechanism under consideration is the higher the larger the warm electron relative content, the higher the electron anisotropy, the larger the Pc1-2 amplitude and wavelength.

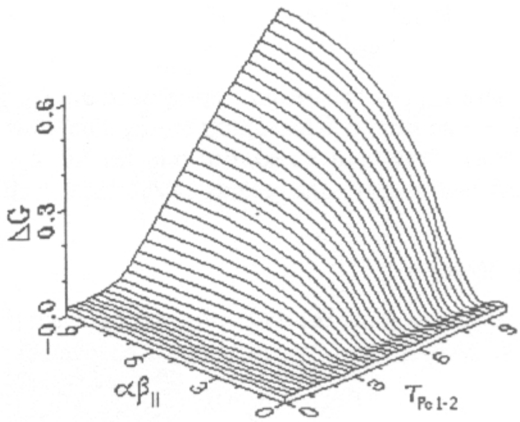

Fig.3. The path integrated growth rate variation under the same magnetosphere plasma conditions as in the Fig.2, as a function of $\alpha\beta_{||}$ product and Pc1-2 period τ for the given undisturbed values of $x_0=\omega/\Omega_{e(eq)}$, D_0 and Alfven velocity v_A=5400 km/s. The compensation effect is dominating by $\tau_{Pc1\text{-}2}$~1-3s and then it disappears.

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