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OBSERVATION OF PERIODIC VLF EMISSIONS AND WHISTLER-TRIGGERED PERIODIC VLF EMISSIONS AT LOW LATITUDE GROUND STATION JAMMU (L=1.17) AND THEIR INTERPRETATIONS

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ABSTRACT

New experimental data on periodic VLF emissions and whistler - triggered periodic VLF emissions during a quiet period at low latitude ground station Jammu (geomag. lat $22^{0}26^{/}$N; L=1.17) is presented in this paper. The present finding is believed to be first such events reported from any of the low latitude ground stations during quiet times. The whistlers recorded during quiet times are one-hop, or short type and the travel times of short whistlers at 4kHz are found to be in the range of 0.15-0.26 sec. corresponding to dispersion in the range of 10-17 $sec^{½}$.The short whistlers were observed continuously for a long period during quiet days in the frequency range normally between 2-5 kHz and are found to be triggered by periodic VLF emissions. From the detailed spectrum analysis of the whistler-triggered periodic emissions observed at Jammu, it is found that the time intervals between the consecutive periodic emissions are almost same with the time delays between any of the two successive hops of multiflash whistlers. The interesting point is that the Time period between any of the periodic VLF emissions and one-hop whistler traces is almost half of the time delay of a one –hop whistler of dispersion $12s^{1/2}$ as explained in this paper.

KEYWORDS: Whistlers, VLF Emissions, Dispersion, periodic VLF emissions.

1. INTRODUCTION

VLF ionospheric noises of natural origin known as 'whistlers' and 'VLF emissions' occur at frequencies between 30 and 30,000 Hz. These electromagnetic disturbances are readily observed at middle and high latitudes with the aid of an audio amplifier connected to an antenna and their occurrence rate is high. Whereas, at low latitudes, the occurrence rat of these electromagnetic disturbances is low and sporadic but once it occurs its occurrence rate becomes comparable to that at mid and high latitudes. Whistlers originate in lightning discharge and their characteristic are relatively well understood (Helliwell, 1965). VLF emissions on the other hand, appear to originate within the ionosphere and magnetosphere and although many types are recognized (Helliwell, 1965), no satisfactory theory of their origin has yet been advanced. In fact several types of VLF emissions are often observed in close association with whistlers. Among the many remarkable types of VLF emissions is one that consists of short bursts of noise repeated at regular intervals, the intervals being of the order of the few seconds. They are found as a sequence of discrete events or clusters of discrete events. These events are called as 'periodic VLF emissions' which have been reported by number of investigators (Helliwell, 1965; Sazhin and Hayakawa, 1994). Periodic emissions are VLF emissions with regular periods below 10 sec. Usually the time seperation between the noise bursts remains constant, but may on occasion change slowly. The period usually falls in the range from 2 to 6 seconds. Periodic VLF emissions are classified as either dispersive or nondispersive. In the dispersive type, the period between burst varies systematically with frequency. Since this variation is often exactly the same as that found in associated echoing whistlers, it is deduced that each burst is the result of whistler-mode echoing of the previous burst (Helliwell, 1965; Sazhin and Hayakawa, 1994 and references there in). In nondispersive periodic emissions, there is little or no observable systematic change in the period with frequency.

Periodic VLF emissions were first reported by Dinger (1957) who linked the sound of these emissions to squeaky weagon wheels. A similar event was reported by Gallet (1959) and Pope and Campbell (1990). These events were observed near college of Alaska (USA) with the period of 0.3 seconds which were named as 'surf' (Pope and Campbell, 1960). The first observation of periodic emissions at conjugate stations Byrd-Hudson Bay (Canada) was reported by Lokken et al., (1961). The spectrograms of these emissions showed that the emissions appeared alternately at the two stations with a time delay of about 0.8 s. Sometimes the observed periodic emission showed a period which was obviously less than the two-hop whistler transit time; in most cases it was a third of this (Helliwell, 1965). However, a careful inspection of the spectrum of these emissions revealed that each third burst appeared to be stronger than the others. This led to the suggestion that stronger emissions constituted one set of periodic emissions so that the true or 'fundamental' period was three times the 'apparent' period (Helliwell, 1965). These emissions were called multiphase periodic emissions; among these emissions three-phase emissions appeared to the most typical and two-phase extremely rare (Brice, 1965). These emissions could be easily understood as a superposition of several periodic emissions. Another model was suggested by Dowden (1971) who related an 'apparent' period of multiphase emissions to the oscillation period of the 'intersection region' as defined by Helliwell (1967). Sometimes the frequency of periodic emissions changed with time and they were called 'periodic emissions with frequency drift' (Helliwell, 1965). The periodic emissions were observed only in the regions of closed magnetic field lines. The period was typically in the range 1-7s, but most frequently in the range 2-6s, the changes in period during observed events did not exceed 1% (Helliwell, 1968).

Recent studies have shown that some types of periodic emission may have periods below 10 s, which are not related to the two - hop whistler transit time. These types of periodic emissions were classified as 'hisslers' and 'pulsing hiss' (Ungstrup and Carpenter, 1974; Sato, 1980; Sazhin and Hayakawa, 1994). These emissions often show a quasiperiodic structure with the same periods as periodic emissions, but which seem to have a different physical nature (Sazhin and Hayakawa, 1994). These types of periodic emissions are observed most frequently with a repetition periods of 0.5-10s on the ground and onboard satellites (Sazhin and Hayakawa, 1994 and references there in).

In order to explain the periodic nature of the periodic VLF emissions observed at high latitudes, two models have been proposed which could explain their periodic nature (Sazhin and Hayakawa, 1994). In the first model the emission period was related to the bounce period of the charged particles bouncing between conjugate hemispheres. In the second model, the emission period was related to the two-hop whistler-transit time (Dowden and Helliwell, 1962). In all attempts to explain both types of periodic VLF emissions, the authors assume a prior existence of a small bunch of charged particles that oscillates between mirror points in the Earth's magnetic field. It is then assumed that the bunch radiates a noise burst each time it passes through a favourable region of the ionospheric plasma, so that the emission period is the same as that of the mirror period of the bunch, known as the 'particle-bunch theory' of nondisperisive periodic emissions. From the new experimental evidence linking whistlers to both types of periodic emissions, Helliwell and Brice (1964), have concluded that most, if not all, periodic emissions are generated through triggering by emissions echoing in the whistler-mode and not by mirroring bunches of the particles. Further Helliwell (1963) has also shown that the generation of periodic VLF emissions observed at high latitude is controlled by an echoing whistler-mode waves, rather than mirroring particle bunches.

Unlike mid and high latitude periodic VLF emissions, low latitude periodic emissions have not been used for the exploration of ionosphere/magnetosphere. The reason being the fact that periodic emissions have never been observed at any of the low latitude ground stations. To our knowledge, no reports have so far been published on the morphological properties of these emissions observed at low latitude. This is for the first time that we have succeeded in recording periodic VLF emissions during nighttime at our low latitude ground station Jammu.

The purpose of this paper is to present a new experimental findings of the periodic VLF emissions observed at Jammu with their possible generation mechanism. The basic mechanism leading to the generation of periodic emissions observed at middle and high latitudes seem to be well understood, but at low latitude, the mechanism leading to the generation of periodic emission is not clear due to the lack of data. An understanding of the generation mechanism of periodic VLF emissions observed at Jammu on June 5, 1997 could be the most useful for inferring the properties of wave-particle and wave-wave interactions in plasma at low latitudes. An attempt has been made to explain the generation mechanism and spectral forms of period VLF emissions observed at Jammu on June 5, 1997 during nighttime.

2. Data Selection and Analysis

Using standard whistler recording equipment consisting of a T-type, transistorized pre- and main amplifiers, and a magnetic tape recorder, we conducted routine observations of whistlers and VLF emissions at our low latitude ground station Jammu (geomag.lat., 22° 26/N; 1.17) between November, 1996 to December, 1997. The observations were taken at night (2000-0600 hrs LT) continuously. The accumulated data on magnetic tapes were analyzed at Physics Department of Banaras Hindu University, Varanasi. The results of the analysis showed a number of whistlers and VLF emissions recorded at Jammu.

Among the data we found some excellent records of periodic VLF emissions observed on June 5, 1997 for the first time at our field station Jammu. The frequency time spectrograms of these periodic VLF emissions are shown in Fig.1 which are photographed from the monitor of the sonograph computer due to non-availability of the printer of the sonograph. The data and time of the observation of periodic emissions are mentioned on the top of the figures. A careful analysis of the spectrum of these emissions reveals unique properties in contrast to those of periodic emissions observed at high latitudes. After the close inspection of all sonograms of VLF emissions, we could find out 39 events, which are definitely identified as periodic VLF emissions triggered by whistlers. On June 5, 1997 at our field station Jammu, the spurt in periodic emission activity started around 2140 IST (Indian Standard Time) and lasted for about one hour ending finally at 2245 IST. The period of observation was magnetically quiet with (Kp = 6) (average Kp ~1) but was preceded by magnetic disturbance on the preceding five days during which the Kp index reached at maximum value of 6.The periodic emission on this day are of nondispersive type having different spectral forms (falling tones, inverted hooks and complex combination of rising and falling tones) as illustrated in Fig.1. The measured period' of these periodic emissions lies typically in the range of 0. 1-0.7s, which is smaller in comparison to that reported from higher latitudes.

During a survey of periodic emission activity at Jammu on June 5, 1997, events of periodic emissions triggered by one-hop whistler were detected during this period. This type of event out of the best records is illustrated in Fig.2 in which the observed emission was triggered by one-hop multiflash whistler. The one-hop multiflash whistlers are clearly detected up to about 12 in numbers on the Jammu record. After the first one-hop, an emission appears at the lower end of whistler spectrum, mostly in the frequency range 1.7 to 2.5 kHz and to a lesser extent in the range 2 to 3.3 kHz. The diurnal variation of the occurrence of nighttime periodic emission observed at Jammu on 5 June, 1997 is shown in Fig.3. It is evident from Fig.3 that no any significant pattern emerges in the daily occurrence of the periodic emissions observed at Jammu. We cannot derive any conclusion about the diurnal variation of the occurrence of periodic emissions at low latitudes from our limited observations The observations of periodic emissions presented in this chapter of the thesis is of limited hours of a single night of June 5, 1997 only. We therefore can't derive any conclusion in general out of this limited data about the diurnal variation of occurrence of periodic emissions at low latitudes. In order to come to a firm conclusion a larger data base is required which will be acquired in the future study. Notwithstanding this limitation the present study of periodic emissions observed for the first time at any of the low latitude ground station is worthwhile and an excellent study.

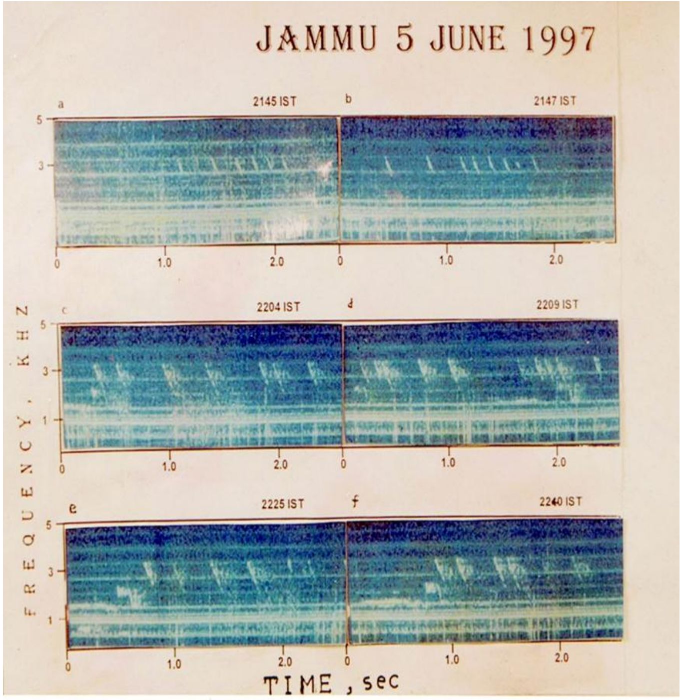

Fig 1: Frequency-time spectrograms of periodic VLF emissions recorded at jammu.

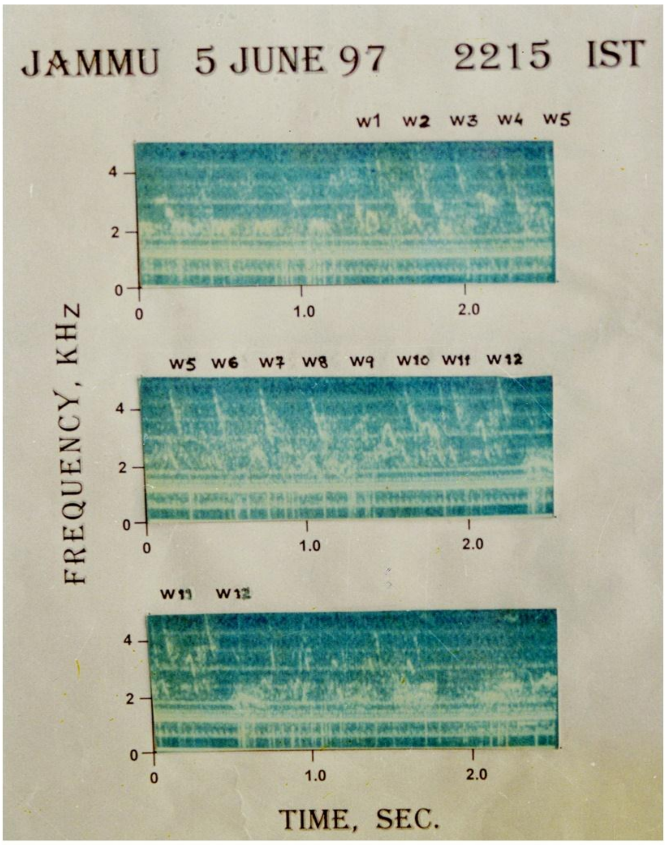

Fig 2: Frequency-time spectrograms of whistler triggered periodic emissions recorded at jammu.

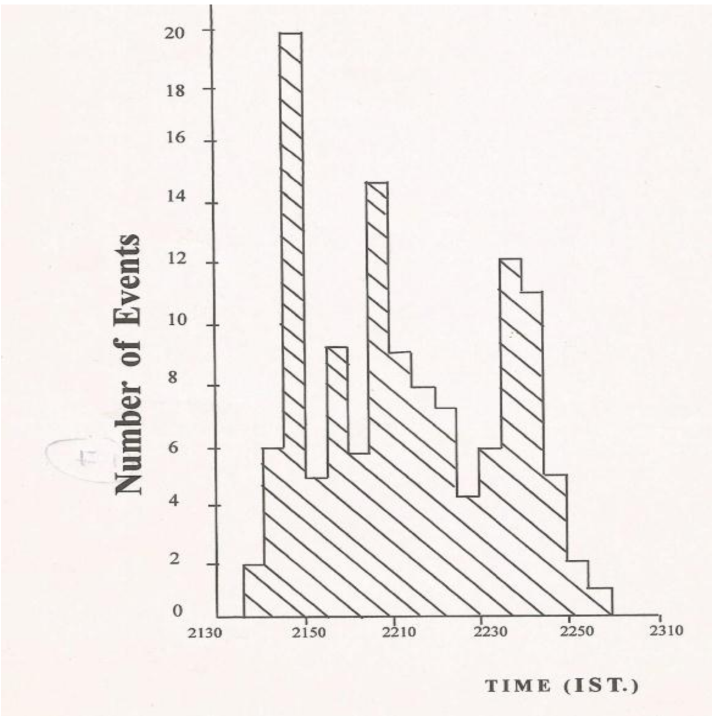

Fig. 3: The diurnal variation of periodic VLF emissions recorded at jammu on june 5 1997.

3. Theoretical Interpretation

The periodic VLF emissions observed at Jammu on June 5, 1997, differ markedly in frequency and rate of change of frequency with time (df/dt) from those of periodic emissions observed at mid and high latitudes. The possibility that these emissions are high latitude periodic VLF emissions which have propagated to our low latitude ground station Jammu in the Earth-ionosphere waveguide of propagation is ruled out because the time period of the observed periodic VLF emissions at Jammu is very small of the order of o.2 s. This gives an evidence of low latitude origin of the periodic emissions observed at Jammu only. Further, the possibility that these emissions are generated at high L-values in the vicinity of the plasma pause and propagated to our ground station after successive magnetospheric reflections in a manner similar to those of extremely low frequency (ELF) hiss observed by satellites in the inner zone does not seem to be tenable (Muzzio and Angerami, 1972; Tsurutani et al., 1975). This is because, at the frequency of these emissions, the attenuation losses during various magnetospheric reflections would be high and waves could not be detected on the ground. Although the exact losses have not been calculated, a rough estimate can be made from the work of Kimura (1966). He has shown from ray tracing computations in a model ionosphere that amount of attenuation suffered by the waves of frequency 1 kHz from 300 km at 30° N reaching L= 3 after 12 successive reflections is about 6 dB. If we include 4dB losses suffered in the lower region of the ionosphere, then the total loss will be about 10dB. To reach the plasma pause near L = 4, the waves have to undergo some more reflections and consequently suffer more attenuation than 10dB. As the attenuation increases with frequency, the waves of periodic emissions generated near the plasma pause would suffer much higher attenuation than 10 dB and may not be observed on the ground. Further, at the base of the F-region ionosphere, the wave normal angles of these waves are such that the downward waves are unlikely to penetrate the lower ionosphere and reach the ground.

Thus, we believe that these emissions are generated in the equatorial plane at the top of the field line corresponding to Gulmarg in the inner zone radiation belt (L~1.2). Cyclotron resonance between whistler mode waves and the inner zone radiation belt electrons seems to be the possible generation mechanism of periodic VLF emissions recorded at Jammu on June 5, 1997 for two reasons :(1) This mechanism has been found to account for the frequency time spectra of periodic VLF emissions observed at mid and high latitude adequately (Rycroft, 1972), (2) It also occurs in the inner radiation belt (Imhof et al., 1973).

4. RESULTS AND DISCUSSION

The measured period of nondispersive periodic emissions triggered by whistlers recorded at Jammu is found to lie in the range of 0.21-0.26 s and this clearly shows that these are generated at only low latitude. The very small value of time period of the observed periodic emissions provides us an important information about the path latitude of whistler-triggered periodic emissions without the use of a direction finding. Since the measured dispersion of the whistlers - triggered periodic emissions are very small of the order of 12 s1/2,it may be inferred that multiflash one-hop whistlers shown in Fig.2 are low latitude whistlers. Using the empirical relation between the dispersion of whistlers (D) and their path latitude propagation given by Allcock (1960) as D = 2.2 (Ø-12), the path latitude of whistler-triggered periodic emissions are found to be~18°. The estimated value of generation of whistler-triggered periodic emissions observed at Jammu is apparently around L =1.1. This L-value are known to fall in the region of inner radiation belt (L = 1.2). It is very acceptable to presume that the associated periodic VLF emission has nearly the same wave normal angle as the causative whistler because both are considered to propagate along the same field line (Hayakawa, 1991).

At the first glance, the whistler recorded at Jammu appear to be first, third, fifth etc., hops of multipath whistlers generated from the successive strokes of a lightning discharge. However, the measured dispersions of these whistlers remains constant and hence this possibility is ruled out. The whistlers shown in Fig.2 are one-hop multiflash whistlers caused by different returning strokes of a lightning discharge.

From detailed spectrum analysis of the whistler-triggered periodic emission observed at Jammu, it is found that the time intervals between the consecutive periodic emissions are almost same with the time delays between any of the two successive hops of multiflash whistlers. The interesting point in Fig.2 is that the time period between any of the periodic VLF emissions and one-hop whistler traces is almost half of the time delay of one-hop whistler of dispersion ~12 $sec^{1/2}$ as shown in Table 1. We interpret this unusual relationship between the time intervals of these periodic VLF emissions and one-hop whistlers as follows: We assume that the consecutive periodic VLF emissions of these events were generated as a result of interactions between the trapped energetic particles and the various hops of multiflash whistlers near the equatorial region under cyclotron resonance mechanism and propagated to our field station in non-ducted mode of whistler propagation. Under this assumption, we measure the time intervals between the consecutive periodic emissions at the frequency of 3kHz and then match them with delays at 3 kHz between various hops of whistlers. We find that the observed time intervals of periodic emissions match closely with those of different hops of observed whistler dispersion of ~12 $sec^{1/2}$ and the time period between any of the two successive periodic emissions and one-hop whistlers of the event are almost half of the time delay of a one-hop whistler of dispersions ~12 $sec^{1/2}$ within about 12 % of the measurement error. This shows that time taken by both of the one-hop whistler and periodic VLF emissions is same to reach our receiving ground Jammu from the equatorial region. The detailed results are presented in the Table 1.

Table 1: A comparison of time period between different periodic VLF Emissions and time delays between different multiflash whistlers of dispersion~ 12 s1/2.

Periodic Emissions	Whistlers				
Traces	Time Period	One-hop	Time Delay at 3kHz Hz kHz Hz dDDD DDDDDDd DDDelay Dddelay	Time period Between Periodic Emissions	
	(At 3 kHz)	Traces		And one hop Whistlers (At 3 kHz).	
1- 2	0.23 s	1-2	0.22 s	1 - 1	0.12 s.
2- 3	0.23 s	2-3	0.22 s	2- 2	0.11 s.
3- 4	0.26 s	3-4	0.25 s	3- 3	0.12 s
4- 5	0.24 s	4-5	0.23 s	4- 4	0.11 s.
5- 6	0.26 s	5-6	0.25 s	5- 5	0.12 s.
6- 7	0.26 s	6-7	0.25 s	6- 6	0.12 s.
7- 8	0.26 s	7-8	0.26 s	7- 7	0.13 s.
8- 9	0.26 s	8-9	0.25 s	8- 8	0.12 s.
9 -10	0.24 s	9-10	0.23 s	9- 9	0.11 s.
10-11	024 s	10-11	0.23 s	10-10	0.11 s.
11-12	0.26 s	11-12	0.23 s	11- 11	0.11 s.

Our results summarised in Table 1 clearly depict that the periodic VLF emissions observed at Jammu on June 5, 1997 shown in Fig.1 are generated near the equatorial region at L~1.2 as a result of interaction between trapped energetic particles and one-hop whistlers under cyclotron resonance mechanism and propagated to our ground station Jammu in non-ducted mode of whistler propagation. This provides a possible explanation of the chorus and the generation mechanism of the observed periodic VLF emissions and whistler-triggered periodic VLF emissions at Jammu (shown in Fig.1 and Fig.2).

5. CONCLUSIONS

From the detailed study of the periodic VLF emissions recorded at our low latitude ground station Jammu we conclude as:

1. The periodic emissions are observed in the frequency range of 1.7 to 2.5 kHz. The measured period of the periodic VLF emissions recorded at Jammu lies typically in the range of 0.1 to 0.7 seconds.
2. The periodic emissions observed during night time are only nondispersive type having different spectral forms (falling tones, inverted hooks, and complex combination of rising and falling tones).
3. The periodic emissions have been observed during quiet days with total Kp index 6 only around midnight at Jammu.

4. It is shown that periodic VLF emissions recorded at Jammu are generated near the equatorial region at L~1.2 as a result of interaction between trapped energetic particles and one-hop whistlers under cyclotron resonance mechanism and propagated to the field line of Jammu in the non-ducted mode of whistler propagation.
5. No firm conclusion can be drawn about the diurnal variation of the occurrence of periodic emissions at low latitudes from the limited observation of Jammu.

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