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RESEARCH ARTICLE

AN EXPLANATION OF HISS – TRIGGERED CHORUS EMISSIONS RECORDED AT INDIAN ANTARCTIC STATION, MAITRI, ANTARCTICA (L = 4.5)

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ABSTRACT

In this paper, we present hiss-triggered chorus emissions recorded at Indian Antarctic Station, Maitri (geomagnetic latitude = 70^0 $46^/$ S, longitude = 11^0 $50^/$ E, L = 4.5) during 3 February 2001. The recorded data has been analyzed we find that the wave intensity of chorus events are usually a function of frequency and also it varies from event to event. Chorus emissions are supposed to be triggered by the non-linear process involving whistler mode wave and energetic electrons. The energy of resonating electrons and its variation with wave frequency, pitch angle and L-value along with temporal evolution of emitted wave frequency have been evaluated. The results are used to explain the observed dynamic spectrum of hiss- triggered chorus emissions.

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INTRODUCTION

Very Low Frequency (VLF) emissions are the audio frequency electromagnetic signals propagating in whistler mode in Earth magnetosphere and detectable on the ground stations. These emissions depending upon their dynamic spectrum are called as hiss or unstructured emissions and chorus or structured emissions (Helliwell, 1965). Chorus emissions usually consist of a succession of discrete elements with rising frequency having repetition period varying between 0.1 and 1 s with typical duration of 0.5 – 1 h. It may be accompanied by hiss emission, which serves as a lower frequency background for the discrete elements (Helliwell, 1965, 1969; Reeve and Rycroft, 1976; Koons, 1981; Sazhin and Hayakawa, 1992; Trakhtengerts, 1999).Chorus emissions were also presented from low latitudes (Sazhin and Hayakawa, 1992; Singh *et al*., 2000 and references there in). A good correlation between chorus emissions, hiss emissions and energetic electron fluxes observed by satellite were reported (Oliver and Gurnett, 1968; Park *et al*., 1981; Cornilleau-Wehrlin *et al*., 1978; Summers *et al*., 2004 and references there in), suggesting significant role of energetic electrons in the generation of hiss and chorus.

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Many researcher have explain the generation mechanism of chorus emissions through backward wave oscillator (BWO) regime of magnetospheric cyclotron maser (Trakhtengerts, 1995; 1999; Trakhtengerts *et al*., 1996; Titova *et al*., 2002; 2003). The generation mechanisms of chorus emissions are confirmed using active experimental and theoretical research (Trakhtengerts, 1999; Singh *et al*., 2000; Singh and Patel, 2004; Singh and Ronnmark, 2004 and references there in). Recently Santolik (2008) has presented new results of investigations of whistler-mode chorus emissions. According to Santolik theory Singh *et al*. (2010) has also computed frequency sweep rate of chorus emissions are verified and compare it. In this paper, we present some dynamic spectrum of hiss triggered chorus emissions recorded at the Indian Antarctic Station, Maitri. The wave intensity of chorus emission is almost equal to or more than the intensity of triggering source hiss. These events are varies from event to event. Generation mechanisms of these emissions are discussed and involved parameters are evaluated.

Experimental data and analysis

The location of the Indian Antarctic Station, Maitri (geomagnetic latitude = 70^0 $46^/$ S, longitude = 11^0 $50^/$ E, L = 4.5). The VLF wave recording setup consists of T-type vertical antenna of 10 m height and 40 m horizontal length supported by two poles, transistorized amplifiers and a digital audio tape recorder. Observations were carried out by the Dr. R. P. Patel, Department of Physics, Banaras Hindu University, Varanasi during the summer part of the XXth Indian Antarctic Expedition from 10 January to 10 March 2001. A pre-amplifier was kept at the location of the pole at which the antenna was installed to amplify the signal.

The output of the pre-amplifier was further amplified by a main amplifier and recorded on magnetic tapes using the digital audio tape recorder (Patel *et al*., 2003). Stored data has been analyzed. During the analysis, it was found that the riser emissions, which is triggered by hiss emissions. The spectrum of hiss-triggered chorus emissions is shown in fig.1. From the figure, frequency of risers are 3 – 5 kHz, which originate from a narrow band of hiss (3.5 kHz < f < 3.75 kHz). These emissions were recorded on February 3, 2001 at 1246:50 hr GMT. The hiss-triggered chorus emissions in sufficient numbers were observed for about 1 hour. df/dt increases as frequency increases. Risers are not equal intervals. Hiss emissions in the frequency band 12 – 14.3 kHz are also present. From the figure the lower frequency is strong noise (Patel, 2002; Patel *et al*., 2003; Singh and Patel, 2004).

The cyclotron resonance condition can be written as (Helliwell, 1967)

$$\omega - {\omega_H}/{\gamma} = kv_{||} \qquad \text{.................(1)}$$

were ω is wave frequency, k is wave vector of whistler waves, k = k = $|k|$, ω_H is the electron gyrofrequency, □□□ is the field aligned component of the electron velocity, $\gamma = (1 - v^2/c^2)^{-1/2}$ is the relativistic correction factor, v is the velocity of interacting particle and c is the velocity of light. And the magnetic field equation with nonlinear effects for slowly varying magnetic field can be written as (Omura *et al*., 1991; Trakhtengerts and Rycroft, 2000)

$$\left(\frac{\partial}{\partial t} + v_g \frac{\partial}{\partial z}\right) B_\omega = \left(\frac{\mu_0}{2}\right) v_g J_R \qquad \text{......................(2)}$$

Were B_ω is complex amplitude of the wave magnetic field, v_g is the group velocity. In an inhomogeneous magnetic field, ω_H, □□□, and k are functions of the coordinate z along the magnetic field B_0. J_R is the current due to the resonant electrons and can be written as (Trakhtengerts and Rycroft, 2000)

$$J_R = -e \int_0^\infty u_\perp du_\perp \int_{-\infty}^{\infty} dv_{||} \int_0^{2\pi} d\phi u_\perp F e^{i\phi - i\psi} \qquad \text{..........(3)}$$

Assuming the background plasma to be cold and neglecting the effects of ions and collisions, then the dispersion relation for

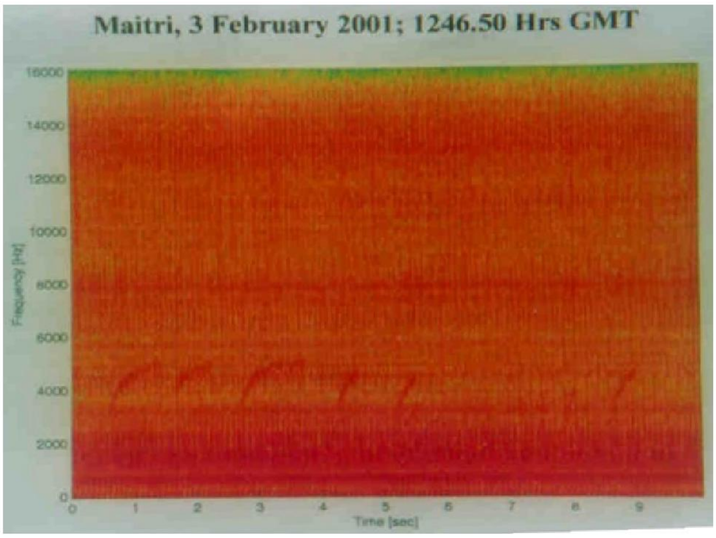

Fig.1. Typical dynamic spectra of the hiss-triggered chorus emissions recorded at Indian Antarctic Station, Maitri on 3rd February 2001 at 1246.50 Hrs GMT

Generation Mechanism

Many researchers has been explain the non-linear self – consistent theory using narrow band of VLF waves in the Earth's magnetosphere discrete triggered emissions (Helliwell, 1967; Karpman *et al*., 1974; Yoshida *et al*., 1983; Molvig *et al*., 1988; Omura *et al*., 1991; Nunn *et al*., 1997; Trakhtengerts and Rycroft, 2000 and references there in). Some microscopic aspects of the essential non-linear theory of wave-particle interaction in whistler mode are analyzed and numerical simulation under certain conditions has been carried out (Nunn and Smith, 1996; Nunn *et al*., 1997; Smith and Nunn, 1998). The discrete wavelets present in the upper part of hiss emissions resonantly interact with counter streaming energetic electrons and generated chorus emissions.

the whistler mode wave propagation along the magnetic field line can be written as

$$k = \frac{\omega_P \omega^{1/2}}{c\,(\omega_H - \omega)^{1/2}} \qquad \text{........................(4)}$$

Where ω_P is the electron plasma frequency. Combining equations (1) and (4), the resonance velocity □□ = □□□we derive the expression for the parallel resonance velocity, which is written as (Patel, 2002; Singh *et al*., 2003)

$$V_R = \frac{c\,cos\alpha\,(\omega_H - \omega)^{\frac{1}{2}}\,[\omega_H\,\{(\omega_H + \omega)(\omega_H - \omega)^2 + \omega_P^2\,\omega\,cos^2\alpha\}^{\frac{1}{2}} - \omega_P \omega^{\frac{3}{2}} \cos\alpha]}{\omega_H^2(\omega_H - \omega) + \omega_P^2\,\omega\,cos^2\alpha} \qquad (5)$$

where α is the pitch angle of the electron. The resonant energy of the electrons E = $mV_g^2/2$ is computed, where m is the mass of electron. Using angular plasma frequency ω_P for computation from equatorial electron density taken as 10^4, 1220, 550 and 65 cm^{-3} for L = 1.2, 2, 3 and 4.5 respectively.

resonance energy decreases with increase in L-value as well as wave frequency. For L = 4.5, as wave frequency varies from 0.1 to 7 kHz, E_R decreases from 900 keV to 30 eV.

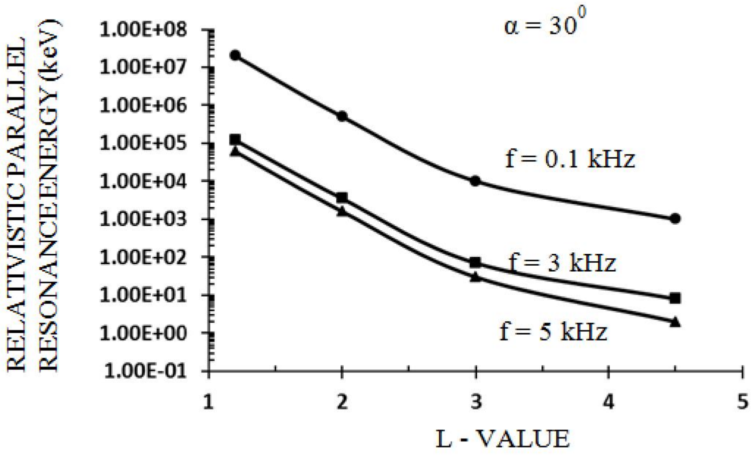

Fig. 2a. Variation of Relativistic Parallel Resonance Energy as a function of L – Value

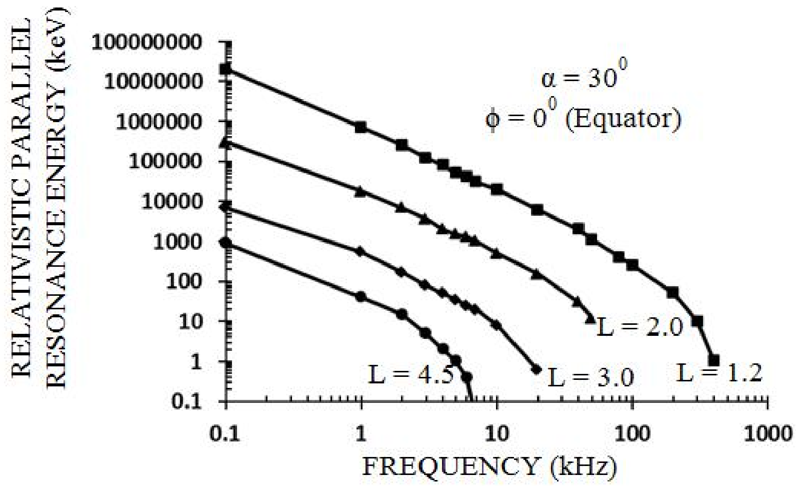

Fig. 2b. Variation of Relativistic Parallel Resonance Energy as a function of frequency

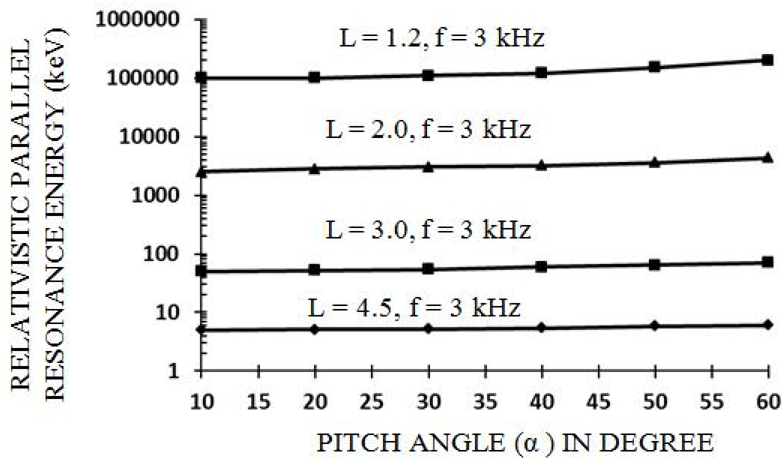

Fig. 2c. Variation of Relativistic Parallel Resonance Energy as a function of Pitch angle

The results are shown in Figure 2 a, b, c. ω_H is computed by using dipolar geomagnetic field variation. Figure 2a, b shows the variation of relativistic parallel resonance energy with L-value for different wave frequency. It is noted that the

For L = 3.0, wave frequency varies from 0.1 to 20 kHz and E_R decreases from 7 MeV to 600 eV. For L = 2.0, E_R lies between 300 MeV to 12 keV and the corresponding wave frequency lie in the range 0.1 to 50 KHz and for L = 1.2, E_R lies between

2000 MeV to 1keV and the corresponding wave frequency lie in the range 0.1 to 400 KHz. In all above computation pitch angle was taken to 30^0.The variation of resonance energy is from 2000 MeV to few keV.

bunching time for L = 2.0 and L = 4.5 for different wave frequency. For f = 1kHz, B_ω = 1 mγ, α = 15^0, bunching time ~ 17 ms for L = 2 and bunching time ~ 31 ms for L = 4.5. For f = 3 kHz, B_ω = 1 mγ, α = 15^0, bunching time ~ 13 ms for L = 2

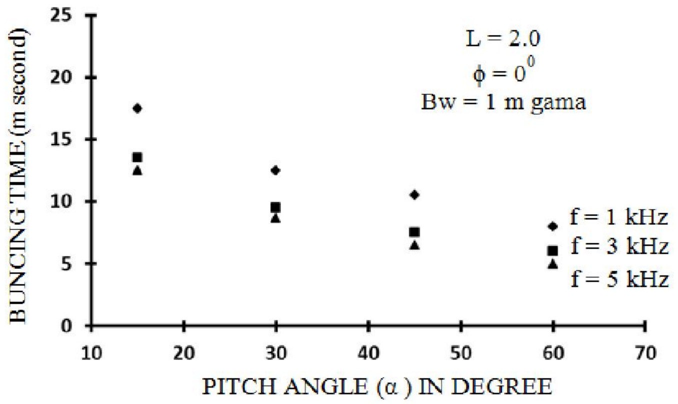

Fig. 3a. Variation of Bunching Time as a function of Pitch angle for L = 2

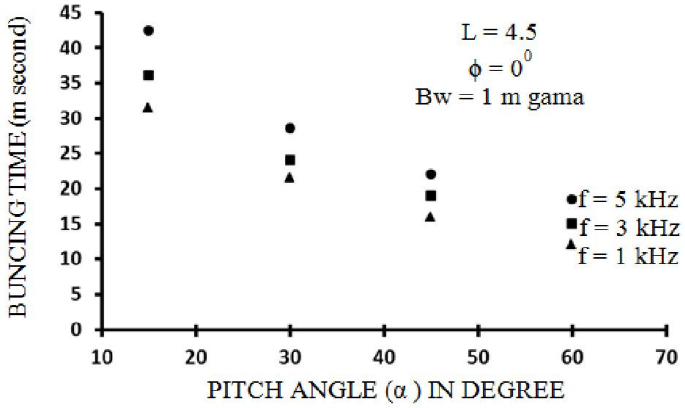

Fig. 3b. Variation of Bunching Time as a function of Pitch angle for L = 4.5

It is clear that in the inner plasma sphere triggering process are generated due to high - energy charge particles. Figure 2c shows the variation of relativistic parallel resonance energy with pitch angle of the resonating electrons. Resonance energy increases with pitch angle increases as well as L-value decreases. It is noted that pitch angle has little control over the variation of resonance energy. Over all pitch angle dependence is non – linear. Assuming the electron resonances are phase bunched by the $ev_\perp \times B_\omega$ force along the magnetic field line then radiate electron coherently and generate the VLF emissions (Helliwell, 1967). Solving the equation of motion of electron in an inhomogeneous medium, in whistler mode, the trapped electrons oscillate with a period can be written as (Dysthe, 1971; Inan *et al*., 1978; Yoshida *et al*., 1983)

$$T_r = \left\{\frac{(2\pi m V_P)}{(eV_\perp f\, B_\omega)}\right\}^{1/2} \qquad \text{...............(6)}$$

These trapped electrons oscillate in the wave field with oscillation frequency Ω_{tr}

$$\Omega_{tr} = (k\, V_\perp\, e\, B_\omega/m)^{1/2} \qquad \text{..............(7)}$$

Yoshida *et al*. (1983) was suggested that the one fourth of the trapping period is called as bunching time of the interacting electrons. Using the above equation 6 and 7, we calculate the and bunching time ~ 36 ms for L = 4.5.For f = 5 kHz, B_ω = 1 mγ, α = 15^0, bunching time ~ 12 ms for L = 2 and bunching time ~ 42 ms for L = 4.5. Bunching time as a function of pitch angle and wave frequency for L = 2 and 4.5 is shown in figure 3a and 3b respectively. Bunching time increases as wave frequency increases but decreases with pitch angle. As L-value increases bunching time increases.

Conclusions

The characteristics of hiss - triggered chorus emissions recorded at Indian Antarctic Station, Maitri are reported. Analysis of the observed dynamic spectra of emissions shows that the each chorus emissions are originated from the underlying narrow hiss band. They are not equal interval. Intensity of chorus emissions varies from event to event. These emissions have been generated near the equatorial region of the L-value corresponding to the observing station. Relativistic parallel resonance energy has been calculated for different L - value. The variation of relativistic parallel resonance energy is from 2000 MeV to few keV. The resonating electron energy of reported emissions lies in the MeV range.

It is clear that in the inner plasmasphere triggering process are generated due to high - energy charge particles. Resonance energy increases with pitch angle increases as well as L-value decreases. It is noted that pitch angle has little control over the variation of resonance energy. Over all pitch angle dependence is non – linear. Bunching time has been also computed for different L-value. An increase of the plasma density or an increase of ambient magnetic field intensity causes a lowering of bunching time. The df/dt increases as frequency increases and the value of df/dt of observed hiss – triggered chorus emissions are 0.4 kHz/second and computed values are same.

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