A new whistler recorder and analyzer developed at Agra*

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A new experimental set-up for recording and analysis of whistlers and VLF emissions has been developed at Agra, which is less expensive, automatic and time saving in comparison to earlier experimental set-up being used in different whistler stations in India. The new experimental set-up employs a crossed loop antenna, amplifiers, low pass filter, a sound card and PC with a software specially designed for recording and analysis of VLF data. Some examples of whistlers and VLF emissions recorded by the new set-up are presented and their frequency-time characteristics are discussed thoroughly.

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1 Introduction

Whistler studies have been started in India since 1963 and whistlers recorded for the first time at Gulmarg and Nainital ground stations were reported by Somayajulu et al. Since then, whistler studies have been carried out at four other low latitude ground stations also, namely, Jammu (geomagn. lat. 24°N), Agra (geomagn. lat. 17°N), Varanasi (geomagn. lat. 15.6°N) and Bhopal (geomagn. lat. 13°47'N). Identical experimental set-up has been used at all these stations which employs a T-type antenna, pre-and main amplifiers, and magnetic tape recorder. Although, the work done at these stations has produced very useful results on low latitude whistlers and emissions\textsuperscript{2,4}, there have been a lot of problems using this set-up. For example, the T-type antenna which was found to be quite useful for whistler recording at hill stations like Gulmarg and Nainital, where it has produced bulk of whistler data consisting of variety of whistlers and VLF emissions\textsuperscript{5}, it has not been successful in plane areas where other stations are located\textsuperscript{6}. One possible reason for this is that it records only $E_z$ component of whistler waves, which is heavily masked by local and atmospheric noises. The whistler observations are carried out during nighttime and the system requires manual presence throughout the night. Further, the recorded data are analyzed at sonograph machine, which is available either at Banaras Hindu University, Varanasi, or Central Electronics Engineering Research Institute, New Delhi, in north India. Hence, recording and analysis of whistlers, using the existing experimental set-up, is time-consuming and expensive.

A real time whistler analyzer was developed by Tsuzuku et al.\textsuperscript{7}, which consists of a filter bank, a whistler detector, an A/D converter with an 8-line to 1-line data multiplexer, a static memory and a microprocessor. The filter bank is composed of a wide-band filter, nine bandpass filters, nine envelope detectors and eight differential amplifiers. Further, whistler is simulated from these eight output signals by pseudo whistler generator and this whistler is transferred to microcomputer in which dispersion is determined based on template matching method. Using this improved whistler analyzer system, the whistler data obtained at Moshiri ground station (Japan) were analyzed and many important characteristics including the properties of whistler ducts at middle and low latitudes were studied.

The difficulties due to antenna system were overcome by Singh et al.\textsuperscript{8,9} partially, who introduced a crossed loop antenna in conjunction with a vertical antenna. The crossed loop antenna measures the horizontal magnetic fields of the incident signals,
which are less affected by the local noises. The vertical antenna was used to measure the \( E_z \) component which, in conjunction with the magnetic field components \( B_x, B_y \), produced information on the direction of arrival of the whistler signal. Similar systems have been used in the past for finding the direction of whistlers \(^{10,12}\).

In this paper, are presented the details of a modified whistler recorder and analyzer, which is based on state-of-the-art technology and digital signal processing (DSP). The new system makes the recording and analysis of whistlers simpler in comparison to traditional whistler recorder in terms of time consumption, manpower requirement, cost of analysis and the recordings involved.

2 Experimental set-up

The new experimental set-up developed at Agra is shown in Fig. 1. The system consists of a crossed loop antenna, pre-amplifier, 10 kHz low pass filter, main amplifier, sound card and a PC (with sound recording software). The signal induced in the antenna is fed to a transistorized pre-amplifier. The gain of the amplifier is 100 (40 dB) with flat frequency response in the audible range. The pre-amplifier has been placed at the base of the antenna to avoid the masking of whistler signal by extraneous noise picked up by the coaxial cable before it is fed to the main amplifier placed in the laboratory. The amplified signal is passed through low pass filter, which has a cut-off frequency at 10 kHz. The filtered signal is further amplified to a voltage level acceptable to the sound card.

Instead of using data acquisition card, a sound card is used for analog to digital conversion, which is relatively very cheap. The sound card is very convenient, because the inputs are limited to a maximum of two channels corresponding to north-south and east-west antennas. The sampling rate used for the present study is 20 kHz, which is sufficient, because the highest frequency of whistlers being recorded is 10 kHz. This meets the Nyquist criterion in which the signal should be sampled at double of the highest signal frequency. A freeware (Jet Audio) software is used to transfer the acquired data from sound card buffer to hard disk.

3 Data analysis

The digital data stored on the computer disk is analyzed offline using DSP technique available in MATLAB software. The analysis is divided into two parts: (i) Pre-event data analysis and (ii) Post-event data analysis. The pre-event data analysis consists of filtering of 50 Hz noise, calculation of FFT, and making a movie of the whole data set. The events of whistlers and VLF emissions are identified from the movie. Then, to make the lower portion of the frequency spectrum clear, 50 Hz and its harmonics are removed by a digital 6-point IIR filter. Thereafter, a 250-point FFT is calculated for each 6-sec data and plotted against time. Each of this kind of spectrum is saved as a frame of movie. Finally, at the end of data set all the frames are saved as AVI movie file, which can be played and examined at the desired rate of frames per second. Unlike the earlier system in which one had to listen the sound in real time to identify the
whistler, the present system can process the data offline at any time of convenience. Once the event is discovered in the movie, post-event data analysis can be applied for that particular frame. The post-event data analysis is done to sharpen the features of discovered events. The background noise is controlled by increasing the frequency resolution by increasing FFT points, and shrinking the window from 6 sec to the duration of event.

4 Results and discussion

The whistler data for a limited test period of four months between 01 Feb. and 30 May 2004 have been recorded and analyzed in this paper. During this period, some unusual cases of whistlers and VLF emissions have been found, majority of which occurred in the month of February 2004. In Figs 2-4 some examples of recorded whistlers and VLF

Fig. 2—High dispersion whistlers recorded at low latitude station Agra at (a) 08:51:07 hrs LT and (b) 09:11:58 hrs LT on 7 Feb. 2004

Fig. 3—Multicomponent whistlers having high dispersion in the range 206-376 sec recorded at Agra station

Fig. 4—Periodic emissions recorded at Agra station on 6 Feb. 2004 (a) at 12:44:23 hrs LT and (b) at 10:47:39 hrs LT
emissions are presented. Figure 2[(a) and (b)] shows the successive occurrences of whistlers with upper and lower cut-off frequencies around 6 kHz and 1 kHz, respectively. The dispersion of whistlers shown in Fig. 2(a) is about 70 sec\(^{1/2}\) and time delay between two successive whistlers is about 0.65 sec. These characteristics indicate that the whistlers originated from high latitudes and propagated to the present station through earth-ionosphere waveguide. The latitude of origin of these whistlers calculated from the formula\(^1D = 1.22(\Phi - 0.72)\) is found to be 58°.

The dispersion of whistlers shown in Fig. 2(b) is 40 sec\(^{1/2}\) and time delay between two successive whistlers is 0.32 sec. The origin of these whistlers is 33.5°. Multicomponent whistlers with high dispersion in the range of 206-376 sec\(^{1/2}\) are shown in Fig. 3. These whistlers are originated either from a single source or from different sources at high latitudes and travelled along different geomagnetic field lines. Such high dispersion of these whistlers suggests that they are 2/3-hop whistlers\(^14\). Some unusual type of periodic emissions are shown in Fig. 4[(a) and (b)]. These emissions are of rising type and are believed to be generated at high L-values. The frequency-time spectrograms of these emissions are found to match with periodic emissions shown by Helliwell\(^1\).

The high dispersion whistlers shown in Fig. 2[(a) and (b)] indicate a temporal fine structure of the type reported by Singh et al\(^9\). However, in the present case the causative lightning strokes are not visible. Hence, there is a possibility that they may be either multiflash whistlers, which are produced by successive lightning strokes occurring at approximately regular interval of 0.65 sec and propagated along the same path, or, multipath whistlers, which are produced by the same lightning stroke but propagated along slightly different paths. The VLF emissions shown in Fig. 4[(a) and (b)] are believed to be generated in the equatorial region at high L-values and propagated from high latitudes to the present station (Agra) through earth-ionosphere waveguide mode of propagation. A model for generation mechanism of periodic emissions has been given by Helliwell and Crystal\(^15\), in which it has been suggested that non-linear wave particle interactions between finite amplitude wave trains and energetic particles produce phase bunching of the electrons and their transverse components act like an antenna which produce these emissions. However, the special nature of these emissions and their generation and propagation mechanisms are still not very clear\(^16\) and a detailed study of these emissions is in progress.

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References

1 Somayajulu V V, Srivastawa K M L & Tantry B A P, Whistler recordings at a low geomagnetic latitude station in India, Indian J Pure & Appl Phys, 3 (1965) 405.
9 Singh B, Singh R R & Singh R V, Transmission characteristics of some unusual whistlers and VLF emissions as determined from their polarization measurements at Agra, J Atmos Electr (Japan), 18 (1998) 11.
13 Hayakawa M & Tanaka Y, On the propagation of low latitude whistlers: Rev Geophys Space Phys (USA), 16 (1978) 111.
15 Helliwell R A & Crystal T L, A feedback model cyclotron interaction between whistler mode waves and energetic electrons in the magnetosphere, J Geophys Res (USA), 78 (1973) 7357.