Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 13, Issue, 12, pp. 20013-20016, December, 2021

DOI: https://doi.org/10.24941/ijcr.42744.12.2021

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

WHISTLER-TRIGGERED VLF EMISSIONS OBSERVED AT LOW LATITUDE GROUND STATION DURING DAY TIME

***Dr. Ravindra Pratap Patel**

Department of Physics, M. M. H. (P. G.) College, Ghaziabad – 201001 (U.P.)

ARTICLE INFO

Article History:
Received 17th September, 2021
Received in revised form
28th October, 2021
Accepted 10th November, 2021
Published online 29th December, 2021

Keywords:

Whistler-Triggered Emissions,
Wave-Particle Interaction,
Bunching Time,
Resonance Condition.

Corresponding author:
Dr. Ravindra Pratap Patel

ABSTRACT

Whistler-triggered VLF emission recorded at low latitude ground station Jammu (Geomagnetic Latitude = $22^0\ 26^{/}$ N, L = 1.17) are reported. The dynamic spectrums of whistler-triggered emissions based on spectral analysis have been carried out. The riser triggered from the bottom side of the whistler spectrum. According to Smirnova theory, the L – value of rising emissions have been computed. An attempt is made to explain the generation and propagation mechanism of these emissions.

Citation: Ravindra Pratap Patel. *"*Whistler-triggered vlf emissions observed at low latitude ground station during day time*", 2021. International Journal of Current Research, 13, (12), 20013-20016.*

INTRODUCTION

Triggered emissions are different variety of VLF/ELF signals follow the apparent source, which could be whistler (Storey, 1953; Nunn and Smith, 1996). A large numbers of workers have suggested that emissions are categorized as unstructured or hiss and other structured and discrete chorus (riser/faller) emissions (Helliwell, 1965; Sazhin, 1982; Hayakawa *et al.*, 1990; Sazhin and Hayakawa, 1992; Hattori and Hayakawa, 1994). Various features of these emissions have been studied from time to time. Also the signals received from the VLF transmitters are reported by (Helliwell, 1965; Bell *et al.*, 1982) and power line radiation from world's power grid (Helliwell, *et al.*, 1975; Park and Chang, 1978; Luette *et al.*, 1979). The other type of emissions are excited from the upper boundary frequency of hiss (Helliwell, 1969; Reeve and Rycroft, 1976 a, b; Koons, 1981; Hattori *et al.*, 1989; Singh *et al.*, 2000b). The study of whistler-triggered emissions plays a significant important role to understanding of magnetospheric parameters.

The non-linear effect can be categorized in to two categories (i) wave-wave interaction and (ii) wave-particle interactions (Harker and Crawfords, 1969). He suggested that the responsible mechanism for the generation mechanism of triggered emissions is non-linear interaction between a finite amplitude wave train and the particles that happen to be in resonance with it. The non-linear theory processes have been explained (Helliwell, 1970; Smith and Nunn, 1998, Hobara *et al.*, 1998; Trakhtengerts and Rycroft, 2000). The idea of a second order cyclotron resonance along an inhomogeneous dipolar magnetic field was introduced (Helliwell, 1967; Nunn, 1974; Karpman *et al.*, 1974). This theory is very useful for explanation of the generation mechanism of triggered VLF emissions. The second – order resonance conditions determine the frequency spectrum of the discrete events generated by the electron beam in the inhomogeneous magnetic field. Whistler-triggered emissions, riser, fallers were rarely reported at any low latitude ground stations. In the present paper, we present a detailed analysis of whistler-triggered emissions recorded at low latitude ground station Jammu (Geomagnetic Latitude =

22^0 $26^/$ N, L = 1.17). An attempt is made to explain the generation and propagation mechanism of these emissions.

Experimental Setup and Data Analysis: At low latitude ground station Jammu (L – 1.17), the whistler – triggered VLF emissions were received by a T-type antenna, pre and main-amplifiers and tape recorder having band with 50 Hz to 15 kHz. T-type antenna is 25 meter in vertical length and 6 meter long horizontally and 3.2 mm in diameter and impedance about 1MΩ. The antenna is rendered a periodic with the help of a suitable RC network for avoiding any noise effect. The antenna is installed at suitable distance from main building to reduce the power line hum and other man made noise. The observations were taken continuously day and night period. The data are stored on the magnetic tapes, which were analyzed using Advance VLF Data Analysis System (AVDAS) and sonogram.

In this paper, whistler – triggered VLF emissions recorded during day time hours of 8th January 2001 at 1523 hours IST and other 29th March 2003 at 1515 hours IST are analyzed. These emissions were recorded on 28th January 2001, the geomagnetic storm K_P – index = 2, (ΣK_P = 17) and D_{St} – index = 5 and on 29th March 2003, $K_P = 4_-$ ($\Sigma K_P = 35_+$) and D_{St} = -52 during the recovery phase of the storm. Typical frequency – time spectrogram of whistler-triggered VLF chorus emissions recorded during daytime at low latitude ground station Jammu on 8th January 2001 at 15:23 h IST is shown in Figure 1. These emissions contain two events of whistler-triggered chorus emissions. The observed whistler wave frequency varies between 4.5 kHz to 7.6 kHz for the first and 4.6 kHz to 7.5 kHz in the second event, whereas the frequency of triggered emission varies between 4.5 kHz to 6.5 kHz in the first event and 4.6 kHz to 6.4 kHz in second event. The relative intensity of whistler wave and triggered emission is approximately same, which is given in Table 1. The df/dt values of the first and second event of triggered emission are found to be 1.61 kHz/sec and 1.51 kHz/sec respectively. The dispersion of the first and second whistlers are 81.9 $s^{1/2}$ and 82.5 $s^{1/2}$ and the corresponding path of propagation are L = 4.35 and 4.37 respectively.

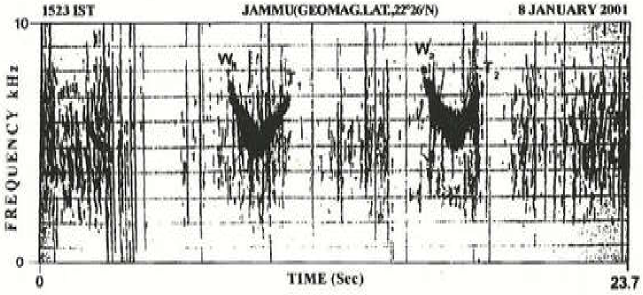

Figure 1. Dynamic spectrum of the whistler-triggered emissions recorded at Jammu on 08th January 2001at 1523 hrs (IST)

Table 1. Relative intensity of whistler and Triggered emission

Whistler wave		Triggered emission	
Frequency (kHz)	Relative intensity (dB)	Frequency (kHz)	Relative intensity (dB)
8.5	60	7.1	58
7.6	61	6.8	59
6.8	61	6.1	60
6.1	62	5.1	61
5.3	62	4.5	62
4.3	62	-	-

In Figure 2 depicts another events contains two events of daytime WTCEs recorded during disturbed period on 29 March, 2003 at 15:15 h IST, which are triggered from the bottom side of the whistler spectrum. The K_P – index value at the time of observation varied between 2_- to 3_+. This figure contains two short one hop-whistlers and the relative intensity of the whistler wave and the triggered emissions is approximately same, which is given in Table 2. The whistler wave frequencies of the first and second events are 4.6 to 6.7 kHz and 5.0 to 7.2 kHz, whereas the frequency of triggered chorus riser varies between 5.0 to 7.2 kHz and 5.0 to 7.5 kHz respectively. The df/dt values of the first and second events of triggered emissions are found to be 22.2 kHz/sec and 21.5 kHz/sec respectively. The dispersion of the two (first and second) triggering whistlers are 16.4 $s^{1/2}$ 16 $s^{1/2}$ respectively and their propagation path is L = 1.9 and 1.96 respectively.

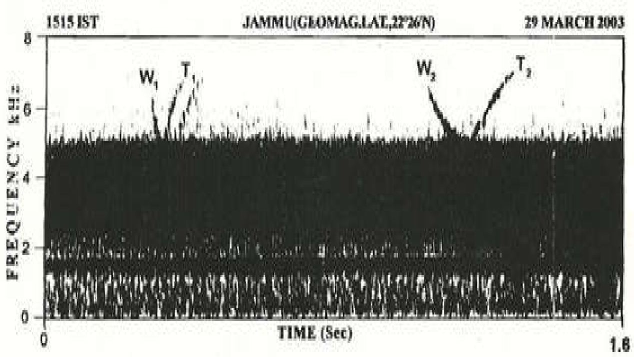

Figure 2. Dynamic spectrum of the whistler-triggered emissions recorded at Jammu on 29th March 2003 at 1515 hrs (IST)

Table 2. Relative intensity of whistler and Triggered emission

Whistler wave		Triggered emission	
Frequency (kHz)	Relative intensity (dB)	Frequency (kHz)	Relative intensity (dB)
7.6	57	6.5	56
6.8	58	6.1	58
6.1	57	5.3	59
5.3	60	4.5	60
4.5	59	-	-

Generation Mechanism: We have followed the upper boundary frequency (UBF) method developed by Smirnova (1984) to find out the location of source for the chorus (riser/faller) events. The upper boundary frequency of the ground based observation of discrete chorus events is determined on the assumption of dipolar geomagnetic field configuration, by the half equatorial electron gyrofrequency in the generation region, irrespective of the latitude of the observation station. Using Smirnova (1984) method, the L – value of the discrete VLF chorus emission source is written as

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

Where f_{UB} is the upper cut of boundary frequency of the observed triggered chorus emissions in kHz. Using eq. (1), the L – value of the source region for the observed events is found to be L_{Source} = 4.07, 4.09 for the figure 1 and L_{Source} = 3.93, 3.88. The higher L – value of the source region compared to the observation station Jammu (L = 1.17) shows that the wave may have propagated towards significantly lower latitude (Smirnova *et al.*, 1976). The non-linear self consistent resonant interaction of energetic electrons with narrow band VLF waves in the Earth's magnetosphere has been used to explain many of the qualitative physical features underlying triggered emissions

(Trakhtengerts and Rycroft, 2000). A large number of workers have been made to solve the problem using different numerical model such as sheet current model (Helliwell and Inan, 1982; Carlson *et al*., 1990), non-linear resonant current model (Nunn, 1984), electromagnetic full particle model (Cuperman and Lyons, 1974; Omura and Matsumoto, 1987), fluid-particle (hybrid) model (Vomvoridis and Denavit, 1980; Vomvoridis *et al*., 1982) and Vlasov hybrid model (Nunn, 1990; Nunn and Smith, 1996). On the basis of non-linear cyclotron resonant interaction between whistler mode waves and counter streaming energetic electrons, the cyclotron resonance condition is written as

$$\omega - \omega H / \gamma = k\, v|| \qquad (2)$$

Where ω and k are the wave frequency and wave vector of the whistler waves, k = |k|, ωH is the electron gyro-frequency, v|| is the field aligned component of the electron velocity, $\gamma = (1 - v2 / c2)-1/2$ is the relativistic factor, v and c is the interacting particle velocity and light velocity in free space. For ducted whistler propagation K||B0, B0 being the vector geomagnetic field. In an inhomogeneous magnetic field, ωH, v|| and k are functions of the coordinate z along the magnetic field B0. The electrons with different v|| interact with the same wave (ω, k) at different points along the geomagnetic field lines. According to non-linear theory, the field equation for slowly varying in magnetic field can be written as (Omura *et al*., 1991; Trakhtengerts and Rycroft, 2000)

$$(\partial/\partial t + v_g\, \partial/\partial z)\, B\omega = (\mu_0/2)\, v_g\, J_R \qquad (3)$$

where $B\omega$ is the complex amplitude of the magnetic wave field, vg is the group velocity and JR is the current due to the resonant electrons. The dispersion relation for the whistler mode waves propagating along the geomagnetic field line is given as

$$k = [\ (\omega P\ \omega 1/2/c\ (\omega H - \omega)1/2\ ] \qquad (4)$$

where ω_P is the electron plasma frequency. Combing equation (2) and (4), the resonant electron energy is written as

$$E_R = mV_R^2/2 \qquad (5)$$

where m is the mass of electron. The resonance velocity $V_R = V_{||}$ written as

$$V_R = [c \cos\alpha\, (\omega_H - \omega)^{1/2}\, [\omega_H \{(\omega_H + \omega)(\omega_H - \omega)^2 + \omega^2_P\, \omega \cos^2\alpha\}^{1/2} - \omega_P\, \omega^{3/2} \cos\alpha]]/[\omega^2_H (\omega_H - \omega) + \omega^2_P\, \omega \cos^2\alpha] \quad (6)$$

Where α is the pitch angle of the electron. In our numerical computation for relativistic parallel resonance energy, we have used normalized electron density verses distance along the field line from the equator according to the collision-less model. We have taken equatorial electron density 550 and 65 electrons cm^{-3} for two path of propagation L= 3 and 4.5 respectively and the corresponding plasma frequency is ~ 211, 72 kHz and electron gyro-frequency is ~ 32 and 9 kHz. Calculate the value of parallel velocity is $V_{||} \sim 2.48 \times 10^8$ m/s and perpendicular velocity is $V_\perp \sim 0.64 \times 10^8$ m/s, which is parallel velocity is greater than the perpendicular velocity of resonant electron. Using equation (5), we calculate the value of relativistic parallel resonance energy for L = 3 and 4.5 for pitch angle ($\alpha = 30^0$) and different wave frequency of electrons. We found that the $E_R \sim 6.61 \times 10^3$ keV to 0.003 keV For L = 3, wave frequency varies between 0.1 to 30 kHz, and for L = 4.5, frequency varies between 0.1 to 8 kHz, E_R decreases from 764 keV to 0.028 keV. The resonant energy decreases with increasing wave frequency. Thus, it is clearly seen that in the inner magnetosphere high energy particles are actually participating in the triggering process. As pitch angle (α) increases, resonant electron energy increases but the overall pitch angle dependence is non-linear. For low latitude ground station Varanasi, the interaction region corresponding to inner magnetosphere for L =2, 3 and 4, E_R varies between Mev to keV have presented by (Patel, 2002; Singh *et al*., 2003).

If the rates of change of electron gyrofrequency and of the wave frequency balance each other, then the electron will remain in resonance for a longer duration and the phase angle remains constant. This means that the full derivative of equation (2) along the particle path is zero. This is concept of second order resonance first formulated by (Helliwell, 1967) and have suggested as necessary for the effective wave-particle interaction in the inhomogeneous magnetic field. The resonant electrons are then phase bunched by the ($eV_\perp \times B\omega$) force acting along the field line. Solving equation of motion of an electron traveling in an inhomogeneous medium, in the presence of a whistler wave, it can be shown that the wave trapped electrons oscillate with a period (Dysthe, 1971; Inan *et al*., 1978; Yoshida *et al*., 1983)

$$T_r = \{(2\pi m V_P)/(eV_\perp\, f\, B\omega)\}^{1/2} \qquad (6)$$

where m is the mass of electron, e is the charge of electron, f is the wave frequency, $B\omega$ is the wave magnetic field, $V_P = \omega/k$ is the phase velocity, $V_\perp$ is the velocity of the electron perpendicular to the field. The trapped electron oscillate with a frequency $\Omega_{tr} = (keV_\perp B\omega/m)^{1/2}$. Yoshida *et al.* (1983) have concluded that electrons whose absolute initial phase (φ) is less than 90^0, will be bunched at $\varphi = 0^0$ after a period of $T_r/4$ is called as bunching time (T_B). We have used some parameters for computing bunching time, wave frequency f = 1 kHz, $\varphi = 0^0$, $B\omega$ = 1mγ, $\alpha = 15^0$, bunching time $T_B \sim 17$ ms for L = 2. The same for L = 4.5 is 54 ms. As initial geomagnetic latitude increases with decreasing bunching time. Also wave magnetic field increases, bunching time is decreases. As wave frequency increases as in the presence of dense plasma, bunching time decreases.

CONCLUSION

In this paper, we have reported characteristics of whistler triggered emissions observed at the low latitude ground Jammu during daytime period. These discrete triggered emissions are rising tones, which were rarely observed at any low latitude ground stations. These events may actually be mid-latitude emissions, because our analysis of whistler waves propagated along geomagnetic field line is higher L-values lying between 4.07 to 3.88. They are propagated along the geomagnetic field lines ($3.88 \leq L \leq 4.07$) and after exiting from the ionosphere and excite the Earth-ionosphere wave guide and propagate towards the equator along with whistlers. The relative amplitude of whistlers and triggered emissions are almost same. The relativistic parallel resonance energy of electrons decreases with increasing frequency but energy increases with decreasing L-value. The reported resonance electron energy lies in the kev range. Bunching time decreases with increasing of both geomagnetic latitude and wave magnetic field. Wave frequency increases as in the presence of dense plasma, bunching time decreases. All these estimated parameters are in good agreement with the results reported by other workers.

Acknowledgements

R. P. Patel is thankful to Professor Lalmani for providing whistler-triggered VLF emissions data.

REFERENCES

Bell, T. F., Luette, J. P. and Inan, U. S. 1982. ISEE-1 observation of VLF line radiation in the Earth's magnetosphere, *J. Geophys. Res.,* 87, 3530.

Carlson C. R., Helliwell R. A. and Inan U. S., 1990. Space-time evolution of whistler mode wave growth in the magnetosphere, *J. Geophy. Res.,* 95, 15073.

Cuperman S. and Lyons L. R., 1974. Comparison of quasi-linear prediction with a computer simulation of whistler wave in unstable plasma, *J. Plasma Physics.,* 11, 397, 1974;

Dysthe K. B., 1971. Some studies of triggered whistler emissions, *J. Geophy. Res.,* 76, 6915.

Harker, H. J. and Crawford, F. W., 1969. Nonlinear interaction between extraordinary waves in a cold plasma, *J. Appl. Phys.,* 40, 3247.

Hattori, K., Hayakawa, M., Shimakura, S., Parrot, M. and Lefeuvre, F., 1989. GEOS-1 observation of hiss triggered chorus emissions in the outer magnetosphere and their generation model, *Proc. NIPR Symp. Upper Atmos. Phys.,* 2, 84.

Hattori, K. and Hayakawa, M., 1994. Consideration of dynamic spectra and direction finding results of hiss triggered chorus emission, *Proc. NIPR Symp. Upper Atmos. Phys.,* 7, 40.

Hayakawa, M., Hattori, K., Shimakura, S., Parrot, M. and Lefeuvre, F., 1990. Direction finding of chorus emissions in the outer magnetosphere and their generation and propagation, *Planet. Space Sci.,* 38, 135.

Helliwell, R. A. 1965. Whistler and related ionospheric phenomena, Stanford University Press, Stanford, California, USA.

Helliwell R. A., 1967. A theory of discrete emissions from the magnetosphere, *J. Geophy. Res.,* 72, 4773.

Helliwell, R. A. 1969. Low frequency waves in the magnetosphere, Rev. Geophys., 7, 281.

Helliwell, R. A. 1970. Intensity of discrete VLF emission in Particle and fields in the magnetosphere, ed. B. M. McCormac, Dodrecht, D. ReidelPublication.

Helliwell, R. A. and Inan, U. S., 1982.VLF wave growth and discrete emission triggering in the magnetosphere: A feed back model, *J. Geophy. Res.,* 87, 3537.

Helliwell, R. A., Katsufrakis, J. P., Bell, T. F. and Raghuram R., 1975. VLF line radiation in the Earth's magnetosphere and its association with power system radiation, *J. Geophys. Res.,* 80, 4249.

Hobara, Y., Trakhtengerts, V. Y., Demekhov, A G. and Hayakawa, M., 1998. Cyclotron amplification of whistler waves by electron beams in an inhomogeneous magnetic field, *J. Geophys. Res.,* 103, 20499.

Inan U. S., Bell T. F. and Helliwell R. A., 1978. Nonlinear pitch angle scattering of energetic electrons by coherent VLF waves in the magnetosphere, *J. Geophy. Res.,* 83, 3235.

Karpman, V. I., Istomin, Y. N and Shklyar D. R., 1974. Nonlinear theory of a quasimonochromatic whistler mode packet in an inhomogeneous plasma, *Phys. Plasma,* 16, 685.

Koons, H. C., 1981. The role of hiss in magnetospheric chorus emissions, *J. Geophy. Res.,* 86, 6745.

Luette, J. P., Park, C. G. and Helliwell, R. A., 1979. The control of magnetospheric chorus by power line radiation, *J. Geophys. Res.,* 84, 2657.

Nunn, D., 1974. A quasi-static theory of triggered VLF emissions, *Planet. Space Sci.,* 32, 325.

Nunn, D., 1984. A quasi-static theory of triggered VLF emissions, Planet. Space Sci., 22, 349.

Nunn D., 1990. A non-linear simulation of VLF nonlinear wave-particle interactions in collision-free plasma using the Vlasov hybrid simulation technique, *Comput. Phys. Co.,* 60, 1.

Nunn, D. and Smith, A. J., 1996. Numerical simulation of whistler-triggered VLF emissions observed in Antarctica, *J. Geophy. Res.,* 101, 5261.

Omura Y., Nunn D., Matsumoto H. and Rycroft M. J., 1991. A review of observational, theoretical and numerical studies of VLF triggered emissions, *J. Atmos. Terr. Phys.,* 53, 351.

Omura, Y. and Matsumoto, H., 1987. Competing processes of whistler and electrostatic instabilities in the magnetosphere, *J. Geophy. Res.,* 92, 8649.

Patel R. P., 2002. Study of whistlers, VLF hiss and triggered emissions at low latitudes, Ph. D. Thesis, Banaras Hindu University, Varanasi, India.

Park, C. G.and Chang, D. C. D., 1978. Transmitter simulation of power line radiation effects in the magnetosphere, *Geophys. Res. Lett.,* 5, 861.

Reeve, C. D. and Rycroft, M. J., 1976a. A mechanism for precursors to whistler, *J. Geophys. Res.,* 81, 5900.

Reeve, C. D. and Rycroft, M. J., 1976b. Unducted VLF energy from tropical lightning as a possible source of mid latitude VLF emissions and electron precipitation, *J. Geophys. Res.,* 81, 6201.

Sazhin, S. S. and Hayakawa, M., 1992. Magnetospheric chorus emissions: A review, *Planet. Space Sci.,* 40, 681.

Singh, R., Patel, R. P., Singh, R. P., and Lalmani, 2000b An experimental study of hiss-triggered chorus emissions at low latitude, *Earth Planets Space,* 52, 37.

Singh R. P., Patel R. P. and Singh D. K., 2003. Triggered emissions observed at Varanasi (India), *Planet. Space Sci.,* 51, 495-503.

Storey, L. R. O., 1953. An investigation of whistling atmospherics, Phil. Trans. Roy Soc. (London), A (246), 113.

Smith, A. J. and Nunn, D., 1998. Numerical simulation of VLF riser, fallers and hooks observed in Antarctica, Singh, J. Geophys. Res., 103, 6771.

Trakhtengerts V. Y. and Rycroft M. J., 2000. Whistler-electron interactions in the magnetosphere: new results and novel approaches, *J. Atmos. Solar Terr. Physics,* 62, 1719.

Vomvoridis, J. L. and Denavit, J., 1980. Nonlinear evolution of monochromatic whistler wave packet in a non-uniform magnetic field, *Phys. Fluids,* 23, 174.

Vomvoridis, J. L., Crystal, J. L and Denavit, J., 1982. Theory of computer simulations of magnetospheric triggered VLF emissions, *J. Geophy. Res.,* 87, 1473.

Yoshida T., Ohtsu J. and Hayakawa M., 1983. A study of the mechanism of whistler-triggered VLF emissions, *J. Geophy. Res.,* 53, 69.

****