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# A SEA WAVE RECORDING SYSTEM USING MAGNETIC TAPE CASSETTES

by

P. J. HARDCASTLE

REPORT NO 61

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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## SUMMARY

A magnetic tape system has been developed to record sea waves and automate the routine analysis of the resulting data. The system was designed to replace chart recorders, and to give similar or better accuracy. Records are made using frequency modulation at low tape speed on audio C90 cassettes. These last for 30 days when records of eleven minutes' duration are taken every three hours. Waves are reproduced in analogue form to an accuracy of ± 1%. The frequency response of the system is better than ± 1% in the range 0.25Hz to 0.04Hz, ie 4 seconds to 25 seconds period. Routine analysis of ten minute samples of the data gives mean rectified wave height (from which significant wave height is derived), zero crossing and crest wave frequency on punched tape. Replay is speeded up by a factor of 70 and one month's records are analysed in 40 minutes, using an oscilloscope for visual checking of the analogue wave record.


## INTRODUCTION

The cassette recording system to be described was developed as a low cost replacement for chart recorders used for sea wave recording. The design criteria were that accuracy should be equivalent to, or better than, existing chart recorders then in use, and that tapes were to be changed monthly instead of the twice weekly requirement for chart recorders. Power consumption was to be kept low so that batteries would only need changing monthly. Tape replay could be automated and hand analysis of charts would no longer be required.

The original cassette logger was a single track frequency modulated type, with an accuracy of ± 2½%, and was originally used at Start Bay from May 1972. This recorder's timing was controlled by a mechanical clock. Other similar recorders were used from 1973 onwards. In April 1975 an improved design was introduced, which had an additional recording track that was used for a clock frequency. This improved the accuracy of the recorders to ± 1%, and also enabled the signal to noise ratio to be improved to 60 dB. The new design also uses a crystal oscillator to control all timing functions. This type of recorder was first used on the East Coast, and has replaced all the previous recorders since January 1977.

DATA ACQUISITION

The system was originally designed for use with the IOS Frequency Modulated Wave Recorder as described by HARRIS et al (1963) and also as modified by HARDCASTLE (1967). This wave recorder is a pressure sensing type, where the pressure transducer is mounted on the sea bed, and connected by cable to the shore. The transducer gives a frequency output which is proportional to the seawater pressure, responding to both waves and tides, and typically gives a change from 90 kHz to 85 kHz with a pressure change of 10 metres of water. By mixing this varying frequency with a fixed frequency of for example 91 kHz, a frequency difference signal can be extracted of from 1 kHz to 6 kHz. For use with the logging system, this frequency output is divided down by ripple counters to give a frequency variation of 5 Hz to 45 Hz for the maximum expected range of wave plus tide excursions. The 5 Hz to 45 Hz frequency is used to drive the recording head circuitry, thus giving no linearity conversion errors for logging the data.

The logging system has subsequently been adapted for use with waverider receivers made by Datawell. The waverider is a wave measuring system which transmits real time wave data from a moored buoy. The buoy contains an accelerometer which responds to sea waves. The acceleration signals are integrated twice to give wave heights, and the wave height is transmitted at 27 MHz from the buoy as a sub-carrier with deviation of 1.86 Hz per metre on a centre frequency of 259 Hz. The waverider receiver converts the frequency modulation to a voltage proportional to the instantaneous wave deviation. For use with the logging system, this voltage must be converted to frequencies in the range 5 Hz to 45 Hz for the maximum expected range of wave heights. The voltage controlled oscillator in the CMOS CD4046, followed by binary ripple counters, has been used for this purpose. This arrangement gives linearity of the order of 0.2%, which is adequate, and the long term zero stability is not crucial for wave recording. A more recent development derives the frequency directly from the modulated 259 Hz of the waverider buoy, with no degradation of accuracy or zero drift.

DATE LOGGING

Data is recorded on standard Phillips type C90 cassettes in a frequency modulated form as pulses of 4 milliseconds length, with repetition frequency varying between 5 Hz and 45 Hz, depending on the instantaneous wave amplitude. The use of pulses enables an adequate level of magnetisation to be obtained at low repetition frequencies with direct recording. Careful design of the recording head drive circuit is needed to ensure that demagnetisation of previous pulses does not occur at high repetition frequencies due to high magnetic flux levels in the head. The frequency response of the head drive and replay circuit is shown in Fig 1, with various head drive resistances. The recording head is a twin track stereo type which is fitted as standard to the proprietary cassette deck used. The top track is used for the signal, and the bottom for a clock track consisting of 4ms pulses at a repetition frequency of 6.07 Hz.

## TIMING AND CONTROL

Record interval and length are controlled by a crystal oscillator running at 1,590,728 Hz. This gives, by simple binary division and gating, a record length of 675 seconds with a recording interval of 3 hours. Where longer records are required it is easy to change the record length to 1350 seconds. The clock track repetition frequency is also derived from the crystal oscillator by binary division. This track is used on replay to give a constant increase in replay speed of seventy times the recording speed.

## RECORDING DECK CONSTRUCTION

The cassette deck used in the logger is a front edge loading type made to Starr designs by Lenco and Garrard, primarily for audio stereo use. Modifications are made to it for our use to reduce the recording speed, and to give simple 'finger proof' operation. The recording tape drive motor is replaced by a Portescap Type 26AR601 governed micromotor fitted with a 16.8 to 1 reduction gearbox. This reduces the tape transport speed to a seventieth of normal, approximately 0.07 cm $s^{-1}$. The facilities for fast forward and reverse winding are removed from the deck, as are the auto eject solenoid and the pause and record buttons. Once a cassette is inserted it is impossible to interfere with it manually, except to eject it. The contacts fitted to the take-up spool, which gives a make and break action on rotation of the spool, are used to make a light emitting diode switch on and off as the tape drive turns, giving a visual indication that the tape is advancing correctly, as it is not possible to see the tape.

## RECORD FORMAT

Records are made sequentially on the tape, without gaps between them. Record starts and ends can be identified by the higher frequencies given on replay when the recording motor starts and stops. Time identification of records depends on the correct start and end date and time being manually written on the cassette before and after insertion in the recorder. The first record is normally made by resetting the clock circuit with the panel mounted push button. Subsequent records are taken automatically every three hours. Power failures can interrupt the sequence, but recent loggers have been fitted with back-up storage batteries to overcome this problem. The recorder has a low power consumption, and operates at 12 volts. It will run for over a month using a 35 amp hour battery with surplus capacity available to drive the transducer.

REPLAY

Tapes are replayed at seventy times the recording speed on a stereo cassette deck. The outputs of both tracks are amplified using automatic level control to give a constant amplitude despite variations in the recorded signal. Amplifiers with a level frequency response in the range 300 Hz to 3200 Hz are used, as the recorded pulses do not vary in amplitude with different frequencies. Both tracks can be switched to a loudspeaker to check signal quality. The frequency outputs are demodulated using linear charge dispensing frequency to voltage convertors (Teledyne Philbrick Type 4702). The clock track is demodulated so that the normal 425 Hz (ie 70 times 6.07 Hz) gives a 5 volt output, and the data track so that 0 Hz to 3200 Hz gives 0 to 10 volts. Both outputs are smoothed with time constant of 0.015 s to remove ripple due to the input frequencies. The resulting small reduction in the higher signal frequencies is corrected by compensation in the later filtering. The clock track output voltage is used to control the replay speed, using a comparator and amplifier to govern the replay motor. The data track output voltage is now an analogue signal which contains wave (and tide) signals proportional to the recorded signal, but includes noise due to the residual wow and flutter introduced in the recording and replay process, and not completely removed by the replay servo. This noise will also be present proportionally in the clock track output voltage. The noise is reduced by dividing the data track voltage by that from the clock track using an analogue divider (Hybrid Systems Type 107C). This gives a noise reduction in the signal of 20 dB. The phase distortion is not removed by this latter process but is negligible. The divider output is amplified and filtered using Chebyshev high and low pass filters to provide attenuation of 18 dB per octave either side of the pass band. Chebyshev filters are used to give this sharp cut off, and the ripple introduced by these filters in the response curve is smoothed by simple R-C filters. The frequency response of the overall record-replay system is within ± 1% in the pass band from 0.04 to 0.25 Hz, where these are the recorded wave frequencies (Fig 2). The filtered output now consists of the required sea waves, which are displayed on a variable persistence oscilloscope for visual validity checks. Data are also taken from this point if analogue to digital conversion is required for spectral analysis of the wave time series. Routine wave data analysis is also performed on signals from this point. The analysis provides mean rectified wave height, number of zero crossings and number of wave crests for a ten minute wave record. The mean rectified wave height is obtained by full wave rectifying the wave record using operational amplifiers, and integrating over the record length, with the resultant voltage being displayed on a digital voltmeter.

The number of up zero crossings on the wave record is detected by a comparator and counted on CMOS Counters. The number of crests on the record are found by differentiating the record and using a comparator and CMOS counter as before. The mean frequency of the data track on the tape (ie the frequency that is modulated by signals) is also obtained by counting its zero crossings during the record. This gives a figure related to tide height for pressure recorders, and will be a constant for recorders with no tide component. These four numbers are punched on paper tape at the end of each record. If the records are of poor quality on the display, the first number (mean rectified wave height) is manually held to zero on punching at the record end.

The start of each record is detected on replay by the discontinuity in frequency on the clock track caused by the recording motor attaining running speed. This gives a high voltage pulse on the demodulated clock track voltage output, which causes a highpass filtered Schmitt trigger to change state. The first 0.6 second of replay is discarded to allow the filters on the wave signal to s ttle. Timing of the record length analysed is obtained from the clock track.

## FIELD EXPERIENCE

Twelve recorders have been in use at coastal sites for a total of over thirty site-years of operation. Early models did not have a clock track and so have a degraded specification of ± 2½% accuracy, but all recorders have now been modified to twin track. Data returns per annum have ranged from 85% to 100% of maximum possible, with an average of 95%, where loss is due to logger malfunction. The most frequent cause of data loss has been corrosion build up on the tape heads, caused by operation in damp salty atmospheres. The corrosion forces the recording tape away from the head, and no signal is recorded. This fault has not occurred where recorders are mounted in environmentally proofed enclosures. Other problems have been incorrect insertion of cassettes in the recording deck, poor cassette tape to head pressure pads, twisted and crinkled tape in the cassettes, and motor failure.

At two sites the recorders are operated as a back up system to Rapco digital data loggers recording waverider data. A graph is shown in Fig 3 of the significant wave height derived from the Rapco (1024 seconds of record) against that from the cassette recording system (600 seconds of record). The best fitting straight line (least squares) is given by Hs (Rapco) = 1.00 Hs (Cassette) + 0.06m.

QUALITY CONTROL

The recording system, when used with FM pressure recorders, is inherently reliable unless there is a transducer or cable fault, as the signal conditioning consists of a binary division of the difference frequency. A similar system is currently being produced for the waverider where the recorded frequencies will be derived directly from the modulated 259 Hz, although faults will arise here with the signal path. The only calibration required with this type of recorder is of the transducer. It is unlikely that a fault would develop that was not immediately obvious on replay.

The replay system is regularly calibrated using a test tape of a sine wave modulating fixed frequencies. This checks the whole replay system, which has to date remained within specification (± 1%). Components in the replay chain which are most likely to affect accuracy are the frequency to voltage converters which have a stability of 0.01% per degree Centigrade and the divider which has a stability of better than 0.1% per degree Centigrade.

Time identification of the recordings is totally dependent on the correct start and end time being written on the cassettes. A continuous power supply to the recorder is also needed to avoid missing records. As previously stated, rechargeable batteries are used in mains supply recorders to obtain an uninterrupted supply. Tapes are checked to see that they contain the correct number of records between start and end times. Tapes from pressure recorders can also be checked against tidal data from the site.

SPECIFICATION

Recording system - when used with IOS Frequency Modulated Pressure Head

Supply - 12 volts

Tape speed - 0.07 cm sec approx

Record length - 675 secs ) Crystal controlled from 1590728 Hz

Record interval - 3 hours )

Tape capacity - over 250 records

Clock track frequency - 6.07 Hz (binary ripple from crystal)

Frequency response (recorders) - DC to 2 Hz

Accuracy and linearity of transducer are not degraded by recorder (output frequency is divided down)

Current consumption (including transducer): recording 35 mA<br>quiescent 24 mA

Current consumption (waverider interfaced): recording 15 mA<br>quiescent 4 mA

Replay

Replay unit is 240v 50 Hz mains driven - consumption 50w

Tape speed - 70 times recording speed: servo-controlled from clock track. Variation of 10% in recording speed will give 0.5% change in replay speed (ie changes reduced by 20:1).

Overall frequency response (at record speeds). Within ± 1% from 0.4 Hz to 0.25 Hz (25 secs to 4 secs period).

Signal to noise: Max output signal of ± 10v contains ± 10mV noise ie S/N ratio of 60 dB.

Replay linearity: Better than 0.2% of maximum output.

Change of ± 10 Hz at data track head (recording) gives ± 2.25 volts at the output of the analogue divider.

Calibration: Change of ± 10 Hz at data track head (recording) gives ± 6.4 volts at filter output and a mean rectified reading of 2163 (sine wave in pass band). This would be a typical maximum design deviation for a FM pressure recorder, where the tidal range was about the same as the maximum expected wave height. The number of binary divisions of the FM output from the transducer is set on installation so that the maximum wave and tide height will nto give a greater range than 5 to 45 Hz.

WAVE STATISTIC CIRCUITRY

Linearity of Mean rectified signal height - better than 0.1%.

Accuracy of Mean rectified signal height - better than ± 1% of max reading.
Accuracy of number of zero crossings and crests - ± 1 count so long as waves exceed 0.2% of full scale.

DATA ANALYSIS (using FM pressure recorder)

Significant wave height, Hs, is derived from mean rectified wave height $H_R$ using the equation:

$$H_S \simeq 2\sqrt{2\pi}\ H_R$$

Corrections for attenuatio  of pressure due to sea waves with increasing depth have been made so far using the equation:

$$A = P\left(0.16 + \cosh\frac{2\pi d}{\lambda}\right)$$

where P is the pressure at the sea bed measured in equivalent head of sea water, A is the surface amplitude, d is the depth of water, $\lambda$ is the wavelength. This equation is an empirical derivation by DRAPER (1957) from the classical form, for use on gently shelving beaches.

However data banked with MIAS*will not be corrected for attenuation of pressure. Measured significant wave height will be given, together with the measured zero crossing wave period and height of the water column above the instrument. The user will thus be able to correct the data using the best corrections available.

The wavelength is obtained iteratively from the zero crossing wave period, $T_z$, using the relationship

$$T_z = \left[\frac{g}{2\pi\lambda}\tanh\left(\frac{2\pi d}{\lambda}\right)\right]^{-\frac{1}{2}}$$

where d  is the water depth.

The water depth is derived from the mean frequency of the signal track, plus a constant representing the depth when the transducer frequency equals the local oscillator frequency.

* Marine Information and Advisory Service

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## ACKNOWLEDGEMENTS

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APPENDIX

RELATIONSHIP BETWEEN THE SIGNIFICANT WAVE HEIGHT AND THE MEAN RECTIFIED WAVE HEIGHT OF A WAVE RECORD

We assume that the wave elevation at a point can be considered to be a random function of the time h(t), given by the sum of an infinite number of sinusoids, thus

$$h(t) = \sum C_n \cos(\omega_n t + \phi_n) \tag{1}$$

where the frequencies $\omega_n$ are densely distributed in the interval $(0, \infty)$ and the phases are random and uniformly distributed in $(0, 2\pi)$, (see Cartwright and Longuet-Higgins (1956) and Cartwright (1958)). By the central limit theorem $h$ has a Gaussian probability density function given by

$$p_r(h) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(\frac{-h^2}{2\sigma^2}\right) \tag{2}$$

where $\sigma^2 = \sum_n \frac{1}{2} C_n^2$ and is the standard deviation of the wave elevation (Kinsman (1965) refers).

The mean rectified value of $h$ is given by

$$H_r = |\bar{h}| = 2\int_0^\infty p_r(h)\, h\, dh = \sqrt{\frac{2}{\pi}}\,\sigma \tag{3}$$

We now define significant wave height by the relation

$$H_s = 4\sigma \tag{4}$$

This equation is discussed in Tann (1976).

Thus (3) becomes $H_r = \sqrt{\frac{2}{\pi}} \cdot \frac{H_s}{4}$ i.e. $H_s = 5.01\, H_r$

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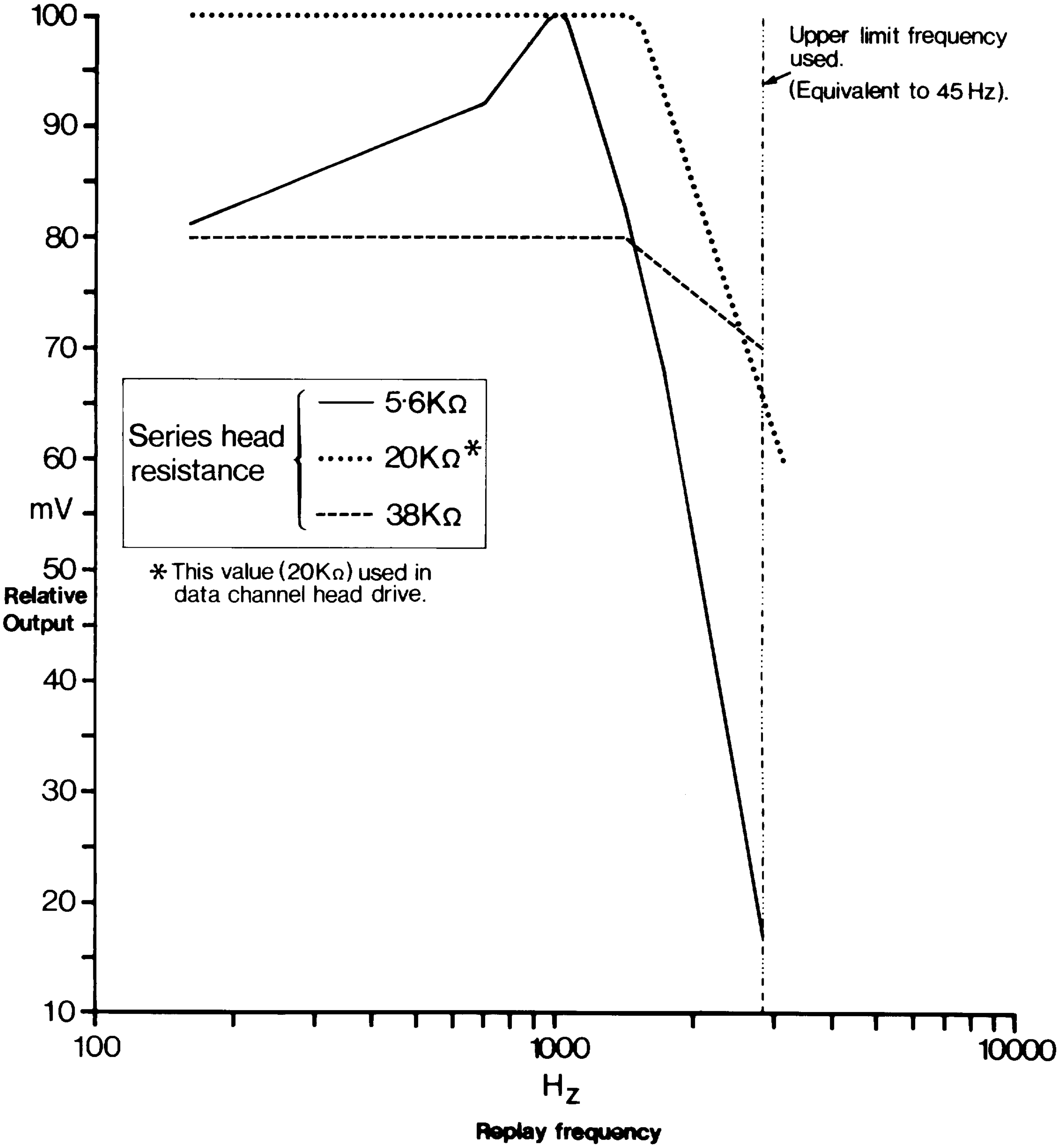
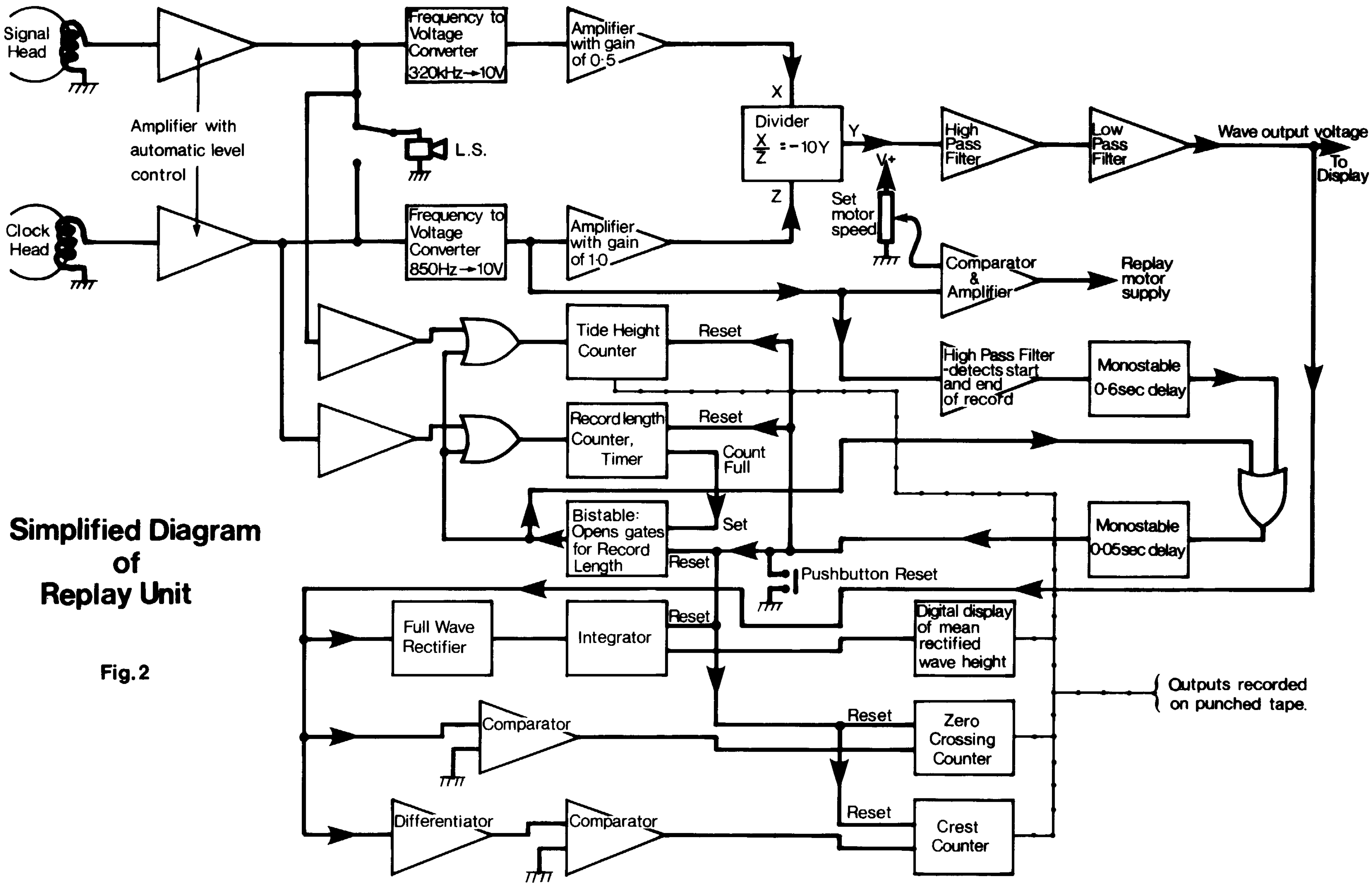


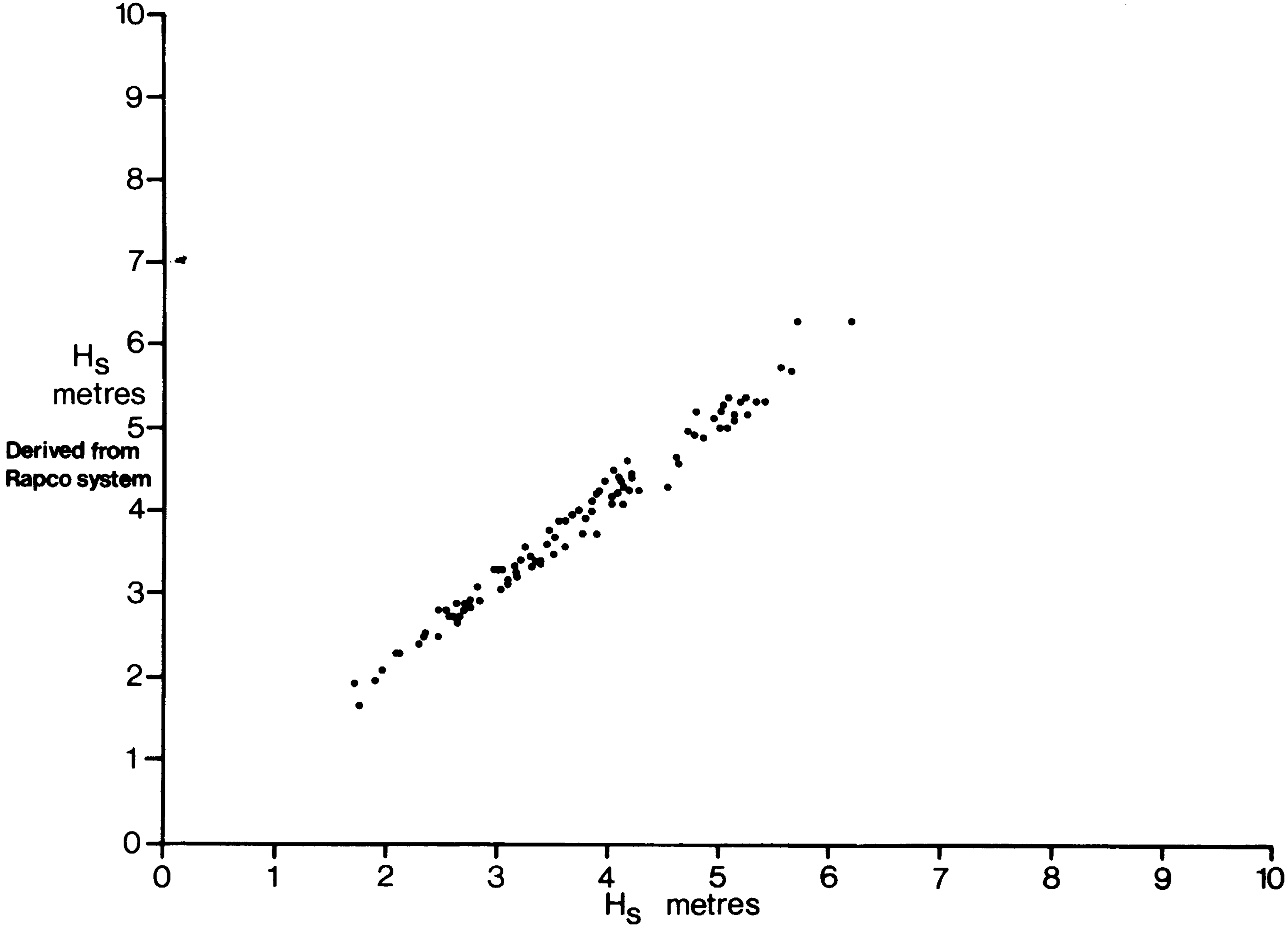

**Frequency response of head drive process.(Recorded at 1/70th replay speed)**

**Fig. 1**




**Simplified Diagram of Replay Unit**

Fig. 2



$H_S$ metres
Derived from Rapco system
$H_S$ metres
Derived from cassette system
0 1 2 3 4 5 6 7 8 9 10


Fig. 3