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A Continuous Spectrum Analyser for Analogue Analysis of ULF Tape Recorded Data

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Abstract

A sweep-frequency spectrum analyser for Pcl geomagnetic pulsations (0·2–5 Hz) is described. It utilizes a rotating head assembly with two replay heads for scanning the data tape which is transported by a standard audio frequency quarter-inch tape deck. Frequency and time resolutions of 0·1 Hz and 6 s in the Pcl band may be obtained.

In the field of upper atmosphere and space research, the investigation of various types of waves propagating in the Earth's magnetosphere and ionosphere often requires a detailed knowledge of the way the signal intensity changes with frequency and time. Digital analysis techniques are available (McPherron *et al.* 1968) but they are too expensive to operate on long continuous-data samples, and analogue analysis is more convenient. Most analogue dynamic spectral analysis has been carried out using a multichannel system or a swept single-tuned-filter system. In a multichannel analyser a large number of narrow bandpass filters cover the desired passband (Helliwell *et al.* 1961). This process, shown schematically in Fig. 1*a*, operates in real time with no intermediate storage system but requires an expensive bank of filters. In a swept single-tuned-filter analyser (Fig. 1*b*) a signal of generally 2–8 s duration is stored and read out rapidly many times and sampled by a single filter which changes frequency slowly (Gruenz 1951; Presti 1966). This involves intermediate storage and does not allow continuous and automatic analysis. Although such a system is relatively cheap it has certain disadvantages. As shown in Fig. 1*b*, only short samples of data can be analysed at a time, and therefore the process is very inefficient for long data samples. In addition, continuous unattended operation is not possible.

A further system of analogue analysis is possible. This is a fast diagonal frequency sweep in conjunction with a relatively slow time-scan, as illustrated in Fig. 1*c*. Here a very short segment of signal is fed to a single filter which changes frequency very rapidly. Analysis time is appreciably reduced compared with that for the system shown in Fig. 1*b*, and continuous analysis of prerecorded analogue magnetic tape is possible. The system described here employs the fast diagonal frequency scan, using a rotating head assembly attached to a standard quarter-inch tape deck. This method has also been used in other forms by Dowden and Emery (1965) and Ellis (1973).

The prototype system was constructed specifically to analyse Pcl (0·2–5 Hz) variations in the Earth's magnetic field that are prerecorded on slow-speed magnetic

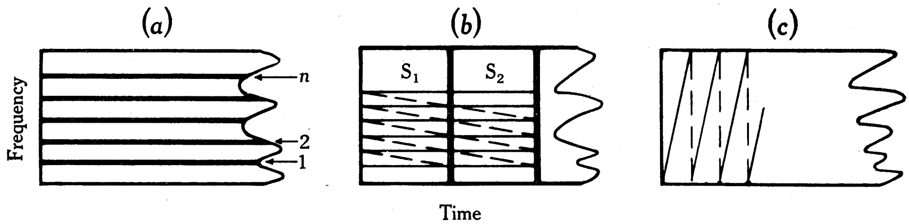

Fig. 1. Schematic diagrams of analogue methods for analysing ULF dynamic spectra:

(*a*) Multichannel analyser, with the filters (labelled 1, 2, ..., *n*) indicated by solid lines.

(*b*) Swept single-tuned-filter analyser, showing the analysis sequence for samples S_1, S_2,... (of about 2–8 s duration); the changeover from sample to sample is edited manually.

(*c*) Present system, using a fast diagonal frequency sweep in conjunction with a relatively slow time-scan.

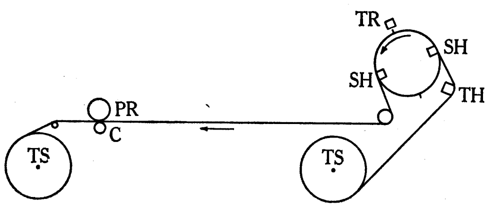

Fig. 2. Motion of the tape through the rotating head system. The abbreviations are: TS, tape spool; TH, time head; SH, signal head; TR, trigger head; PR, pinch roller; and C, capstan.

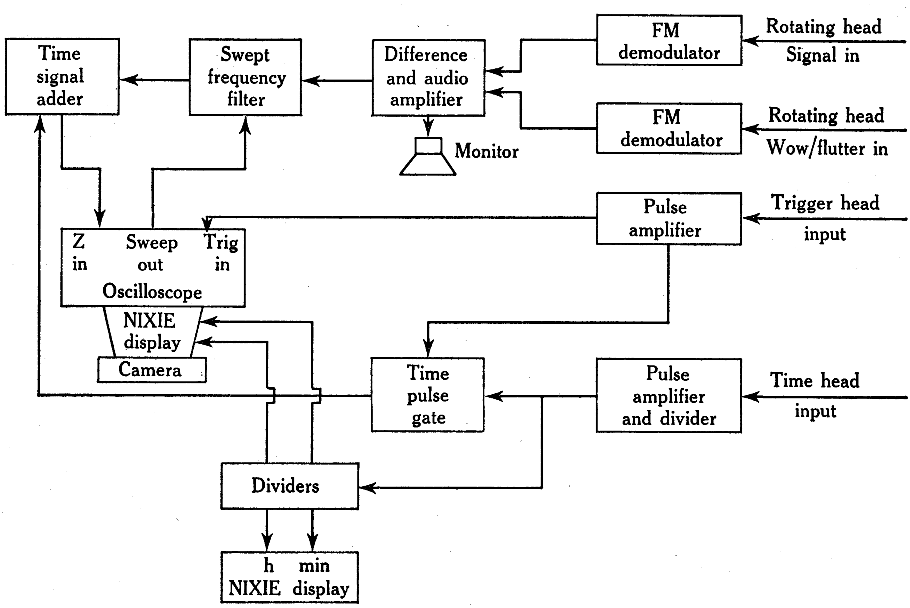

Fig. 3. Block diagram of the rotating head analyser.

tape moving at $3 \cdot 8$ cm min^{-1} (Ellyett *et al.* 1967). The north–south and east–west geomagnetic field components are recorded using frequency modulation (FM) with a carrier frequency of $22 \cdot 5$ Hz and a 40% maximum deviation. The remaining two channels of the four-in-line head record 5 s time pulses and a 25 Hz carrier for wow-and-flutter compensation. The use of FM recording is an essential feature of the system since it provides a fairly narrow band signal which can be transformer-coupled out of the rotating head assembly.

The motion of the tape through the rotating head is shown in Fig. 2. It leaves the right-hand spool and passes the fixed head mounted close to the rotating head assembly. This head detects the 5 s time pulses recorded on the tape. The tape then makes a 180° wrap around the rotating head assembly, so that one of the two four-track playback heads is always in contact with the tape. The tape then passes through the transport in the usual way. Two ferromagnetic pins, spaced 180° apart on the rotating head, induce a pulse in the trigger head, which is used to initiate the display time-base sweep.

Table 1. Specifications of analyser for Pcl pulsation data analysis

Frequency range (band)	0–9300 Hz [Playback];	0·14–4·1 Hz [Record (Pcl)]
Frequency resolution (filter bandwidth)	300 Hz [Playback];	0·1 Hz [Record (Pcl)]
Time resolution	78 ms [Playback];	6 s [Record (Pcl)]
Rotating head speed	386 r.p.m. (effective tape speed is 144 $\mathrm{cm\,s^{-1}}$)	
Tape transport speed	4·75 $\mathrm{cm\,s^{-1}}$	
Ratio (rotating head speed : record speed)	2260	
Ratio (recording time : analysis time)	75	
Camera film speed	6·5 $\mathrm{cm\,s^{-1}}$	

The specifications of the analyser for displaying Pcl geomagnetic pulsation data are listed in Table 1, and a block diagram of the system, which employs solid state electronics, is shown in Fig. 3. During analysis the double head assembly rotates at 386 r.p.m. or 6·43 r.p.s., which results in about 13 scans per second from the two heads connected in series. Each scan has a duration of 78 ms. The velocity of the head relative to the tape (the effective tape speed in Table 1) is 144 $\mathrm{cm\,s^{-1}}$, and the length of tape scanned is 11·3 cm. This corresponds to a time sample of 2·4 s duration in playback time at 4·75 $\mathrm{cm\,s^{-1}}$, or about 3 min in record time at 3·8 $\mathrm{cm\,min^{-1}}$.

During a single diagonal-scan, the filter is swept 0–9300 Hz. Successive scans are overlapping in time, so that any point on the tape is sampled 32 times, each time at a different frequency. This is equivalent to a 32-channel analyser with channel spacing and frequency resolution of about 300 Hz on playback or 0·1 Hz for the ULF recorded signal. The time resolution at playback is the time between successive scans, 78 ms, and in terms of the ULF recorded signal is approximately 6 s.

The outputs of the signal and wow-and-flutter channels from the rotating head (see Fig. 3) are FM signals with carrier frequencies of about 55 kHz. These signals are demodulated by standard circuits to produce a 0–10 kHz signal. The cathode-ray-tube sweep voltage is synchronized to the rotating head and it controls the frequency of the swept frequency filter. The detected output from the filter is mixed with one minute time pulses derived from the tape recorded 5 s timing pulses and then applied through the time pulse gate to the grid of the cathode-ray-tube. The time pulse gate is opened at the high frequency end of the sweep and a sequence of time dots is thus recorded on the top of the film as shown in Fig. 4 (below). The even hours of time are also recorded on the film (not shown in Fig. 4) by a NIXIE tube display in the camera, while time is continuously monitored with an external NIXIE tube display. The film moves continuously past the cathode-ray-tube and the film speed is adjusted for optimum time resolution with one-third overlap of successive traces. Since the analyser scans in both frequency and time, the trace is inclined at a certain angle to the film direction in order to obtain orthogonal frequency and time axes on the resulting spectral record.

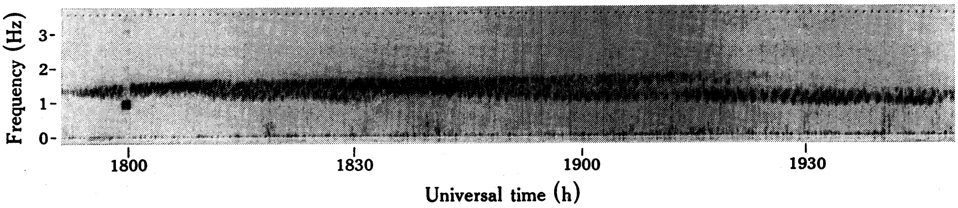

Fig. 4. Film record of a typical fine-structured Pcl emission event recorded at Hobart on 17 February 1968.

A typical film record showing a Pcl emission event generated in the magnetosphere is illustrated in Fig. 4. The frequency resolution in this example is 0·1 Hz and the time resolution 6 s. Both of these are controlled by the scanning velocity of the rotating heads and the tape transport speed.

The principle of the rotating head system may be applied to the design of a more general audio frequency spectrum analyser for prerecorded tapes. However, the rotating head speed, tape transport speed and FM carrier frequency would need to be proportionally higher.

The prototype instrumentation described here provides a simple method for continuous high-speed analysis of prerecorded Pcl geomagnetic pulsation tapes. It has proven extremely reliable and has analysed some 1200 reels of quarter-inch FM data tape with very little wear to the tapes and the rotating heads.

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