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RESEARCH ARTICLE

COMPUTATION OF GROWTH RATE OF VLF HISS EMISSIONS RECORDED AT INDIAN ANTARCTIC STATION, MAIYRI, ANTARCTICA (L = 4.5)

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ABSTRACT

VLF hiss emissions are the naturally occurring phenomena in audio frequency range electromagnetic signal propagating in whistler mode and readily detectable at middle and high latitudes. They have constant spectral density in the limited frequency band with right hand polarization. In this paper, we present some VLF hiss data were observed for the first time at the Indian Antarctic Station, Maitri, Antarctica (geographic latitude 70^0 $46^/$ S, longitude 11^0 $50^/$ E, geomagnetic latitude 66^0 $03^/$ S, longitude 53^0 $21^/$E) during February 17, 2001 has been analyzed. The typical dynamic spectra of VLF hiss emissions in the frequency range of 11 to 13 kHz and three harmonic lines in different frequency range at 6.2, 8.0 and 9.2 kHz are presented. The lower frequency harmonic line is stronger intensity in comparison to higher frequency harmonic line. To explain about these emissions, we propose that the hiss emissions are generated through Doppler – shifted cyclotron interaction near the geomagnetic equator and propagate towards the Earth in the whistler – mode. We have computed growth rate of the waves for different anisotropies and present the results.

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INTRODUCTION

VLF emissions depending upon their spectral shapes can be broadly divided in to hiss, discrete, periodic, quasi periodic and triggered emissions (Helliwell, 1965). Quasi-periodic or Periodic structure emissions with periods ranging from less than a second to several minutes have been reported (Sato *et al*., 1974; Sato, 1980; Ward *et al*., 1982; Sazhin and Hayakawa, 1994; Patel, 2002; Singh *et al*., 2005; Singh *et al*., 2008; Singh *et al*., 2009 and references there in). The VLF emissions received on the Earth's surface indicate that the waves after generation may have propagated in the ducted whistler mode or pro-longitudinal mode, because VLF wave propagating in any other mode may not reach the Earth's surface (Singh, 1993; Calvert, 1995 and references there in). Vero *et al*. (1997) suggested that whistler ducts and geomagnetic field line shells may be connected with each other. VLF hiss emissions are well known forms of electromagnetic signals that arise in the magnetosphere and have constant spectral density in the limited band reported by Kimura (1967). Earlier hiss was supposed to be high latitude phenomena, but recent observations shows that there are three principal zones of intense hiss activity: the first zone is located near invariant latitude of 70^0, the second zone is near 50^0 invariant latitude and the third zone less below $\pm 30^0$.

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The hiss events occurring in the third zone are called as low latitude or equatorial hiss and they are less intense than the mid/high latitude hiss. Hiss emissions recorded at the Indian station Varanasi belong to this category. Hiss events observed in the first zone is also called as auroral hiss (4 kHz < f < 30 kHz). The presented events recorded at Indian Antarctic Station Maitri Antarctica belong to this category. The generation mechanism of VLF hiss is described through Doppler – shifted cyclotron resonance interaction (Gendrin, 1975; Smith *et al*., 1998; Marcz and Vero, 2002; Patel, 2015 - A and references there in). Characteristics of modulating VLF hiss observed at Indian Antarctic Station Maitri (L=4.5) reported by Singh *et al*. (2010-A). Hiss triggered chorus emissions observed at low and high latitude are reported (Singh *et al*., 2000; Patel, 2002; Patel *et al*., 2003; Singh *et al*., 2003; Singh and Patel, 2004; Singh *et al*., 2010-B; Patel, 2015 - B). In this paper, we present some dynamic spectrum of VLF hiss emissions observed at Indian Antarctic Station, Maitri. Computed growth rate of the wave are also presented.

Experimental data and analysis

The location of observation place at the Indian Antarctic Station Maitri (geographic latitude = 70^0 $46^/$ S, longitude = 11^0 $50^/$ E, geomagnetic latitude = 66^0 $03^/$ S, longitude = 53^0 $21^/$E, L = 4.5). The VLF wave recording setup consists of T-type vertical antenna of 10 meter height and 40 meter length supported by two poles, transistorized amplifier and a digital 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. Pre-amplifier is kept at the bottom of the pole at which an antenna is to install to amplify by main-amplifier. The data are stored in digital audio tapes. The recorded data were analyzed and choose the low noise level VLF waves. Figure 1 shows a dynamic spectrum of VLF hiss emissions at relatively higher frequency 11 kHz to 13 kHz observed on February 17, 2001 at 11:30:35 hrs GMT. The upper cut – off frequency is about 13 kHz whereas lower cut-off frequency is about 11 kHz. From figure 1, on the bottom three harmonic lines are seen at frequency 6.2, 8.0 and 9.2 kHz, which were present throughout the recording period and the intensity of the wave is decreases as frequency increases. That is the line of 6.2 kHz is strongest and 9.2 kHz line has lower intensity Patel (2002). Similar harmonic line on the dynamic spectrum were recorded by Helliwell *et al.* (1975) from the ground based station at Siple, Antarctica and Roberval (Quebec) in the frequency range 2 – 5 kHz.These lines were termed as magnetospheric lines. ISIS2 satellite data have analyzed and reported magnetospheric lines in the frequency range 1.8 to 2.3 kHz (Rodger *et al.*, 1995). This events presented in figure 1 continued for two hours having the same intensity. During the day of observation magnetic activity are quit day.

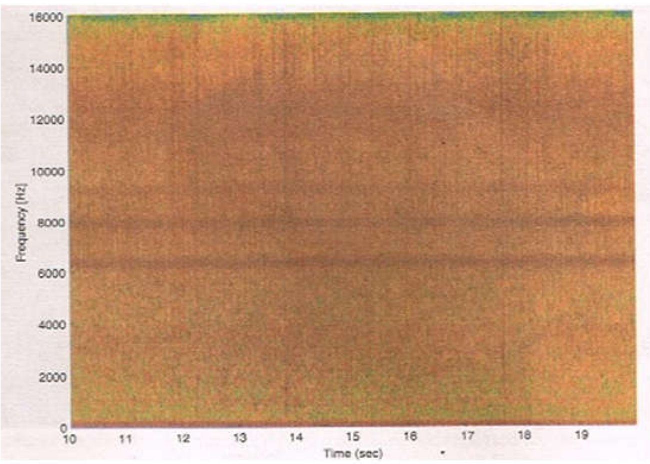

Fig. 1. VLF hiss emissions recorded at Indian Antarctic Station, Maitri, Antarctica on February 17, 2001 at 11:30:35 Hrs GMT

Growth Rate

The generation of VLF hiss emissions, there are two possibilitiesone is hiss generated near the equatorial region of L-value corresponding to the receiving station (L = 4.5) and may have propagated in whistler-mode. The secondpossibilities is that it may have been generated at high/low L-value, in that case the emissions could have traversed magnetospheric path in ducted whister mode and after exiting from the duct could excite the Earth-ionosphere waveguide and may have propagated towards the pole to be received at Indian Antarctic Station Maitri Singh *et al.*, 2010).The upper boundary frequency (UBF) method has been generally used to find out the location of source on the ground observed VLF emissions. The L-value of the VLF source waves is computed proposed relation by Smirnova (1984)

$$L = (440/f_{UB})^{1/3} \quad (1)$$

wheref_{UB} is upper boundary frequency of the emissions in kHz and using the observed parameter f_{UB} = 13 kHz. Thus, the source location of VLF hiss observed Maitri, Antarctica is calculated to be L = 3.23.

To explain the deficiency in the experimental and theoretical power, it is suggested that the generated waves of small amplitudes interact with the energetic electrons while bouncing back and forth along geomagnetic field lines and are thus, amplified. The amplitude wave finally may be received at the Earth's surface. The wave temporal growth rate γ in the case of wave propagating parallel to the main magnetic field can be expressed as (Cornilleau Wehrline *et al.*, 1985; Solomon *et al.*, 1988)

$$\frac{\gamma\,(E_R)}{\omega_{ce}} = \frac{1.7 \times 10^{-6}}{f_{pe}^2}\,(E_R)^{\frac{1}{2}}\,(1 \quad x)^2[A\,(E_R) \quad A_c]\int_0^{\pi/2} J\,(\alpha, E)\,tan\alpha\,d\alpha \quad (2)$$

where$f_{ce} = \omega_{ce}/2\pi$ is the electron cyclotron frequency, f_{pe} is the electron plasma frequency, E_R (in keV) is the resonant energy of electrons, $x = f/f_{ce}$ is the reduced wave frequency, A is the electron temperature anisotropy and A_c is the critical anisotropy. One has

$$E_R = 253\,\left({f_{ce}}/{f_{pe}}\right)^2 \frac{(1-x)^3}{x} \quad (3)$$

$$A\,(E_R) = \frac{\int_0^{\pi/2} tan^2\alpha\,({\partial J}/{\partial\alpha})_E\,d\alpha}{2\int_0^{\pi/2} \tan\alpha\,J\,(\alpha,E)d\alpha} \quad (4)$$

and $A_c = \frac{x}{(1-x)}$

where J (α, E) is the differential flux of energetic electrons of pitch angle α and energy E. Equation 2 states that the wave amplification will take place only when $A\,(E_R) > A_c$. Solomon *et al.* (1988) have calculated the value of anisotropy A from the flux data and they have shown that $A > A_c$ for the reduced wave frequency $x < 0.4$. The derived value of A lies between 0.2 and 1.5. In the present computation we have chosen some discrete value of A such 0.5, 1.0 and 1.5. In the absence of simultaneous measurements of the wave and energetic electrons, the term $\int_0^{\pi/2} J\,(\alpha, E)\,tan\alpha\,d\alpha$ can be approximated by the omnidirectional flux of electrons with the energy greater than resonance energy E_R. For numerical evaluation the flux of energetic electrons at different values are taken from the measurement of Katz (1966) who reported the variation of electron flux as a function of energy for different L – values. The wave temporal growth rate for various frequencies and different values of anisotropies are evaluated and shown in figure 2 for L = 4.5. it is seen that the growth rate decreases with frequency but increases with anisotropy. The computed amplification factor is less than the required value to explain the observed spectral power If we assume that the wave bounces back and forth along the geomagnetic field line before being received at the Earth's surface, then the wave passes through the interaction region many times and each time it interacts with ambient energetic electrons and is amplified.

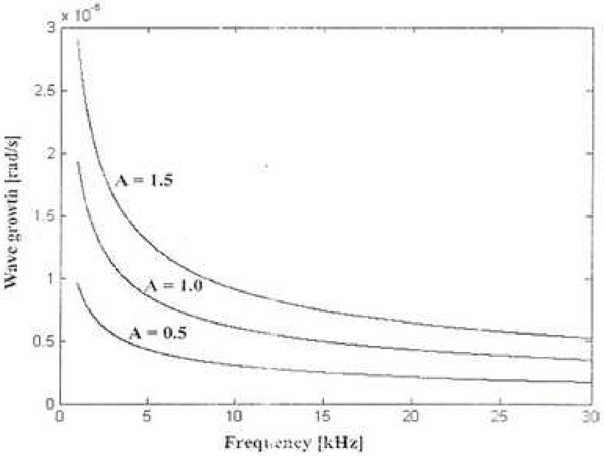

Fig. 2. The variation of wave growth rate with frequency for different isotropies (A = 0.5, 1.0, 1.5) at L = 4.5

Thus, if in each passage the amplification factor remains the same then the required experimental wave intensity can be achieved in 50 bounces of the wave across the equator for L = 4.5.Helliwell(1993) has stressed that ducted signals may echo repeatedly back and forth over one duct for hundreds of times. Whereas, Huang *et al.*(1983) have explained that net growth rates are too small and that the cyclic waves do not provide a satisfactory explanation for hiss generation. In fact a quasi-linear theory of wave-particle interaction should be considered to explain the details of observed spectra. In computing the wave-amplification, the effect of an inhomogeneous magnetic field should also be considered. The non-linear effects also came into existence when the wave-amplitude becomes finite. Thus, the non-linear effects may explain the observed maximum amplitudes of the reported VLF hiss. The magnetospheric lines observed at the Indian Antarctic Station Maitri appear to be the same phenomena as the semicoherent emissions (power line harmonic radiation) described by other workers (Helliwell el al., 1975; Park and Helliwell, 1978; 1981; Rodger el al., 1995). Analyzing ISIS – 2 satellite data Rodger *et al.*(1995) have shown that the observed magnetospheric lines do not support generation by power line harmonics. They did not find any evidence of harmonics of 50 or 60 Hz power lines in the magnetospheric line events. Even in the frequency spacing of these events harmonics of 50 or 60 Hz could not be ascertained. This shows that the generation mechanism of magnetospheric lines needs further investigations.

Conclusions

In this paper, we have presented some dynamic spectrum of VLF hiss emissions observed at the Indian Antarctic Station, Maitri, Antarctica. These emissions are generated in the equatorial region of lower L-value through the process of Doppler shifted cyclotron resonance mechanism. We have tried to explain the observed VLF hiss emissions. After analysis of the spectrum there are three harmonic lines appears.They are different frequencies. Lower frequency harmonic line are very much intensity in comparison to higher frequency harmonic line but the generation mechanism of these lines is not known. We have also computed the growth rate for the wave. The growth rate decreases with increases frequency. Anisotropies increases then the growth rate are increases but decreases with increasing frequency.

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