AVDAS – A MICROPROCESSOR-BASED VLF SIGNAL ACQUISITION, PROCESSING AND SPECTRAL ANALYSIS FACILITY FOR ANTARCTICA

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ABSTRACT. A microcomputer-based system is described for the spectral analysis of VLF (0.5–20 kHz) radio waves received at Halley, Antarctica. The data are used for studying magnetospheric and ionospheric phenomena including whistler-mode propagation, wave-particle interactions, plasma distribution and drifts, and charged particle precipitation into the ionosphere. The system was installed in 1983 and enables the Antarctic field scientist to monitor and analyse the spectral characteristics of incoming signals in real time. The broadband signals are digitized and processed in ways which can be flexibly determined by the system software. Subsets of the data may be saved on floppy disc or transferred to the UK via a satellite data link; the link can also be used in reverse to send updated processing and analysis software to Halley. Apart from the microcomputer and standard peripherals (VDU, printer, disc drives, serial and parallel interfaces, analogue–digital converters), the hardware consists of a specially designed spectrum analyser and spectrographic display unit. Extensive software has been developed. In this paper a technical description is accompanied by representative examples of data acquired and processed by the AVDAS.

INTRODUCTION

The recording and analysis of natural Very Low Frequency and Extremely Low Frequency (VLF and ELF; typically 0.5–20 kHz) radio wave phenomena at ground observatories have played an important role in the study of several aspects of magnetospheric and ionospheric physics. Particularly in studies of plasmapause structure, plasma convection, and wave-particle interactions, such ground data have proved complementary to *in situ* measurements made by spacecraft-borne sensors. The analysis of whistlers received on the ground (see Park, 1982) has proved a powerful tool in pursuing these investigations. The literature is extensive; the monograph by Helliwell (1965) provides a comprehensive bibliography up to that date. More recent reviews are by Corcuff (1975), Park and Carpenter (1978), Carpenter (1983), and Park and others (1983).

A VLF goniometer receiver (Bullough and Sagredo, 1973) has been operated at Halley since 1967, as a joint experiment of the British Antarctic Survey and the University of Sheffield. Papers by Matthews and Yearby (1981), Smith and others (1981), Smith and others (1984), Smith and others (1985), and Hurren and others (1986) describe some of the recent research which used data from this experiment. In 1985 a similar receiver was deployed at Faraday.

In 1982 a new computer-based receiving and analysis system was designed and built at Sheffield University, and was deployed at Halley in early 1983 to augment the existing goniometer equipment. This system was called AVDAS (Advanced VLF Data Analysis System) and its aims were:

(i) To provide a real-time spectral analysis and display of incoming VLF signals,

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thus enabling the field scientist to recognize and log the VLF phenomena being observed.

(ii) To provide an on-site interactive analysis capability for use with previously recorded data.

(iii) To provide a real-time analogue–digital conversion and digital recording capability, both to overcome certain limitations of analogue recording, and to permit the rapid return of sample data to the UK via a geostationary satellite data link (see Jones, 1984).

(iv) To provide flexible programmable control over the VLF receivers and analogue recorders.

(v) To provide a general purpose microcomputing capability, including word-processing, for the Antarctic field scientist.

The purpose of this paper is to describe the AVDAS from a technical point of view and to describe some results. First we will give some background to the need for and the philosophy behind the AVDAS concept.

ANALOGUE VERSUS DIGITAL RECORDING FOR VLF GROUND OBSERVATIONS

Traditionally VLF data have been recorded in analogue form on magnetic tape and in general have been spectrum analysed, also by essentially analogue methods; the spectrogram, i.e. the frequency-time-amplitude plot, is a very commonly used way of presenting VLF data. The reasons for using analogue rather than digital data handling are partly historical, in that ground observations of whistlers became common at the time of the International Geophysical Year (1957–59) when digital processing for geophysical data was in its infancy and the analogue technology necessary for audio frequency recording and analysis was comparatively cheap, simple, and widely available. (This is still true to some extent today, but probably not for much longer.) The systems and expertise of experimental VLF and whistler researchers today have evolved from these early methods.

The information about magnetospheric plasma structures, for example, which may be inferred from whistler analysis is extracted by detailed analysis of the fine structure of the whistlers and requires high frequency and time resolutions; this implies the necessity for wide bandwidth (typically 20 kHz) recording. Digital recording of the complete signal bandwidth requires a high data rate (of the order of 400 k-bits/s) and, with the present state of the art, the data can be recorded more compactly, conveniently and cheaply on analogue magnetic recording tape than on the digital equivalent, unless some pre-processing is done.

It is interesting to compare this situation with that for other geophysical sensors such as magnetometers or riometers which are frequently deployed alongside VLF receivers at observatories such as Halley. In general these have now been converted from analogue to digital recording but they have much lower bit rates (than VLF recording), either because the frequency is intrinsically lower ($\gtrsim 3$ Hz for magnetometers, ULF sensors) or because at higher frequencies (~ 30 MHz) it is the modulation envelope that is recorded (e.g. riometers). Even the Advanced Ionospheric Sounder (Dudeney and others, 1983) at Halley is normally operated with a schedule of ionospheric soundings for which the average data acquisition rate is only of order 2 k-bits/s (perhaps increasing by an order of magnitude during occasional intensive recording campaigns).

For spacecraft-borne observatories, although most data are returned to earth in digital form, plasma wave experiments are sometimes an exception for which it is desirable to use wideband analogue data telemetry, e.g. the plasma wave experiment on Dynamics Explorer 1 (Shawhan and others, 1981). Where data telemetry is digital, e.g. on GEOS (Jones, 1978) or AMPTE-UKS (Darbyshire and others, 1985), on-board processing techniques such as correlation or swept frequency analysis are used to increase the effective bandwidth, but this may be at the expense of time resolution.

At Halley the strategy has been to retain the analogue broadband recording as the primary means of data collection but to use the AVDAS for real time or near real time analysis and the saving of some periods of data in digital form. The requirement for the latter capability was largely motivated by the establishment of a link for the direct transfer of data from Halley to the UK via geostationary communications satellite (Jones, 1984), thereby short-circuiting the 6–18 month delay usual for Antarctic data returned by ship. The digital recording was designed to have a low average bit rate by (*a*) saving only relatively few short events at the full bit rate and (*b*) sampling a filter bank continuously but at a very low sampling rate. Data compression and thresholding techniques were developed to enable all but the scientifically most significant data to be discarded. A real time spectrographic display was provided to alert the field scientist to the types of whistlers or VLF phenomena being received, thus facilitating the optimization of the recording schedules to meet the current scientific objectives.

TECHNICAL DESCRIPTION OF THE AVDAS

Overview

The system is built around a Windrush 6809 microcomputer with 168 k-bytes of RAM memory, two double-sided double-density 8-inch disc drives, and the usual peripherals (VDU terminal, printer). It runs under the FLEX operating system. Parallel input/output ports connect the computer to a spectrum analyser, a spectrographic display unit, a keyboard, a time code generator/reader, analogue–digital converters, and switches for controlling the analogue hardware (receivers, tape recorders). Serial interfaces connect to a remote terminal and other computers. Fig. 1 shows a block diagram of the AVDAS. Fig. 2 is a photograph of the system installed at Halley in 1983.

Detailed description of the hardware

The computer. The computer is based on a 2 MHz 6809 microprocessor installed in an SS50 bus. In addition to the microprocessor, the processor board also contains a battery backed up real time clock and a dynamic address translator. The latter device allows the computer to address up to 1 M-byte of memory instead of the normal 64 k-bytes. The computer is at present fitted with 168 k-bytes of RAM memory.

The two 8-inch double sided, double density disc drives have a formatted capacity of 1 M-byte each. They are interfaced to the computer via a disc controller with an on board memory buffer. This buffer allows the disc drives to be used simultaneously with interrupt driven real time processes such as data sampling. The maximum data transfer rate when accessing the discs via the FLEX operating system is about 1 k-byte/s.

A total of 16 parallel ports (each with 8 data lines plus two control lines) are available. Six of these are buffered output ports, while the other ten are unbuffered and may be used as inputs or outputs. There are four serial ports. Two are used for the local and remote VDUs, one for the printer, and one for communication with other computers.

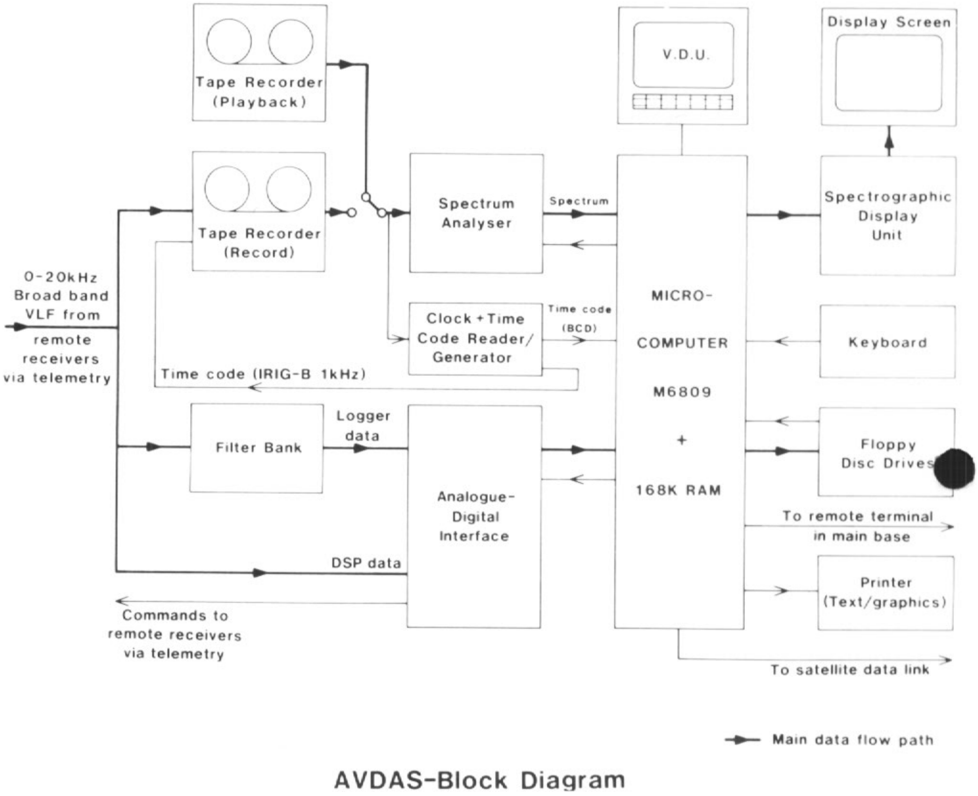

Fig. 1. Block diagram of the AVDAS.

The spectrum analyser. The spectrum analyser provides a real time spectrum analysis of an analogue input waveform up to 20 kHz in frequency. The analysis is done by an analogue implementation of the chirp Z-transform algorithm (Benjamin, 1979) using a quad-chirped transversal filter and evaluation board manufactured by the Reticon Corporation. This transform is mathematically equivalent to the discrete Fourier transform. The analogue output from this board is applied to an analogue to digital converter to provide a digital output. This approach results in a spectrum analyser of adequate performance at a cost very much less than that of commercially available digital fast Fourier transform analysers.

Frequency ranges of 1, 2, 5, 10 and 20 kHz can be analysed. The dynamic range of the analyser is about 40 dB. This is rather low compared to most digital spectrum analysers but adequate for VLF signals, provided the analogue input gain is set appropriately.

As supplied, the evaluation board does a 512-point transform on adjacent but non-overlapping segments of the input waveform. This is known as 'redundancy equals one mode' ($R = 1$). In VLF work, transforms on overlapping segments of the input waveform are often required. An overlap factor of two ($R = 2$) has been obtained by specially pre-processing the analogue input to the board. In addition the transform size is reduced to 256 when working in this mode. The net effect is that for a given frequency range the time resolution is four times better while the frequency resolution is halved.

Fig. 2. Photograph of the AVDAS, as installed at Halley in 1983.

An unusual consequence of the chirp Z-transform is that each point in the spectrum is based on a slightly different segment of the input waveform. For example, if the zero frequency point is based on samples n to $n+511$, then point i will be based on samples $n+i$ to $n+i+511$. This is not usually important but must be allowed for when the precise time at which a spectrum is calculated must be known, for example when determining arrival bearings from the amplitude modulation of a goniometer signal.

In addition to the actual spectrum analysis, the analyser can also process an azimuth reference signal which is normally recorded on the second track of the analogue VLF recordings. An 8-bit digital output is provided which gives an instantaneous read out of the goniometer rotation phase at any moment in time.

Most of the functions of the analyser can be controlled by the computer. These include input gain, linear or logarithmic output, frequency range and choice of $R = 1$ or $R = 2$ mode.

The spectrographic display. The spectrographic display unit was specially constructed for the AVDAS. The principal function of the unit is to display on a video monitor in real time the data from the spectrum analyser in spectrographic form, i.e. with the x and y axes corresponding to time t and frequency f respectively, and brightness corresponding to spectral amplitude A. A bright flicker-free 256 × 256 pixel picture is achieved with a 16-level grey scale. A cursor consisting of a single flashing pixel may be moved around the screen, while its current co-ordinates (t, f, A) are shown in the top margin. The display unit consists of a dedicated memory board, separate from the main computer memory, mapped to pixels on the screen to provide a standard 625-line interlaced scan video picture. In the normal mode of operation the screen represents 1.6 s of spectral data with a frequency range of 0–10 kHz or 0–20 kHz.

An essential attribute of the display unit is the speed at which it is possible to write data to it. When displaying the real time output from the spectrum analyser the pixel data rate can be as high as 80 kHz. The display unit must be able to accept the data at this rate if real time display is to be possible. It was principally this speed requirement that prohibited the use of any commercially available display hardware.

Another unusual feature of the display is horizontal scrolling. This is used to provide a moving picture of the VLF spectrum with the newest data being written to the righthand side of the screen and the oldest data scrolling off the left.

The keyboard. The keyboard provides convenient control of the display cursor during interactive analysis sessions, together with manual tape recorder control and special function keys.

Time code generator/reader. The time code generator/reader (Datum model 9300) writes to or reads from the analogue data tapes a standard IRIG-B 1 kHz time code. It also simultaneously provides a digital output which can be read by the computer. This enables the computer to read the time and date of recording during the replay of a previously recorded data tape, and also allows the computer's own real time clock to be accurately synchronized to the time code generator.

Analogue inputs. There are 16 analogue inputs, each of which enables a 0–5 V signal to be digitized to 8-bit accuracy. Currently 12 of the channels are used for routine continuous low-speed logging (12 samples per channel per hour) of the outputs from a VLF filterbank, thus providing a continuous synoptic recording in digital format of VLF activity at Halley. The remaining four channels are available for special purposes and have, for example, been used for high speed digitization (up to 48 kHz), for short periods, of the full bandwidth VLF signal. This permits the use of sophisticated digital processing techniques, which would be difficult with data subsequently digitized from the analogue tape records, because of tape speed fluctuations.

Software description

A comprehensive suite of software has been specially written for the AVDAS and may be categorized as follows: (i) spectrum analysis software to read the data from the spectrum analyser, to write it to the spectrographic display unit and to handle interactive analysis of the dynamic spectra of VLF signals appearing on the display; (ii) control software for driving the experimental hardware (receivers, tape recorders, calibration and 'housekeeping' equipment, etc.); (iii) data logging software for low speed synoptic logging; (iv) high-speed digital sampling and processing software; (v) graphics software for writing graphical data to the display screen or printer.

The software has been written mainly in a combination of Pascal and 6809 assembly language, and is being continually improved and developed. Recently the 'C' language has also been used. The advanced and customized capabilities of the AVDAS rely heavily on the sophisticated software; this is a great advantage in the Antarctic context since new software can easily be sent via the satellite data link whereas replacement of hardware may have to wait up to 12 months for the annual re-supply ship.

Spectrum analysis software. The spectrum analysis software consists of a large Pascal program and a set of assembly language device drivers. The program operates in two modes; 'real time' and 'scaling'.

In real time mode the output from the spectrum analyser is simultaneously written to the display and to a large array in the computer's memory. While this is happening the output from the time code reader is read and used to time mark the data in memory. The array is operated as a circular buffer with the oldest data being overwritten by the newest.

When required, the real time display may be stopped and the program switched to scaling mode. A cursor may then be moved around the spectrographic display while the frequency, time and amplitude of the cursor position is indicated at the top of the screen. This information may be input to one of several scaling procedures.

One important procedure is to determine the characteristics of whistlers. The 'three-point nose extrapolation method' of Ho and Bernard (1973) is normally used. This requires the operator to mark three points along the trace of the whistler in question. The program will calculate the nose frequency and nose travel time of the whistler and then, using the method of Park (1972), calculate the latitude and equatorial electron density of the whistler path.

Another procedure is used to calculate signal arrival bearings. This is based on the standard goniometer method (Bullough and Sagredo, 1973) which involves measuring the phase of the amplitude modulation of the signal produced by a loop aerial rotating at 25 Hz, the rotation being synthesized electronically. The first stage is to determine the frequency–time profile of the signal concerned (cf. Smith and others, 1979). In the AVDAS this may be done either by the operator marking a series of points which specify the profile as a number of straight line segments, or by using a standard whistler profile fitted to three points marked on the trace of a whistler. Once the profile is determined the modulation phase is estimated by fitting a sine wave to the amplitude-time variation of the signal using a harmonic least squares fit.

Procedures for saving a spectrogram to disc and making a hard-copy of the screen on a suitable printer are available.

Control and data logging software. Two small assembly language programs permanently resident in memory are used to control the VLF receivers and tape recorders and to record data from a VLF filter bank. Both programs run automatically and are usually transparent to normal use of the FLEX operating system. A real time clock-calendar integrated circuit is used to generate program interrupts once per second which activate the control program. The program compares the current time with entries in a look-up table to decide what action, if any, is required. Typical actions would be switching a tape recorder or the VLF receiver on or off.

One special action which occurs every five minutes is to activate the data logger program which runs under the multi-tasking facility of FLEX. The program reads 12 channels of data from the VLF filter bank and saves them to a disc file.

Digital sampling and processing software. Sometimes it is useful to have more information about the signals received (e.g. polarization) than can be obtai[illegible] from a simple spectrum analysis of goniometer signals. This can be obtained by simultaneous analysis of two or more separate components of the wave (such as H_x, H_y and E_z). The existing spectrum analyser can only process one channel, and so the alternative approach of using the analogue to digital converter to sample directly the wideband signals has been used. A maximum total sampling rate of 48 kHz can be attained which allows a 0–8 kHz range on three channels.

The data are initially recorded in a buffer in memory (up to 120 k-bytes in size, corresponding to 2.5 s of data) and then written to disc. The data are then processed off-line using fast Fourier transforms to calculate complex spectra which in turn can be used to obtain power spectra, cross spectra or 'spectra' representing quantities such as the direction of arrival or polarization of the signals

DEPLOYMENT AND USE

After the design, construction and testing phases at Sheffield University, the AVDAS was shipped to Antarctica in October 1982 and was installed at Halley some 400 m from the main base in a surface caboose, one of an array of huts housing the Advanced Ionospheric Sounder (Dudeney, 1981) and associated experiments and support facilities. This location combined convenience for field scientists when studying linked ionospheric and magnetospheric phenomena (e.g. Smith and others, 1987) with proximity to the Halley end of the Antarctic–UK satellite data link, a Per[illegible]Elmer computer to which the AVDAS was connected by a serial data communications cable.

The sensitive VLF aerials and receivers at Halley are sited 1500 m from the main base to reduce the effects of locally generated interference; a two way radio telemetry link was used to transfer data and commands between the AVDAS and the remote receiver site. A multiway cable between the AVDAS and the main base enabled the system to be operated remotely from there, except of course for tape and disc changes; the cable carried an audio signal monitor, a video signal for a slave spectrographic display, and a serial communications line serving a remote terminal.

The AVDAS has worked extremely well since its deployment, and has fully realized all the objectives summarized in the introduction. In early 1984, the entire VLF experiment including the AVDAS was moved to the new base site some 13 km to the east of the old site. In early 1986, the AVDAS was rehoused in a new larger caboose

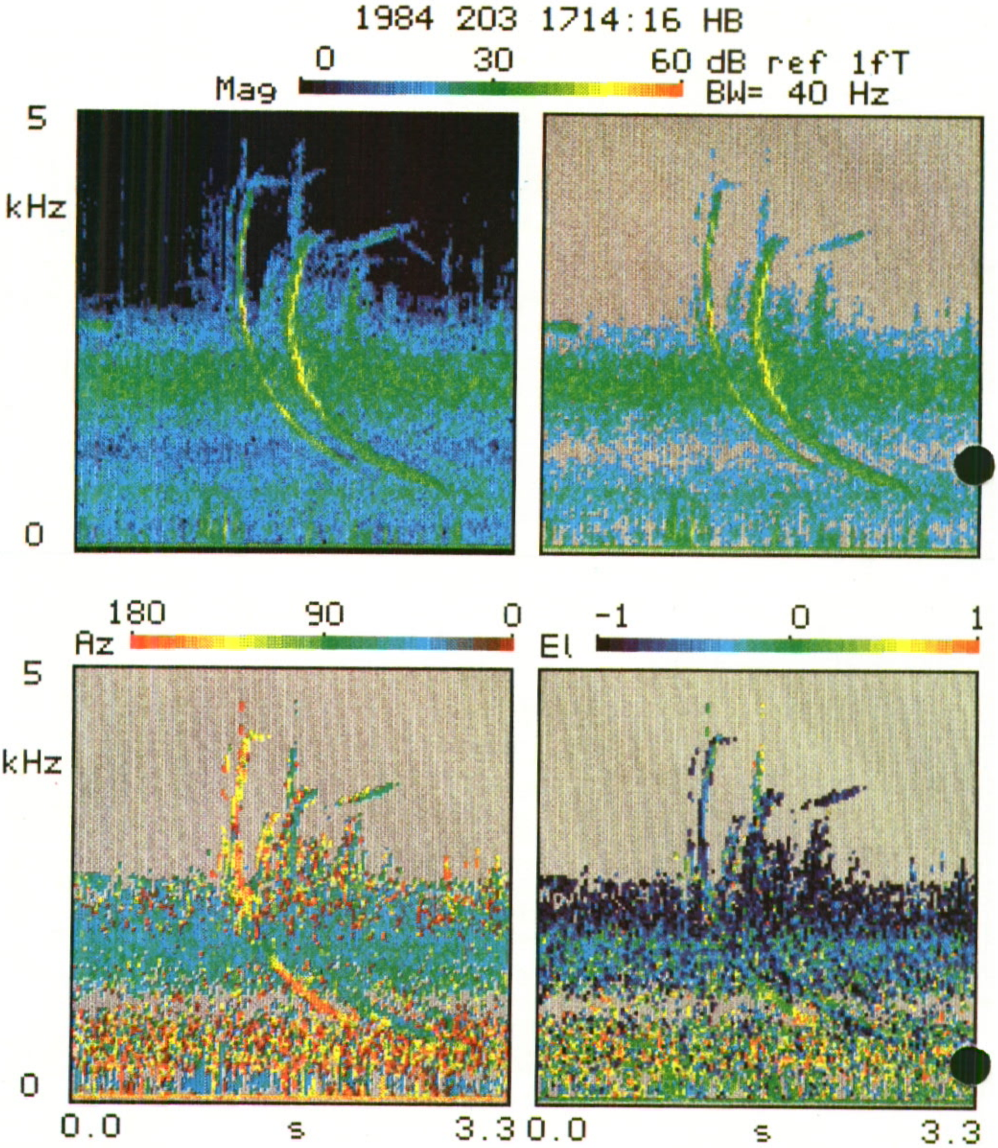

Fig. 3. 0–5 kHz spectrograms produced from the 3.3 s AVDAS DSP time series data frame taken on 21 July 1984 beginning at 1714: 16 UT. Upper left: full power spectrum; upper right: ditto except that only signals more intense than a certain threshold are shown. Lower left and lower right: azimuth and ellipticity of the polarization ellipse respectively, with the same threshold applied.

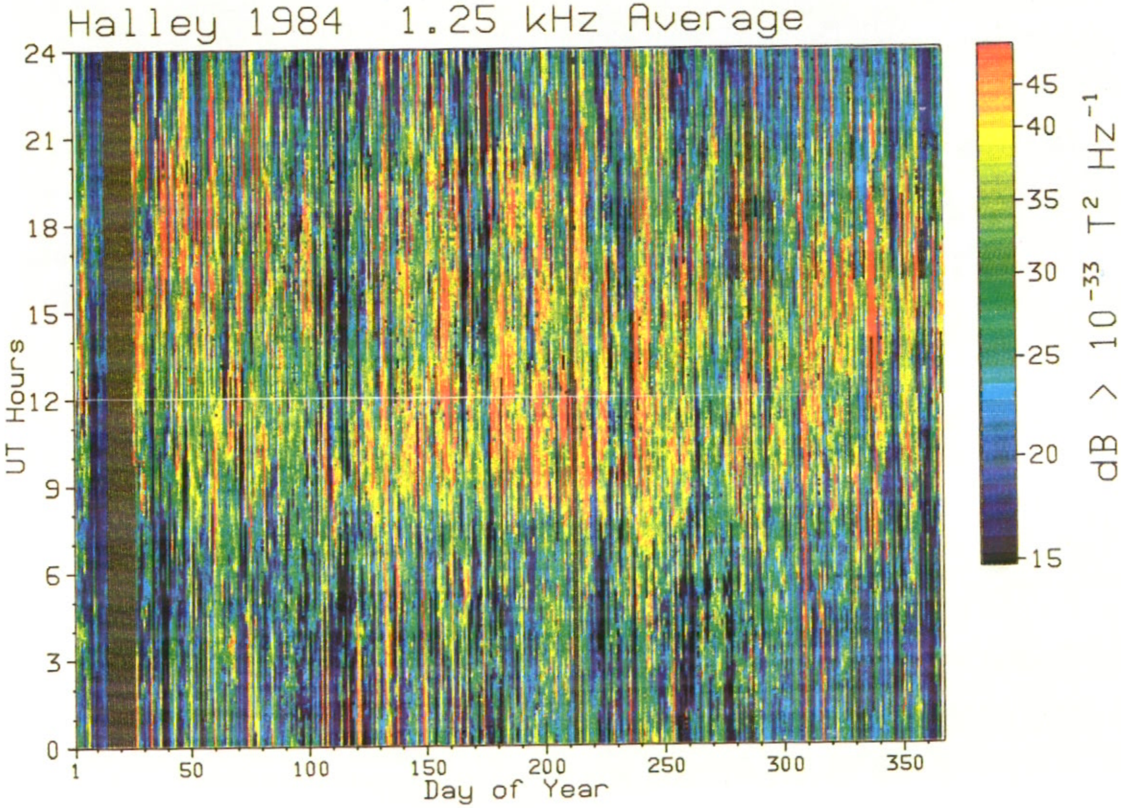

Fig. 4b. 1.25 kHz average channel data for a whole year (1984). Axes represent UT (= LT + 2 h) and day of year, whilst power spectral density is shown by the colour. The bandwidth of the channel is 1 kHz.

which also accommodated the new ULF/VLF logger system at Halley. In 1984 a second AVDAS was constructed and installed at Sheffield University for operator training, replay and further processing of data obtained by the system at Halley, and for further system development. An example of such development is the recent addition of hardware and software which allow the spectrographic display to use sixteen selectable colours as an alternative to the standard 16-level gray scale; colour hardcopy screen dumps may be made to a Diablo colour ink-jet printer. A third system has recently been supplied to the VLF group at Natal University and this will facilitate the current collaborative work involving comparative VLF studies at Halley and Sanae stations.

To illustrate some of the capabilities of the AVDAS and the use which has so far been made of them we will, in the next section, give some examples of data which have been acquired, processed, and saved using the system. Since this paper is intended as a technical description we will not discuss in detail the scientific significance of the results presented here.

EXAMPLE RESULTS

Digital sampling and processing (DSP) results

As indicated in the technical description above, it has been possible to configure the AVDAS to digitize separately, at a high rate (up to 16 kHz each), the waveforms received simultaneously by each of the three VLF aerials (two magnetic loops and a vertical electric monopole). From the resulting time series it is possible to compute off-line, using either the AVDAS itself or some other computer, complex Fourier transforms corresponding to the H_x, H_y, and E_z components of the incident wave. The magnitudes of these spectra yield the power spectrum of the incident wave, whilst the cross spectra between the different components can be used (with certain assumptions) to infer the wave normal direction and polarization characteristics of the received waves. In the case of whistler mode waves, such information is crucial in understanding their propagation through the magnetosphere and ionosphere.

In Fig. 3 we show a 3.3 s 0–5 kHZ DSP data frame taken in 1984 when only the two magnetic components of the wave vector were being received. The upper left panel shows a power spectrogram, with time and frequency plotted along the x and y axes respectively and the power spectral density indicated by the colour scale. The plot shows 128 spectra, each consisting of 128 spectral points and computed from a 256-point fast Fourier transform. The sampling rate was 10 kHz per channel and the consequent time and frequency resolutions are 25 ms and 40 Hz respectively. In computing the power spectrum it is assumed that the wave magnetic field is horizontal (approximately true in most cases).

The upper right panel is the same as the upper left except that signals below a certain threshold of power spectral density have been suppressed. The threshold has been chosen in order to select the dominant signals – in this case two knee whistlers and a band of hiss centred on 2 kHz. Such thresholding is done routinely for data to be sent via the satellite data link, in order to minimize the quantity of data sent and hence the transmission costs.

The lower left and lower right panels are computed on the assumption of a single elliptically polarized plane wave (at each frequency); they show respectively the azimuth and ellipticity of the polarization ellipse. The time and frequency scales are the same as for the power spectrograms, and the same intensity threshold is used. It is immediately clear that the whistlers and hiss arrive from different azimuths although both have a negative ellipticity, corresponding to clockwise polarization, as expected for whistler-mode signals received in the southern hemisphere.

Approximately 200 data frames of the type illustrated, covering a wide range of VLF phenomena observed at Halley, have been acquired since the AVDAS began operating, and these are currently being analysed.

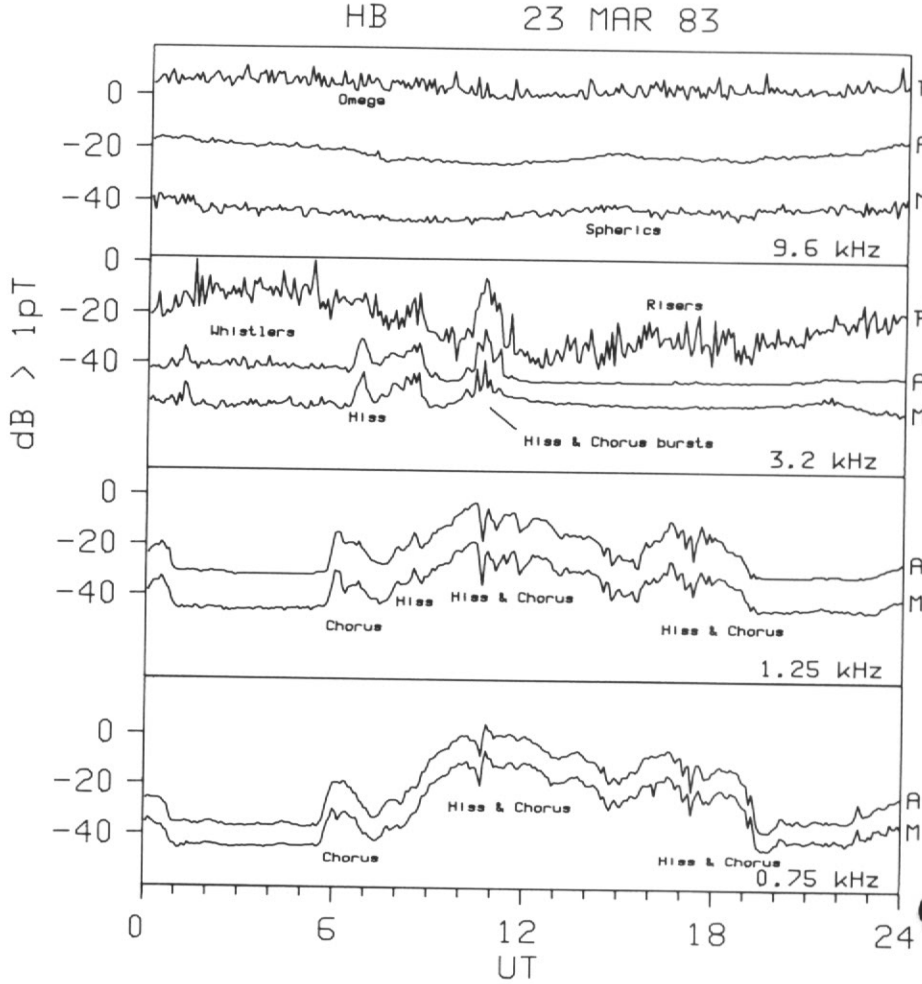

Fig. 4a. Halley low-speed logger data for a typical day – 23 March 1983. The 0 dB level for each of the 4 frequencies represents 1 pT rms in the bandwidth of the filter (equivalent to 2×10^{-27} T^2 Hz^{-1} for the two ELF channels and 1×10^{-27} T^2 Hz^{-1} for the two VLF channels). Local noon is at 14 UT.

Results from the low-speed synoptic logger

As indicated in the technical section above, the AVDAS has been operated as a low speed logger. Logging has been carried out continuously since installation in 1983. The main aim is to obtain a statistical picture of VLF activity at Halley. Analogue data from a filter bank containing narrow band filters at 0.75, 1.25, 3.2 and 9.6 kHz have been digitized to 8-bits per channel (12 channels logged) and recorded

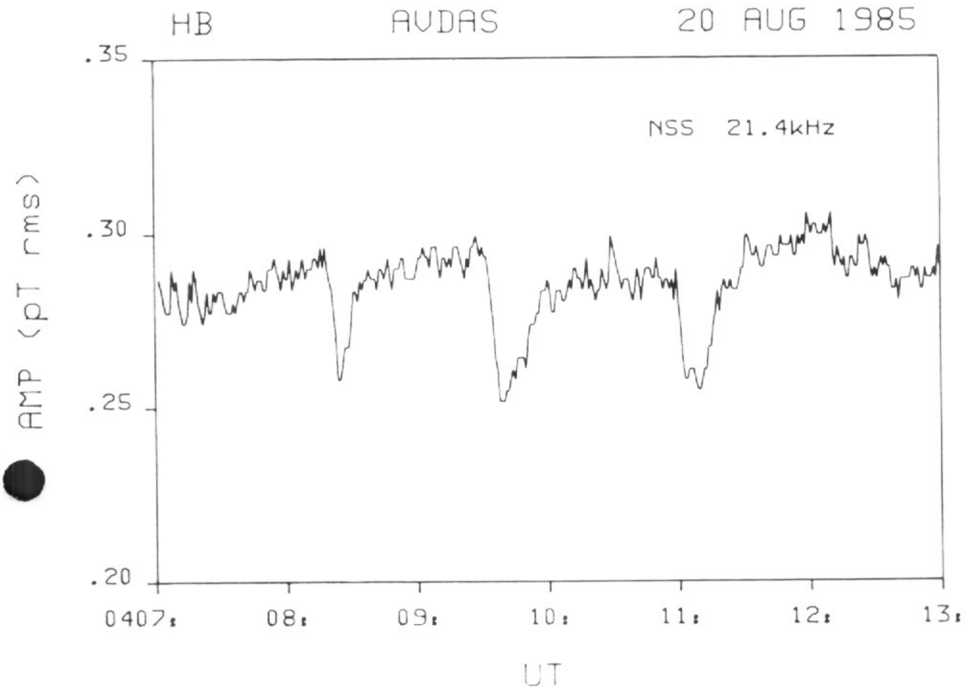

Fig. 5. Example of amplitude perturbations (Trimpi events) in the NSS 21.4 kHz signal, recorded by the Halley AVDAS on 20 August 1985.

once every 5 min. This sampling rate was chosen to be compatible with the 1 minute in five sampling schedule of the goniometer receiver (which provides the input to the filter bank) and is low enough for the quantity of data acquired to be manageable by a floppy disc based system.

The filter bank is almost identical to that used by the wave experiment on board the Ariel-4 satellite (Tatnall and others, 1983). The bandpass filters have a logarithmic response, and their analogue outputs are processed to yield the peak, average, and minimum signal levels in a 30 s sampling interval. Ratios of these, particularly the average/minimum ratio, can be used to discriminate time structured phenomena, such as chorus, from an unstructured signal such as hiss. The time constants of the peak and minimum detectors, 10 and 100 ms respectively, were chosen to discriminate against impulsive signals such as spherics.

Fig. 4a shows the logger output for a typical day. Contributions are shown from different sources: magnetospheric signals such as hiss, chorus and whistlers, as well as subionospherically propagating signals such as spherics from electrical storms, and pulses from transmitters of the Omega VLF radionavigation system.

In Fig. 4b we display the data from the 1.25 kHz average channel for a whole year, in a way which shows the diurnal and seasonal variation trends. Detailed analysis and comparison with the 1.25 kHz minimum channel data for the same year show that the broad daytime peak in activity appears to comprise a morning peak of predominantly chorus, especially during magnetically disturbed times, and an afternoon peak in which hiss is important.

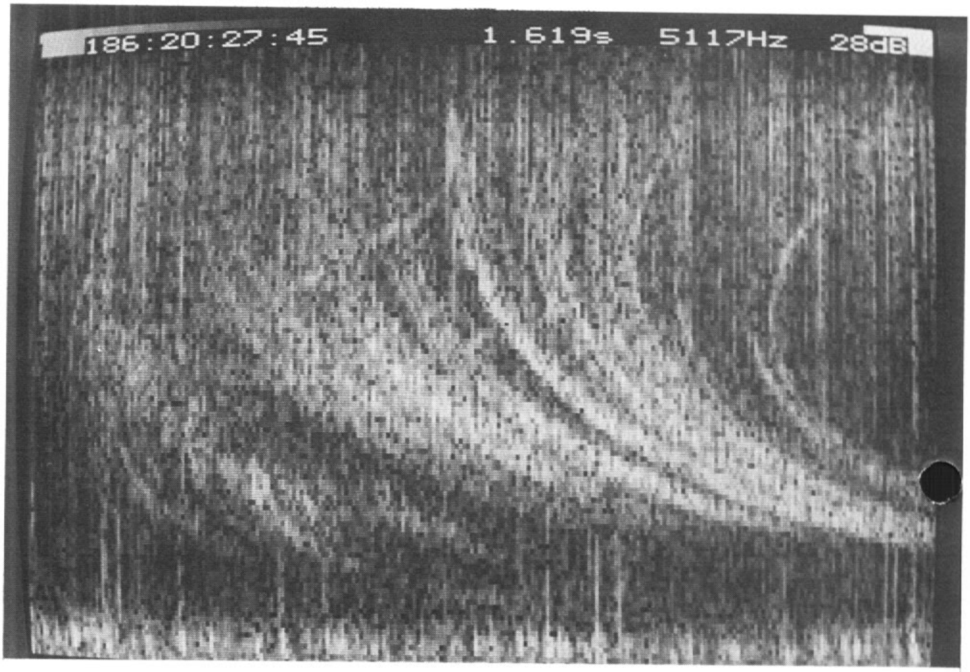

Fig. 6a. The AVDAS spectrographic display showing a multicomponent whistler group recorded on 4 July 1984 at 2027 UT. Time (1.6 s full scale) and frequency (0–10 kHz) are represented horizontally and vertically, respectively.

Measurements on VLF transmissions

An important technique has recently been developed for investigating wave induced particle precipitation into the lower ionosphere. This uses the so-called Trimpi effect (Carpenter and others, 1985; Hurren and others, 1986), in which bursts of such precipitation produce transient perturbations in the amplitude and/or phase of subionospherically propagating signals from VLF transmitters. Previous studies of Trimpi events have mostly involved band pass filtering the broadband analogue tape recordings at the transmitter frequency. An alternative procedure which avoids this stage of processing is to use the AVDAS to digitize and record at Halley, at a suita[illegible] rate, the output from a filter tuned to the transmitter frequency.

Fig. 5 shows an example in which the amplitude of the signal from the NSS transmitter (21.4 kHz) in Maryland, USA, was digitized at a 1 Hz rate. Three Trimpi events, with a characteristic rapid onset and slower recovery, are evident. It is also possible to detect corresponding perturbations in the arrival bearing of signals and, in the case of CW transmissions, also of the phase.

Whistler scaling and analysis

As an example of the on-site analysis capabilities of the AVDAS, we show in Fig. 6a a typical multicomponent whistler group, as it would have been seen by the Antarctic field scientist on his display screen. In Fig. 6b we show the results of an analysis session in which the whistler traces were scaled interactively, using the screen cursor and analysis software described above. The whistler nose frequencies and times

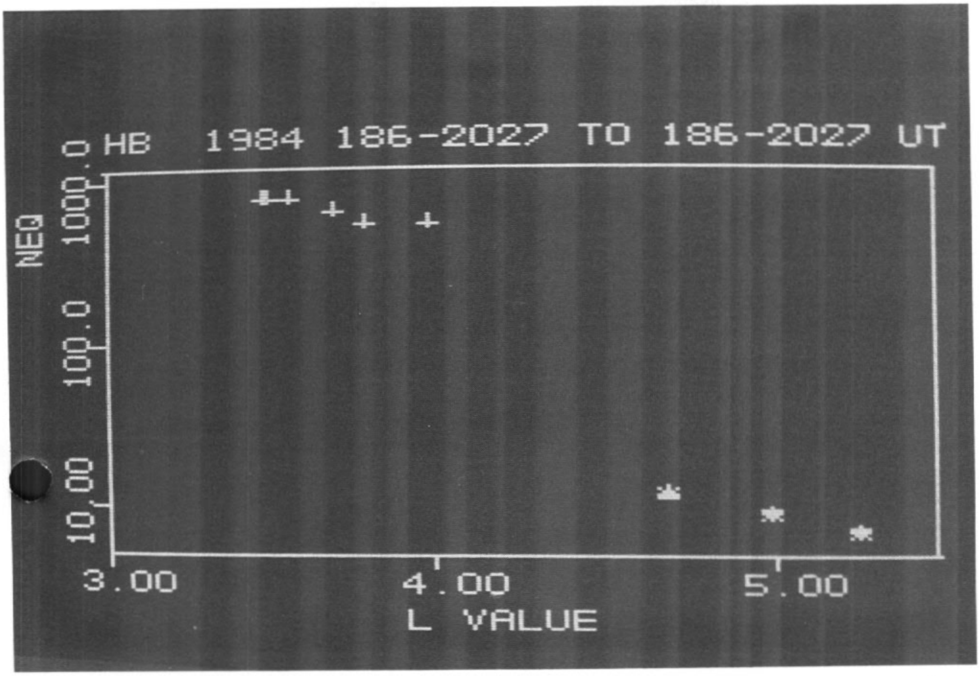

Fig. 6b. An equatorial electron density profile (in units of cm^{-3}) across the plasmapause, computed from dispersion analysis of the whistlers shown in Fig. 6a.

were measured using, where necessary, the nose extrapolation algorithm of Ho and Bernard (1973). An equatorial electron density profile was computed using the method of Park (1982), assuming a diffusive equilibrium density distribution model and a dipole geomagnetic field. The result is presented using the AVDAS graphics facility which would have been available to the field scientist.

CONCLUSIONS

(i) A microcomputer-based system known as AVDAS (Advanced VLF Data Analysis System) has been designed and built for the purpose of analysing VLF waves which are received in Antarctica as part of the BAS magnetospheric and ionospheric research programme. The digital processing capability thus provided complements the analogue processing and recording methods used previously. Besides standard peripherals, the computer is connected to a special purpose fast spectrum analyser and a spectrographic display unit; these are controlled by the computer using specially developed software.

(ii) AVDAS provides real-time spectral analysis and display of broadband VLF signals received live or played back from a previously recorded analogue tape. The spectral information may be saved to disc or may be further processed, for example to obtain arrival bearings, whistler dispersions, etc.

(iii) AVDAS provides a real-time analogue–digital conversion and digital recording capability. Applications include high speed digitization at the full signal bandwidth ($\sim$ 20 kHz) for short intervals, and continuous low speed logging of the outputs from a filterbank.

(iv) Processed data files may be saved on floppy disc and returned to the UK for further analysis, or alternatively sent back over the satellite data link. The link may also be used to send to Halley modifications to the system software.

(v) AVDAS provides flexible programmable control over the VLF receivers and analogue recorders at Halley.

(vi) AVDAS was deployed at Halley in 1983 and has been working well ever since. A second, almost identical system has been built for use in the UK, for training, development and analysis purposes.

ACKNOWLEDGEMENTS

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