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ON THE RECORDING OF LOW FREQUENCY SIGNALS ON MAGNETIC TAPE

by

J MARTHINS

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ABSTRACT

A short review of the different methods of recording on magnetic tape is given together with the advantages and disadvantages of each method. Particular emphasis was given to the ability to record low frequencies. This review is given to verify a particular choice of recording technique, where the signals, in a frequency range from 1 - 100 cps, are recorded by the direct record method at a tape speed of 0.06 in. per sec. The playback is performed on a high quality machine operating at one of the conventional speeds (in this case 7-1/2 in. per sec was chosen). Thus a time compression of 125 times and a frequency multiplication with the same factor are obtained, in addition to a very long recording time.

A tape recorder based on these principles has been construçted and details concerning the mechanical and electronic units are given.

INTRODUCTION

A magnetic tape recorder, which uses direct record technique, has been built and tested by this laboratory. The recorder operates at a speed of 0.06 in. per sec and has a frequency range of up to about 100 cps (depending on playback characteristics). This paper describes the mechanical and electronic units and gives some experimental results. The recorder is used for recording purposes only, playback is performed on a standard machine operating at a conventional speed. Thus the recorded signals will be transformed into a frequency range that is suitable for playback. It appears that this technique is not too well known.

It is very convenient to have data recorded on magnetic tape. When the measurements site is remote from the analysis point some form of data storage is mandatory. Data can be transmitted immediately by telemetering, but this is desirable only when many channels are needed. Also, the data collection point may impose certain restrictions as to weight, size, and electric power.

The data to be collected were the outputs of transducers used in geophysical and oceanographic research. The chosen site was as isolated as possible from "man-made" electrical and acoustical noise. The signals to be recorded were of a transient nature with a large dynamic range of about 80 db. The frequency range was restricted from one cps to one hundred cps. The data had both short and long term fluctuations, i.e., day time - night time variations and seasonal variations. Therefore, continuous recording over long periods of time was desirable. Fortunately, the short term fluctuations had a much smaller dynamic range, so recording for a day or two could be done without any danger of overloading.

The type of analysis to be carried out on the recorded data was to find the power spectrum as a function of time. Also, correlation measurements were to be made between two or more recorded channels for the purpose of identifying signals in noise.

In the following sections a review of the different methods of recording will be given to select the simplest and most efficient type of recording to fulfil the requirements given above.

DIRECT RECORDING PROCESS

Since the direct recording process is used for recording speech and music, it is the best known recording technique. The technique consists of amplifying the signal to a suitable level and superimposing it on a high frequency ac bias. This combined signal then drives the recording head and thus records on the magnetic tape. However, since the output of the playback head approaches the noise level at low frequencies, direct recording is not suitable for frequencies lower than 50 cycles at conventional tape speed.

One of the problems of the direct record method is the signal to noise ratio. With 1% harmonic distortion measured at playback, the signal to noise ratio will be about 35 db, i.e., the noise level will be 2% of the full scale signal level. If 3% harmonic distortion can be tolerated the signal to noise ratio will be 40 db or 1% of full scale. The figures quoted are measured with wide-band noise at a normal bandwidth for a given tape speed.

Another problem of direct recording is amplitude instability. This is caused by the magnetic non-uniformity of the tape and by foreign material such as dust on the tape. The effect of the magnetic non-uniformity is a low-level, low frequency modulation, which may reach 5% at the 1% distortion level.

Direct recording has the advantage of giving the widest frequency range for any given tape speed and has the ability to handle moderate overloads without sudden or drastic increases in distortion.

FREQUENCY MODULATION RECORDING PROCESS

Frequency modulation is the most logical method for recording low frequencies. Basically, the FM system uses a carrier, or center frequency, which is modulated by the input signal so that the frequency of the carrier changes in proportion to signal amplitude change. The frequency swing of the carrier is $\pm$ 40% in the wide band FM, and the center frequencies are 54 kc, 27 kc, 13.5 kc, 6.75 kc, 3.375 kc, 1.687 kc and the tape speeds are respectively 60, 30, 15, 7.5, 3.75, and 1.875 in. per sec. The frequency response is from dc up to about 1/5 of the carrier frequency at each speed. The tape

is driven to saturation and no ac bias is used. This system avoids any instability due to tape imperfections because all the information is in the form of frequency changes, and any amplitude change will not give any output. The drawback of the system is the requirement for constant speed, since any change in speed will change the recorded frequency and give an output. The required tape speed is about 10 times that of the direct record process for a given upper frequency limit. The system also requires a more complex and power consuming electronic circuit.

CARRIER-ERASE RECORDING PROCESS

Carrier-erase recording is a rather new technique of tape recording, but it is interesting because it is simple and requires a minimum of electronics for the recording process. The principle is as follows: a carrier frequency is recorded on the tape so that the tape becomes saturated. This is done before the data is recorded on the tape. No ac bias is used. During the actual recording the signals are used to erase part of the pre-recorded carrier, the amount of erasure being proportional to the amplitude of the signal. After recording there will be a carrier frequency on the tape, which is amplitude modulated with the signals. In playback, this carrier is amplified, rectified, and filtered out, giving the recorded signal. The technique was tried in the laboratory with different types of record heads, none of which was specially made for this purpose. In spite of this, the system worked very well, although the dynamic range was quite small.

During the recording it is necessary to place the operating point on the linear position on the erase curve with a bias current (see Fig. 1). This bias, however, is a dc current and the signal current is superimposed on it. As can be seen from the curve, the dynamic range can be increased if signals of only one polarity are expected. If so, the dc bias current would normally be selected near the top or the bottom of the curve depending on the polarity of the signal.

The carrier frequency selected should be six to ten times higher than the highest signal frequency but, of course, must be within the frequency range of the playback machine. A high carrier frequency facilitates the filtering after detection.

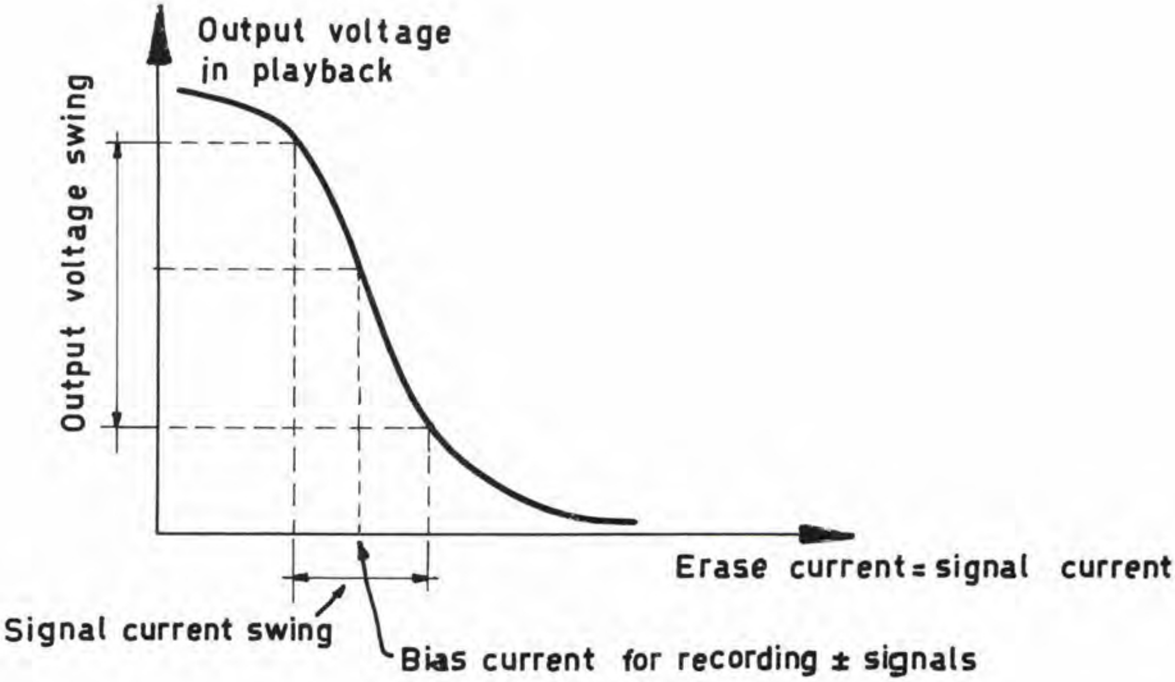

Fig. 1
Erase Characteristic

THE HALL-EFFECT PLAYBACK SYSTEM

Another new technique in playback of low frequencies on magnetic tape is the use of the Hall-effect[1]. The Hall-cell is a semi-conductor device, which is capable of transforming a magnetic induction into a voltage. This voltage is proportional to the product of the magnetic induction and a control current passing through the cell. By using such a Hall-cell in the magnetic circuit of a tape head, it is possible to overcome some of the drawbacks of a conventional inductive head. Here the only concern is with the playback process,

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1) F. Kuhrt, G. Stark, F. Wolf, "Wiedergabe von Magnettonaufzeichnungen mit Hilfe des Halleffektes", Elektronische Rundschau, No. 11 (November 1959), 407-408, (in German).

because, in the recording process, there are no important limitations as to low frequencies. Therefore, a normal inductive head can be used for recording down to very low frequencies and even dc, provided, of course, the record amplifiers are made to handle such low frequency signals.

It is well known that an inductive playback head has an output voltage proportional to the rate of change of magnetic flux. This means that the output is proportional to the frequency of the recorded signal. For the Hall-cell, on the other hand, the output is independent of the frequency and will give an output even if the tape were not moving. To play back dc and low frequency signals, it would be convenient to use a high frequency ac current for the control current through the Hall-cell. The cell will then work as a multiplier and the ac current will be modulated by the varying magnetic field on the tape. The playback amplifier must be tuned to the ac signal and the detector must be of a synchronous type in order to recover the original signals on the tape.

It must be recognized that the system described is only a modified direct record technique and, as such, will still have the problem of amplitude instability.

FINAL CHOICE OF RECORDING METHOD

After the preliminary work of studying the different techniques of recording, a decision had to be made as to which technique best suited the problem. As mentioned before, low frequency signals were to be recorded. They were of a transient nature and had a rather high dynamic range. Any choice of a particular type of recording system would be a compromise between the various electrical and mechanical factors.

The choice was a modification of the direct record technique, which enabled the recording and playback of low frequencies and, at the same time, kept all the advantages of the direct record process. The modification is extremely simple and consists of recording at very low speed and reproducing at one of the conventional speeds. In other words, the wavelength on the tape was the same in record and playback. This system has been used by the Pacific Naval Laboratory in Canada for their geomagnetic work[2)].

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2) H. J. Duffus and others, "Sub Audible Geomagnetic Fluctuations", Nature, Vol. 181, 1258-1259, (May 3, 1958).

The great advantage to this system is the time compression obtained at the same time that the low frequencies are lifted to a range where instruments of standard design can be used for analysis. For instance, if a frequency range from 1 - 100 cps is recorded at 0.06 in. per sec and played back at 7-1/2 in. per sec, there is a time compression with a factor of 125 and the recorded frequency range is lifted to 125 - 12,500 cps. This is a practical range for playback at 7-1/2 in. per sec.

Electrically this is rather simple since no provision is made for playback at the recording site. It is intended that this will be done on a high quality machine in the laboratory.

Mechanically, the only requirement is a rather simple tape deck with certain modifications for operation at the low speed.

The type of analysis to be made from the collected data was to find the energy spectrum and also to perform correlation measurements between two or more channels for the purpose of bringing signals out of noise. In the first case the unavoidable amplitude instability and drop-out effect of the direct record process would give an error. For correlation analysis, however, these drawbacks of the direct record process are not important. For this type of analysis, the amplitude information is of no interest since only the frequency and the phase are used.

The dynamic range of a tape recorder using the direct record process is not very much inferior to the FM record process. In this case the frequency band 1 - 100 cps, or the equivalent 125 - 12,500 cps at 7-1/2 in. per sec, is smaller than is normal at this speed; therefore, a better signal to noise ratio could be expected by proper filtering. Even if a signal to noise ratio of 40 db at 1% harmonic distortion could be reached, this is only one half of the expected dynamic range. Therefore, it appeared that by making a multichannel tape recorder, it would be advantageous to split up this large range into two or three channels, each with a gain difference of somewhat less than the dynamic range of the tape recorder, and to record each channel on separate tracks. In this way, the use of a logarithmic amplifier could be avoided. But, as mentioned in the introduction, the short term variations were of a much smaller dynamic range, so no splitting of the range was necessary in this case. In view of this, it was decided to use a 7-channel head with 1/2 inch tape.

A table which summarizes the pros and cons of the five different recording processes that have been described will be found on the following page.

Recording Process	Low Frequency Response	High Frequency responce for same tape speed	Complexity	Speed-up Slow-down feature	Dynamic Range for same Bandwidth
Direct record	Poor	Good	Small	Yes	Good
FM - record	Good - down to dc	Medium	High	Yes, but only at discreet intervals within the range of conventional speeds	Good
Hall-Effect	Good - down to dc	Good	Small record higher playback	Yes	Good
Carrier Erase	Good - down to dc	Good	Small record higher playback	Yes	Poor
Low Speed record High Speed reproduction	Good	Good	Small	Yes	Good

TABLE I

DESCRIPTION OF MECHANICAL UNIT

The materials used in this unit (see Fig. 2) are of sea resistant aluminium and stainless steel These are obvious requirements for equipment that would be used in the field. The driving motor (see Fig. 3) is a 6 volt dc motor, and the current consumption under load is 170 ma. The motor drives a rather heavy flywheel and the motor itself is governor-controlled by means of a switching transistor. This is to reduce contact wear and sparking, as well as weight and size of the rotating contact.

The motor and flywheel combination was borrowed from a commercially available unit, which was guaranteed to have a flutter and wow below 1% at a linear velocity of 3-3/4 in. per sec. The coupling to the capstan is through a worm gear with a ratio of 96:1 giving the capstan a linear velocity of 0.06 in. per sec. Naturally, the worm gear will somewhat impair the wow and flutter figure given above, but even 1 - 2% is quite reasonable for a battery operated tape recorder.

The mechanical system is rather simple, because there are no provisions for fast forward winding or rewinding of the tape It is possible only to record. This greatly simplifies such things as the brakes and drive of the tape. Also, because of the very low speed, such things as inertia roller and take-up tension arm are not required.

The supply reel has a simple adjustable brake that presses on the hub from below. This brake provides the tape hold back tension when the tape is moving and insures that the tape will be in contact with the record head. The pressure roller is forced against the capstan with a force of about 1 kg by a strong spring. There is a belt drive from the capstan to an adjustable friction drive on the take-up reel. This keeps the tape in tension after it has passed the capstan and winds up the recorded tape.

The recording time is almost six days and nights with a 10-1/2 in. reel of 2,500 feet of tape. It is possible, of course, to increase this some 50% by using thinner tape.

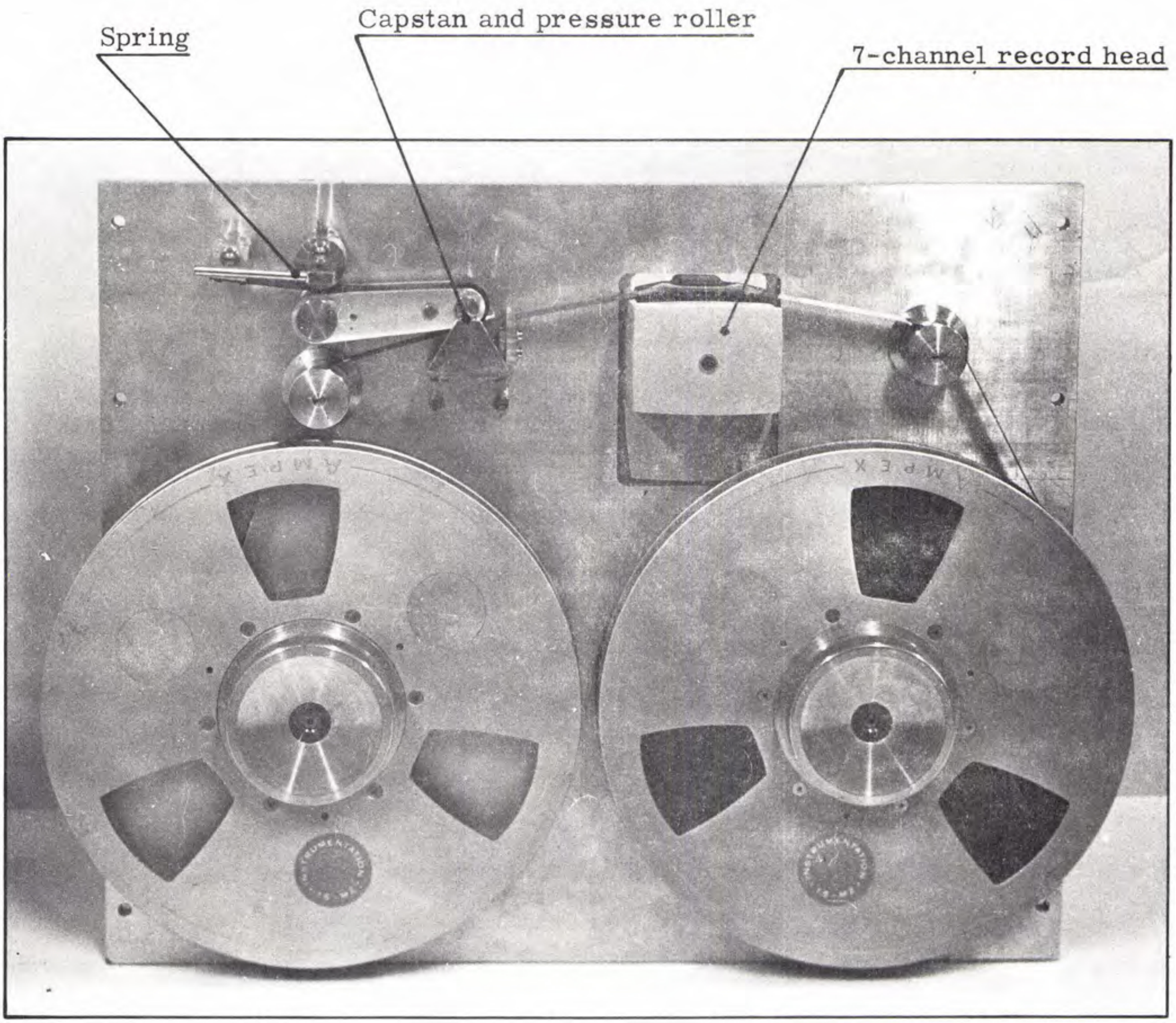

Fig. 2

Mechanical Unit (Front)

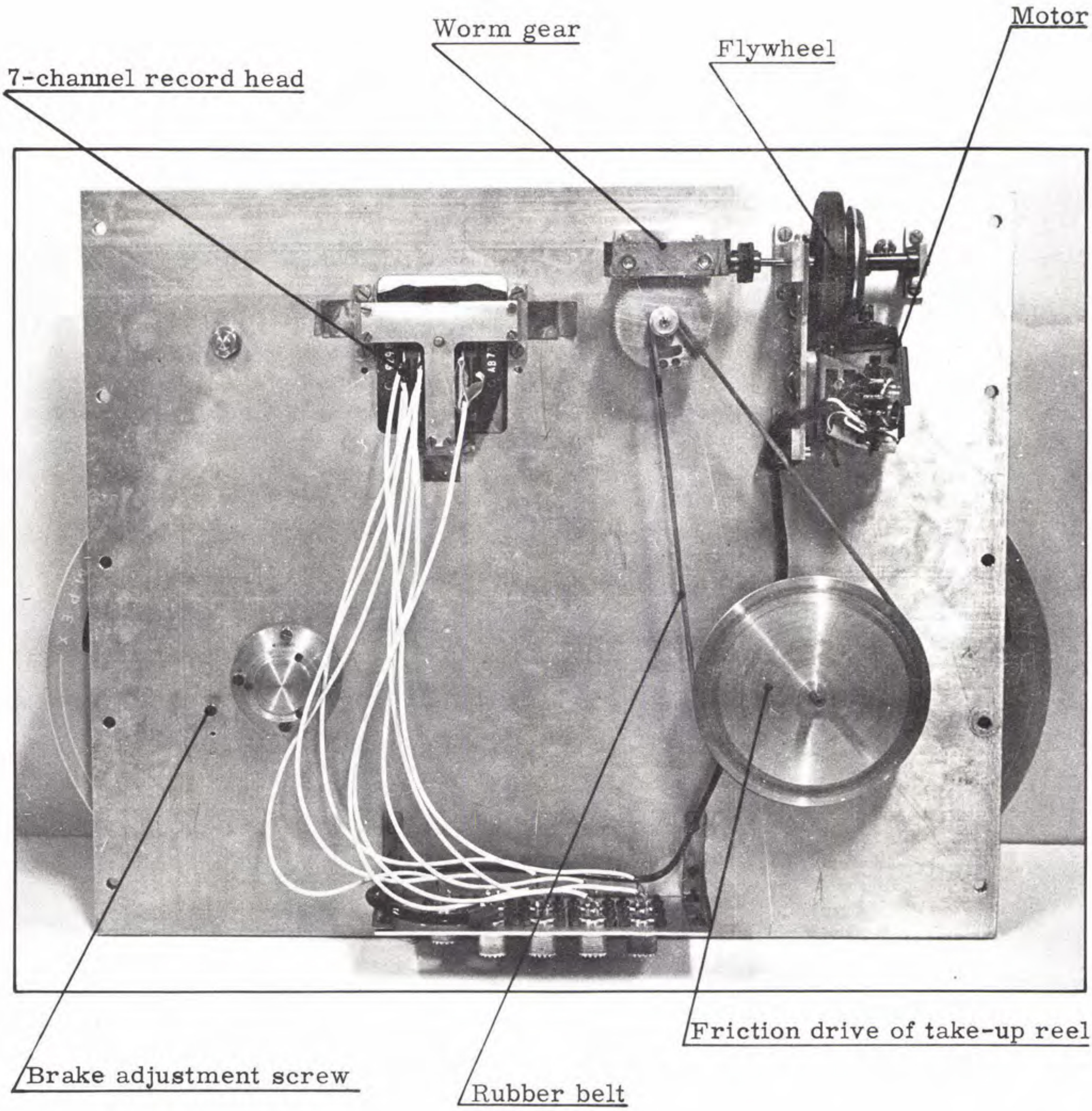

Fig. 3

Mechanical Unit (Back)

ELECTRONIC UNIT

(See Fig. 4)

As mentioned before, the record electronics are fairly simple. All that is necessary is an amplifier, which gives a signal current through the head proportional to the input voltage. At low frequencies, below a few hundred cycles per second, the impedance change of the head for change in frequency is negligible, so that a constant current drive is easy to arrange. An instrumentation recorder was planned for playback of recorded data. In such a recorder most of the equalization takes place in playback and only the eddy losses, leakage, etc., inherent in the record head are compensated during recording. These losses are typically high frequency losses, and therefore no equalization would be needed during recording of low frequencies.

The record head used is an AMPEX 7-channel interlaced type intended for wide-band recording. Its impedance and resistance is very low, thereby requiring high driving current both for signal and bias. The only reason for selecting this head was that it was available and the certainty that it would be compatible with the playback system on hand. Another head of higher impedance would do equally well and large savings in current drive could be made.

The record-amplifier (see Fig. 5) is of the complementary symmetry type. The circuit gives push-pull operation without the use of a phase splitter or phase inverter by utilizing an n-p-n and a p-n-p transistor. The required signal current to the head is 1 ma rms. This current corresponds to 0 volume units (VU) on the meter. The amplifier is so designed that it can give 2 ma rms without overloading. The rather high supply voltage is necessary because constant drive is required. The lower frequency limit of the amplifier is 1 cps. The requirement for bias, as specified by the manufacturer of the head, was 18 ma at 1 Mc. In this recorder the bias frequency has been reduced to 50 kc and the current requirement could be reduced to 13 - 14 ma. This value of current was found experimentally to give the best uniform frequency response.

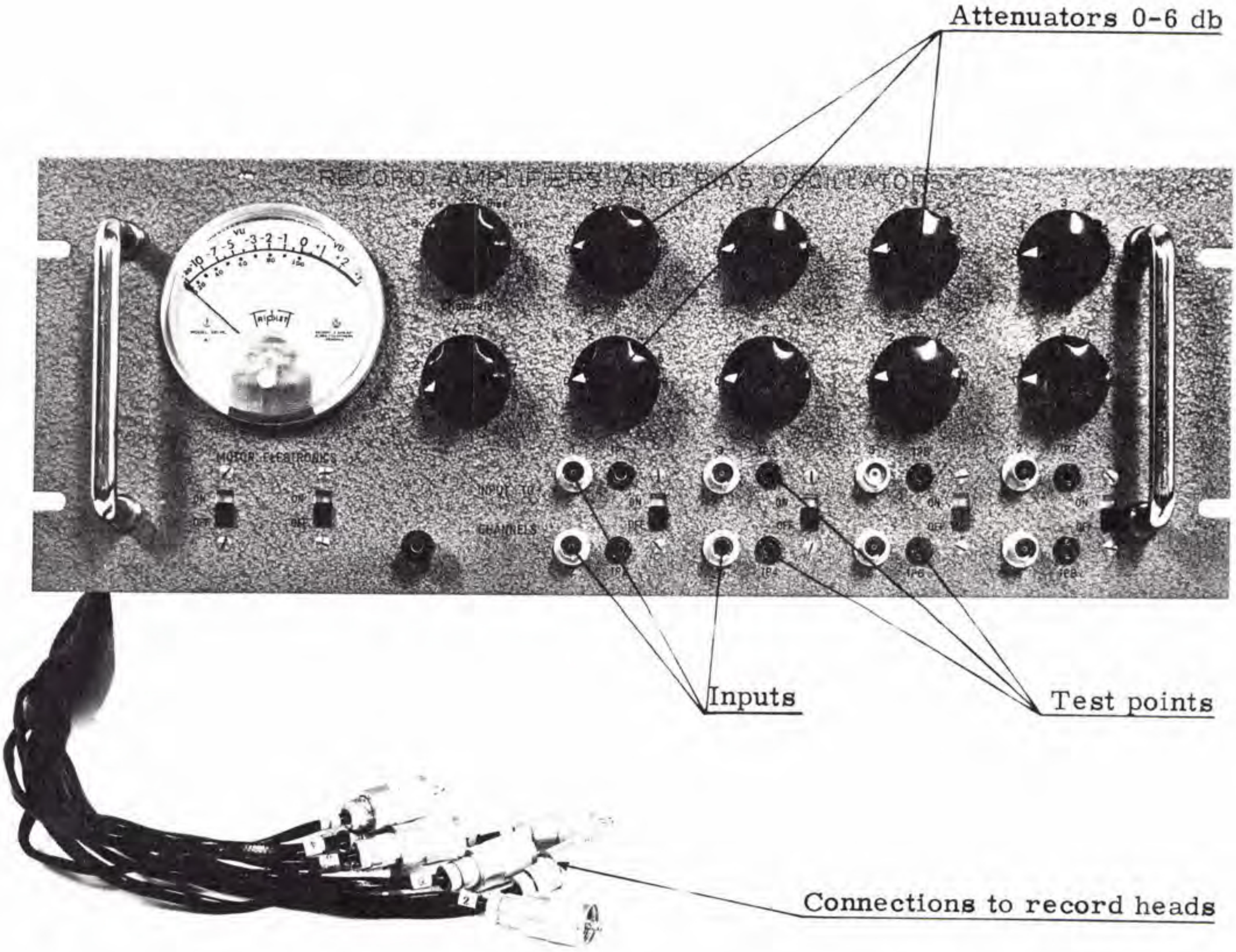

Fig. 4

Electronic Unit

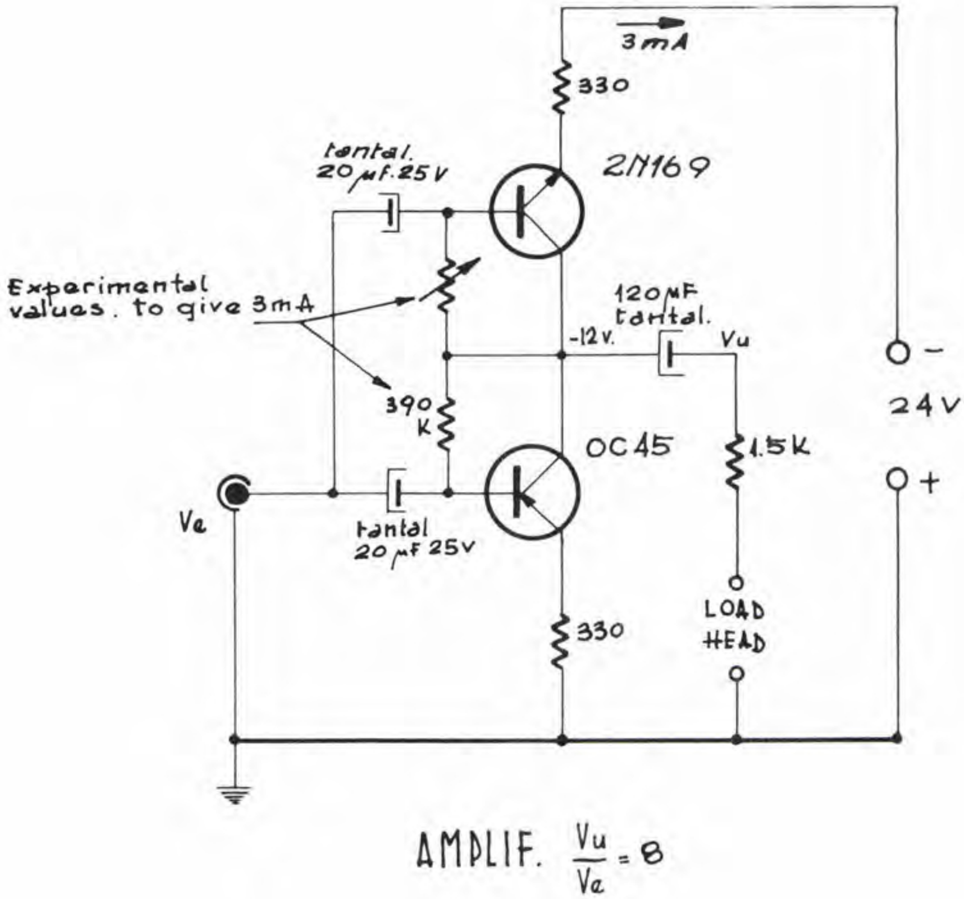

Fig 5

Recording Amplifier

The bias oscillator (see Fig. 6) is of the push-pull transformer coupled type. The harmonic content was measured to be 0 2%. This circuit has a number of features such as high efficiency, low distortion and low output impedance[3].

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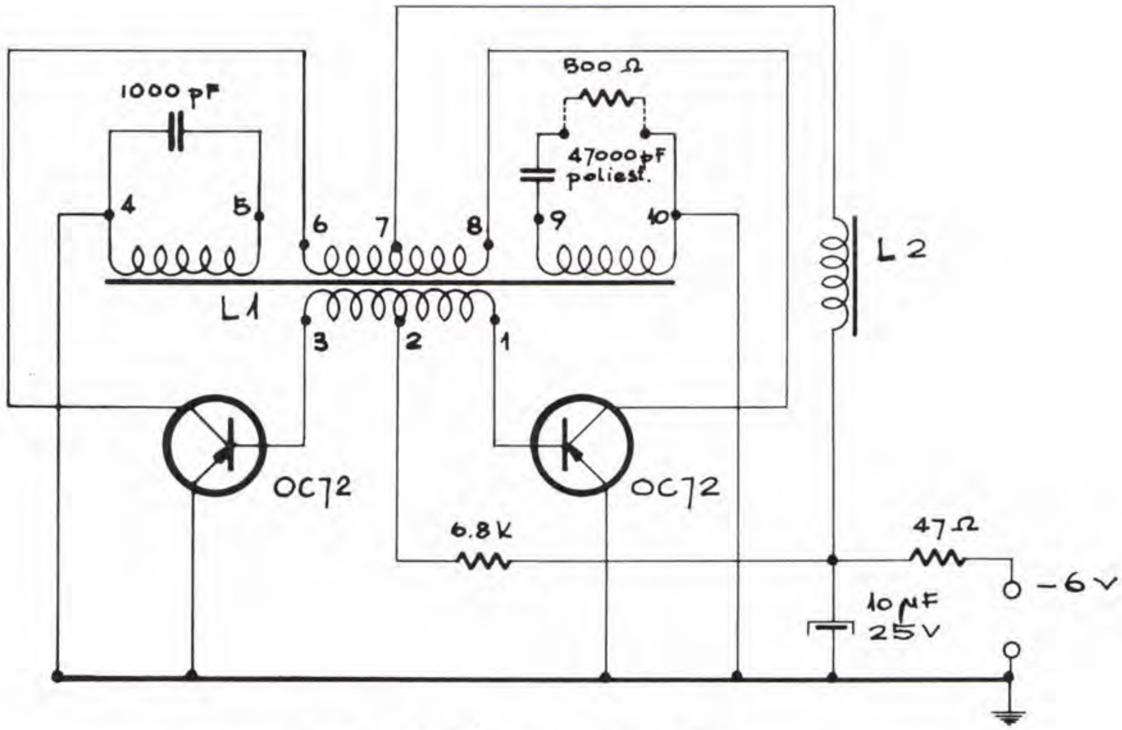
3) P. J. Baxandall, "Transistor Sine-wave LC Oscillators", The Proceedings of the IEE, Vol. 106, 1959, Part B Supplements Nos. 15-18, 748-758.



L2 = 73 TURNS 0.5E
1-3 = 4 TURNS 0.25E
4-5 = 160 TURNS 0.14E
6-8 = 32 TURNS 0.25E
9-10 = 23 TURNS 0.25E

Fig. 6

Bias Oscillator

The bias current and record current can be checked by observing the voltage drop across a 100 ohms resistor in series with the head, (see block diagram Fig. 7). This voltage drop can be measured externally at the test points and internally with the VU meter.

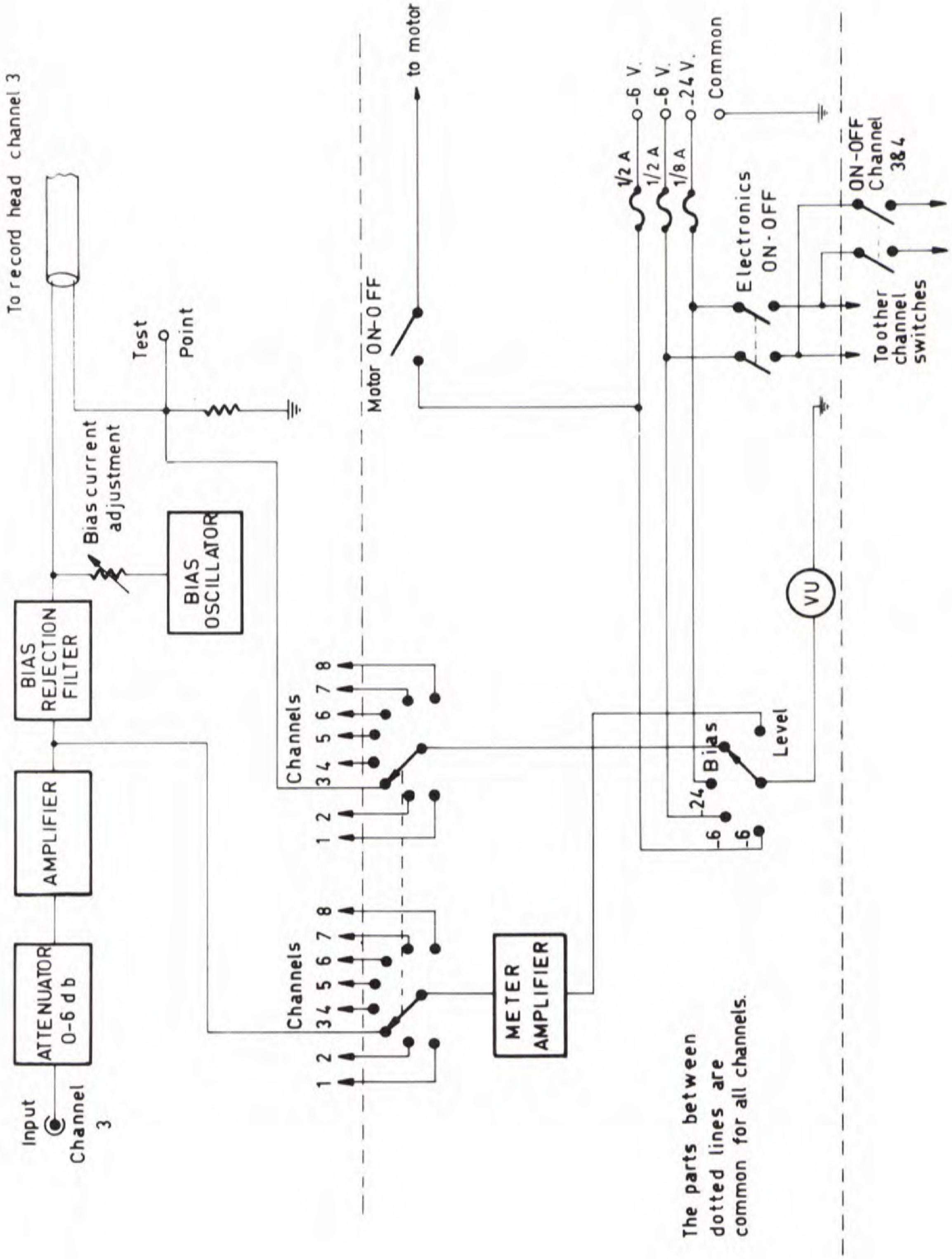


Fig. 7

Block Diagram

MEASUREMENTS

The results of some tests performed on the tape recorder will be given in the following. In all cases the playback was done on a high quality tape recorder with a flutter below 0.3% peak to peak.

The tape speed was checked simply be recording a precise 10 cps square wave from an electronic counter on the low speed, low frequency recorder. When played back on the high quality machine at 7-1/2 in. per sec the output signal was measured with the same counter and its frequency was found to be 1244 cps. This means that the speed-up factor is 124.4, and that the speed of the low frequency recorder is 7.5/124.4 = 0.0603 in. per sec. This small deviation from 0.06 in. per sec is due to the tolerance on the mechanical parts of the recorder.

To measure the flutter of the recorder, a precise 100 cps square wave was recorded with a level high enough to saturate the tape; therefore, no ac bias signal was needed. The tape was then played back on the high quality unit and the output was fed through low-pass and high-pass filters to a discriminator.

The playback speed used was 30 in. per sec giving a speed-up of 500 times. Therefore, the playback frequency would be 50 kc and low-pass and high-pass filters ahead of the discriminator were arranged to have a broad band pass around this frequency in order to hinder noise from entering the discriminator. The output of the discriminator was filtered with a low-pass filter with a band from dc - 10 kc, for the purpose of removing the 50 kc and to restrict the band width for the measurements of the flutter components. The output of the discriminator was measured with an oscilloscope and an rms volt meter. The flutter measured in this way was 1.6% rms or 12% peak to peak.

To check the overall signal to noise ratio of the recording and playback system, a signal source with a low distortion was used to record on the tape using the low speed, low frequency recorder. One recording was made with a current of 1 ma through the recording head corresponding to 0 VU on the meter, and a second recording was made at a level 6 db higher.

The signal frequency was 40 cps giving 5000 cps in playback at 7-1/2 in. per sec. The second and third harmonic was measured to be 0.45% and 0.6% respectively for the 0 VU level, and 1.5% and 1.8% for the +6 VU level recording. These figures give a total harmonic distoration of 0.75% at 0 VU and 2.35% at +6 VU. The corresponding signal to noise ratios were measured to be 44 db at 0 VU and 50 db at +6 VU when the bandwidth of the playback system was restricted to 125 - 12.500 cps.

LIST OF SPECIFICATIONS

Tape speed	0.06 in. per sec
Tape width	1/2 in.
Number of tracks	7 interlaced
Power:	
Motor	6 volt 1 watt
Electronics (all channels on)	22-24 volt 1.2 watt 6 volt 0.6 watt
Frequency response (when played back on Ampex FR 600)	1 - 250 cps
Flutter	1.6% rms, 12% peak to peak
Signal to noise ratio:	
at less than 1% harmonic distortion	44 db
at less than 3% harmonic distortion	50 db
Recording time with 10-1/2 in. reel 2,500 feet of tape	140 hr
Bias frequency	50 kc, less than 0.2% harmonic distortion.
Recording level indicator	VU meter
Electronics:	
7 independent record channels plus one spare each with its own bias oscillator. Input impedance	10 kohm

No provision for erasure of tape

Both tape deck and electronic unit will fit a 19 in. rack.

CONCLUSIONS

The tape recorder that has been dealt with in the preceding sections should be of general interest in many fields, because it can be adapted easily for other work. The tape speed and the speed-up ratio in play-back can be altered to make the recorder respond to other frequency ranges. It seems that in cases where reproduction of the dc component of the signals is not necessary, often the system can replace an FM type of recording, thereby reducing the complexity of the recording apparatus.

ACKNOWLEDGEMENT

The author desires to thank Mr. L. Brock-Nannestad for his generous advice on the preparation of this paper.