The Journal of

THE BRITISH INSTITUTION OF RADIO ENGINEERS

FOUNDED 1925 INCORPORATED 1932

"To promote the advancement of radio, electronics and kindred subjects by the exchange of information in these branches of engineering."

VOLUME 20 OCTOBER 1960 NUMBER 10

SPECIALIZED GROUPS

FROM the development of *wireless* for communication purposes there has arisen an ever increasing variety of application. In the more appropriate connotation of radio engineering there has grown an industry whose products are required by every nation, by nearly every other industry, and whose techniques now reach into almost every form of scientific activity.

Less than forty years ago, the new art of radio was regarded by some as a small and rather specialized form of scientific and engineering activity. Educationally and otherwise it was hardly regarded as of sufficient importance to warrant special encouragement. Today, in the vast field covered by radio science and engineering, a number of specialized techniques have been developed, many of which call for engineers who have received specialized training and education, albeit based on the principles of radio engineering.

Whether these relatively new industrial applications justify the special appellation "electronic engineering" is often debated. In the Institution the term is not a new one having, in fact, been described by the first President in 1932.* Sufficient that the Institution has always promoted development of these specialized activities and, with the growth of membership interest, professional activity in one or more of these specialized branches has resulted in the formation of Groups within the Institution catering especially for members with those particular professional interests.

It is in this way that the Institution will best be able to cater for those members wishing to exchange ideas by means of meetings, publication of papers in the *Journal*, etc., but in all other respects such members will remain within the framework of the Institution and will join together in fulfilling the main object of the Institution as stated in the *italics* in the heading of this page.

The first five of these specialized Groups have already made their impact on Institution activity. Let it not be thought, however, that in this work the Institution is to be divided. It is impossible for anyone to be the compleat radio engineer in the sense that all the various developments of the art may be wholly encompassed by any individual. Specialized activities emanate, however, from the fundamental study of radio engineering; the techniques which are developed for application to, say, television, may readily find application to wider fields, such as radar and, in different form, to biological and medical research.

Thus there is still the need for a common pool of knowledge so that the engineer with specialized interests is not entirely deprived of using his fundamental training and experience, and that specialists may have contact with each other within the broad field of radio engineering. It is still the responsibility of the Institution to provide the means for such contact.

The success of the first specialized Groups now permits implementation of the editorial "Meeting Different Needs".† A response to the notice recently sent to all members will enable the Group Committees to sift replies and collaborate with the local Section Committees in providing opportunity for members with specialized interests, wherever they may be situated, to meet and discuss their ideas.

G. D. C.

---

* See "A Twentieth Century Professional Institution —The Story of the Brit.I.R.E.", page 18.

† *J.Brit.I.R.E.*, August, 1959.

B

INSTITUTION NOTICES

Convention on "Radio Techniques and Space Research"

The 1961 Convention will be held in Oxford from Wednesday, 5th July, to Sunday, 9th July, inclusive. The headquarters of the Convention will be at Christ Church which, as members may recall, was the venue of the 1954 Convention. It is probable that it will be necessary for additional residential facilities for delegates to be provided in other Colleges. The technical meetings will be held in the lecture theatres of the University.

Details of registration fees, etc., will be published in the New Year together with an outline programme. The Council has set up a 1961 Convention Committee under the chairmanship of Mr. Ieuan Maddock, O.B.E., B.Sc. (Member). Members are invited to send offers or suggestions for papers for inclusion in the programme to the Institution for consideration by the Convention Committee.

Date of the Annual General Meeting

The Annual General Meeting of the Institution will be held on Wednesday, 11th January, 1961, at 6 p.m. in the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, W.C.1. Formal notice of the meeting and the Agenda will be published in the November issue of the *Journal*. Corporate members wishing to raise points for discussion are invited to give notice to the General Secretary not later than 30th November.

In accordance with custom, the Annual General Meeting of the Institution will be followed at 6.45 p.m. by the Annual General Meeting of the Subscribers to the Brit.I.R.E. Benevolent Fund.

Programme of Institution Meetings

The booklet of Institution meetings to be held in London and by Local Sections during the first half of the 1960-61 Session (up to January) has been sent to all members in the United Kingdom.

Members are asked to note the following alterations which have been made since the booklet was distributed :

London—Electro-Acoustics Group.

The papers announced for reading on Wednesday, 23rd November, and on Tuesday, 13th December, have been interchanged.

North Eastern Section.

The meeting announced for Wednesday, 7th December, will be held a week later, on Wednesday, 14th December.

The Programme for the second half of the Session (generally from January to May) will be circulated to all members in December together with diary "stickers".

Facilities for Overseas Members

For the convenience of members and *Journal* subscribers outside Great Britain, the Institution has set up local banking accounts or made other special arrangements for the payment of subscriptions, etc. The following banks accept payment in local currency.

CANADA AND U.S.A. :	Imperial Bank of Canada, 304, Bay Street, Toronto.
SOUTH AFRICA :	Barclays Bank D.C.O., 40, Simmonds Street, Johannesburg.
NEW ZEALAND :	The Bank of New South Wales, P.O. Box No. 53, Auckland.
AUSTRALIA :	The Bank of New South Wales, 341, George Street, Sydney.
INDIA :	The State Bank of India, 40, St. Mark's Road, Bangalore 6.
PAKISTAN :	The National Bank of Pakistan, PMA Building, Nicol Road, Karachi 2.
FRANCE :	Barclays Bank (France) Ltd., 33, Rue du 4-Septembre, Paris.

Other countries where banking arrangements have been made in order to facilitate payment in local currency:

GREECE :	Any branch of the Ionian & Popular Bank of Greece or of the Commercial Bank of Greece.
ISRAEL :	Any branch of the Anglo-Palestine Bank.

In these cases the bank should be requested to remit the money to the Institution through their London correspondents.

Instrumentation Magnetic Recording †

by

P. E. AXON, O.B.E., PH.D. ‡

A paper read at a Symposium on Magnetic Recording Techniques, held in London on 15th December, 1959.

In the Chair : Dr. G. L. Hamburger (*Member*).

Summary : The paper surveys the general field of instrumentation magnetic recording. The individual requirements for analogue and digital recorders are examined and the influence of these requirements on mechanical design, electronic equipment and magnetic tape is illustrated.

1. Introduction

Instrumentation magnetic recording is a description of magnetic recording applications concerned with the acquisition and processing of data. The data recorded may represent physical quantities or numbers expressed either as an analogue or a digital signal.

The copious memory property of the system is employed to enable both the data, and calibrations or instructions connected with it, to be reproduced for subsequent analysis and calculation. The magnetic recording system is capable of recording and reproducing information covering a wide frequency range at a high rate and with a convenience which is unequalled by any other system yet developed.

The recording process is frequently an analogue process based on the ability of the magnetic pattern on the tape to form an analogue of quantities being measured. In an experiment or process under investigation, measuring devices or transducers are employed to convert various physical magnitudes or changes to electrical voltages which can be amplified and applied to the recording head. In the reproducing process, the reproducing head provides a signal which can be made representative of the signals recorded. In other applications, such as the memory units of digital computers, the information recorded may be in digital or coded form, and special arrangements may be incorporated into the mechanical system of the recording machine to enable it to record or reproduce information in a discontinuous manner, in accordance with the demands of the data processing system. A memory tape may consist wholly of a programme of instructions intended to control the operation of a computer, a machine tool, or an industrial process.

In the fields of both data acquisition and data processing, the errors introduced by the recording and reproducing processes must at least be known so that, if necessary, they can be allowed for. Preferably, however, they should be small in comparison with the inaccuracies inherent in the information supplied to the recording system. This requirement has led to highly-developed pieces of recording equipment which incorporate all the techniques of telecommunications and servo-engineering to reduce the contribution of the recording system to amplitude errors, timing errors and noise signals.

In a survey of the field it is convenient to deal with requirements and possibilities under the two general headings of "Analogue Recording" and "Digital Recording." There is an increasing tendency nowadays for analogue

---

† Manuscript received 16th August 1960. (Paper No. 583.)

‡ Ampex Electronics Ltd., Reading Industrial Estate, Whitley Kiln, Reading, Berkshire.

U.D.C. No. 621.395.625.3

recording to be largely associated with data acquisition, and for digital recording to be associated with data processing, but the related classifications are by no means rigid, so that much data acquisition is in digital and much data processing is in analogue form.

2. Frequency Response and Signal/Noise Ratio

The first requirement of the recording system is that it should be capable of recording the frequency and amplitude ranges of the signals being fed to it with acceptable signal-to-noise ratio. Figure 1 shows the direct-recording frequency response which production high-grade recording equipment can provide at various speeds using the longitudinal recording method and suitable high-frequency bias. Extended frequency responses are, of course, obtainable at any of these tape speeds, and at higher tape speeds, but we are concerned here with a standard which may be obtained, on a regular and dependable basis, by a user who is prepared to devote a normal amount of time to the maintenance and operation of his recording equipment, but not to find it an uncertain or unduly time-consuming link in his apparatus chain.

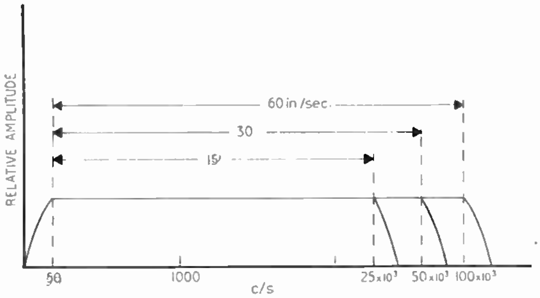


Fig. 1. Direct recording frequency response at various tape speeds.

The signal/noise ratio obtainable depends, of course, on the bandwidth which is employed at any particular tape speed. At 60 inches per second, for example, using a normal recording level, the signal-to-noise ratio over a bandwidth of 100 c/s to 100 kc/s is 34 db. If the bandwidth is reduced to cover from, say, 300 c/s to 60 kc/s, the signal-to-noise ratio rises to 42 db.

3. Speed Constancy

A second important requirement of the recording system is that the arrangement of the signals in time which it has recorded and reproduced shall be preserved to the accuracy required. This means that (a) transient tape speed variations (wow and flutter) must be known and acceptable, and (b) that the mean, absolute tape speed must be reproducible with known and acceptable limits in both the recording and reproducing processes.

Wow and flutter can arise from inaccuracies in the rotating elements of the system. In high-grade instrumentation equipment, therefore, manufacturing tolerances must be held to a minimum, so that regular wow or flutter patterns are, for practical purposes, small. However, this counsel of perfection has its practical limitations, and transient effects will always arise from the tape spooling system, the tape, the motors, and other sources over which the machine manufacturer may have less precise control. In order to reduce these effects to a minimum, various forms of mechanical filtering must be introduced, and, in extreme cases, sufficiently quick acting servo-mechanisms must be provided to correct tape speed over the heads.

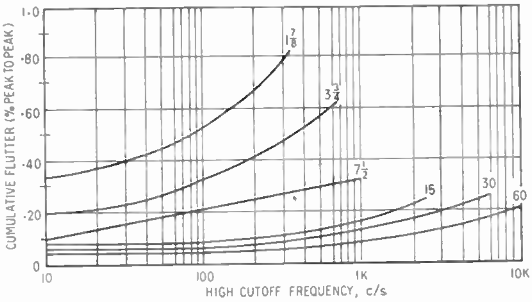


Fig. 2. Maximum cumulative flutter at various tape speeds. Recorded and played back at speeds indicated.

Speed transients, or wow and flutter, appear in a variety of fundamental frequencies, depending on their origin and the design of the equipment. The magnitudes which can be specified for any equipment, depend on the wow or flutter frequency range over which a measurement is made. Figure 2 illustrates conservative standards which can be obtained on a controlled production equipment. The curves apply to one-inch and half-inch tape transports, and they illustrate maximum cumulative flutter.

As higher flutter frequencies are taken into account, the maximum cumulative flutter rises with a slope depending on the nominal tape speed. For any given design of multi-speed machine, the cumulative flutter is lower at the higher tape speeds. This is because the filtering action provided by the inertia of the principal moving elements, such as flywheels, reels of tape, motor rotors, etc., is increased with the increasing frequency of rotation associated with higher tape speeds.

Variation in the mean tape speed is another factor of great interest in high-accuracy investigations. The order of error pertaining to an average equipment giving wow and flutter as shown in Fig. 2 is ±0·25 per cent. at 60 in./sec. This represents a timing accuracy of ±150 milliseconds per minute in information recorded on such a machine. If higher mean-speed accuracy is required, it is usual to introduce a servo tape-speed control. In such a system, a frequency standard signal is recorded simultaneously with the recording of the rest of the information. Any transient or mean-speed errors which occur in the recording process will then appear as frequency changes in the standard signal when it is reproduced with the other information recorded. At the same time, frequency changes in the standard reproduced signal due to imperfections in the reproducing process will be superimposed on those registered in the recording process. The resultant frequency variations, which are directly indicative of the overall speed variation in both recording and reproducing processes, form the basis of an error signal which may be used to energize the servo speed-control system. The absolute accuracy obtainable in such a system cannot, of course, be greater than the stability of the frequency standard itself. Normal accuracy time standards are available commercially having an accuracy of two parts in 10^4 in 24 hours or four parts in 10^4 in one week. Where higher accuracies are required, standards may be obtained having an accuracy of two parts in 10^5 in 24 hours, or four parts in 10^5 in one week. A suitable servo system used in conjunction with these frequency standards enables the instantaneous time displacement errors due to random disturbances to be reduced to the order of ±0·25 msec at 60 in./sec rising to ±1 msec at 1⅞ in./sec. Figures of the same order specify the mean speed error.

4. The Heads

For reasons pertaining to efficient manufacture and to ease of interchange of tapes between machines, it is desirable that certain physical dimensions and parameters of multi-track heads should be standardized. Such factors are the number of tracks which are to be provided for various standard widths of tape, the width of these tracks and the separation between them. The key dimensions adopted are, of course, a compromise based on the influence of various conflicting requirements, and the performance which it is possible to obtain by careful design and manufacture of the head. Two important factors are signal/noise ratio in the recording, and the utilization of the information storage capacity of the tape to a maximum. Good signal/noise ratio demands a certain minimum width of track, with each track being separated from its neighbour by a distance which reduces crosstalk to an acceptable degree. In analogue recording, a standard of seven tracks on ½ in. tape, or 14 tracks on 1 in. tape, is commonly employed with a track width of 0·050 in., and a spacing of 0·070 in. between the centres of tracks. These dimensions provide the order of signal/noise ratio discussed previously. Narrower tracks and closer spacings maybe, and have been, employed, but reduction of signal/noise ratios are to be expected.

In digital recording, where some aspects of signal/noise ratio are less important (but other aspects, as will be shown, are more important) 8 or 16 tracks are commonly employed, these numbers being, of course, determined by the requirements of the coding system employed in the computer design.

Since multi-track recording is usually adopted for the purpose of recording many pieces of information simultaneously, it generally follows that the relative timing accuracy between tracks must be high. The head manufacturer must, therefore, pay much attention to the scatter of gaps within the stack, i.e. to the relative longitudinal displacement of the various gaps along the direction of motion of the tape. Errors of this kind introduce phase errors between the signals recorded on the various tracks. Having regard to the nature of the two processes, it is usual to define scatter with reference to the trailing edge of the recording-head gap and the centre line of the reproducing-head gap. In either case, it is possible by careful manufacture to reduce recording-or-reproducing-gap scatter in a 7 or 14-track head to within a band of 0·0001 in.

A further factor of great importance in the manufacture of multi-stack heads is the accuracy of alignment between gaps in the stack. As is well known, if the maximum performance, especially at short wavelengths, is to be obtained from the recording system, the recording and reproducing-head gaps must be identically aligned with respect to the tape motion. In a fixed or potted head stack, such as is now generally employed, only one position of alignment between recording and reproducing head stacks is possible. It follows that this must, ideally, be the correct alignment for all tracks. For analogue recording it is possible to manufacture production heads with gap alignment within ±1 minute of perpendicular for all gaps in the head stack relative to, say, the baseplate, the same figure applying to all heads. In such circumstances, no provision need be made for head alignment.

5. The Tape

A principal element in the system, which determines both possibilities and limitations, is the tape itself. With the head, it forms a fundamental combination on which depends signal/noise ratio and frequency response. Although some years ago the tape itself was a governing feature of high-frequency (or short-wavelength) response, it is probably true to say that nowadays the advances in magnetic tape manufacture are such that the tape is capable of recording shorter wavelengths than can be satisfactorily recorded by the recording head or resolved by the reproducing head.

All modern tapes are composed of a non-magnetic flexible backing and a magnetic coating, consisting of magnetic particles and a binding agent. In the coating, the particle size, the coating thickness, and its composition have an important bearing. The coating should be a highly-uniform mix of uniform thickness, and it should be free from either major magnetic or non-magnetic discontinuities. Large particles, either magnetic or non-magnetic, which project from the surface must be avoided at all costs, for their presence provides a major noise contribution, commonly referred to as "drop-outs." The projections cause separation of the tape from the head in both the recording and reproducing processes, and severe amplitude fluctuations result. "Drop-outs" become especially important as the track width is reduced (as in multi-track recording) and when very short wavelengths are being recorded and reproduced.

The ability of the coating to withstand frequent recording and reproduction without damage is also essential, for both in modern analogue and digital recording a set of signals, or a programme, recorded on any piece of tape may have to be reproduced some hundreds of times with a high expectation of reliability.

These conditions also impose severe requirements on the backing, which must be mechanically stable over a long period of time, often in adverse environments, and which must withstand severe forces imposed by driving and guiding at high speed.

The dimensional tolerances of the tape must also be closely controlled to adhere to the standards laid down for machines and heads. Correct guiding of the tape is especially important when short wavelengths are being recorded and reproduced, in order that the angle of the tape with respect to the heads does not vary and create losses due to misalignment. Clearly, the high accuracy of head manufacture will be wasted if the correct alignment, or guiding, of the tape itself over the heads cannot be maintained. High accuracy guiding must assume that the tape width is controlled within close limits, and that it is free from any of the undesirable effects, such as curling or rippling, which arise from a poor slitting technique.

6. Analogue Recording

6.1. *Types of Recording*

6.1.1. Frequency modulation recording

The nature of the conventional reproducing process, which involves the generation of a voltage in the reproducing head dependent on the rate of change of flux around the core, presents a fundamental difficulty in dealing with the lowest recorded frequencies of from, say, 0-30 c/s. The long wavelengths associated with these frequencies can also lead to difficulties, for the head becomes an inefficient collector of flux as the wavelength on the tape becomes comparable with its overall dimensions. The first of these difficulties, but not the second, may be overcome by the use of a flux-sensitive head, but these have found no widespread application in analogue recording work, since they require the introduction of extra electronic units, they are complicated to manufacture and, as noted, they solve only part of the problem. All of the reproducing difficulties can be resolved by the use of a modulated-carrier system, which enables all the information to be recorded in frequency and wavelength ranges in which the reproducing head is efficient. When, as is common, frequency modulation is employed, the noise-limiting properties inherent in the frequency-modulation detection system may be utilized to improve the signal-to-noise ratio of the wanted information. The direct recording frequency response, as shown in Fig. 1, is therefore utilized to accommodate the carrier, and sufficient of the sideband information which results from its modulation. The fraction of this available recording bandwidth which is taken up by the carrier and its sidebands depends on the bandwidth of the modulating information and the deviation employed. Figure 3 illustrates the information which can be satisfactorily recorded when a wide deviation giving a high signal/noise ratio is employed. If a low-frequency, low-bandwidth modulating signal is to be recorded, lower deviations and lower tape speeds may be used. If desired, a frequency-modulation multiplex system may also be introduced which allows the wide direct-record bandwidth to be utilized for the recording of several, suitably displaced, carriers and their sidebands. The carriers and their deviations must, of course, be chosen so that no overlapping of sidebands occurs.

A frequency-modulation system must also be employed when high-accuracy recording of the input-signal amplitude is required. In such a system, the registration of amplitude is dependent on frequency deviation only, and is removed from the direct influence of the frequency/amplitude characteristics of the heads, tape and the associated electronics. In arrangements such as that illustrated by Fig. 3, the signal/noise ratios obtainable in the modulating frequency ranges shown are about 48 db at 30 and 60 in./sec tape speed, falling to 40 db at $1\frac{7}{8}$ and $3\frac{3}{4}$ in./sec.

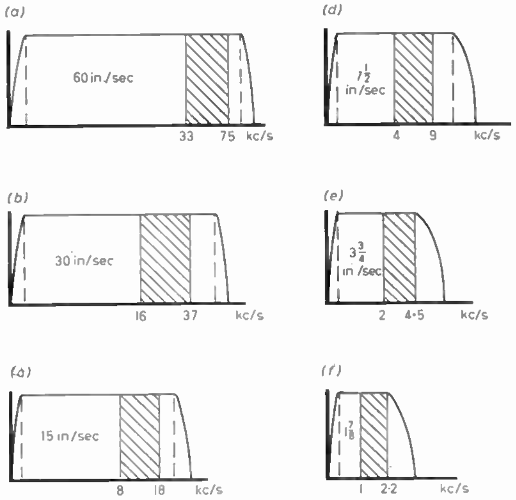


Fig. 3. Carrier and modulation bandwidths at various tape speeds.

(a) Frequency response d.c. to 10 kc/s (20 kc/s with reduced quality).

(b) d.c. to 5 kc/s. (c) d.c. to 2·5 kc/s.

(d) d.c. to 1·2 kc/s. (e) d.c. to 600 c/s.

(f) d.c. to 300 c/s.

Absolute timing accuracy in the signals recorded dictates the same requirements for speed control as were described earlier. It must now be remembered, however, that wow and flutter manifest themselves also as a frequency modulation of the carrier, and this results in unwanted noise components. Wow and flutter compensation, in addition to increasing timing accuracy, therefore, improve signal-to-noise ratio, and up to 10 db improvement may be obtained by the introduction of a servo speed-control equipment.

6.1.2. P.d.m. recording

An instrumentation recording system is frequently required to record the output of many different sources of information simultaneously. It is for this reason that the multi-track system is commonly employed. Mention has already been made of the use of a multiplex frequency-modulation system where the tape speed, and the bandwidths of the various pieces of information to be recorded, allow this to be done. Another system of multiplexing is sometimes employed, known variously as pulse-duration modulation (p.d.m.) or pulse-width modulation (p.w.m.). A schematic diagram illustrating the system is shown in Fig. 4. The principle of the system rests on the fact that the frequency and amplitude of any sine-wave can be accurately expressed from information obtained by sampling or measuring its amplitude at regular intervals. If the information obtained is to be meaningful, an adequate number of samples must be taken in the course of one cycle. Therefore, the more complex the waveform, or the greater the accuracy with which the variations in it must be expressed, the greater must be the sampling rate applied. Here again, then, the circumstances under which the p.d.m. method may be applied depends on the recording-frequency bandwidth available and the frequency content of the information signals being recorded. The lower the frequency content of the signals, and the higher the recording bandwidth, the greater is the number of multiplex channels which it is possible to record on one track.

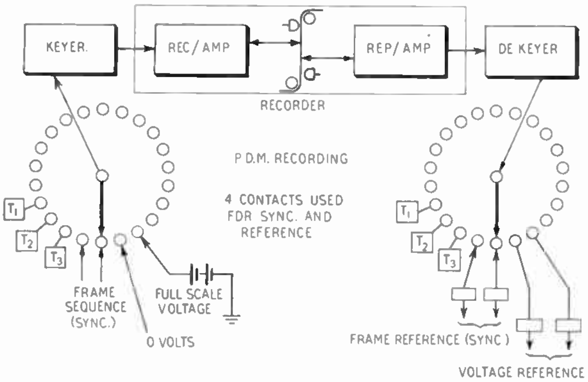


Fig. 4. Schematic diagram of p.d.m. recording system.

In practice, each of the signal sources to be recorded is fed to one pole in a multi-pole rotary switch. A mechanical switch is frequently employed, but more sophisticated applications may include an electronic switching system. As the switch rotates, amplitude samples of each of the incoming signals are fed to the recording system and recorded on tape. One pole of the switch is usually fed with an identification or sequence, synchronizing signal for the purpose of identifying the various channels on reproduction. On reproduction, the output of the tape is applied into a similar rotary switch system, synchronized by means of the sequence signal already recorded, and the output of the various channels is then fed, through suitable low-pass filters, to the analytical or other apparatus with

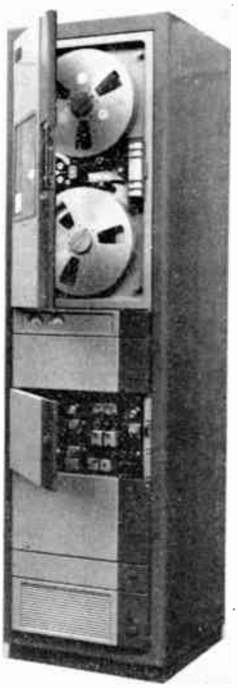


Fig. 5. Static instrumentation type multi-channel magnetic recorder.

which the data is to be examined. It is also usual to include in the original recording a calibrating signal of known voltage, which allows the absolute amplitude from any of the channels to be known in conditions where tape or head sensitivities, or any other factors, may be varying.

6.2. *Static Apparatus*

Figure 5 illustrates a static or laboratory type instrument in which the principles and facilities discussed are embodied. The essential feature of such an apparatus is flexibility, so that the same basic design may be used, with suitable heads and mechanical elements, for recording and reproducing $\frac{1}{4}$ in., $\frac{1}{2}$ in. and 1 in. tapes, at the standard speeds of $1\frac{7}{8}$, $3\frac{3}{4}$, $7\frac{1}{2}$, 15, 30 and 60 in./sec. The information recorded on various tracks may employ direct recording, frequency-modulation (f.m.) recording, and f.m. or p.d.m. multiplex recording. The electronic system is therefore of modular construction which permits appropriate units to be installed for operation on the various tracks.

6.3. *Airborne or Mobile Equipment*

In considering more lightweight equipment, for mobile and airborne use, all the requirements already set out must, of course, be fulfilled as far as reduced physical size and weight will permit. Such equipment should, of course, be completely compatible with the static equipment, so that tapes recorded in the field, or in the air, may be replayed and analysed at the base locality. In addition to the reduction in size and weight, however, the apparatus must be designed to operate from portable power sources in a wide range of environmental conditions, the latter including extremes of temperature, severe vibration and mechanical shocks.

The environmental conditions in which the apparatus may have to function are largely dictated by the user. An existing military specification, for example, calls for operation between −54°C and +95°C, and specifies an ability to withstand 18 impact shocks of 15*g*, duration 11 msec ±1 msec. Figure 6 shows a seven-track airborne recorder which is designed to this end. The transport itself is capable of operating between −54°C and +71°C without cooling air. The upper temperature limit under these conditions is dictated not so much by the mechanical system of the transport as by the yield point of the mylar-base tape which is commonly used, and by the junction temperature of the germanium transistors which are employed in the motor control circuits. Although silicon transistors employed in this latter rôle could provide higher temperature capabilities, they cannot at present be used because of their higher saturation resistance—0·6 ohms at saturation for silicon transistors as opposed to 0·05 ohms at saturation for germanium transistors. With the introduction of cooling air, however, the apparatus is capable of operation up to 95°C. Below −20°C, some heating of the transport is necessary to ensure continued free running. In the apparatus shown, built-in heaters, controlled by thermostats, are installed at necessary points for this purpose.

Fig. 6. 7-channel airborne recorder with remote control and test equipment.

This airborne recorder represents a fairly specialized and advanced design—an easing of the performance or environmental specifications could, of course, result in weight reductions. An interesting feature of this design is the provision of electronic units in a separate container which does not need heating, cooling or shock-mounting to operate within the limits specified. This enables, in aircraft use, for example, the electronics to be placed remote from the tape transport in some convenient locality where power, or forced air sources are not provided.

6.4. *Wide-band Requirements*

There are undoubtedly a variety of analogue recording requirements which have so far not been met, by the magnetic or any other method, due to limitations of bandwidth in the recording system. The impetus provided by television magnetic recording has, however, greatly extended the horizon and many such requirements can now undoubtedly be met. Details of a wideband recorder employing the principle of the rotating magnetic-head system[1] in common use for television magnetic recording, have recently been announced and are to be described elsewhere in the literature[2]. The equipment will record one or two wideband tracks (each allowing input signals up to 4 Mc/s) together with three auxiliary audio frequency tracks and the control track necessary to ensure accurate tracking of the rotary heads. The system, being fully transistorized, is applicable to ground or airborne recording, and in the latter application various features are introduced to take account of the environmental conditions.

7. Digital Recording

7.1. *General*

Any of the apparatus so far described may be used for the recording of digital information. Largely, although not completely, however, the field of digital recording is of great interest in its application to electronic computers. A computer makes great demands upon the reliability and accuracy of its recording elements. In addition, however, the requirements for the tape transport to be capable of fast start, fast stop and quick reversal of the tape, in accordance with instructions from the computer, impose very specialized design features on the tape transport mechanism, and on the tape which is to be employed with it.

In general, the requirement is to record trains of pulses which represent binary-coded numbers or instructions. The pulses, which represent a succession of ones and zeros, may be recorded on a return-to-zero or non-return-to-zero basis. In either case, full positive or negative saturation of the tape is employed, since only the presence or absence of the pulse is significant. For obvious reasons, therefore, the full signal strength which the tape can provide is utilized. Figure 7 illustrates the two possible systems. In return-to-zero (R.Z.) recording, one state of saturation (say, positive) represents the binary digit 1, and the opposite saturation state (negative) represents the digit 0. After each 1, however, the tape is returned immediately to its 0 magnetization state. In the figure shown, the recorded pattern, therefore, represents 0 1 0 1 0 1 0 1 0. In the non-return-to-zero (N.R.Z.) system, the **direction** of magnetization is reversed each time the binary digit 1 is recorded —it remains unchanged when recording the digit 0. This latter method is clearly the more efficient, because it permits twice the number of digits to be recorded for the same number of reversals, or pulses, and thus permits higher pulse-packing density on the magnetic track.

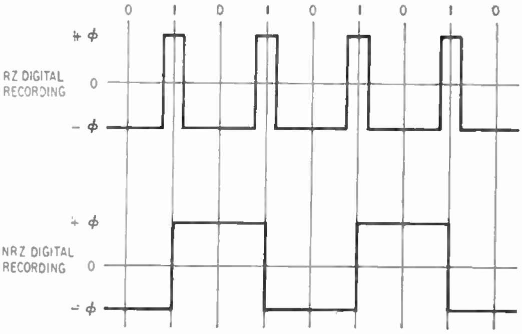


Fig. 7. Idealized flux variation in RZ and NRZ digital recording systems.

In either case, in order to increase the pulse packing in the tape as a whole, the digits or bits making up a given number or character are recorded simultaneously in parallel across the tape width, each bit being on a separate track.

7.2. *Accuracy Requirements*

Relative timing accuracy is of the greatest importance in digital recording. Clearly, the digits making up the given number or character must be reproduced in the sequence in which they were recorded, otherwise errors will occur. Skew of the tape and gap scatter in the head must, therefore, be controlled within strict tolerances. The degree to which these, and similar factors, may be controlled, determines finally the pulse-packing density which can be employed in recording on the tape. If too great a pulse-packing density is employed, without reference to the limits within which tape skew and gap scatter are controlled, obvious sequential errors in the recording and reproduction of the bits, and hence errors in the characters, will result.

Another factor which has great influence on the pulse packing which it is possible to employ in digital recording is the quality of the tape surface and the conditions under which the tape transport is called upon to operate. Impurities in the tape coating, discontinuities in the tape surface or dust from the environment can lead to a separation of the tape from the head surface in both the recording and reproducing processes. The effect is especially serious in the reproducing process, where attenuation due to separation is expressed by a function[3] which indicates that approximately 56 db loss of signal level is to be expected if the tape is separated from the head by a distance equal to the wavelength recorded on the tape. Clearly, when very short wavelengths, or closely packed pulses, are recorded, even small separations will have a disastrous effect on reproduced signal level. High density pulse packing therefore demands a tape surface of the highest quality, with operation of the recording devices, storage and handling of the tape, under conditions where dust is firmly excluded.

The consequences of error in the computer are, however, so important that it is frequently desirable to take added precautions. In one method, known as the redundancy technique, each bit of information fed to the tape recorder is recorded on two separate tracks, on the usually valid assumption that a drop-out occurring on one track is unlikely to be duplicated on another. Arrangements are incorporated into the control circuits which indicate the presence of an error when, due to a drop-out, the same information is not reproduced from both tracks. By the provision of "read-after-write" facilities, i.e. immediate monitoring of the information recorded, an error can be detected immediately after recording. Subsequent errors, which may be due to unsatisfactory storage or operation in unhygienic conditions, are detected in subsequent replay. The consequence of error can be much reduced, or even eliminated, if the presence of an error is known.

An alternative method for the detection of errors is the use of a parity check, in which one recording track on the tape is reserved for the registration of a pulse derived from all the pulses being recorded simultaneously on the other tracks. The polarity of the parity check pulse is arranged to be such that the sum of all pulses or bits on reproduction (including the parity pulse) will be an odd number. An error is therefore indicated if one or any other odd number of pulses is not recorded or reproduced. Parity checking will not detect two, or any even number of errors, but here again, as in the redundancy method, the probability of drop-outs occurring simultaneously on two or more parallel tracks is very low.

7.3. *Mechanical Requirements*

In order to exploit the information storage capacity of the tape to maximum advantage, and to allow synchronization between computer operations and the input and output tape stores, it is essential that the tape transport mechanism should be capable of starting, stopping and reversing the tape very quickly. These operations must be possible with the tape proceeding in either the forward or backward direction, and in advanced designs they will be associated with the fairly high tape speed—of the order of 100-200 in./sec—which is required to record or reproduce the high information-rate employed in a modern computer.

In practice, in either direction the tape must be brought up to speed over the heads, or brought from full speed to halt, in a few milliseconds. The power required, and control arrangements necessary, to perform such motions with full reels of tape would take the problem beyond practical considerations. It is, therefore, quite general to achieve the result required by isolating the main bulk of tape, in both feed and take-up spools, from the portion of tape immediately over the heads by means of tape-reservoir systems. The purpose of the reservoir is to act as a secondary "source" or "sink" of tape which is either drawn upon or replenished to maintain correct tape tension over the heads during the longer time required for the heavy reels to acquire the state of motion desired. The inertia associated with the tape in the reservoir is, of course, very small, and this allows it to be accelerated or decelerated at a high rate. The computer programme of commands must, obviously, be prepared with reference to the properties of the tape store. To assist the situation, the whole tape handler can itself be directly isolated from the computer by a "buffer store" which can be designed to hold information temporarily and feed it out at a rate suitable to the mechanism. The programme of commands given to the tape mechanism from the computer will then depend on the properties of the tape mechanism and the amount of "buffer storage" which is available. Clearly, the more efficient and flexible the tape mechanism the more attractive it is to the computer designer, since less "buffer storage" must be provided.

7.4. *The Tape Reservoir*

The design and sophistication of the reservoir system vary greatly with the tape speed and with the time specified for starting and stopping. In its simplest form when comparatively long (5-10 msec) start or stop times are permitted, the reservoir may consist of a more or less complicated jockey-pulley system. The elements of such a system are shown in diagrammatic form in Figure 8, where the fixed tape guide support holds three low-inertia idlers and the movable jockey are (beneath the tape deck) three more, the tape following a zig-zag path between them. The amount of tape in the reservoir depends on the position of the movable jockey arm. In a more advanced form, however, which, for a given tape speed, is adaptable to much faster start and stop times, the reservoir may consist of an actual chamber into which tape is fed and from which it is extracted as required. A suitable servo system is provided for controlling the amount of tape within the reservoir between maximum and minimum limits. These limits, and the nature of the control system associated with them, determine the programme of instructions which the tape handler can be called upon to fulfil. No programme of instructions must be imposed which, for example, would reduce the tape in one reservoir below the safety limit and correspondingly cause an excessive accumulation in the other. Basically, the problem of controlling the tape in a reservoir is one of measuring the amount of tape in it so that a departure from some mean or optimum amount results in an error signal. This signal can be used to control the speed of rotation of the feed or take-up spool with which the reservoir is associated. The resulting acceleration or deceleration of the spool has the effect of altering the amount of tape in the reservoir to return it to the desired value.

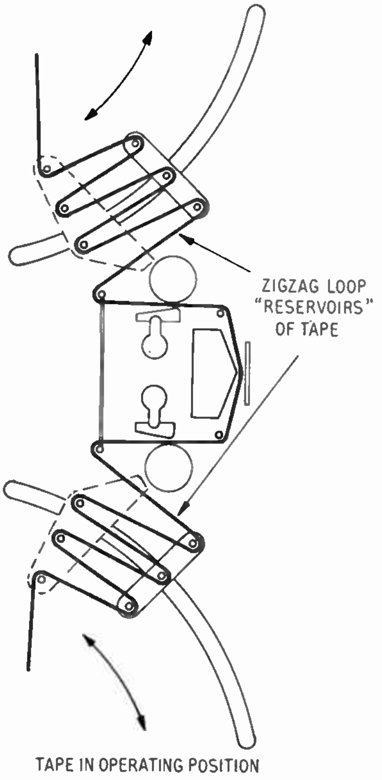


Fig. 8. Movable jockey arm reservoir system.

Various methods of measuring the amount of tape in the reservoir have been employed, and they depend largely on the design and type of reservoir used. In the system shown in Fig. 8, the position of the movable jockey arm provides a convenient measure. In much equipment in successful operation, the measure is provided by the position of the arm, or some connected element, over a series of electrical contacts. In other equipment, a continuous measure has been obtained by allowing the arm to control one plate of a variable capacitance system or an optical shutter associated with a photo-electric cell.

In the chamber type of reservoir it is invariably the tape itself which provides the measure either by virtue of its position in the chamber, e.g. the size of a loop, or by virtue of its actual presence affecting some physical quantity such as the magnitude of an effective capacitance. A system of the latter type is described in another paper in this Symposium[4]. Some suitable measure of the size or position of the tape loop in the reservoir is, however, more common, and one system, which is in wide use, will be described to illustrate the principles involved in the design of the reservoir and its associated servo tape-control system.

7.5. *Servo Control of a Tape Reservoir*

A plan view of the reservoir chamber is shown in Fig. 9. Its shape is such that an approximately elliptical tape loop is formed, bounded by the walls and the base of the chamber and a plate glass cover which fits over the top. Air is pumped from the chamber at its upper and lower ends, and the fit of the tape within the chamber is such that a pressure difference can be maintained between the inside and outside of the loop. This pressure difference is increased by a slightly positive pressure, which is created within the loop. The first effect of this pressure difference is to tension the tape to form, within the chamber, a loop the size of which depends on the amount of tape available. If more tape is extracted from the chamber at one end of the loop than is fed into it at the other, the loop is reduced in size. If more tape is fed in at one end than is extracted at the other, then the loop is increased in size. Two narrow slots in the base of the chamber, in the positions shown, are connected by tubing to a pressure-sensitive transducer which is mounted in a sealed compartment. As the loop in the chamber expands or contracts so that more or less of the slot length lies within the loop, corresponding changes take place in the position of the moving element of the transducer. This, in turn, is arranged to generate an electrical error signal which, by suitable treatment, is made proportional to the rate of change of the loop size. The error signal is then converted into a form suitable to drive the d.c. drive motor connected to the tape reel with which the chamber is associated. The servo-system is, of course, "backed off" so that the error signal is zero at the desired mean or optimum position of the loop. With one such reservoir on either side of a bi-directional drive system and head unit, we thus have a tape-tensioning system which is a null-seeking servo. On either side, the controlling parameter is the position of the tape loop in the reservoir chamber, and the control element is the associated reel drive motor.

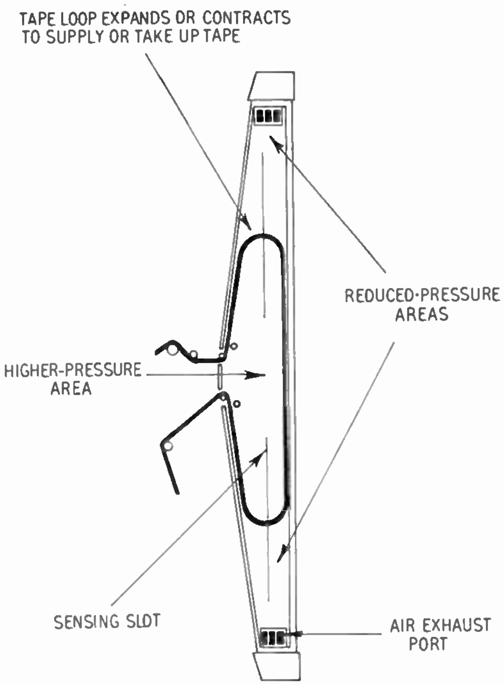


Fig. 9. Reservoir chamber with variable tape loop

8. Conclusions

This paper has surveyed, of necessity, only a limited field, but the requirements for memory systems of all types for use in science, technology, business and industry are steadily increasing. The magnetic recording system is a memory device with many peculiar advantages. Much remains to be done to exploit these advantages to the full in situations where restricted bandwidth, environmental conditions or physical size have made it unsuitable. The fundamental limitations of the system have not yet been approached, however, so that we may expect the next few years to bring steady advances in the capabilities of the tape, the recording and reproducing devices and in the mechanical systems associated with them.

9. References

1. C. P. Ginsburg, "A new magnetic video recording system," SMPTE, 79th Convention, New York, May 1957. Also "Recent developments in video tape recording." Paper read at Brit.I.R.E. Television Engineering Convention, Cambridge, July 1959.
2. J. Pritchard, "Instrumentation wideband magnetic tape recording," *Electronic Engineering* (to be published).
3. E. D. Daniel, P. E. Axon and W. T. Frost, "A survey of factors limiting the performance of magnetic recording systems," *Proc. Instn Elect. Engrs*, pp. 158-168, **104B**, (I.E.E. Paper 2296R), March 1957.
4. H. M. Harrison, "The development of a high performance tape handler," *J. Brit.I.R.E.*, **20**, November 1960 (to be published).

APPLICANTS FOR ELECTION AND TRANSFER

As a result of its September meeting the Membership Committee recommended to the Council the following elections and transfers.

In accordance with a resolution of Council, and in the absence of any objections, the election and transfer of the candidates to the class indicated will be confirmed fourteen days after the date of circulation of this list. Any objections or communications concerning these elections should be addressed to the General Secretary for submission to the Council.

Direct Election to Member

PEATHEY-JOHNS, Col. Francis Royston, B.Sc.(Eng.). *London, W.1.*

Transfer from Associate Member to Member

BENNETT, Wg. Cdr. Herbert E., M.B.E., R.A.F. *Watford, Herts.*
BRENCHLEY, Lt.-Col. Raymond Basil, R.E.M.E. *Salisbury, Wilts.*
EDWARDS, Anthony Paul John, B.Sc.(Hons.), A.K.C. *London, S.W.1.*
MOTT, Wg. Cdr. Albert James, O.B.E., R.A.F. *Marlow, Bucks.*
NEWSON, William Kenneth. *Little Chalfont, Bucks.*
VARLEY, William Eric Clifford. *Sanderstead, Surrey.*

Direct Election to Associate Member

DRAKE, Capt. Anthony Frederick, R.E.M.E. *Melton Mowbray.*
GOODMAN, Gp. Capt. John, R.A.F. *Northwood, Middlesex.*
HAYES, Peter Burton. *Nairobi, Kenya.*
McCANN, William, B.Sc. *Reading, Berkshire.*
MISRAHI, Jacob. *London, N.W.9.*
MOORE, Peter. *Brighton.*
NESS, Terence. *Wallasey, Cheshire.*
REES, David Thomas, B.Sc.(Hons.). *Llangathen, Carmarthen.*
ROWLEY, Geoffrey Charles. *Cheam, Surrey.*
STACEY, Peter John Harry. *Coventry.*
STUBBS, Raymond Frederick. *Burgess Hill, Sussex.*
WILLISON, William Ernest. *London, N.12.*

Transfer from Associate to Associate Member

DOWDING, Peter. *Chigwell, Essex.*
NISBET, Thomas Ronald. *Palo Alto, California.*
TURNER, Sqdn. Ldr. Sidney Cornelius, R.A.F. *Wolverhampton.*
TYLER, Eric. *New York.*
WARDMAN, Derek. *Leeds.*
WILLIAMS, Clifford. *Cheltenham, Glos.*

Transfer from Graduate to Associate Member

BARNES, Anthony Charles. *Cardiff.*
BRACE, William James. *Newport, Mon.*
CROXSON, Derek Henry. *Burnham, Bucks.*
CRYER, Frank Stanworth. *London, W.14.*
ELLIS, Reginald Heber. *London, S.W.19.*
EVENS, Ronald Clarence. *Amersham, Bucks.*
FELLOWS, Edgar Clayton. *Reading, Berks.*
SARMA, Capt. D. Rarameswara, Prasad, M.Sc., E.M.E. *Poona.*
THOMPSON, John Edward Harold. *Worthing, Sussex.*
TROTMAN, Donald Rex, B.Sc. *Nottingham.*

Transfer from Student to Associate Member

GUNNINGHAM, Foster Gilbert Cole. *Basingstoke, Hants.*
JONES, Peter. *Romford, Essex.*
LEVI-MINZI, Gad. *Haifa, Israel.*
SMALE, Phillip Herbert. *Lancing, Sussex.*

Direct Election to Associate

CHAMBERS, David Walter. *Chandlers Ford, Hampshire.*
FOX, Clifford. *Pinner, Middlesex.*
JAMES, Philip George. *Bolton, Lancs.*
MEHTA, Flt. Lt. Harcharan S., B.Sc., M.Sc., I.A.F. *Bangalore.*
REED, Neville Stanley. *Farnham, Surrey.*
SAEED, Sqdn. Ldr. R. M., B.Sc.(Hons.), P.A.F. *Karachi.*
WHITE, Lawrence George. *Leverstock Green, Hertfordshire.*

Transfer from Student to Associate

BUNYAN, Stanley Andre. *London, W.1.*
JOHNSON, Oliver Norman. *Cheadle, Cheshire.*
TOMKINSON, Robert Christopher. *Whitley Bay, Northumberland.*

Direct Election to Graduate

ALARIBE, Augustine S. *London, S.W.5.*
BETTELL, Peter James. *Southend-on-Sea.*
BODELL, Ronald Hall. *Liverpool.*
BORYSIUK, Eugeniusz. *Chelmsford, Essex.*
CLARKE, Leslie Thomas. *Wallasey, Cheshire.*
DAVIE, Ian Donald. *Ilford, Essex.*
DODGSON, Peter. *Chalfont St. Peter, Buckinghamshire.*
GIBBARD, Douglas James. *Stone, Staffordshire.*
GODDARD, Frederick Edward. *Chalfont St. Giles, Bucks.*
HARDMAN, David Leonard. *Bolton, Lancashire.*
HILLIER, William Edward. *Harpenden, Hertfordshire.*
HOOPER, Peter Roderick. *Kennington, Oxford.*
JOHNSON, Stephen Olufemi Olayiwola. *London, N.W.5.*
MARSHALL, Anthony Robert John. *London, S.E.18.*
MASKREY, Derek. *Bolton, Lancashire.*
MERRICKS, David John. *Welwyn Garden City, Herts.*
OAKEY, John Kenneth. *Cheltenham, Gloucestershire.*
ORELAJA, Richard Adeyinka Adedipoola. *London, N.W.5.*
PEARCE, John William. *Feltham, Middlesex.*
PHILLIPS, Stephen. *Buckingham.*
POTHECARY, James Edwin. *Isleworth, Middlesex.*
SHUKLA, Padam Narain. *Chelmsford, Essex.*
SRIVASTAVA, Flt. Lt. Uma S., M.Sc., B.Sc., I.A.F. *Bangalore.*
TRIM, Bernard John. *Wimborne, Dorset.*
TURNER, Christopher Paul. *Arlesey, Bedfordshire.*
WARD, Brian Douglas, B.Sc. *Auckland, New Zealand.*

Transfer from Student to Graduate

CHHABRA, Plt. Off. Surinder Lal, M.Sc., I.A.F. *Chandigarh.*
CLAYTON, Robert Alexander Alfred. *Northwood, Middx.*
COTTRILL, Norbert Francis. *London, W.2.*
DUTTA, Ajoy Kumar. *London, S.E.3.*
HUTCHINS, Maurice David. *Crowthorne, Berks.*
INNES, John Somerville. *Queensland, Australia.*
LAWRENCE, Dennis. *Bracknell, Berks.*
MUTHUKUMARASWAMY, N. *Hyderabad, India.*
POULSON, Barrie Kenneth. *Abbots Langley, Herts.*
QUINNEY, Ronald Ernest. *Reading, Berkshire.*
RAMADORAI, T. C., B.Sc. *Madras, India.*
SMIKT, Oded. *Rishon le Zion, Israel.*
WYATT, Kenneth *Edgware, Middlesex.*

STUDENTSHIP REGISTRATIONS

ALLINSON, John Michael. *Birmingham.*
BAYLEY, Royston John H. *Cambridge.*
BROWN, Norman George. *St. Albans.*
CALDICOTT, Jack Richard. *Coventry.*
COLEMAN, Garry. *London, E.17.*
FAIRCLOUGH, Basil John. *Chelmsford.*
GALLAGHER, Thomas. *London, E.12.*
GLOSSOP, Anthony A. *West Drayton.*
GOTHAM, Peter, B.Sc. *Wells, Somerset.*
GROVES, Charles Morley. *Bexhill-on-Sea.*
HARVEY, John Arthur. *B.F.P.O.63.*
HEBDEN, Colin Stanley. *Harlow, Essex.*
HUMPHRIES, Michael, J. *North Wembley.*
HUSSAIN, Capt. Akhtar Sindhu, B.A. *Disstt Montgomery, West Pakistan.*
*JAMES, Evan Douglas. *Dishforth, Yorks.*
LARKIN, Plt. Off. Derek Edward, R.A.F. *Wendover, Buckinghamshire.*
LEE, John Henry. *London, N.6.*
MANAP, Abdul Aziz Bin Abdul. *Malacca.*
MARZBAN, Sub. Lt. Reza Hadi, Iranian Navy. *London, W.8.*
MAWDITT, Alec F. R. *Chippenham, Wilts.*
MORTON, Brian W. J. *London, S.W.11.*
NEWMAN, Edward Victor. *London.*
*OBODAL, Emmanuel K. *Sierra Leone.*
ONUKWUBE, Lawrence C. *Lagos, Nigeria.*
PACIFICO, Roger Ernest. *Southampton.*
RHODES, Flg. Off. Peter MacDonald, R.N.Z.A.F. *Wellington, New Zealand.*
SAUNDERS, Barrie. *Harlow, Essex.*
SHEPHERD, Leslie John. *Hayes, Middlx.*
SMITH, John L., B.Sc. *Surbiton, Surrey.*
STEVENS, Iain R. *Stroud.*
THOMAS, Victor Herbert. *Wolverhampton.*
TILL, Peter Gordon. *Cowes, I.O.W.*
VERMA, Vidya D. *Jhunjhunu, India.*
WEATHERILL, William R. *Baughurst.*
WHITE, Ernest R. J. *London, N.8.*
WONG, Sin Pul, B.Sc. *North Borneo.*

---

* Reinstatements.

# of current interest . . .

A New Transatlantic Telephone Cable to the U.S.A.

A new Transatlantic telephone cable—the fourth to be laid since 1956—will come into operation in 1963. It will be known as TAT 3 and carry 128 telephone circuits between the United Kingdom and the United States, and will provide for the increasing telephone traffic between the two countries.

The landing points for the cable have not yet been settled. It will run directly between the United Kingdom and the United States unlike the two existing transatlantic telephone cables which both land in Newfoundland. Its total length will thus be about 3,400 nautical miles.

The cable will be of the lightweight type, using polythene insulation without external armouring. This form of cable will find its first application in the cable between the United Kingdom and Canada which is to be laid next year. Overall diameter of the deep sea cable will be about 1¼ in. A single cable will be used to carry speech in both directions and about 180 rigid type repeaters of a new design developed by the Bell Telephone Laboratories will be installed at intervals of about twenty miles along the length of the cable. The bandwidth will not be sufficient for live television.

Further B.B.C. Stations for Television and V.H.F. Sound

The Postmaster-General has approved, in principle, the second stage of the British Broadcasting Corporation's plans for extending and improving the coverage of the television service and of the three sound services on v.h.f. by building additional low-power satellite stations. The stations in this second group are to be in the following areas:

Satellite stations for both Television and V.H.F. Sound:

Forfar, Angus; Grantown-on-Spey; Lewis; Pitlochry/Aberfeldy; Shetland; Skye.

Satellite stations for Television:

Caernarvon; Hastings; Scarborough; Swindon.

Satellite stations for V.H.F. Sound:

East Lincolnshire; Enniskillen*; Pembroke/Milford Haven*; Sheffield*; South-West Scotland.

Until sites have been chosen and surveys made, it is not possible to say what will be the precise range of each of these stations; some of them will serve only the town where they are to be built, but others will have somewhat wider coverage.

Most of the stations will use "translators," which receive the programmes by direct reception of an existing station and relay them on another channel for local viewers and listeners. The television station at Hastings is to be an experiment in the use of a very low-power translator of a new type which has been developed in the hope that at a later stage such translators may be found suitable for use in a number of other towns where reception is at present unsatisfactory. The translator at Hastings will receive the programme directly from the Crystal Palace and relay it on another channel for local viewers.

Although completion of Stage 2 is scheduled for March 1964, it is expected that most of the stations will be completed by the end of 1963. There are, however, considerable difficulties in finding suitable sites and channels, particularly for television stations, and in carrying the programmes to places remote from the present network. Since all the television stations have to be fitted into the five channels in the Broadcasting Band I, which are the only channels so far made available to the B.B.C., the power of the stations will have to be limited.

Ultra-sensitive Amplifier for Electro-physiology

A new range of extremely weak high-frequency electrical signals from muscular tissues has been detected by means of a recently perfected ultra-low noise transistor amplifier, according to a paper presented at this year's international convention of the Institute of Radio Engineers in New York. The detection of electrical signals emitted by muscles is of course not new. Standard equipment however can detect only fairly powerful signals, and these occur only at low frequencies, in the range of a few hundred cycles per second. The new equipment can detect the much weaker signals that occur at higher frequencies, up to 50 kc/s according to the authors.

---

* Television transmitters are being provided at these stations under Stage 1.

The Assessment of the Reliability of Magnetic Tape for Data Processing †

by

R. NOBLE, B.SC., PH.D.‡

A paper read at a Symposium on Magnetic Recording Techniques, held in London on 15th December 1959.

In the Chair : Dr. G. L. Hamburger (*Member*).

Summary : A large number of specimens of tape have been tested for drop-outs over a wide range of operating conditions. All specimens showed the same characteristic behaviour and lead to the conclusion that there is a drop-out distribution which is inherent in the structure of tape and independent of any foreign particles or mechanical damage introduced in the manufacturing process or subsequent handling. The observed distribution permits of simple mathematical expression in terms of two of the major variables of operation, drop-out discrimination level and pulse packing density. A simple theory of the origin of the observed behaviour is given, and a method of tape testing is suggested which appears to be more basic than the present "go/no-go" type of test. The method permits batch testing for most purposes and saves valuable time in the selection of suitable tape even if complete testing if insisted upon. It also gives information which should be useful in the design of systems to handle tape and in the calculation of the improvement of reliability resulting from methods of introducing redundancy into the storage system.

1. Introduction

The improvements in recent years in the performance and reliability of magnetic tape have made possible its use as a storage medium in electronic computing equipment. The small volume which a given amount of information occupies when recorded on magnetic tape, and the speed at which it can be read, offer obvious advantages.

The disadvantage of tape is that it is not the perfectly homogeneous medium which is desirable; the inhomogeneity is inherent in the structure of the magnetic coating and the nature of the base material upon which it is spread. The inhomogeneity persists even in tape made under the cleanest possible conditions of manufacture and will continue to do so in spite of the improvements which will be made in the dispersion of oxides and in the production of uniform base materials. Such precautions naturally mean that the inhomogeneity will be less extensive, but this does not mean that its effects will be less than they are at present, because by then the demands made upon the tape will be greater.

In facing this fact and setting aside the myth of "perfect" tape, the questions which remain to be answered are, "*How much* error will the tape introduce?" and "How can it be measured?" It is possible to give more fundamental and satisfactory answers to these questions than to the question, "Is this piece of tape perfect?" Economic advantages and improved performance can be obtained by this approach.

The answer to the question, "How much error will be introduced?" is necessarily of a statistical nature; but since the systems using the tape incorporate error-correcting procedures, a statistical answer should be satisfactory. It is only necessary that the amount of error correction taking place be reduced to a suitably low value.

---

† Manuscript received 2nd December 1959. (Paper No. 584.)

‡ M.S.S. Recording Co. Ltd., Colnbrook, Bucks.

U.D.C. No. 621.395.625.3

Consequently, the experimental method adopted in this investigation was to examine the performance of a large number of tapes under a wide range of operating conditions in the hope of being able to relate the performance to the operating conditions.

A "drop-out" is defined in this paper as any temporary loss of signal greater than a stipulated amount, the loss being measured in decibels and denoted by *D*. "Drop-out density" is adopted as a measure of tape performance and defined arbitrarily as the number of drop-outs per unit length of tape track; it is obtained by counting the total number of drop-outs and dividing by the length of tape and the number of tracks used. Since a particular fault does not always give rise to a drop-out as defined above, the drop-out density is *not* the fault density for the tape but is presumably related to the fault density in some way.

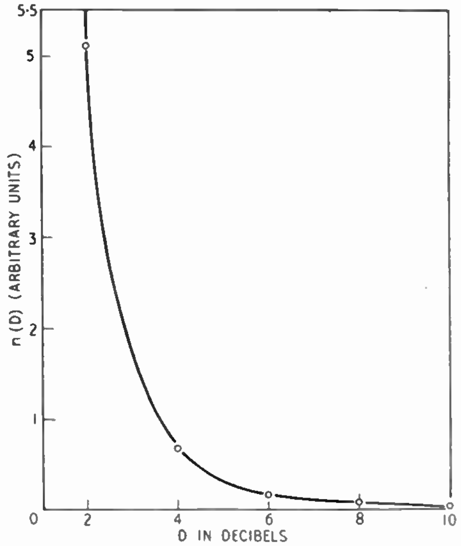


Fig. 1. Drop-out density against drop-out level (constant wavelength).

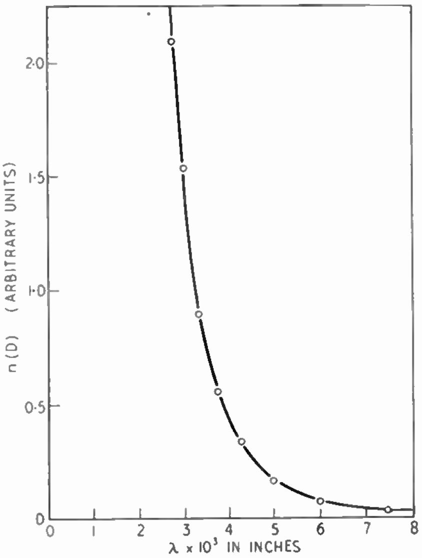


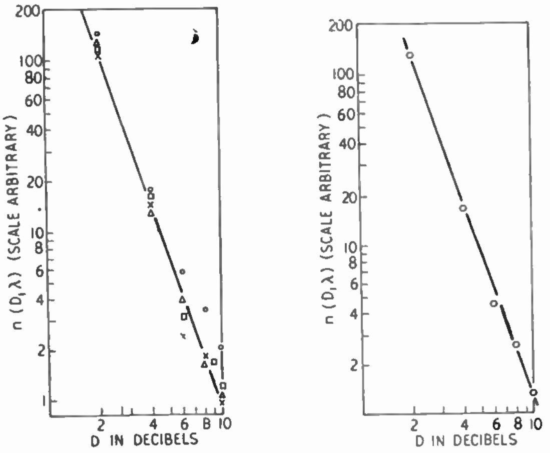
Fig. 2. Drop-out density against wavelength (constant drop-out level).

The drop-out density may be expected to be related to the stipulated signal loss, *D*, and to the wavelength of the recorded signal, λ and is denoted by a function of these quantities, $n(D, \lambda)$. It may also be related to certain other parameters, such as track width, gap length, recording current and tape speed, but since these are quantities less often varied in practice they were held constant during the investigation.

2. Experimental Investigation

A series of experiments was performed in which drop-out densities were measured for $D = 2$, 4, 6, 8 and 10 db and at wavelengths between 0·0015 in. and 0·015 in. Batches of tape made under very clean working conditions and samples obtained from a variety of manufacturers were examined in this way. All the specimens behaved in a similar manner and typical experimental results are shown in Figs. 1 and 2, which show the relation between drop-out density and drop-out level, *D*, and between drop-out density and recorded wavelength, λ.

The results can be made more informative if both axes of the graphs are made logarithmic as is done in Figs. 3 and 4. Figure 3 (a) shows drop-out densities plotted against drop-out level obtained from four lengths of tape taken from the same production batch and Fig. 3 (b) shows the average performance of these same lengths. When drawn in this way, the graphs indicate that there is a linear relationship between the logarithms of drop-out density and drop-out



(a) (b)

Fig. 3. (a) Drop-out density against drop-out level (four tapes from same batch).
(b) Drop-out density against drop-out level (average of four tapes in (a)).

level. Figure 4 (a) shows the drop-out density plotted against a quantity, $\lambda_{\rm eff}$, the effective wavelength, defined as $(\lambda - l)$ where l is the length of the gap in the head. This procedure introduces a first-order correction for the effect of the gap-length and the effective wavelength was defined in the above way because it yields the linear relation shown and also permits a simple physical interpretation of the gap-length effect.

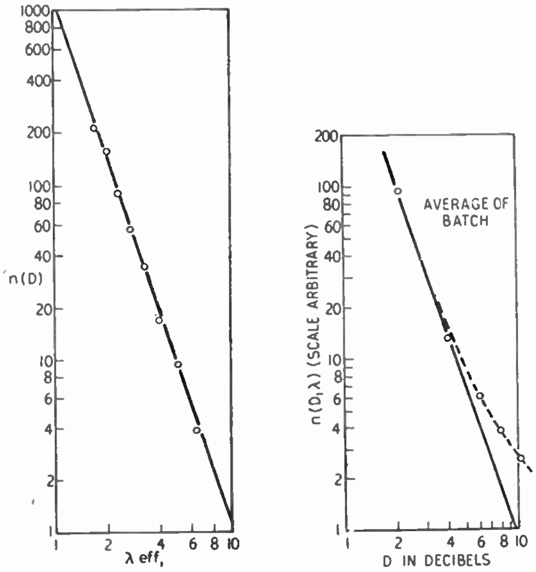
The results presented in these graphs imply that the quantities plotted are related by a power law. The graphs are of particular interest in that the straight line has not been drawn with slope corresponding to that of the experimental points, but with a slope corresponding to a 3·00 power law. This is the case for both the drop-out density versus drop-out level and drop-out density versus wavelength graphs. The reason why this has been done will appear later, but the implication is that in both cases the quantities are related by an inverse cube law. If it is possible to combine both relations in the single algebraic expression

$$n(D, \lambda) = \frac{C}{D^3 \lambda^3_{\rm eff}},$$

then the constant C, introduced by this procedure, should be a measure of the basic "quality" of the tape.

All the samples prepared in clean conditions and certain samples from tape manufacturers exhibited the behaviour described above. The only variations observed from one sample to another were changes in the value of the constant C. This gives support to the suggestion that the value of this constant is a measure of tape quality. It is important to note that all samples taken from a particular production batch were observed to give the same value for C, the variation only taking place from one batch to another.

A small number of manufacturers' samples exhibited a minor variation on the behaviour described above: Fig. 4 (b) shows that at low values of drop-out density the observed results are greater than those given by the expression quoted previously, while for high drop-out densities the results approach asymptotically those given by the expression. This is exactly the behaviour which would be expected if a small number of comparatively large foreign bodies were introduced into the tape by bad handling. The faults introduced in this way would not belong to the inherent fault distribution described above, but would be added to it; the addition of a fixed number of faults to the



(a) (b)

Fig. 4. (a) Drop-out density against wavelength (average of batch).
(b) Drop-out density against drop-out level (damaged tape).

distribution will have a greater effect where the inherent drop-out density is low than where it is high. It proved possible to reproduce this behaviour by deliberately damaging samples of tape and it was assumed that the specimens originally found to behave in this way had been faulted either in manufacture or in subsequent handling.

In applying the results of tests on tape, it will be important to know what relation any individual drop-out density measurement is likely to bear to the average values determined as above. The distribution of 180 individual measurements about the mean value is displayed in the form of a histogram in Fig. 5. The individual drop-out densities were first expressed as percentages of the mean value and then divided into groups, each group covering a 5% range. The numbers in each group were then plotted against the percentage deviation from the mean value. These same results are plotted again in Fig. 6 with one linear scale and one probability scale. A normal distribution appears on this type of graph as a straight line. This is an insufficient number of results to determine the exact form of the distribution but it would not appear to be greatly different from a normal form. It is proposed to carry out further work along these lines when new test equipment is completed. The results obtained so far do indicate that the majority of measurements lie well within an order of magnitude. The value of the standard deviation for the measurements in Figs. 5 and 6 is 22%.

3. Theoretical Explanation

The emergence of an inverse cube relation from the experimental results is interesting and suggests that a simple theoretical explanation might be possible. The following, though by no means a complete explanation, does throw some light on the problem.

It has been observed in previous work that most drop-outs were caused by small projections from the surface of the magnetic coating. A fault of this type lifts an area of the tape away from the gap and causes a loss of replay signal. In the case of replay from a sinusoidal recording this loss with separation is well known and can be expressed quantitatively by

loss = 54·6db per wavelength separation

The type of signal recorded for computer purposes is not sinusoidal, but neither is it really a square wave as it is considered ideally to be. Hence as a first approximation a relation was postulated of the form

loss = K db per wavelength separation

where the wavelength is taken to be that of the fundamental of the square wave and K is some constant (not necessarily 54·6). If the separation is represented by R, this can be written

$$\text{signal loss} = D = K.\frac{R}{\lambda}$$

If this is re-written $(D.\lambda) = K.R$ and applied to a particular fault it shows that the signal loss × wavelength is proportional to the separation; but the separation is itself representative of a linear dimension associated with the fault. Thus on the present simple view the product, signal loss × wavelength, is proportional to a quantity which might be interpreted as, say, the mean radius of the fault.

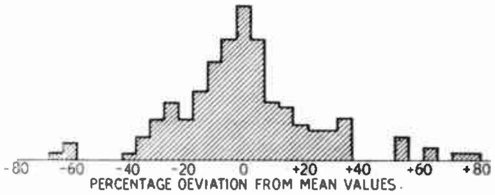


Fig. 5. Histogram of percentage difference from mean on drop-out results.

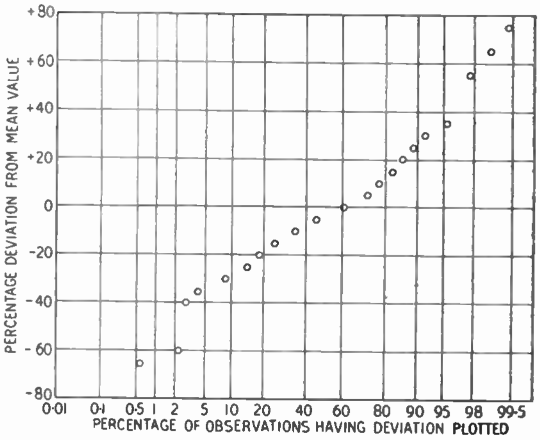


Fig. 6. Results of Fig. 5 re-plotted on probability paper.

Consideration must be given now to the size distribution of the faults on the tape. Suppose the distribution is such that the number of faults having greater than a certain volume is inversely proportional to that volume. There is no immediate reason for choosing this except that it describes the distribution in terms of a simple property of the faults, namely their volume and that it seems reasonable intuitively. It makes large faults rare and small faults common. Quantitatively, this can be expressed as

$$n_f(V) = \frac{\text{constant}}{V}$$

where n_f is the number of faults of volume greater than V.

Writing this in terms of the quantity previously interpreted as the mean radius, gives

$$n_f(R) = \frac{\text{constant}}{R^3}$$

But a definite value of the product of signal loss times wavelengths can be associated with each value of R and the distribution can then be written

$$n_f(D\,\lambda) = \frac{\text{constant}}{(D\,\lambda)^3} = \frac{C}{D^3\,\lambda^3}\text{, say.}$$

If λ is kept constant and D alone is permitted to vary it can be seen that the above density function includes all faults for which the signal loss is greater than D. In other words this function is just the drop-out density as defined previously; dropping the suffix f and allowing for the gap-length effect by writing λ_{eff} for λ, gives

$$n(D, \lambda) = \frac{C}{D^3\,\lambda^3_{\text{eff}}}$$

This is why the lines on the graphs presented earlier were drawn with the slope of a 3·00 power law.

The analysis presented implies that the faults take the form of small nodules protruding from the surface but it does not necessarily imply that they are spherical. The magnetic coating of tape consists of a suspension of aggregates of oxide particles in a binder material. The coating is produced by a ball-milling process and it is reasonable that the postulated distribution with volume could be the result of such a process.

4. Assessment of Tape Reliability

If a standard track width and tape speed can be agreed for the purpose of tape testing, then the value of the constant, C, could be made a figure of merit in the assessment of tape reliability. Manufacturers could then divide tape into a convenient number of grades in each of which the figure of merit would be between certain limits. It should not be necessary to specify a standard track arrangement, since it does not matter what *particular* area of the whole batch of tape is examined, provided a sufficient area is tested.

The type of equipment required for testing would be rather like the "kick-sorter" used in nuclear research and would count drop-outs of 2, 4, 6, 8 and 10 db magnitude simultaneously. A system based on this idea is now under construction.

A grading method of this type should enable a system designer to choose operating conditions which, for a selected grade of tape, will ensure the particular standard of reliability required of the system.

For appliiations where a certain known level of error can be permitted, the designer could specify a grade of tape such that errors due to the tape bear a suitable relation to those arising elsewhere. Examples of this type are the recording of nuclear particle counts or coincidences, which a certain proportion of spurious background counting has to be allowed for in any case, automatic blood-counts and, in fact, any automatic counting in which a statistical answer is sought.

For data processing systems the operating conditions and grade of tape could be chosen so that error correction takes place at some optimum rate. The considerations governing this rate will presumably vary from one application to another; in the case where large amounts of accounting data must be stored for long periods, tape cost may be an important consideration. On the other hand in a computer used for scientific purposes, overall reliability or operating time may be of more importance. Assuming that the error-correction equipment is as reliable as the rest of the computer, then there is no reason why it should not be made to work at some suitable rate, rather than merely stand by to correct the occasional error. In this way it may be possible to use the highest feasible pulse packing density on the tape, consistent with not slowing down the operation of some other part of the computer.

The information obtained from the proposed test could also be of use in estimating the effect of introducing redundancy into the system. As a simple example, it is possible to estimate the resultant reliability of a system in which information is recorded in duplicate on widely spaced tracks and the pulse packing density is doubled to restore the original storage capacity. More efficient methods can no doubt be devised for introducing redundancy but their effectiveness can be estimated in a similar manner.

In cases where, for some reason, fault-free performance under specified conditions is insisted upon, then the test proposed is still of value in sorting out those batches which are most likely to give a high yield of tape capable of passing a test under these conditions.

5. Other Applications

All that has been said so far refers to tape systems in which the tape is in contact with the heads. However, in an out-of-contact system, it seems likely that spurious signals, or in other words "drop-ins" will behave in some similar way. A nodule producing a drop-out in an in-contact system might produce a drop-in in an out-of-contact system, though the magnitude of the effect may be different in the two cases.

6. Acknowledgments

This work was carried out at the M.S.S. Recording Company Limited and acknowledgment is due in particular to Mr. J. F. Doust who gave valuable and constructive criticism.

A Magnetic Read Head with Output Signal Independent of Tape Speed†

by

D. KERR ‡ and E. J. M. QUIRK, B.SC. ‡

A paper read at a Symposium on Magnetic Recording Techniques, held in London on 15th December 1959.

In the Chair : Dr. G. L. Hamburger (*Member*).

Summary : The paper describes a variable-reluctance magnetic read head, designed for use in digital computer output and editing equipments, which can read digits recorded at normal packing densities over a wide range of tape speeds down to zero. Each head is a "double" head, consisting of a variable reluctance read head and a conventional write head. The centre line separation between the read and write sections is one digit interval; with the 100 digit per inch system used, this separation is 0·010 in. The packing density is a function of the separation between the read and write sections only when the head is used for digit-by-digit checking of a writing operation. Eight such heads are built as one unit having external physical dimensions of 1·5 in. × 1·1 in. × 0·75 in. and can be accommodated across standard one-half inch wide magnetic tape. Attention is drawn to the suitability of the reading head for use in off-line editing equipment where the tape speed can be reduced to correspond with the speed of operation of mechanical teleprinters or typewriters, so simplifying the tape transport mechanism and circuitry.

1. Introduction

Magnetic tape is often used as the information input and output medium of a digital computer because it has the advantages of a higher signal packing density and higher information transfer rate than paper tape or punched cards. However it suffers from the disadvantage that it gives no visual indication of the presence or absence of recorded signals.

The reading of information recorded on magnetic tape is usually effected by moving the tape past a magnetic reading head so that as much as possible of the tape leakage flux links with the winding on the head. The induced voltage in this winding depends directly on the rate of change of this flux and hence the amplitude of the read-out signal is proportional to the tape speed. When using the head to be described a relative velocity between tape and head is unnecessary as the flux change in the read winding is attained by varying the reluctance of the head itself.

In the preparation of a magnetic tape on a keyboard printer the most comprehensive check that can be made of the information being recorded is a digit-by-digit check wherein a character is not printed until the previous one has been correctly recorded. This system implies the moving of the tape in discrete steps; it is difficult to visualize how a conventional head could be conveniently used as the tape would have to be moving in excess of a certain minimum speed in order to obtain a signal from the head. The output rate from conventional tape readers is very high, and this rate is far in excess of the speed at which a teleprinter or electric typewriter will operate.

A variable reluctance read/write head of the type to be discussed makes possible the con-

---

† Manuscript received 1st January 1960. (Paper No. 585.)

‡ Ultra Electronics Ltd., Western Avenue, London, W.3.

U.D.C. No. 621.395.625.3

struction of such a magnetic tape printer with digit-by-digit checking facilities since it is arranged that the centre line separation between the read and write sections in each of the eight tracks is equivalent to one digit interval. Similar heads form the basis of a system used at Manchester University where digital computer output information can be read one digit interval after having been written, and checked for correct recording without the need for storing more than one row of digits at a time.

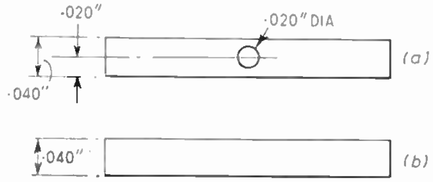


Fig. 1 (a). Strip used for the read section; (b) Strip used for the write section.

The variable reluctance reading head is useful in association with a teleprinter or electric typewriter as it allows the tape speed to be changed to correspond with the speed of operation of such devices.

2. Principle of Operation

Basically, the read head consists of a thin strip of Permalloy C with a small hole centrally disposed between the long sides and bent so as to form a small gap between its ends; this is the read gap. (Fig. 1(a).) Around the hole, and in the manner shown in Fig. 2(a), is wound the modulation winding through which is passed a sinusoidal current of frequency f. The flux produced by this current circulates round the hole and tends to saturate the material when the current reaches its maximum value. This flux is balanced with respect to the main path formed by the bent strip and the read gap. Hence the information recorded on the tape is not affected by the modulation flux of the head.

When the head is situated so that a region of leakage flux on the tape is directly opposite the read gap some of the flux circulates round the head and some is shunted across the read gap. The reluctance of the head is modulated by the cyclic saturation of the central section in the neighbourhood of the hole, and thus leakage flux circulating round the head will also be modulated.

The region round the hole is saturated twice per cycle of modulation current and this results in a voltage appearing across the read winding which contains a large second harmonic component. When the sense of the leakage flux circulating round the head circuit is reversed, the phase of the voltage across the read winding changes by π radians with respect to the phase of the modulation current. Hence oppositely magnetized regions on the tape are manifested by a reversal of phase of the read-out voltage. The head is therefore sensitive to both static and alternating magnetic fields in the vicinity of the gap which have components linking the main magnetic circuit.

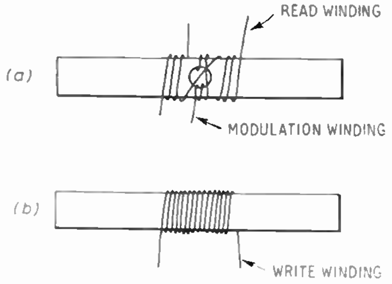


Fig. 2 (a). Completely wound read strip; (b) Completely wound write strip.

3. Construction

3.1. *Preparation of the Strip*

The magnetic material used for the heads is Permalloy C, 0·002 in. thick, and the dimensions of the strips used for the read and write sections are given in Fig. 1. An etching technique[3] is used to shape the strip and form the hole; by this means the formation of burrs is avoided.

The strips are then heat treated in an atmosphere of dry hydrogen in order to obtain the highest permeability. Brass spacers are used to define the gaps and are produced by a similar etching process to that used for the Permalloy strips.

3.2. *Windings*

The modulation winding is wound round the hole in the strip in such a sense as to cause the flux to circulate round the hole. Close to this winding, and arranged in two sections for symmetry, is the read winding. Figure 2(a) shows a read head strip with completed windings.

The write winding consisting of 15 turns of enamelled wire, is wound in the middle of a plain Permalloy strip as shown in Fig. 2(b).

After winding, both the read and write heads are bent to the shape shown in Fig. 3, and brass shims are then inserted to define the read and write gaps and the space between the two heads. This operation is facilitated by the use of a special fixture designed for holding the heads in position.

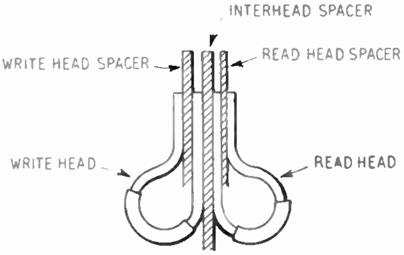


Fig. 3. Formation of a read/write head.

Eight such read/write head assemblies are then built into a stack using an arrangement of spacers and clamping plates. The track spacing of a completed block of heads is 0·020 in. and the track width is 0·040 in. The lead-out wires from each head assembly are soldered to a pair of miniature socket connectors accommodated in the base of a perspex body which is screwed to the completed block.

Excess magnetic and shim material which protrudes from the curved surface of the block is cut away before grinding and lapping to the required profile.

The alignment of heads across the block is maintained to within ±0·0005 in., and uniformity of read gap reluctance from track to track is ensured by the method of construction adopted. A completed unit has the approximate external physical dimensions 1·5 in. × 1·1 in. × 0·75 in. (See Fig. 4.)

3.3. *Plating of Contact Surface*

The properties of various materials were investigated to discover one which could be plated onto the head contact surface in order to reduce wear. Palladium was found to be a suitable material, since apart from having good wearing properties itself, it does not abrade the tape.

On the basis of the work already carried out on head to tape spacing a plating thickness of 5 microns should not reduce the signal by more than about 10 per cent.

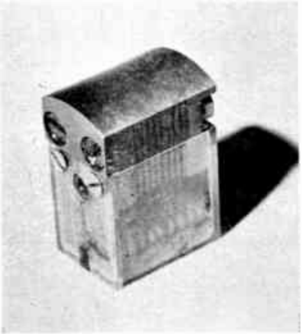


Fig. 4. The completed eight track read/write head.

4. Mechanism of Reluctance Variation

Assume the material has a hysteresis loop as shown in Fig. 5. The permeability is high and constant when the material is unsaturated, and zero when saturated. Sinusoidal modulating current drives the material into and out of saturation as shown, and any leakage flux from the tape which links the head will alternate between (a) a very low value when the strip is saturated, and (b) a comparatively large value determined by the relative reluctances of the unsaturated strip and the read gap.

The transition time between these two states will depend upon the frequency and amplitude of the modulation current, but if it is assumed that these transitions are instantaneous then the voltage induced in the read winding will be a series of infinitely tall spikes of infinitesimally small duration. In practice, however, the assumption of a constant permeability when unsaturated and zero permeability when saturated is not valid. It has been shown[1] that

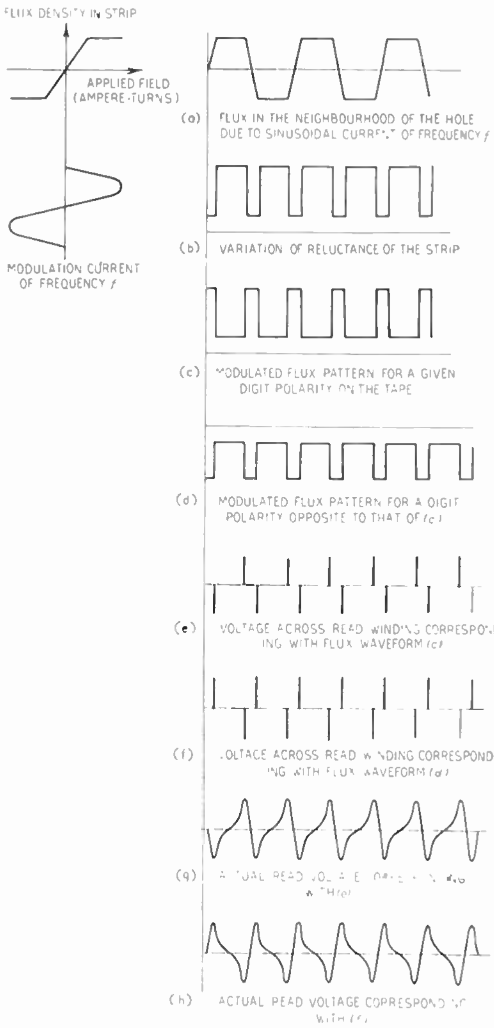


Fig. 5. Principle of operation of a variable reluctance read head.

the relationship between incremental permeability and the applied field is very approximately of the form of a rectangular hyperbola. Thus the voltage pulses appearing across the read winding have finite height and width.

4.1. *The Read Gap Reluctance*

A simple equivalent circuit for the read head would be as shown in Fig. 6. The equivalent m.m.f. causing flux to circulate in the two reluctance paths is therefore

$$F_1 \cdot \frac{r_g \cdot r_H}{r_g + r_H}$$

where F_1 is the total leakage flux from the tape,

r_g is the read gap reluctance,

and r_H is the main head circuit reluctance.

Thus the flux circulating through the main head circuit is given by

$$F_1 \cdot \frac{r_g}{r_g + r_H}$$

and this may be written in the form

$$F_1 \cdot \frac{1}{1 + r_H / r_g}$$

Inspection of this expression shows that for a given value of r_g the maximum flux change in the head is achieved when r_H varies between a value which is small compared with r_g to a value which is large compared with r_g. Thus the flux change in the head tends to F_1.

Case 1.—If r_g is large then r_H must also be made large to achieve the largest flux change, and this requires a large value of modulation current. Hence maximum second harmonic signal will occur at a relatively large value of modulation current.

Case 2.—If r_g is small then r_H does not have to become as large as in Case 1 and hence the maximum second harmonic signal output will be obtained at a lower value of modulation current.

4.2. *Dependence of Output Voltage on Modulation Frequency*

The second harmonic output voltage from the head at constant modulation current increases linearly with increase of the frequency of this current up to about 50 kc/s. It has been shown[2] that above this frequency the second harmonic component of the output voltage is no longer linearly dependent upon the modulation current frequency, although the signal does continue to increase as the frequency is raised to 200 kc/s. There would therefore seem to be no point in using a modulation frequency in excess of this value.

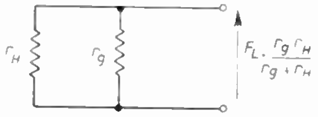


Fig. 6. Equivalent read head circuit.

5. Performance

The maximum peak-to-peak amplitude of the second harmonic component of signal voltage from the read heads in use is 3 mV at 50 kc/s. This component of the signal is amplified by a tuned amplifier of voltage gain 60 db.

Under constant frequency conditions and for large values of modulation current the flux change within the strip takes place in a shorter time interval and the second harmonic component of the voltage induced in the read winding is reduced. This is because a disproportionate amount of the input energy is spent in the production of the higher harmonic components associated with the shorter rise times. Thus the curve relating the second harmonic output voltage and modulation current falls after reaching a peak (see Fig. 7). The value of modulation current for peak output depends upon the head and gap reluctances as previously discussed (see Fig. 8).

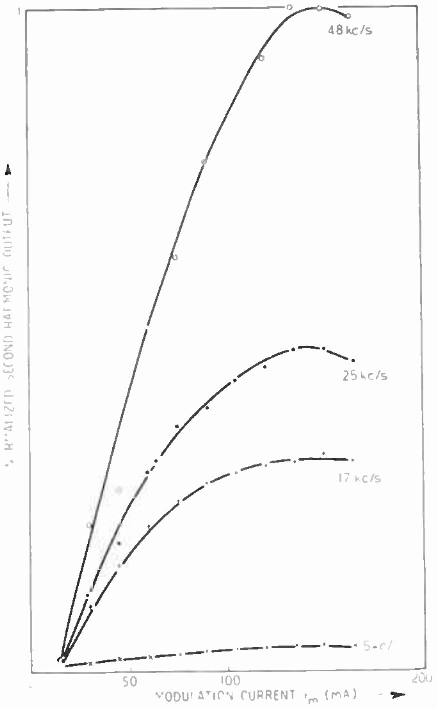


Fig. 7. Dependence of output signal on current and frequency.

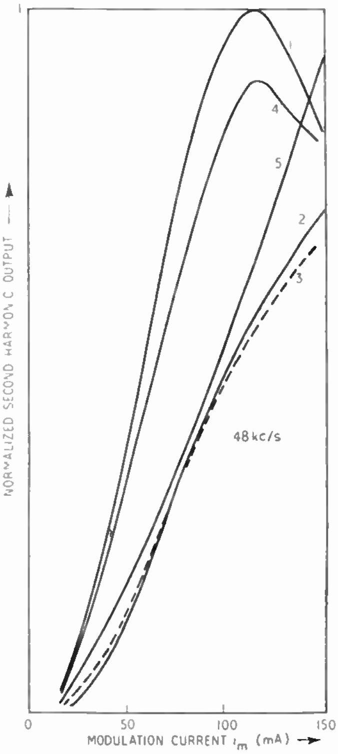


Fig. 8. Effect of variation of read gap reluctance from track to track.

Signal packing densities in use at the moment are up to 125 digits per inch, but these can be improved upon and it is envisaged that packing densities of 200 digits per inch will be possible with modified designs.

Rates of reading depend on the speed of response of the tuned amplifiers, but rates of 2,000 characters per second have been obtained[2].

A slow-speed tape reader with typewriter or teleprinter output has been constructed and is in operation. The reading rate in this application is set by the maximum operating speeds of the teleprinter and typewriter.

During a writing process a large signal is experienced by the read heads and it is thus advisable to inhibit the read amplifiers during this period.

Because of the large remanence of Permalloy C the balance of the read heads would be upset on reversal of writing current in the write heads Consequently a uniformly magnetized tape is

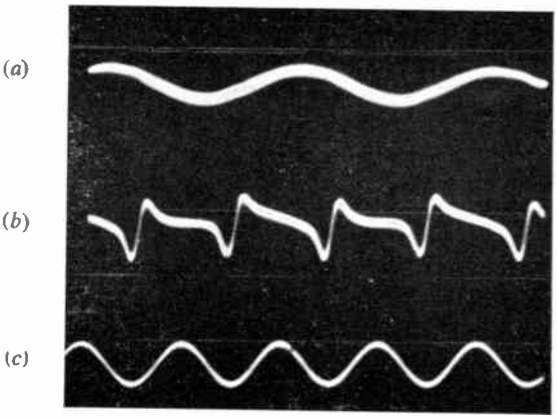


Fig. 9. Read head waveforms for a given digit polarity. (a) modulation current; (b) read head voltage; (c) second harmonic component of (b).

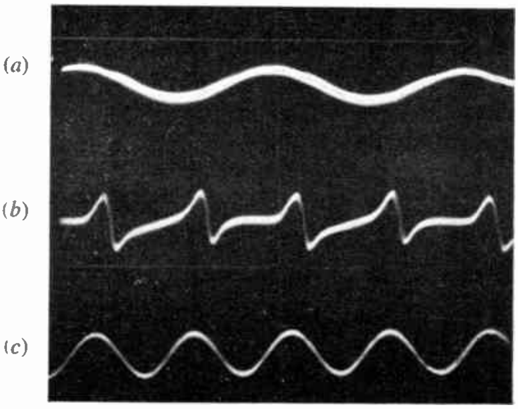


Fig. 10. Read head waveforms for a digit polarity opposite to that in Fig. 9. (a) modulation current; (b) read head voltage; (c) second harmonic component of (b).

used and the write heads are pulsed in one direction only.

Spurious signals due to extraneous magnetic fields linking the head are reduced by making the heads of small physical dimensions, and compensation for the effect of the large remanence of the magnetic material is accomplished by passing a small d.c. bias current through the read winding.

6. Conclusion

The effects of cross-talk were negligible and signal to noise ratio was certainly in excess of 40 db, the noise level due to the reading mechanism being barely detectable.

With the combination read/write head described recordings can be checked digit-by-digit with the need for storing only one row of digits at a time. Hence it is possible to record under conditions where permanent and transient drop-outs are present, since a character can be checked before the next is recorded. Also for the preparation of a magnetic tape, such a read/write head used in conjunction with a printer having similar checking facilities to the tape output system used at Manchester University could effect economies in computer time and in tape verification procedures.

Since the signal output from the read head is independent of tape speed, tapes printed at high speed by the computer can be used at very much reduced speed in off-line editing equipments in order to operate such devices as teleprinters and typewriters.

In the field of space research an artificial satellite might use similar read/write heads in conjunction with an analogue-digital converter for storing data on magnetic tape until the vehicle is in the most favourable position for transmission of the recorded information

7. Acknowledgment

The authors are indebted to Ultra Electronics Ltd., for permission to publish the paper, and to Dr. G. R. Hoffman of Manchester University for his advice and assistance. Thanks are also due to many colleagues for their help and co-operation.

8. References

1. R. M. Bozorth. "Ferromagnetism," p. 541 (D. Van Nostrand. New York, 1951).
2. C. J. Tunis. "Some Input-Output Systems for Digital Computers" (Ph.D. Thesis, University of Manchester, 1958).
3. A. F. Harvey. "Parallel plate transmission systems for microwave frequencies," *Proc. Instn Elect. Engrs.* **106B**, p. 129. March 1959.

Magnetic Tape Digital Recording for Nuclear Research †

by

F. H. WELLS, M.SC.(ENG.) ‡, I. N. HOOTON, M.A. ‡.
J. G. PAGE, B.SC., GRADUATE ‡.

A paper read at a Symposium on Magnetic Recording Techniques, held in London on 15th December 1959.

In the Chair : Dr. G. L. Hamburger (*Member*).

Summary : The paper describes two magnetic tape digital recording techniques developed for nuclear physics research. Both 1 in. 16-track and ¼ in. 4-track systems are used with maximum bit packing densities of 200 and 400/in. respectively. The tape writing and reading technique uses a return to zero method chosen to facilitate "drop out" detection; a "0" is written by a short duration current pulse of one polarity and a "1" but a similar pulse of reverse polarity. The absence of a pulse on any track during reading indicates a "drop out" and the particular event is then rejected. This error check permits the use of tape systems with overall drop out performance as bad as 1 in 160 bits.

1. Introduction

Recent nuclear physics research on the interactions of neutrons with various atomic nuclei has necessitated the measurement, recording and computation of large amounts of numerical data. In some experiments recording and computation methods of the digital, rather than analogue, type are necessary to preserve the accuracy inherent in the physics measurement, so that most instruments developed for this class of work have used digital principles. The design of these electronic instruments is complicated, but it is essential to reduce the complexity until the instrument is very reliable, reasonably small and inexpensive, since many such instruments are required. The problem has been solved by restricting the functions of the instrument used during the experiment to those of measurement and recording; the computation is performed after the experiment by a digital analyser, the design of which is far more complicated than that required for measurement and recording. The recording medium must be able to record fast enough to accept the data from the physics experiment and the final record must be compatible with the input requirements of the analyser. In a very few cases, such as experiments with cosmic rays, the rate of data recording is so low that punched cards or paper tape can be used as the recording medium. However, in most cases, magnetic tape is more suitable since it has the required speed and digital capacity. These considerations have led to the design of measuring and recording equipments using both ¼ inch and 1 inch wide magnetic tapes, together with the computing equipment for reading and analysing the recorded tapes.

2. Typical Recording and Analysing Arrangements

Bird and Waters[1] have used a magnetic tape system to record the data of an experiment shown in Fig. 1. This experiment was an investigation of the high energy γ-ray spectra resulting from resonant neutron capture in platinum for neutron energies up to 600 eV. Bursts of neutrons having 0·25 microseconds duration and repeated 400 times per second were

---

† Manuscript received 23rd December 1959. (Paper No. 586.)

‡ U.K. Atomic Energy Authority, Atomic Energy Research Establishment, Harwell, Didcot, Berkshire.

U.D.C. No. 621.395.625.3 : 539.1.

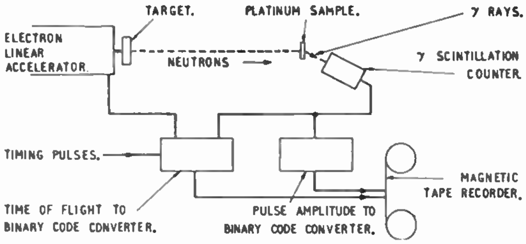


Fig. 1. Typical nuclear physics experiment. (Study of γ-rays from resonant neutron capture in platinum).

obtained from a linear accelerator. These neutrons travelled a flight path of 6·5 metres and then bombarded a platinum sample. The resultant γ-rays were detected by a scintillation counter and the pulse amplitude from this counter gave a measure of γ-ray energy, while the time of flight of the neutron from the linear accelerator target to the platinum sample gave a measure of neutron energy. The resultant binary code characterizing each nuclear reaction was marked on 14 tracks across the width of a 16-track tape [6 digits (63 channels) for γ-ray energy and 8 digits (255 channels) for neutron energy] so that any one out of 16,065 combinations of γ-ray and neutron energy could be recorded. Auxiliary gating circuits were used so that only neutrons causing γ-ray emission from the platinum were recorded, the average rate of recording being about five per second. The experiment lasted for about 100 hours giving five reels of recorded tape, each of 7,200 ft. length. These tapes were then read into the analyser which counted the total number of nuclear reactions occurring with each of the 16,065 possible combinations of neutron and γ-ray energy. Figure 2 shows a graphical presentation of number of events versus neutron and γ-ray energy, and is an illustration of how a magnetic tape recording and analysing system can elucidate very complex phenomena.

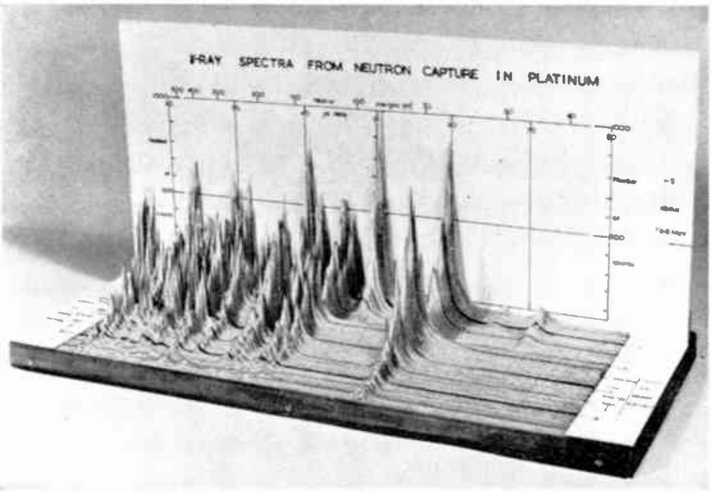


Fig. 2. γ-ray spectra from neutron capture in platinum.

There are two points of interest in this typical experiment which control the design of the tape recording system.

(a) The experimental data occurs at approximately random time intervals so that sufficient paralysis time must be included in the tape recording circuits to avoid one event being recorded too soon after the previous event. This time is chosen to give a minimum bit spacing along the tape of 0·005 in. for the 1-in. tape system and the tape speed must be chosen so that this paralysis time does not cause too much loss of information; e.g. in the experiment previously described the paralysis time was 5 milliseconds causing an average loss of 2·5 per cent. of the data. This requirement also has the result that only a small proportion of the tape length carries a record.

(b) If a magnetic tape error in recording or reading occurs, then each such error will only affect the data of *one* nuclear event. Thus a considerable number of such errors can occur before the final experimental result is significantly affected. The criteria on how many errors can be tolerated will be considered in section 4.1.

The wastage of tape due to effect (a) above can be greatly reduced if a "buffer" store is introduced in the recorder. Figure 3 shows a block diagram of such a recorder arranged for neutron energy measurement by "time of flight" methods. The timing gate is opened by the "start" pulse and allows timing pulses from a crystal oscillator to be passed to a binary scaler. This scaler continues counting until a neutron pulse arrives from the scintillation counter at the end of the flight path. The binary scaler then stops counting and its binary number is written into the temporary or buffer store, which uses small square-loop ferrite cores. The scaler is then allowed to continue counting, after a suitable correction for lost time, until the next neutron pulse arrives and so on. The buffer store information is read out in a regular manner on to the magnetic tape so that the store is being "filled" with neutron binary information at random time intervals and is being "emptied" at regular time intervals. The rate of reading out and the capacity of the store must be chosen to give a negligible chance of too many neutron events occurring in a short time and "overfilling" the store. On the other hand the store will often be empty when the tape is ready to receive information, so some of the tape is still not used. Thus the introduction of this buffer store increases the recorded fraction of each reel of tape from perhaps 2 per cent. to 50 per cent. at the expense of increased complexity.

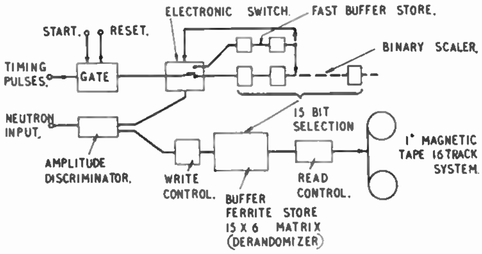


Fig. 3. Typical arrangement of 1 inch magnetic tape recorder for neutron "time of flight" technique.

The analyser accepts the recorded tape and accumulates the data into a small ferrite matrix store; Fig. 4 shows the arrangement. The ferrite store has a capacity of 1,023 addresses (each containing 10 binary digits) and each address counts the number of events in a particular category defined by one of the binary codes. These numbers are then read out on to a suitable medium such as punched cards for transfer to a digital computer where further computation may take place. Each event or row of digits from the tape reel is checked for accuracy and if an error occurs this event is rejected. The total number of possible codes is 32,736 on the 1-in. tape system so that the reel of tape has to pass through the analyser 32 times, each time selecting a different batch of 1,023 codes, before all the data is read.

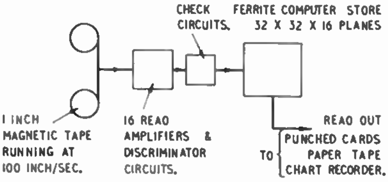


Fig. 4. Arrangement of 1 inch magnetic tape reading and analysing system.

The following sections will now consider the problems and techniques associated with the magnetic tape writing and reading processes.

3. Performance needed from Magnetic Tape Transport

The main requirement is for a tape guiding system which will position the tape very accurately, and with minimum skewing as the tape passes over the writing or reading head (in contact recording). The necessary performance factors may be listed as follows :

(1) The distance between the centre line of the tape and a fixed point on the head must be constant to within ±0·003 in.; alternatively if the tape is guided on one edge then this tolerance refers to the variation of distance between this edge and a fixed point on the head.

(2) The "skewing" of a 1-in. tape with 200 bits/in. packing density should not exceed ±0·0005 in. This refers to the recorded bit on one outside track being advanced or retarded relative to the corresponding bit on the other outside track.

(3) The speed range of the recording deck can be varied from 0·25 to 7·5 in./sec for the 1-in. tape and $\frac{15}{16}$ to 30 in./sec for the ¼-in. system. The reading deck of the analyser runs at a fixed speed of 120 in./sec both forward and reverse. The guiding requirements of (1) and (2) must be met under all these speed variations without any mechanical readjustments.

(4) Long recording times are required so that large reels of tape are used. The 1-in. tape system uses 14-in. reels containing 7,200 ft of tape. Smaller reels are used in the ¼-in. system since this equipment must be kept reasonably small.

(5) Speed flutter of the tape is relatively unimportant and variations of ±10 per cent. for the recorder and ±5 per cent. on the analyser can be tolerated.

(6) The starting and stopping times of the deck need not be fast and several seconds can be allowed for this.

(7) The cost of the recording deck must be kept to a minimum since many are required; thus any unnecessary mechanical refinements should be deleted. This is of special importance for the 1-in. tape system where the cost of the deck could exceed the cost of the associated electronic equipment.

These requirements differ considerably from those of computers especially that of (6) and make it desirable that the deck should be specifically designed for digital data recording.

4. Recording and Reading Technique for 1-inch Tape System

The method used has been chosen to minimize the errors in the data caused by "drop-outs." These "drop-outs" include the effects of faulty tape, dust on the tape or transport, and mechanical damage to the tape surface or edges caused by wear and careless handling.

4.1. *Drop-out Error Considerations*

It is fundamental to the counting of random nuclear events that some losses of data occur (due to the finite resolving time of the apparatus used, etc.) and that it is necessary to count a large enough number of events to achieve the desired statistical accuracy. Loss of information due to a drop-out falls into the same category as resolving time losses, provided *all* data relevant to the event is lost or rejected; if this is not the case, an error may be introduced in addition to a loss. In principle losses due to drop-outs of, say, 50 per cent., can be tolerated provided that a negligible number of errors is introduced and that the user is prepared to double his counting time. In practice, usually for economic reasons, an experiment is kept as short as possible, and losses are required to be kept down to 10 per cent. or less. *If errors are introduced* these must be several times less than the statistical errors of the experiment. The store capacity of one of the present 1-in. 16-track systems provides a statistical accuracy of ±0·25 per cent. and words in error (not rejected) must therefore be kept down to better than 1 in 1,000; i.e. 1 drop-out in 16,000 bits. Compared with this an earlier 1-in. 16-track system provides only ±3 per cent. statistical accuracy and errors due to drop-outs of about 1 in 2,000 bits are acceptable.

In all these counting systems the tape may be handled by relatively unskilled users in dusty atmospheres; furthermore, normal usage (e.g. bulk erasure) increases the frequency of drop-outs. Even the use of high-quality instrumentation tape, therefore, offers little advantage on a long term basis as it is unlikely to remain in its original condition for very long; plastic-covered tape may offer an improvement, however, due to its better wearing properties.

Clearly, writing and reading methods are needed which make possible the detection and subsequent rejection of words containing drop-outs, in which case drop-outs of 1 in 160 bits would be acceptable as compared with 1 in 16,000 for the system without drop-out rejection.

4.2. *Description of Recording Methods*

The predominant factor influencing the choice of recording method in these counting systems is, as one would expect, the relative ease of drop-out detection. Two recording methods (both of the return to zero type) have been used one of which incorporates drop-out error detection.

The first method which is employed in the low-accuracy 1-in. system, does not allow drop-out detection and entails magnetizing a small area of tape when writing the binary digit "1" whereas the "0" is not recorded. A drop-out in this system produced an error in addition to a loss and the following example demonstrates the difficulty of detecting this or applying a correction to the final result. Consider a neutron data word or "address" 00111: a drop-out occurs when any "1" is interpreted as a "0" by the reading circuits; such counts will be lost from this address and will be distributed amongst addresses 00011, 00101 and 00110. Apart from losses, address 00111 may be subject to errors if addresses 10111 and 01111 sustain losses due to drop-outs in the most significant tracks. It will be seen therefore that the magnitude of the errors because of additions to an address is related to the number of "0's" it contains and the losses from the address depend on the number of "1's". Both effects depend heavily on the number of counts in the addresses involved, and to the relative position of the addresses in the spectrum.

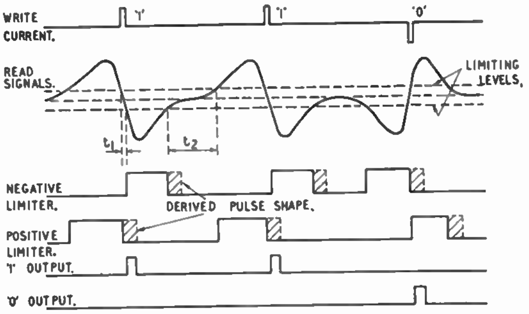


Fig. 5. Recording and reading waveforms. 1 inch magnetic tape, 200 bits/inch.

With this method the tape, when it has deteriorated to a certain point, becomes unusable and this occurs roughly when the frequency of drop-outs is ten times the level when new.

In the high-accuracy 1-in. system (and in the $\frac{1}{4}$-in. system) steps have been taken to detect and reject drop-outs. In addition to magnetizing a small area to denote "1," a small area is magnetized in the opposite sense when writing "0." This allows effectively a check on each bit and if neither "0" or "1" is present on replay, the whole 16 bits in an address can be rejected; i.e. there is a counting loss but no error. Tape which has deteriorated considerably below the level already mentioned can safely be used with this method of writing.

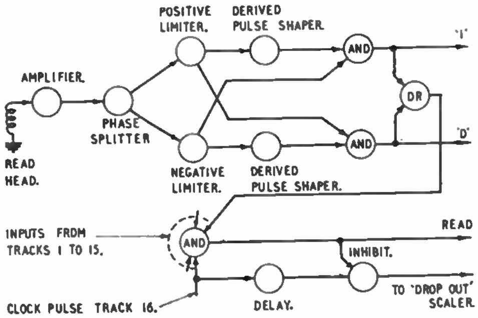


Fig. 6. Logic diagram of reading system. 1 inch magnetic tape, 200 bits/inch.

Writing, reading and drop-out detection is shown in outline in Figs. 5 and 6. Writing is performed by current pulses in the record head which saturate the tape, and, due to the field spread from the gap, produce bits about 0·0025 in. in length; the movement of the tape during the writing pulse duration (100 microsec) is almost negligible. The maximum packing density is 200 bits/inch.

On replay a signal is produced which is approximately the time differential of the flux pattern on the tape. To separate "0" from "1" signals these are first limited at a level consistent with cross talk rejection. A gating waveform is produced as shown in Fig. 5 and it can then be determined whether a positive peak is followed by a negative or vice-versa. The former combination denotes a "1" signal and the latter a "0." An OR gate between "1" and "0" outputs on each track feeds an AND gate common to all sixteen tracks and must give an output before the analyser is allowed to accept the 16-bit number. Subsidiary circuits count the number of rejected words, these being shown by the presence of signals on some tracks and not on others.

It should be noted that on replay the voltage waveform of one digit crosses from positive to negative (or vice-versa) at a comparatively fast rate compared to the rest of the waveform, (see t_1 and t_2 in Fig. 5); this portion of the waveform is used in the detecting circuit and so gives a good indication of the arrival time of the centre of the digit over the replay head. It is important to minimize the time shift in the detection circuits caused by signal amplitude variations, since the AND gates in the detection logic require that pulses from all tracks should occur within a certain time interval of each other. In addition to these circuit effects, errors in timing are also caused by "skewing" of the tape due to mechanical deficiencies of the tape and transport. These combined electrical circuit and mechanical effects have limited the maximum packing density to 200 bits/inch on the existing 1-in. tape system.

4.3. *Amplitude Variations of Replay Signals*

Apart from magnetic tape defects substantial loss of replay signal amplitude can occur due to the accumulation of tolerances, electrical, magnetic and mechanical.

4.3.1. Mechanical tolerances

These arise from variations in tape width, guiding problems on both record and replay decks and relative misalignment of record and replay heads. All these effects contribute to a decrease in the bit area "seen" by the replay head.

(i) Tape width: 1-in. wide tape is normally cut to a tolerance of (+0, −0·004 in.), and unless guiding takes place on the same edge on both record and replay transports a relative track shift of up to 0·004 in. may occur through the system.

(ii) The position of the tape relative to the head may vary:

(a) on the record deck according to speed.

(b) on the replay deck according to direction. Single edge guiding again minimizes these variations which are then mainly a function of longitudinal bowing of the tape. If guiding lengths on record and replay are similar and guides are close to the head then the track displacement from this source should not be more than about 0·002 in.

(iii) Head block alignment: The positions of both record and replay head blocks may be displaced up to ±0·001 in. relative to the tape deck giving a further possible displacement of 0·002 in.

(iv) Track alignment: Individual head gaps may be misaligned ±0·002 in. from the design centre on both record and replay heads giving a further possible track displacement of 0·004 in.

(v) Track width tolerance: Individual gaps may vary in width up to ±0·001 in. causing a relative track displacement of 0·002 in.

4.3.2. Electrical tolerances

These are mainly confined to the electrical characteristics of the heads at the frequencies of interest. The maximum possible overall variation of frequency response on replay is ±2½ db at 20 kc/s from track to track and head to head. This variation is eliminated on recording if the tape is saturated and on replay by adjustment of amplifier gain.

Saturation also minimizes the effect of variations in record current; e.g. a 5 per cent. variation in current amplitude produces a signal amplitude variation of about 1 per cent. in the saturation region.

4.3.3. Magnetic tolerances

A commercially available instrumentation tape in use by the authors is quoted as having a maximum possible signal variation of ±3 per cent. within a roll and ±10 per cent. from roll to roll; i.e. ±13 per cent. overall.

In the 1-in. tape system all suggestions made above for minimizing or eliminating variations have been put into effect except guiding on one edge. The maximum variations in signal level obtainable (apart from drop-outs) is therefore about 3 : 1 with the prospect of further improvement with better guiding to 2 : 1. Amplitude discriminator levels are set at 20 per cent. of nominal amplitude and this gives a safety margin over the worst cross-talk level which can arise.

4.4. *Experiment Labelling*

In some investigations it is required to carry out a series of short counting runs varying the parameters from run to run. Under these circumstances a 16-bit code in one run may represent information different from that of the same 16-bit code in other runs. It is proposed therefore to label the start and end of each experiment with a single word address coupled with a negative clock pulse ("0"), as distinct from the normal positive ("1") clock pulse; (one track is normally marked with "1" to signify that data has been written and this is called the clock track although to some extent this is redundant information). The code will be set up manually at the start and finish of recording each experiment. A decoding circuit can be preset to recognize any desired code and can feed out pulses both to stop and start the analysis.

4.5. *Comparison with other Writing Techniques*

The other methods are usually of a non-return to zero type and differ from the method in use (Sect. 4.2) in the following respects:

(a) The maximum packing density on a single track can be increased by a factor of two.

(b) No erase head is needed.

(c) To obtain a satisfactory drop-out rejection performance at least one parity check digit must be included.

(d) Due to the tape saturation, drop-outs in any position can appear as extra input pulses during reading. The use of parity check digits will usually reject these pulses provided the tape fault does not affect two adjacent tracks. This latter fault may occur if there is a large area of tape surface damaged, or dust on the tape surface or reading head.

The advantage in (a) is nullified for the 1-in. 16-track system because the maximum longitudinal packing density of 200 bits/in. is set by the "skewing" and timing errors (Sect. 4.2.). Item (d) above is a serious disadvantage compared to the method in use because in some of the applications only a small percentage of the length of tape may contain data. Thus a method which is only sensitive to the tape when data has been recorded is clearly more suitable than a method where the reading circuits are affected by the whole tape length. In addition, when the number of drop-outs is becoming serious the user requires to know the percentage of data lost; this figure cannot be obtained from the non-return to zero method without extra recorded information, whilst in the present method the drop-out counter gives the amount of rejected data. In the case of the $\frac{1}{4}$-in. tape system the need for redundant parity checks is a great disadvantage of the non-return to zero method.

Because of these considerations the present writing method in Section 4.2 has been designed for both $\frac{1}{4}$ inch and 1 inch systems.

5. Recording System using $\frac{1}{4}$-inch Magnetic Tape

This instrument was designed to be cheaper and more portable than the 1-in. system and to have greater flexibility in its application. Since only four tracks are available it is necessary to write digits serially so as to have sufficient bits available for any one event. The total number of digits in a block may be varied to suit the particular experiment, up to a maximum of 38 (10 digits serially along each of the four tracks, but with the first digit omitted from each of the inside tracks in order to identify the beginning of a block). In order to increase the number of digits on a reel the packing has been made 400 bits per inch. This is possible because skewing of the tape has less effect than with the 1-in. system. A rigorous check must be made to ensure that any block with missing digits due to drop-outs is ignored.

The digit layout of the tape is shown in Fig. 7. Plus and minus writing as described in Section 4·2 is used. When reading digits from the tape the beginning of the block is identified by the absence of signals on tracks B and C. This identification is used to reset the equipment and, in particular, to start a counter. The digital information in position 0 on tracks A and D is fed to two ferrite cores and stored. When position 1 passes the replay head the digital information is stored in further cores and a check is made that there is a signal on each track. If this is so, the counter is moved to its next position. This procedure is repeated for as many positions as may be required. When the last position has been read out the counter will have advanced to a preset number and opens output gates. The stored information is transferred out by the reset signal. The absence of a signal at any position within the block will prevent these gates being opened so that the incorrect block cannot be transferred although the equipment will be reset, and the next block unaffected.

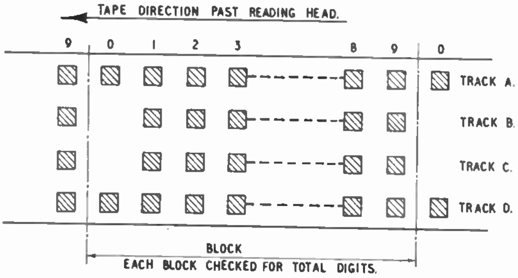


Fig. 7. Layout of digits on $\frac{1}{4}$ inch tape system.

Since this system uses 400 bits/in. packing density, the replay waveform given in Fig. 8 differs from that shown in Fig. 5. The time intervals t_1 and t_2 in Fig. 5 no longer differ so markedly and therefore the method of detecting "1" and "0" in Fig. 6 is not sufficiently reliable. The method employed for the $\frac{1}{4}$-in. tape system is shown in Fig. 8.

After amplification the replay signal is fed to two discriminators giving outputs corresponding to the positive and negative excursions of the original signal. The leading edges of these are combined and used to trigger a binary circuit the output of which is a regular waveform, and may be regarded as a clock for that particular track. Coincidence between the clock and the positive discriminator output indicates a "1" while the absence of a coincidence indicates a "0." This system has the advantage that it is not dependent on relative rates of change or spacing and hence may be used without change at any replay speed—or even at irregular speeds. Since the information is transferred to ferrite cores half switching currents from the clock and the positive discriminator may be used to perform the coincidence check.

To confirm the presence of signals on all tracks it is merely necessary to establish that all four clock pulses are present. The counter is arranged so that it will only move to its next position when instructed by a check circuit.

On the recording side the method of writing along the tracks involves storing information until tape is available to accept the signals. The input data circuits are cleared into a buffer store immediately a signal has been received, leaving the input circuits available for a further signal. This is equivalent to a two word derandomizer similar to that shown in Fig. 3 for the 1-in. tape system and gives a considerable increase in the mean rate of random pulses that may be handled for a given percentage loss.

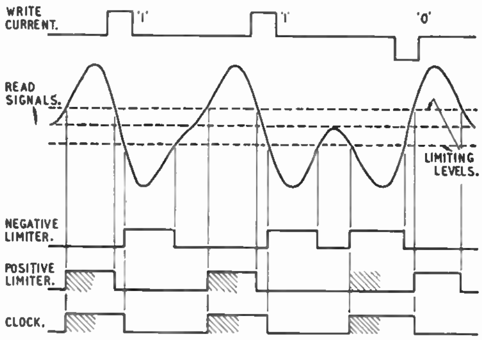


Fig. 8. Recording and reading waveforms. $\frac{1}{4}$ inch magnetic tape, 400 bits/inch.

The six speeds incorporated in the tape transport (30 in./sec to $\frac{15}{16}$ in./sec) enable a storage time appropriate to the experiment to be selected. At the highest speed it takes 830 microseconds to write a 38-bit number or 166 microseconds to write a 6-bit number.

The storage capacity of a standard $8\frac{1}{4}$-in. reel is approximately 4×10^7 bits arranged in blocks; for example 10^6 38-bit binary numbers, or six times as many 6-bit numbers.

6. Conclusion

Magnetic tape digital recording is becoming a useful tool in nuclear physics research and it will soon lead to a great increase in the rate of data accumulation. Many ½-in. and 1 in. tape recording systems will be used and suitable analysis instruments installed. Transistors and square loop ferrite cores are used to give maximum reliability and the tape transports employed must give comparable service. There are still two outstanding problems which need a reasonable solution.

(a) The presentation of sufficient recorded data in a suitable visual form to satisfy the user during an experiment.

(b) An improvement in the flow of digital information from the analyser to the large digital computers. Magnetic tape may be required to reduce the time lost in punching cards or paper tape.

Thus a programme for a steady development of these techniques is being pursued.

7. Acknowledgments

The interest in magnetic tape recording at A.E.R.E. was started by Dr. P. E. Cavanagh's design of ½-inch tape system[2] and the present system owes much to his appreciation of the usefulness of tape to the physicist. The 1-inch tape system was originated under the guidance of Dr. P. A. Egelstaff and later developments were made in collaboration with Drs. J. R. Bird and J. R. Waters. The ½-inch tape system was designed under the supervision of Mr. K. Kandiah.

8. References

1. J. R. Bird and J. R. Waters, "The use of digital recording on magnetic tape for the study of γ rays from resonant neutron capture in platinum," A.E.R.E. report NP/GEN/12.
2. P. E. Cavanagh and D. A. Boyce, "Magnetic recorder for nuclear pulses," *Rev. Sci. Instrum.*, **27**, p. 1,028, December 1956.

News from the Sections . . .

North Western Section

On 3rd September last a party from the Section visited the Winter Hill Station of the Independent Television Authority by the courtesy of the engineer-in-charge, Mr. W. H. Jarvis. The tour of the station started at the incoming land lines and terminal distribution boards, where the Post Office responsibility ends and the station takes over.

After inspecting the video and sound amplifier racks, some time was devoted to the auxiliary equipment for the projection of films and slides and turntable for disc recordings. At the station control and monitoring console the party was able to see an outside broadcast coming in on a radio link, being re-radiated and the transmission received on a separate dipole; monitors on all three channels permitted direct comparison of quality and of waveforms at various points.

Other features of interest included the elaborate system of interlocking on the transmitter and associated h.t. supply cubicles for protecting both personnel and the equipment itself. The system of tuning the coaxial grid, anode and cathode lines was also examined. The output coaxial line goes to a vestigial sideband filter, and the outputs of the vision and sound transmitters are de-coupled by tuned stubs to prevent interchange of power between them. A reflectometer with built-in probes is installed for setting up the various filters and matching the feeder.

F. A. M.

Montreal Section

The Annual General Meeting of the Section was held on 2nd May, and the following officers were re-elected: Chairman. T. A. Cross (Member), Vice-Chairman, G. Zelinger (Member). Secretary-Treasurer, K. N. Coppack (Associate Member). In addition two additional members were elected to the Committee: P. H. Carey and K. G. Reid (Associate Members).

On 26th May a party of 50 members of the Section and their guests visited the Bell Telephone Company of Canada's exhibition "Panorama of Telephone Progress." Many of the exhibits are working models, including early automatic exchanges and a diagrammatic model of the direct dialling system now in use in Canada and the U.S.A. A model of a section of a microwave link was used to demonstrate the transmission of microwaves. Ferrite core memory storage was demonstrated and a model of the "Discoverer" satellite was shown. The visit was followed by a film describing the construction of a microwave link.

The Section's plans for the coming session include presentation of the following papers: 26th October—"The Mid Canada Line" by D. Gilvary (Graduate); 23rd November—"Printed Circuits" by D. Grierson; 22nd February—"Radio and Electronic Equipment in the Modern Airline" by D. W. Griffiths. All meetings will be held in the McConnell Engineering Building of McGill University; further details of these and other meetings will be circulated to all members of the Section by the honorary secretary whose address is 1000 Marlboro Drive, Apt. 205, Town of Mount Royal, Que.

K. N. C.

Union of South Africa Section

At a meeting of the Section held in Johannesberg in June, Mr. H. Rothenberg (Associate Member) presented a paper entitled "Induction Heating for Manufacturing Industry." After a discussion of the principles and design of induction heaters, the paper dealt at length with the advantages which the technique has over the more conventional methods of applying heat.

Mr. Rothenberg first of all pointed out that heat is generated within the charge itself, which is therefore the hottest part of the furnace, thermal efficiency is hence high and very rapid melting is possible. Melting can be carried out in a vacuum or in a reducing atmosphere if required, and the charge can be thus kept clean from impurities, while the inherent stirring action gives uniformity of composition. Accurate control of the temperature and the location of heating is possible while the "surface" can be hardened to any required depth with immunity from damage to the steel due to over-heating. Finally, heating starts instantly when radio frequency power is applied and stops instantly power is removed. The heat is confined to the area required, leaving the remainder of the part unheated.

Cablefilm Equipment†

by

S. N. WATSON‡

A paper based on a short informal contribution given on 4th July, 1959, during the Institution's Convention in Cambridge.

Summary: Cablefilm motion picture facsimile equipment has been developed for transmitting short lengths of 16 mm film over long distances as quickly as possible. A good quality music circuit for about 6 kc/s bandwidth is required. Techniques similar to those found in television are used, and although, in view of the narrow bandwidth of transmission circuit, a considerable time is employed in transmission, the system is nevertheless many times faster than previously used facsimile systems. The reasons for the choice of the particular transmission standards employed are given.

1. Introduction

Extensive facilities exist throughout the world for the distribution of news in the form of the written and spoken word. Similar facilities provide facsimile copies of still pictures, but until the development by the Engineering Division of the British Broadcasting Corporation of the equipment described in this paper had taken place, no comparable facilities existed to supply moving pictures suitable for presentation in news transmissions by television broadcasting organizations. Except where a television network is available, news pictures are usually supplied on film and, in an attempt to provide a quicker news service, it was decided to develop a facsimile process for use with certain music circuits. The equipment to be described is capable of providing copies of short lengths of 16 mm news film with the minimum delay.§

2. Picture Standards

From the beginning of the development of this equipment it was clear that one of its most important uses would be to exchange news pictures across the Atlantic between Europe and America. Accordingly, the characteristics of the music circuits which exist in the transatlantic cable between New York and Montreal on the one hand, and London on the other, largely determined the transmission characteristics of the system. It appears that a typical item of a news programme is approximately thirty seconds long and if the facsimile system is to be successful, its transmission time for this amount of film should not exceed say one hour, i.e. a ratio of 120:1 between the playing time and time of transmission by the facsimile process. It follows that everything possible must be done to reduce the bandwidth requirements since the ratio between the bandwidth associated with a normal television signal, for example, and the 6·4 kc/s of bandwidth which is available on the transatlantic music circuit is more like 1,000:1.

It was, therefore, necessary to choose picture standards requiring the minimum bandwidth commensurate with reasonable picture quality. Previous experience indicated that a 200-line picture would be acceptable, and that each line should contain about 360 picture elements. A further economy has been obtained by portraying motion at the rate of 12 pictures per second, although the number of complete pictures transmitted per second must, of course, remain at 25 for the eventual broadcast, in order to avoid brightness flicker.

With these major decisions taken, the details of the standards finally used followed almost

---

† Manuscript received 18th August 1960. (Paper No. 587.)

‡ The British Broadcasting Corporation, Designs Dept., London, W.1.

U.D.C. No. 621.397.12

§ Features of this system are protected by U.K. Patent Applications Nos. 18277/59, 18853/59 and 16323/59.

automatically. These details are listed in Table 1. (The considerations which led to a choice of 4·5 kc/s for the video bandwidth will be discussed in Section 4 which deals with the line transmission equipment.) This choice of standards has led to each single frame of the film requiring a transmission time of eight seconds. This, together with the fact that only 12 frames are transmitted where normally double this number would be employed were normal information about motion being sent, means that the time of transmission is approximately 100 times greater than the eventual playing time of the film.

Table 1

Number of lines per field	200 sequentially scanned
Line scan frequency	25 c/s nominal
Number of picture elements per line	360
Interline blanking period	6 millisec
Interfield blanking period	100 millisec
Duration of each frame or picture scan	8 sec
Maximum video signal frequency	4·5 kc/s

With these standards in mind it was possible to commence the design and manufacture of suitable equipment. Briefly it was necessary to make a film scanner which could generate a television type waveform of sufficiently small bandwidth. The transmission equipment had, in turn, to translate the video signal so that its spectrum fell within the passband of the cable. Then, after transmission, the signal had to be converted back to video frequency and recorded on 16 mm film.

3. Film Console

The film console is basically a 16 mm slow speed, flying spot film scanner or, alternatively, a 16 mm telerecording channel, the same piece of equipment performing either function at choice.

3.1. *Film Traction Mechanism*

Wherever possible in the equipment the design is such as to give some degree of flexibility. This equipment is in many ways a new venture and circumstances may arise when it is desirable to change the picture standards employed. One good example of this occurs in the film traction mechanism. Under normal conditions of working, only every other picture is transmitted, each picture being recorded in duplicate at the receiving end. This produces a film capable of being used in a normal projector, etc., i.e. at 24 pictures per second. If, however, the film to be transmitted has a subject which moves quickly, it may be desirable to transmit the full number of pictures. In this case the sending and receiving equipment can be switched to operate frame by frame. The intermittent mechanism which drives the pull-down claw and the associated sprockets is essentially a magnetically triggered clutch, transmitting the power provided by a small induction motor. The electrical triggering signal can be modified so as to make the clutch perform either one or two revolutions as required.

3.2. *Optical Assembly*

Figure 1 is a diagram of the optical assembly and associated equipment. In the send condition only one lens is in use and the equipment operates as a flying spot scanner. In the receive condition the photocell is no longer required and both lenses are used to record two images of the film. Great care has to be taken to ensure that these two pictures are as nearly identical as possible and in the correct position, since any

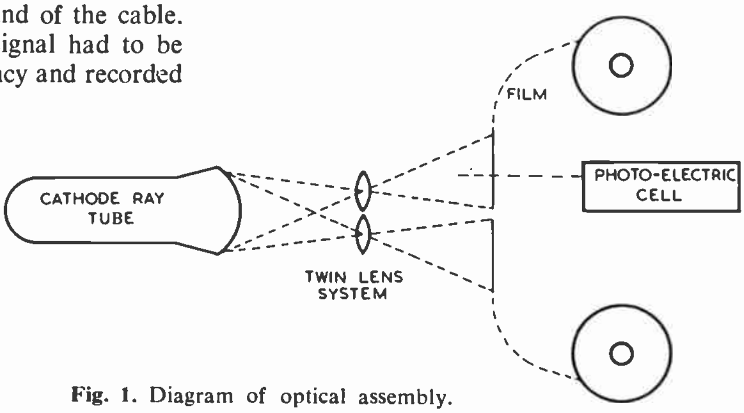


Fig. 1. Diagram of optical assembly.

discrepancy will introduce a 12 c/s per second flicker.

3.3. *Electrical Equipment*

3.3.1. The waveform

More or less conventional master oscillator and dividers produce line and field pulses which drive the waveform generator, the latter in turn producing the necessary synchronizing signals for blanking waveforms.

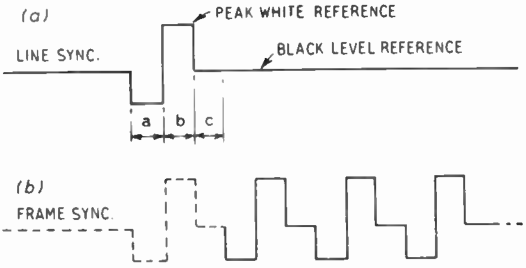


Fig. 2. Synchronizing waveform.

In normal television an occasional failure or irregularity in the synchronizing signal can often be tolerated. Unfortunately the time scale in the proposed system is such that a faulty signal of this form could be most objectionable and so a signal without even momentary faults is required for an hour or more for each transmission. As in some circumstances the signal could be subject to considerable noise or other interference signals there was a need for a very strong and robust synchronizing system. The waveform employed is shown in Fig. 2. The line waveform is similar to that used in television broadcasting systems except that a further pulse has been added immediately after the synchronizing pulse. This pulse commences with the timing edge which extends from the bottom of synchronizing signal to peak signal, then immediately after this edge there are two reference levels, one at peak white and the other at black level. The complete synchronizing waveform is about 6 millisec long, which is equivalent to approximately 50 picture elements. This information is available for synchronizing, blanking, providing the appropriate reference levels, and also giving an opportunity for obtaining the reference carrier required later in the demodulating equipment. The circuits employed are such that the liability to interference, etc., is improved by some 10 db over that realizable with a normal synchronizing waveform.

The waveform in the lower part of Fig. 2 illustrates the frame synchronizing waveform. This consists essentially of a further three line sync. pulses in rapid succession.

3.3.2. Scanning circuits

To complete the description of the film console, it should be explained that two cathode-ray tubes are used, one to provide the scanning raster and the other, with a long afterglow phosphor, to provide a monitoring picture. Magnetic deflection is employed on both of these tubes.

The very low frequency frame scan is provided by a direct feed to a specially designed scanning yoke and a permanent magnet shift arrangement is provided to allow the picture to be centred in its correct position.

3.3.3. Video circuits

Figure 3 is a block schematic of the video equipment. This includes a non-linear correction for the various film processes required. The equipment normally transmits a negative film and produces the appropriate positive film at the receiving end. If desired, however, a positive can be transmitted and again a positive is reproduced at the receiving end. In both these cases the signal is, in fact, sent to line as a negative picture, but when a positive film is employed, the electrical signal is corrected by a non-linear network in such a way at the sending end so as to make it appear that it has originated from the corresponding negative. It is evident that the equipment employs a technique very similar to that used in normal television practice.

The problem of mains interference presented a major difficulty throughout the design of this equipment. Hum on the picture appears as a relatively high frequency pattern which cannot be removed by clamps and similar circuits. The low hum levels required can only be achieved by careful design and extensive use of magnetic screening. For example, the cathode-ray tubes described previously are surrounded by a double mumetal screen and all mains transformers are mounted in a separate cubicle several feet away.

4. Transmission Equipment

4.1. *Introduction*

The first step in the design of suitable equipment was to determine the amplitude and delay characteristics of the music circuit. Measurement of the noise level and noise spectrum was also made with the volume compandors, normally used on music and speech, out of circuit.

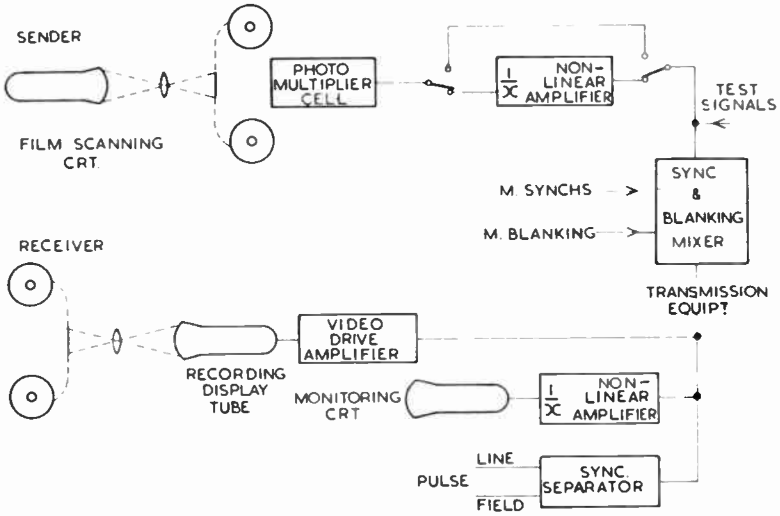


Fig. 3. Block schematic of video equipment.

It was clear from these results that some equalization of the amplitude/frequency characteristic and considerable equalization of the delay/frequency characteristic would be necessary and that even with equalization, the delay distortion at each end of the band would limit the usable bandwidth to about 5·0 kc/s, extending from 500 to 5.500 c/s. It had already been decided that an amplitude modulated vestigial sideband system would be used and accordingly a carrier frequency of 5 kc/s was chosen, the spectrum occupied by the signal being shaped to fall within the band from 500 to 5,500 c/s. In order to obtain the best signal/noise ratio the modulation factor exceeds unity and that part of the modulation envelope which extends beyond zero carrier is "folded back" in a positive-going direction. The modulation factor is, however, limited to 3·3 in order to simplify the terminal equipment. This type of signal requires synchronous demodulation and this type of demodulator has the subsidiary advantage of producing the minimum quadrature distortion normally associated with the demodulation of a vestigial sideband signal. The synchronous demodulation is achieved using an oscillator whose frequency is controlled by the incoming carrier frequency, as gated once per line. The gating waveform is conveniently obtained by envelope demodulation of the incoming signal. Figure 4 illustrates a typical envelope of the modulated carrier. It will be seen that the amplitude falls to zero at a point corresponding to approximately fifty per cent. of the picture signal range and then reverses in direction; at maximum picture voltage the amplitude of the modulated carrier is again nearly as great as at zero picture voltage. The two parts of the modulated carrier envelope disposed about the zero point are characterized by a difference of phase of π radians. The synchronous detector is able to recognize this difference of phase in addition to differences in amplitude so that the required video waveform is obtained.

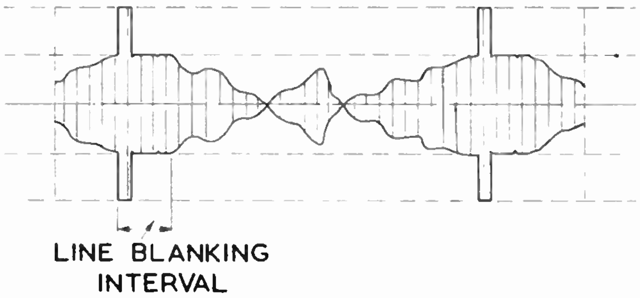


Fig. 4. Envelope of modulated carrier.

4.2. *The Sender*

Referring to Fig. 5, the video signal is first band-limited to 4·75 kc/s in a phase corrected filter.

The spectrum of the signal after it has been through this filter and associated video pre-emphasis network is shown in Fig. 5(b). This pre-emphasis network is a resonant equalizer having a maximum loss of 4 db at 2·5 kc/s and it is used to reduce the level of video components around this frequency which might otherwise produce unwanted intermodulation effects in the modulator. The carrier supply for the modulator is provided by a 5 kc/s crystal oscillator unit and buffer amplifier.

A relatively simple form of direct modulation is employed. A good balance is achieved and the resulting signal is free of unwanted interference, etc., even though the frequency spectrums of the input and output signals overlap. (Frequency spectrum Fig. 5(c).)

The output from the modulator then passes through the following three networks:

(i) A 400-c/s high-pass filter to remove low frequency components, especially those due to mains hum. (Frequency spectrum Fig. 5(d).)

(ii) A modulated signal pre-emphasis network. This network has a slope of approximately 3 db per octave over the required band and raises the low frequency components with respect to the carrier, thus partly compensating noise characteristics of the trans-atlantic cable. (Frequency spectrum Fig. 5(e).)

(iii) A 4·85 kc/s linear phase vestigial sideband shaping filter which has a loss of 3 db at the carrier frequency and provides half the total shaping necessary in the overall system. (Frequency spectrum Fig. 5(f).)

Finally, the signal passes through a regulating amplifier which automatically adjusts the level of the signal sent to line.

4.3. *The Receiver*

Figure 6 shows the position of the signal in the frequency spectrum in various parts of the receiving equipment.

The received carrier signal passes first through the amplitude and delay equalizers which compensate for much of the distortion of the music channel. Most of the distortion is corrected by fixed equalizing networks but a two-section variable amplitude equalizer is

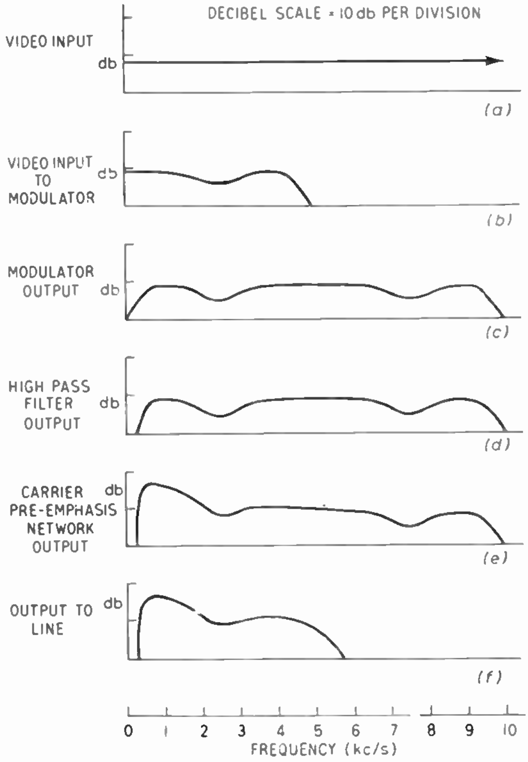


Fig. 5. Send terminal spectrum diagrams.

included together with a six-section variable delay equalizer. These variable equalizers are adjusted while observing the test waveforms on an oscilloscope provided for this purpose. The signal then passes through a 400 c/s high-pass filter, a modulated signal de-emphasis network (complementary to the pre-emphasis network used in the sender), and the linear phase vestigial sideband shaping necessary for vestigial sideband transmission. (Signal spectrum shown in Fig. 6(c).) The signal then passes through the regulating amplifier which has two functions. It raises the level of the modulated signal such that it is suitable for demodulation and also provides an output which is eventually used to phase lock the local oscillator. The local oscillator is, of course, used to demodulate the signal as described earlier. These two outputs from the regulating amplifier are stabilized in level and are virtually independent of changes in the input signal of up to ±6 db. The output from the demodulator (frequency spectrum of Fig. 6(d)) is passed through a 4·75 kc/s phase corrected low pass video filter and a video de-emphasis network which restores the loss at 2·5 kc/s as introduced in the sender. The signal so obtained (frequency spectrum Fig. 6(e)) is then amplified and passed back to the film console for recording as described earlier.

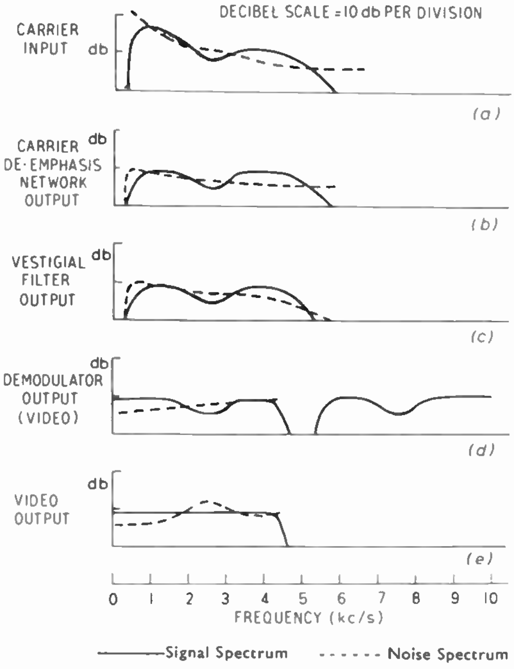


Fig. 6. Receive terminal spectrum diagrams.

5. Conclusions

The equipment described in this paper has been used on many occasions for the transmission of short lengths of film between the United Kingdom and Canada, in both directions. In particular it should be mentioned that it was used extensively on the occasion of H.M. The Queen's visit to Canada in June-August 1959.

The hour or so which the system takes to transmit a length of film which will normally be on the television screen for about thirty seconds has proved a very convenient unit. It is possible that in some circumstances this system will provide a much cheaper method of exchanging short lengths of film than, for example, the use of normal television transmission and recording systems, although the major benefit of the use of this system at the moment is obviously over very long circuits such as those across the Atlantic and those which will eventually link the British Commonwealth.

6. Acknowledgments

The active co-operation of the British General Post Office, the Canadian Overseas Telecommunications Corporation and the American Telephone & Telegraph Company during the testing of the circuits and equipment is gratefully acknowledged.

In conclusion, the author would like to thank the Director of Engineering of the British Broadcasting Corporation for permission to publish this paper.

A Computer Storage Matrix Using Ferromagnetic Thin Films †

by

E. M. BRADLEY, B.SC. ‡

Summary: A new method for selecting a magnetic film storage element from a matrix of elements which exploits the coherent rotational mode of reversal is described. It is shown that, by using a film made of a newly developed alloy "Gyralloy I," the reproducibility problems previously encountered can be solved. It is shown that the use of aluminium as substrate for the film enables the signal/noise ratio to be increased to an acceptable level even for very large stores; the drive power requirements are shown to be correspondingly reduced. Details are given of performance and construction of a storage device, which contains 50 words each of 50 bits.

List of Symbols

E	Energy.	
E_K	Film anisotropy energy.	
E_H	Energy due to magnetic field.	
K	Anisotropy constant of magnetic film.	
M	Saturation magnetization of magnetic film.	
α	Angle between magnetization vector and film preferred axis.	See Fig. 4
θ	Angle between external applied magnetic field and the preferred axis.	
$\emptyset$	Angle between magnetic field and magnetization vector.	
T	Torque acting on magnetization vector.	
T_K	Torque acting on magnetization vector due to anisotropy.	
T_H	Torque acting on magnetization vector due to external field.	
H	Magnetic field in oersteds.	
H_K	$= 2K/M$. Expresses anisotropy constant in oersteds.	
H_C	Coercivity of film in easy direction.	
h	Normalized field $h = H. M/2K$.	
h_P	Normalized field applied near to "hard" (perpendicular) direction.	
h_S	Normalized field applied near to "easy" (parallel) direction.	
s	Area resistivity of thin sheet.	
I_w	Word selection current.	
I_d	Digit selection current.	
I_{wt}	Word selection current threshold for storage.	See Section 4.4.
I_{dt}	Digit selection current threshold for storage.	
I_{dd}	Digit selection current threshold for disturbance.	

1. Introduction

It is now several years since Blois[1] first described a new technique for the manufacture of very thin ferro-magnetic material by a vacuum evaporation process. He showed that films of Permalloy between 1,000 Å and 10,000 Å thick had rectangular hysteresis loops with a coercivity of the order 1-10 oersteds. Such a property was required of magnetic material for the use as storage elements in the computer storage matrix first proposed by Forrester[2] and Rajchman[3]. The possible advantages over a ferrite core matrix of a storage matrix employing elements made by this technique were hoped to be lower manufacturing cost and higher operating speed.

Blois further suggested that the mechanism of magnetization reversal was different from that occurring in thicker materials in that it was a coherent magnetization rotation process rather than a domain wall movement or nucleation process. The hysteresis loops exhibited by a material which possesses a single axis of easy

---

‡ International Computers and Tabulators Limited, Stevenage, Herts.

† Manuscript received 12th March 1960. Sponsored by the Institution's Computer Group. (Paper No. 588.)

U.D.C. No. 621.318.132:681.14

magnetization and which reverses by the coherent magnetization rotation process have been worked out in detail by Stoner and Wohlfarth[4]. However, although a material which reverses by this process would be expected to have a rectangular hysteresis loop in the easy direction, it can be shown[5] that the hysteresis loops of those films considered suitable in other ways for computer storage application are the result of a domain wall movement and nucleation process.

It has been found[6] that control of this coercivity within the limits required for the computer storage application is difficult and further the switching speed is lower or not much greater than that found for ferrite materials. It has been concluded that the exploitation of the square loop property in a coincident current computer storage matrix is very difficult.

It is the purpose of this paper to describe a new technique for selection of a given element in a matrix of elements. This technique exploits the property of coherent magnetization rotation which films, within a certain thickness range, and prepared by a suitable process, have been found to exhibit.

Any design of thin film storage device has to allow for the fact that the signal/noise ratio problem is intrinsically two or three orders of magnitude more severe than with ferrite cores. This is because the amount of magnetic flux change occurring when a selected element is switched is lower by this amount whilst the drive currents are still of the same size and thus magnetic fields are approximately of the same size. Hence some radically new solution to the problem is required.

The converse to this problem is that the drive power can be very much smaller since the impedance of the individual elements whilst switching is very much lower. This enables cheaper and/or faster selection switching nets to be designed.

2. Selection of Storage Element

2.1. *Qualitative Description*

It is the property of coherent magnetization rotation which can be used for selection of an individual element, and the rotation phenomenon will therefore be described first.

A magnetic film when no magnetic fields are present will be in one of two states. Figure 1 shows this; the arrows here represent the direction of magnetization. This direction is called the "easy" or preferred direction. If a magnetic field is applied at right angles to the preferred direction, i.e. in the "hard" direction, the field will exert a torque on the magnetization vector which will rotate it towards the field direction. A torque tending to oppose this rotation occurs as a result of the magnetic anisotropy of the film. The cause of this anisotropy, which we know must be a result of the structure of the film, has not yet been determined in detail and this is the major problem in film physics. The position of equilibrium of the magnetization vector occurs when the torque due to the magnetic field and the anisotropy are equal and opposite to one another. If the field is sufficiently large the magnetization vector can align itself with the field; the process is shown in Fig. 1(b). If the magnetic field is now removed the anisotropy will exert a torque on the magnetization vector tending to turn it back towards the preferred direction, where the torque due to the anisotropy is zero. This is of course the reason why the preferred direction is a position of stable equilibrium.

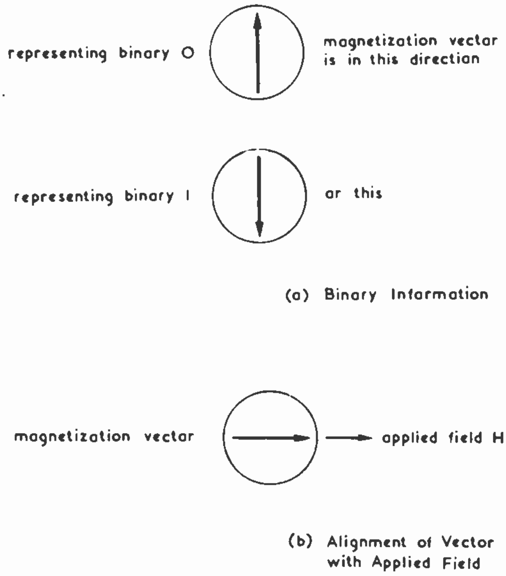
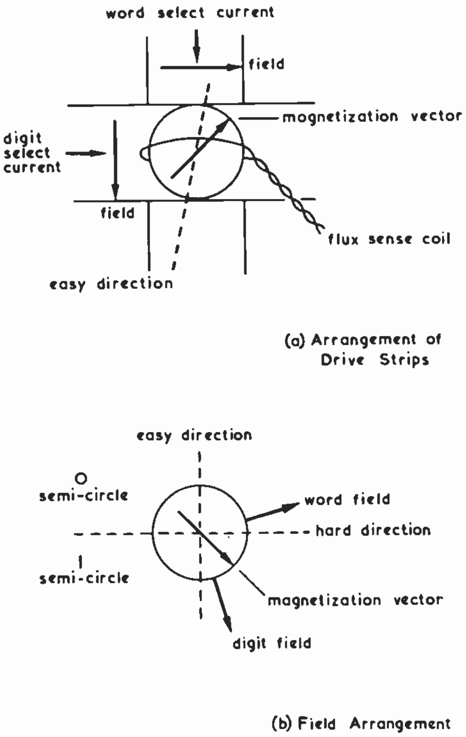


Fig. 1. Magnetization rotation process.

Information storage may be achieved if a binary 1 is represented by the magnetization vector pointing in one direction, and a 0 by it pointing in the opposite direction as shown in Fig. 1(a). The problem is how to control the direction of magnetization of an individual element in a matrix by a coincident current technique and of course how to sense the direction of the magnetization.

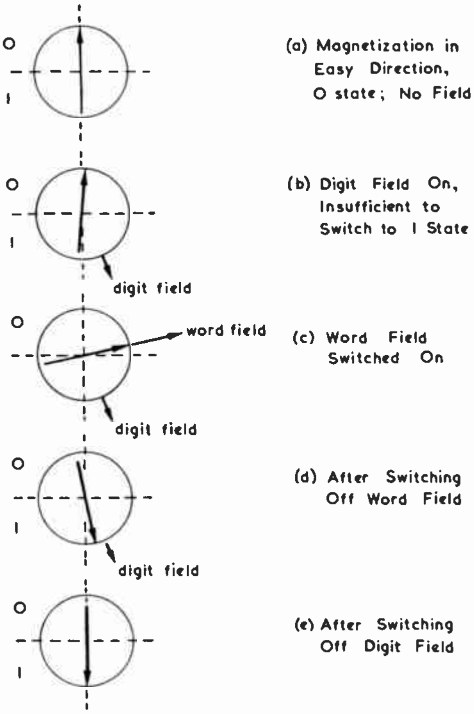
This can be achieved in the following way. Consider a magnetic film at the intersection of two strips as shown in Fig. 2(a). A current through one strip can be used to apply a field at a small angle to the preferred direction; this is the digit line of a word-organized or Cambridge-type system. A current through the other strip causes a field at right angles to that from the digit line, and is thus at a small angle to the "hard" direction; this is the word-select line. The sense coil is orientated so that it cuts flux in the direction of the digit field. The arrangement of the fields and their position relative to the preferred direction of the film is shown in Fig. 2(b).



(a) Arrangement of Drive Strips

(b) Field Arrangement

Fig. 2. Storage element.



(a) Magnetization in Easy Direction, O state; No Field

(b) Digit Field On, Insufficient to Switch to I State

(c) Word Field Switched On

(d) After Switching Off Word Field

(e) After Switching Off Digit Field

Fig. 3. Element selection process.

Consider first the write process. At the start of this process the magnetization vector is in the 0 state (Fig. 3(a)). A current is allowed to flow in the digit drive line, if it is required to store a 1 in the chosen element. The field must be less than the coercivity in this direction (Fig. 3(b)), otherwise it could reverse the film by itself. A few millimicroseconds later the word line is activated and the current flowing is sufficient to cause a field which can bring the vector almost into line with it (Fig. 3(c)). The word current is then switched off, leaving the digit current on. The vector can now swing right round almost into line with the digit line field, since the nature of the anisotropy is such that it exerts only a small torque tending to turn the magnetization back to the 0 sense if under 90 degrees, and tending to turn the magnetization to the 1 sense if larger than 90 degrees, i.e. the torque due to the anisotropy changes sign at the "hard" direction.

The magnetization is now as shown in Fig. 3(d). The digit field is removed and the magnetization now relaxes into the preferred direction in the 1 sense (Fig. 3(e)). If it had been desired to write a 0, no current would have been passed down the digit line and the magnetization would have been rotated back into the 0 state by the anisotropy torque. The read process is simpler since current is passed only along the word line. If the element was in the 1 state it first rotates nearly into line with the word field and at the end of the pulse relaxes back into the 0 state under the action of the anisotropy torque.

If the element was in the 0 state it rotates first in the opposite direction nearly into line with the word line field, and at the end of the pulse rotates back again to the 0 state. The sense coil is arranged to sense changes of flux in the digit field direction and different polarity voltage outputs will appear for the two different directions of rotation. Thus the voltage output for a 1 and 0 are as shown in Fig. 5.

This mode of operation has all the requirements for a matrix storage element, and it will be shown that the tolerances available for the magnetic field are large and that the switching time can be very short.

2.2. *Theoretical Analysis*

2.2.1. The rotational switching process

Stoner and Wohlfarth[4] have given a detailed analysis of the rotational switching process which they suggested should apply to permanent magnetic materials. D. O. Smith[7], together with Olson and Pohm[8], have suggested that some of the properties of their magnetic films can be explained by postulating this model, and have calculated some of the hysteresis loops expected. We have extended the analysis further, in a paper[5] to include some other hysteresis loops expected.

The method of calculation is to add the various terms contributing to the energy E of the system and to say that the equilibrium of the magnetization vector is attained when

$$\frac{\mathrm{d}E}{\mathrm{d}\alpha} = 0 \qquad \text{.........(1)}$$

where α is the angle between the magnetization vector and the preferred axis.

The contribution to the energy by the anisotropy is assumed to be of the form.

$$E_k = K \sin^2 \alpha \qquad \text{.........(2)}$$

where K is the anisotropy constant. If an external field H is applied at an angle θ to the preferred direction then the energy contributed to the system is given by the equation

$$E_H = MH \cos(\alpha - \theta) \qquad \text{.........(3)}$$

The action of the device may be more easily understood by calculating and equating the torques acting on the magnetization vector. An expression for torque may be obtained by the differentiation of energy with respect to angle.

Thus the value of the torque acting on the magnetization vector due to the anisotropy would be given by the equation

$$T_k = \frac{\mathrm{d}E_k}{\mathrm{d}\alpha} = K \sin 2\alpha \qquad \text{.........(4)}$$

and that due to an external field given by the equation $T_H = MH \sin(\alpha - \theta)$. Figure 4 shows the arrangement of the two driving fields and defines the various angles. h_P is provided by the word line and h_S by the digit line. The sense wire cuts flux in the direction of the digit field.

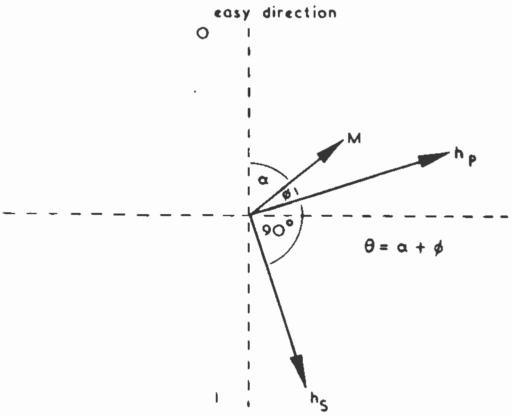


Fig. 4. Definition of angles and magnetic fields.

Four cases must be considered: (a) Write 0, (b) Write 1, (c) Read 0, (d) Read 1. In the analysis which follows the write 1 process will be considered in detail with write 0 as a special case of this. The two read processes will be considered separately.

The only disturbance it is necessary to consider is the effect on the magnetic state of an element which receives only a digit pulse.

2.2.2. The write process

Before application of the magnetic fields the magnetization vector is in the preferred direction 0 sense.

Thus at the start of the process the fields h_S and h_P are both acting on the magnetization vector†. The torque exerted on the magnetization vector will therefore be:

$$\frac{T}{K} = -\tfrac{1}{2}\sin 2\alpha + h_P \sin \phi + h_S \sin(\phi + 90) \qquad \ldots\ldots.(5)$$

$$= -\tfrac{1}{2}\sin 2\alpha + h_P \sin \phi + h_S \cos \phi$$

Equilibrium occurs when $T = 0$, thus

$$h_P \sin \phi + h_S \cos \phi = \tfrac{1}{2}\sin 2\alpha \qquad \ldots\ldots\ldots(6)$$

After this equilibrium point has been reached h_P is removed leaving only the h_S field and the anisotropy exerting a torque on the magnetization vector.

All that is required of the h_S field is that it should cause the vector to rotate to an angle greater than 90 deg because there the torque due to the anisotropy changes sign and rotates the magnetization vector towards the 1 sense preferred direction. Since $\sin 2\alpha$ is decreasing with increasing α if $\alpha > 45°$ then h_S need only be large enough to satisfy the expression

$$h_S \cos \phi = \tfrac{1}{2}\sin 2\alpha \qquad \ldots\ldots\ldots(7)$$

where α is the angle satisfying eqn. (6).

It is required to solve this equation in terms of h_P, h_S and θ; so inserting (7) into (6) produces

$$h_P \sin \phi = 0 \qquad \ldots\ldots\ldots(8)$$

whence $\phi = 0$ deg or 180 deg. But 180 deg is a physically inadmissible solution, being a position of unstable equilibrium.

Thus inserting $\phi = 0$ into (7) we have

$$h_S = \tfrac{1}{2}\sin 2\theta \qquad \ldots\ldots\ldots(9)$$

It is interesting to note from this analysis that to carry out the write process satisfactorily the combined fields must make $\alpha > 45$ deg at equilibrium. The position of the vector under the action of the two fields will be in line with h_P or $\alpha > \theta$. Apart from the 45 deg condition the functioning of the device is independent of the magnitude of h_P, i.e. if the combined fields can rotate the vector round to 45 deg and the magnitude of h_S is greater than $\tfrac{1}{2}\sin 2\theta$, then the element will be switched into the 1 state. It should be noted that the digit field h_S by itself must not be large enough to switch the element, i.e. must not exert sufficient torque to overcome the torque due to the anisotropy.

Stoner and Wohlfarth[4] have tabulated (their tables I and II) these critical fields as a function of an angle and these are reproduced here in Table 1. (Angle θ refers to Fig. 4 not the angle given by Stoner and Wohlfarth.) The magnitude of h_S required to effect writing, i.e. $h_S = \tfrac{1}{2}\sin 2\theta$, is also tabulated; these two quantities are the maximum and minimum of the range of values of h_S within which, the theory indicates, that the storage device will work.

Table 1

θ degrees	h_S critical	$\tfrac{1}{2}\sin 2\theta$
90	1·0	0
88	0·86	0·03
86	0·79	0·06
84	0·74	0·09
80	0·67	0·16
70	0·57	0·31
60	0·52	0·42
50	0·50	0·49

This Table shows that for a film reversing accurately by the simple rotation process, values of θ between 80 deg and 88 deg would allow very large tolerances in h_S. It also illustrates the fact that the device would not work in the form described when $\theta = 90$ deg since the magnetization vector would be brought round to $\alpha = 90$ deg and the direction of its subsequent rotation would not be under control if $h_S = 0$ as it is in write 0 or read 0 processes. In practice when a value of $h_P > 0{\cdot}8$ to $0{\cdot}95$ (depending on film) is applied by itself at 90 deg and then removed, the film splits into domains and subsequent reversal does not take place by coherent rotation until the film is again saturated.

Other modes of operation are possible of course; h_P may be limited to values less than

---

† It should be noted that h_S and h_P are reduced fields and related to the magnitude of the applied field in oersteds by the following relation:

$$H = h.\, 2K/M$$

0·8 or a permanent d.c. bias in the h_S direction may be applied. However, it appears that alternative schemes are either more complicated or would not allow such tolerances in the driving fields as are available with the proposed mode of operation.

It should also be noted that the h_S field must be on after the h_P field has decayed to zero or there can be no reversal. The write 0 process is similar except that $h_S = 0$ and it can be seen that even an infinite value of h_P will only bring the magnetization vector into line with h_P. When h_P is turned off the torque due to the anisotropy will rotate the vector back into 0 sense preferred direction.

The magnitude of the minimum h_P and h_S fields required to rotate the vector to an angle greater than 45 deg, which is the position for maximum anisotropy torque, is given by the following equation which is derived from eqn. (6). Inserting $\alpha = 45$ deg

$$h_P \sin(\theta - 45°) + h_S \cos(\theta - 45°) = \tfrac{1}{2} \quad \ldots\ldots\ldots(10)$$

from which

$$(h_P + h_S)\sin\theta - (h_P + h_S)\cos\theta = \sqrt{2}/2 = 0{\cdot}71.$$

If θ is near to 90 degrees (the usual angle is 85°) then

$$h_P + h_S = 0{\cdot}71$$

and if h_S has the minimum value of

$$h_S = \tfrac{1}{2}\sin 2\theta = \sin\theta \ \cos\theta$$

then the minimum value of h_P to accomplish the read-in process will be:

$$h_P = 0{\cdot}7.$$

2.2.3. The read process

It is required of the read process that no matter which state the film was in prior to the read pulse it must be in the 0 state after this pulse. Second, in the response to the pulse it must be possible to distinguish between the two states by a suitable arrangement of sense wires.

In the tilted element device the sense loop is arranged so that flux whose direction is parallel to the h_S field will be cut by the loop. The rotation process for read 1 occurs in two stages, at the front and back edge of the read-out pulse respectively. The response to the front edge of the pulse is to bring the vector round from the 1 sense nearly into line with the h_P field. This causes the flux cut by the sense wire to change from, say, a positive value to zero. During the fall of the h_P field to zero the vector rotates round into the 0 state thus the flux cut by the pick-up wire changes from a zero value to negative. Both these changes, will cause the same polarity voltage to be induced in the pick-up wire, say, positive.

If now the element were in the 0 state, on application of the h_P field the flux would change from a negative value to zero and when the h_P field is removed, from a zero value to a negative value. The voltage induced in the sense wire will thus be a negative voltage spike followed by a positive spike. These responses are sketched in Fig. 5.

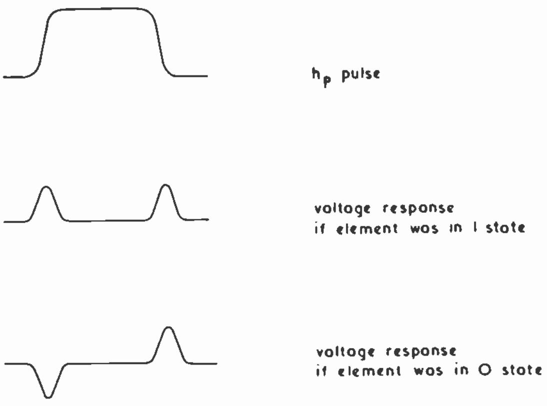


Fig. 5. Voltage induced in sense wire.

It is necessary to examine the magnitude of h_P fields required to effect these desired changes.

The read 0 process is, of course, the same as write 0 and since no discontinuous transitions occur there is no lower limit in h_P. It can be seen from the previous arguments that there is no upper limit either.

There is a lower limit to the field required for the read 1 process, and it can be seen that this is the critical field discussed by Stoner and Wohlfarth[4] and given in their table IV and presented in Table 2.

2.4. *Conclusions*

In a storage system it is desirable that h_P should have the same value for read and write; thus, since in both processes there is a critical lower field, the larger of the two will be minimum. It can be seen that this is the critical field for the read 1 process.

Table 1 has given the range of values which h_S may assume and Table 2 has given the lower limit of h_S. The tolerances available are very large if a real film can be made to obey the simple theory. In practice this is not possible in all details, but it will be shown that a device can be made with practical materials.

Table 2

θ degrees	h_P critical value
90	1·0
88	0·86
86	0·79
84	0·74
80	0·67
70	0·57
60	0·52
50	0·50

The upper limit in h_p is again infinity

This theory has given no indication of the possible switching time. In fact the theoretical predictions seem extremely confused at present. There is no doubt that the switching process can be very fast where large h_P fields are applied near to the "hard" direction as in this device.

Switching times of a few millimicroseconds are expected[9]; thus when pulses with rise-times of a few tens of millimicroseconds are used, the response of the film to the driving pulse should only lag behind the driving pulse very slightly.

3. Considerations of Construction of Store

3.1. *Advantage of Flat Metallic Plate as Film Substrate*

It was decided that the storage elements should be deposited on flat plates rather than on tubes as proposed by Hoffman *et al*[10]. There are two reasons for this; first, the flat form is more favourable for the rotational switching process since the demagnetizing field is the same at every position of the magnetization vector. Second, it is easier to deposit by evaporation on a plate than a tube and the units made are two dimensional rather than one dimensional thus making for easier assembly.

Pohm and Rubens[11] have constructed a small plane matrix, using a different form of selection but they showed how strips etched from printed circuit boards, through which the selection currents are passed, could be used to provide a magnetic field localized at the elements. In the sense line they used wires critically mounted to reduce the air mutual inductance between the drive lines and the sense loop. Raffel has used a similar form of construction but has reduced the thickness of the glass to 0·1 mm to reduce the difficulty of adjusting the sense line to give zero coupling.

It is clear that if the film is deposited onto an insulating substrate such as glass, there is a practical minimum thickness of glass substrate which may conveniently be used and this limits the air pick-up. The writer and his colleagues have made experiments to determine whether a magnetic film with useful properties can be deposited onto thin mica, but even when the very highest quality grade of ruby mica is used no way has yet been found to deposit films having the required characteristics.

It has sometimes been suggested that wiring deposited by evaporation would ease the constructional problem. However, this approach has been rejected because the thickness of metallic coating conveniently deposited by present techniques would have resistances too large for this application.

It is of course true that in the device proposed the sense line is at right angles to drive field and hence will not cut the flux due to this field during the read process. However if the area of the sense loop is large, say caused by wrapping the sense line around glass of the order of thickness 1 mm, then extremely accurate orientation of the word and sense lines has to be made to achieve cancellation. In addition the flux from the digit drive field cuts the sense loop so that a very large voltage is induced during the write process. This leads to great difficulty in the design of the sense amplifier and its associated circuits.

It has been realized that a new approach to this problem could be made if ferromagnetic film of the desired characteristics could be deposited onto a metallic substrate. This plate must be a good conductor and aluminium was thought to be most suitable. The metallic substrate itself could then provide the return path for the sense wire and the sense wire could be very closely spaced from the film and substrate by using a very thin insulating layer over the magnetic film. This sense line may be obtained by an electro-plating process and can easily be 0·001 in. thick thus eliminating attenuation difficulties.

There is a further advantage which results from the presence of the aluminium plate; it is that eddy currents induced in it, when the current is changed in the drive strip, increase the field at the film and thus more field can be obtained for a given current. There is the possible disadvantage that the reversal of the film may be damped by the presence of the conducting layer so near to it but this has not been found in practice. Both these latter effects will be considered in detail.

3.2. *Eddy Current Doubling of Drive Field*

The effect of the metal plate may be more easily understood if it is thought of as a reflecting surface which forms an image of the real drive strip in such a way that the image strip causes a magnetic field to add to that due to the real strip between the plate and the real strip. The additional field is caused by eddy currents induced in the metal plate. These eddy currents decay, and Smythe[12] has shown that if the metal plate is thinner than the skin depth, the decay in magnetic field may be calculated, and that the image moves at a constant velocity which is a function only of the resistivity and thickness of the plate. The important point is therefore that the decay of the magnetic field should be small compared with the duration of the pulse used.

Smythe, in his book, only considers the case of a thin plate. The plate to be used in practice should be about 1 mm thick, which cannot be considered as thin. However, the calculation will be made for a plate which has a thickness less than the skin depth at 5 Mc/s, and experiments comparing the performance of a sheet of this thickness and the 1 mm thick plate will be described.

3.3. *Image Theory for Thin Plate Case*

Smythe shows that the image recedes with a constant velocity $2s$ where s is the area resistivity of the sheet for a thin sheet. The aluminium sheet used was $1{\cdot}5 \times 10^{-5}$ cm and the image recession velocity is given for this thickness by:

$$\text{velocity} = 2s = 2{\cdot}1 \times 10^5 \text{ cm/sec.}$$

(Presumably for a thick plate much thicker than the skin depth the velocity is not constant but decreases as the eddy currents penetrate into the plate).

It is required to find the time after which the total field at the film will have decayed by 10 per cent., i.e. the field due to the image will have decayed by 20 per cent.

The field at the centre of the drive strip only will be considered. M. Williams[13] has shown that the magnetic field in the plane of the film due to a strip subtending an angle θ at the point considered on the film is given by:

$$H' = H.\ \theta/180$$

where H is the horizontal field with the film and the strip in this same plane.

At the beginning of the pulse the image will be a distance of 0·1 mm away from the film since this is the distance from the real strip to the film.

The image strip thus produces a field, for a strip width 2·5 mm,

$$H' = H\,\frac{166}{180} = 0{\cdot}92\,H.$$

If H is to be reduced by 20 per cent. we require to find the distance which the image strip moves to cause this.

Thus $H' \nless 0{\cdot}73\ H$ at the end of the pulse. Hence the angle subtended at the strip must be:

$$\theta \nless 0{\cdot}73 \times 180 = 132 \text{ degrees}$$

$$\text{or } x \nless 0{\cdot}57 \text{ mm. for a width } 2{\cdot}5 \text{ mm.}$$

Hence the image can move away by 0·47 mm during the pulse. Thus if the velocity is $2{\cdot}1 \times 10^5$ cm/sec, this will occur after 0·2 microsec.

To compare the effect of the thin aluminium reflector with the 1 mm plate an experiment was designed in which a small loop of wire was arranged near to a drive strip as shown in Fig. 6, and the effects of bringing the aluminium foil and 1 mm thick plate up to the loop were compared by observing the voltage induced in the small pick-up coil. Both thicknesses of alu-

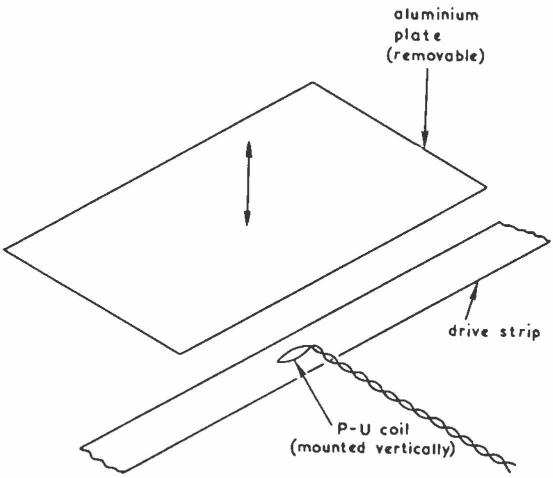


Fig. 6. Diagram of drive and sense wire arrangement in aluminium reflector experiment.

minium doubled the magnitude of the spikes due to the front and trailing edges of the pulse, which was one microsecond wide. Some lifting of the line between the spikes could clearly be seen when the foil (about 0·015 mm thick) was brought up to the pick-up coil, indicating that there was some droop in the top of the pulse. The raising of the base line was only just discernible using the 1 mm plate. This experiment indicated that (a) a doubling of the field was achieved, and (b) the droop in the field pulse using the 1 mm plate was considerably less compared with the 0·015 mm foil. Theory indicated that the 0·015 mm foil was adequate if the pulse length did not exceed 0·2 microsecond, hence the 1 mm plate is several times better than this and should be usable with pulse durations up to one microsecond. Another experiment suggested that the field decays by 10 per cent. after approx. 3 microsec. with the aluminium plate 1 mm thick.

3.4. *Damping of Reversal Process*

It was thought possible that the presence of a conducting sheet so near to the magnetic film element could cause damping of the reversal process by generation of eddy currents. Attempts have been made to extend the analysis given by Smythe for the case of the damping of a rotating magnetic dipole above a conducting sheet, but the problem is one of great theoretical complexity. It has been found however, that there is no experimental evidence for any eddy current damping for reversal times of the order of 50 millimicroseconds.

The reason for this would appear to be due to the fact that the magnetic moment of the dipole rotating is so small that interaction with its image is negligible. If this is true, the presence of the aluminium plate will not damp the reversal process at any speed of operation, since for speeds of rotation of the order of 50 millimicroseconds the elementary theory suggested maximum damping should occur.

Similarly the presence of the metallic drive strips has no damping effect on the film reversal. In point of fact the drive strips have to be slotted, to prevent eddy currents, for an entirely different reason: that the presence of one drive strip must not damp the build-up of magnetic field at the film due to a current pulse in the other. It is necessary to slot both drive strips to ensure that this does not happen.

4. Experimental Results on Film Performance

4.1. *Introduction*

It has been shown that if a ferromagnetic film can be made in which the magnetization reversal process is that of coherent rotation and if it has a uniaxial anisotropy of the form described, then a storage device can be made which can use matrix selection techniques. This storage device should be very fast and very large tolerances in the drive fields should be available. It is the purpose of this section to describe the performance of films which can be made by vacuum deposition onto aluminium plates and to compare this with the predicted performance.

A previous publication[6] showed that nickel iron films deposited on glass from ingots of 81 per cent. nickel 19 per cent. iron alloy could behave very closely according to the simple rotational model. In another publication[14] the conditions have been described under which these films can be prepared. It has since been found that films deposited on polished aluminium have similar hysteresis loops to those deposited on glass, other conditions being the same.

All these experiments were made to determine the low frequency hysteresis loop properties of films of about 2 cm diameter. It is important therefore to find if the performance under pulse switching conditions of a much smaller area of film is that predicted. Similarly it is important to show that the size of the magnetic fields required to effect the rotational switching are compatible with those which can be generated conveniently by components likely to be available.

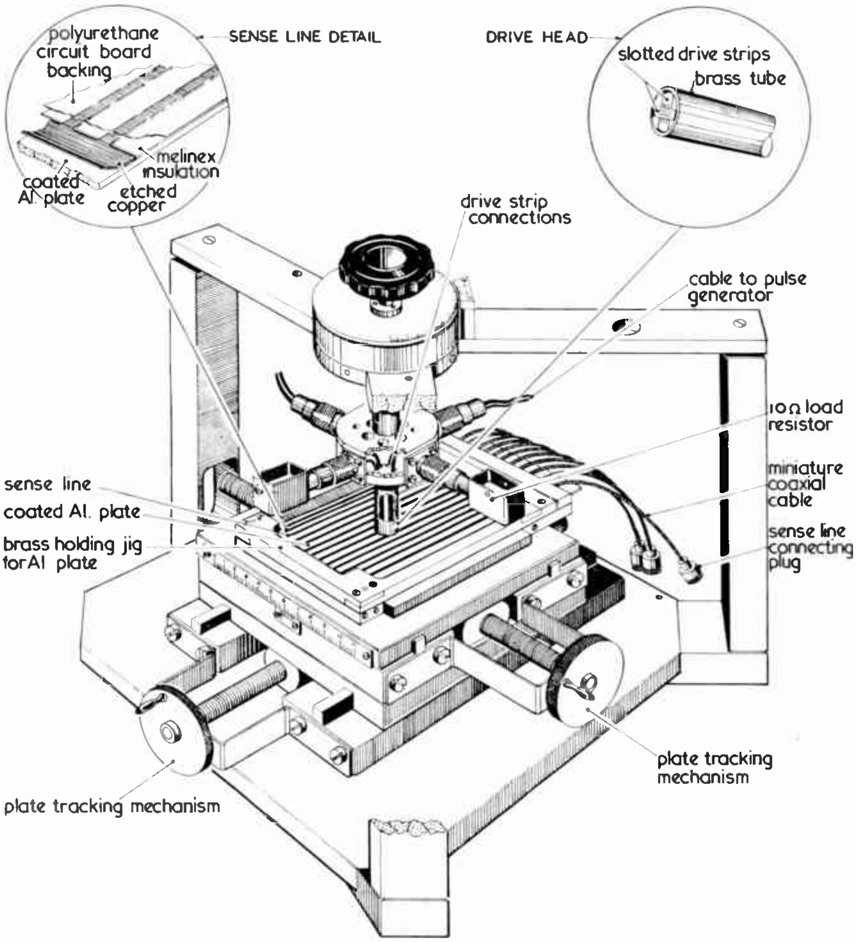


Fig. 7. Apparatus to determine the response of small areas of magnetic film to magnetic field pulses.

4.2. *Description of Apparatus*

Figure 7 shows a drawing of the apparatus used to examine the response of small area of magnetic film to magnetic field pulses.

It was decided that it should be possible to examine small sections of large area plates, since one of the important problems in magnetic thin film work is to obtain control of the magnetic properties over a large area of film. As a first step towards this it is important to make the relevant measurements easily. Therefore, a mechanism was incorporated for moving any portion of the film to a position under the drive head. The drive head itself consisted of a pair of copper strips through which a current pulse was passed. These strips cross each other at right angles to provide the "digit" and "word" fields and they were slotted where they intersect to prevent eddy current screening of one strip by the other. The strips were made 2·5 mm wide and as they were very close to the film the magnetic field in the plane of the film, was confined in width to little more than this dimension.

It was possible to rotate the head and thus the drive strips and to measure accurately the angle between the drive field and the edge of the plate. The sense lines were fixed to the clamping arrangement holding the coated aluminium plate since it was difficult to arrange the sense line to rotate with the drive head and still allow the sense line to make good contact with the aluminium plate without damaging the film.

This apparatus has been used to examine the response of the film to magnetic field pulse trains which can be applied at any angle to the preferred axis of the film at any position on a large area plate. In use it was connected to pulse train generators by means of coaxial cables. The generators were terminated in 10 ohm precision carbon resistors, so that a measure of the potential across the resistors enabled the current to be calculated. The pulse train generator gave up to 4 amps output in a pulse of 1 microsec duration with a rise time of 80 millimicrosec. This pulse was generated by means of a hard valve "pulse modulator" type circuit which had a 4 : 1 step down ferrite core transformer in the output circuit. The two output generators could be triggered from circuits generating sequential and coincident pulse trains of the desired pattern to simulate conditions in a storage matrix.

4.3. *Variation of Angle of Preferred Axis over Film Area*

It has been shown that the theory of the storage device predicts that its performance is critically dependent on the angle between the preferred axis and the applied field. It is important therefore that this angle should be well controlled in any deposition process. The apparatus described was used to study the variation in this angle over the plate. The measurement of it was made using word current pulses only in the following way. The amplitude was set well above the critical value expected. The voltage response generated in the sense line to such a pulse train should be a spike of one polarity at the leading edge followed by a spike of the opposite polarity at the trailing edge of each drive pulse, if the hard direction is at an angle of only a few degrees to the edge of the plate. The polarity of the spikes will be dependent on the direction of the rotation of the magnetization vector. This direction will depend on the sense of the anisotropy torque since this is the only torque acting on the magnetization vector when no magnetic field is present and thus controls which remanent state the film area will return to after the magnetic field pulse.

For instance if the field is applied so that at the end of the pulse the vector rotates back into one state under the action of the anisotropy torque then the output appearing on the sense line is say, a positive spike followed by a negative spike. If now the field is applied at a different angle, where the anisotropy torque has the opposite sense then the vector will rotate back into the other state at the end of the pulse and the output will be a negative spike followed by a positive spike. If the field is applied exactly at 90 deg to the preferred direction no output will be induced in the sense line since the anisotropy torque is zero and the magnetization instead of rotating coherently splits into domains after the end of the first pulse with possibly one set of domains magnetized in one state and the other in the opposite state[5, 8].

Therefore, as the head is rotated a few degrees through the position where the field is applied at right angles to the preferred direction it will be observed that the response reduces to zero and then increases again but the spikes will have changed polarity. It has been found that films can differ greatly in the sharpness of the transition from one polarity to the opposite one with angle. The magnetization of most films, which unless prepared so that the hysteresis loops approximate to those predicted by the simple theory, will hardly rotate at all in this test and very little change in output was observed over angles of the order of 20 or 30 deg.

Those films prepared from 81 : 19 NiFe alloy on well polished aluminium plates do not behave well when deposited onto the large 4 in. square plates. Figure 8 shows the plot of angle of the preferred axis observed at different points on the plate for a film 1700 Å thick. The letters refer to the quality of the rotational behaviour.

NR No rotation, hence no output induced in the sense line; it was impossible to identify the preferred axis.

- P Poor rotation: it was just possible to identify a zero position but change of angle by 10 deg or 20 deg away did not alter output greatly.
- G Good rotation.
- E Excellent rotation: it was possible to identify the zero position to within a few minutes of arc; full output was obtained 1 deg away from zero position.

The hysteresis loop experiments reported in an earlier publication[4] have been extended to alloys other than the binary nickel iron system and have found that an alloy named "Gyralloy I" possesses greatly improved rotational reversal properties. Figure 9 shows the variation in the angle of preferred axis to the edge of the plate for a film 1750 Å thick made of Gyralloy I on a well polished aluminium plate. Comparison of Fig. 8 with Fig. 9 shows that the new alloy has greatly improved rotational properties since it was possible to obtain the zero position to within a few minutes of arc. Thus, in this respect, the film was found to be very close to simple rotation model. During the manufacture of both these films the annealing field was applied at an angle of 0 deg to the edge of the plate.

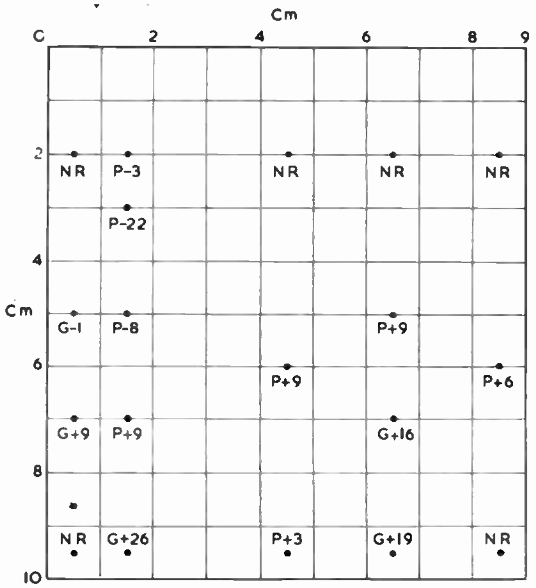


Fig. 8. Variation in angle between preferred axis and edge of plate for a film deposited from 81:19 NiFe alloy on a polished aluminium plate.

It should be noted that in these experiments a complete sheet of film was used, not an etched or masked dot pattern. The area of film examined was controlled only by the magnetic field pattern generated by the current passing through the strip. The horizontal components of the field did not in practice extend very much beyond the edge of the strip because the strip was very close to the film. Some experiments have been made on a film which was etched into a dot pattern (each dot 2·5 mm dia.) after testing the complete sheet. It was found that even if a film having "excellent" rotational properties before etching was used, the rotational performance after etching was "poor." This is thought to be due to the effect of small domains which it is known can easily nucleate at the edges of a film and which are very difficult to remove even when the film is subjected to very large magnetic fields.

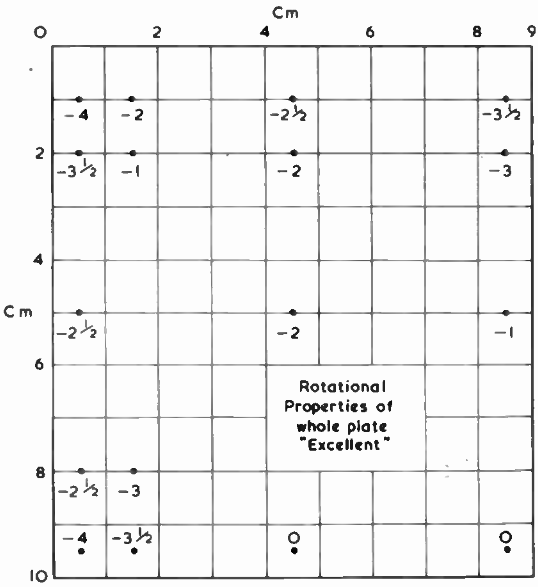


Fig. 9. Variation in angle between preferred axis and edge of plate for a film of Gyralloy I on a polished aluminium plate.

4.4. *Storage Action*

Preliminary experiments suggested that good storage action with a wide difference between the two critical digit fields could be obtained if the angle between the word field and the preferred axis was set at 85 deg.

Figure 10 shows schematically the pulse trains applied to the digit and word strips in the apparatus previously described. The photographs show oscilloscope traces of the waveforms applied and the voltage induced in the sense wire. The noise level in response to a word pulse is also shown; this photograph was obtained when the film was saturated by the field from a permanent magnet.

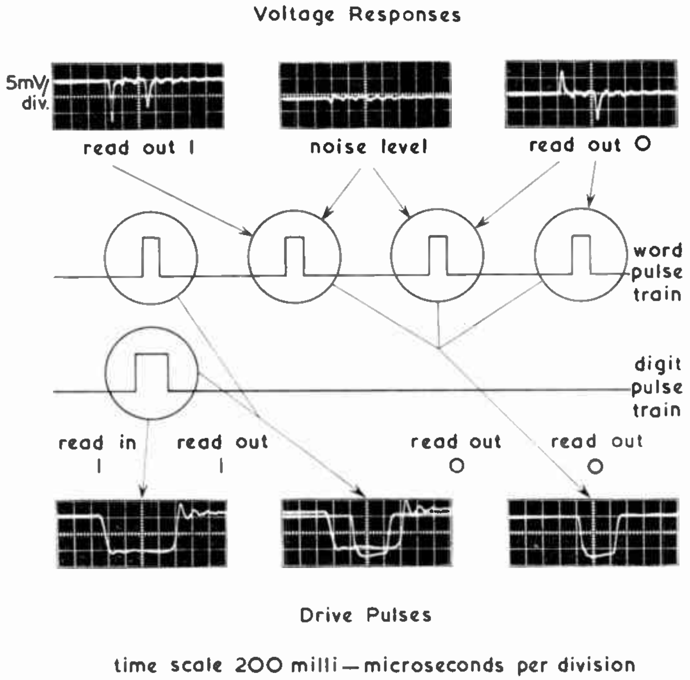


Fig. 10. Magnetic field pulse train applied to a small area of magnetic film and the voltage response induced in the sense line.

Curves have been plotted of the variation in amplitude of the leading edge spike output in response to the read word pulse as a function of digit current previously applied coincidentally with a word pulse (write-action). Similar curves were also plotted of the output as a function of the digit current previously applied by itself (disturb-action).

In these curves the output voltage is proportional to the rotating flux change since duration of the spike is only dependent on the rise time of the word pulse. The word pulse was of course not changed in amplitude or rise time throughout the experiment.

Figure 11 shows curves of this voltage output taken under these conditions for a Gyralloy I film of about 1200 Å thickness with the angle between the preferred axis and the word field set to 85 deg (referred to as a tilt angle of 5 deg). There was, however, the slight difference that in the curve obtained for the digit pulse alone a train of 16 pulses of 0·5 microsec duration was applied instead of a single pulse because it was known[6] that the switching process occurring in response to a field applied near to the easy direction can be long; however it had been found that the effect of 16 pulses was not substantially different from an infinite number of pulses.

The curve was plotted as a function of digit current; the conversion factor to magnetic field for a 2·5 mm strip, allowing for the doubling effect due to eddy currents in the aluminium plate, is 4·6 oersted/amp and the dimensions of the area of the film switched were approximately 2·5 mm × 2·5 mm.

Several points emerge from these curves when comparing the observed behaviour with that predicted from the rotational theory. It predicts first that the sense voltage output should stay constant until a certain calculable digit field has been applied, when the sense voltage output will change polarity discontinuously. It can be seen that this does not happen exactly since a change in field is required to change the output from the saturated negative to a saturated positive output.

Measurements on many film samples show that there appears to be some correlation between the slope of the curve found experimentally and the quality of the rotational behaviour detected in the measurement of the direction of the preferred axis. Second, the output signal representing either 0 or 1 should be of the same amplitude; it can be seen that in both curves the 1 signal is larger than the 0 signal. It should be noted that the switching time is indeed very short and by examination of the photograph it can be seen that the film response hardly lags behind the increase in the drive field and thus the intrinsic switching time must be considerably shorter than the rise time of the pulse.

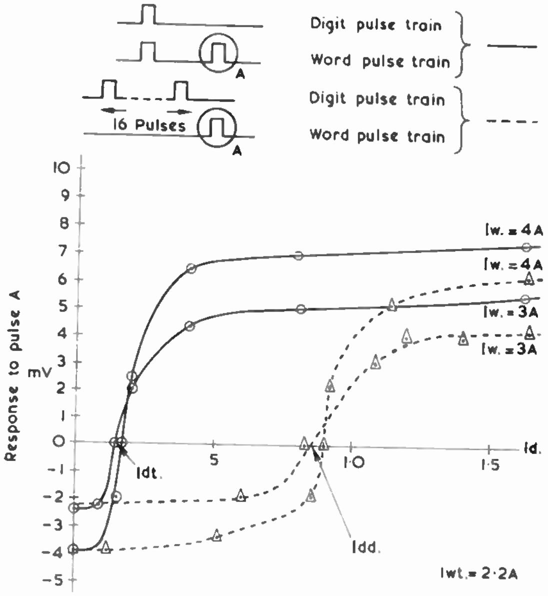


Fig. 11. Response of a small area of "Gyralloy I" magnetic film.

From these curves it is convenient to define threshold parameters, which are easy to measure and which define the performance of the plate at a given angle.

(a) Digit current threshold, I_{dt}, is defined as the current applied along the digit wire coincidentally with a word pulse which causes zero output at the leading edge of the word read-out pulse applied subsequently. The word pulse amplitude should be well over the threshold, where it can be seen from Fig. 11 that I_{dt} was almost independent of the word pulse amplitude.

(b) Digit current disturb threshold, I_{dd}, is defined as the current applied along the digit wire, which without a coincident word pulse, causes zero output at the leading edge of the word read-out pulse applied subsequently. Normally, since the switching process is slow, 16 digit current pulses 0·5 microsec long are applied. Again the word pulse amplitude used should be well over the threshold level and the value of I_{dd} was almost independent of word pulse amplitude.

(c) Word current threshold, I_{wt}, is that current which will change half the available flux from the 1 state to the 0 state. It was measured by applying a pulse train as shown in Fig. 10. In this measurement the digit current level is set well over the threshold value I_{dt}. The amplitude of all the word pulses is then varied. If this is below the threshold, the response to all the word pulses will be the same and in the form of a negative spike followed by a positive spike. If the amplitude is above the threshold, the response to the first pulse will be two negative spikes and to the second a *positive* spike followed by *negative* spike. The threshold current is that word current which causes the response to the second read-out pulse to be zero, i.e. the spikes are just at the point of changing polarity.

All these threshold parameters are accurately repeatable by different observers and are almost independent of the other pulse amplitude or pulse rise times. There is the further consideration that the threshold parameter measures the field which one might expect to correlate best with the theoretically predicted values.

4.5. *Measured Variation of Threshold Parameters with Tilt Angle*

Measurements were made of the variation of the three threshold parameters I_{wt}, I_{dt}, I_{dd} with the angle of tilt and comparison was made with that expected from the simple theory.

Figure 12 shows the results obtained for a Gyralloy I film of about 1200 Å thickness. The theoretical values for I_{dt}, I_{dd} and I_{wt} have been calculated. It was found that there was a good fit for I_{dt} and I_{wt} if the value of H_k were chosen to be some three times higher than that found from the hysteresis loop test. This result is different from that obtained from experiments on 1 cm diameter spots where a good correlation between the theory and experiment for fit and magnitude was obtained. However, the theoretical values for I_{dd} were completely different from the observed curve in respect of fit and different from the values for I_{dt} and I_{wt} in respect of proportionality constant. The latter effect might be expected since it is known that the predominant mechanism for reversal in response to fields applied near the easy direction is one of domain nucleation and subsequent wall motion.

It can be seen that the I_{dd} value gradually decreases with decrease in tilt angle with the specimen shown and when an angle of 1 deg is reached it falls very steeply. Other plates whose rotational performance is not so good have been found to behave similarly except that the steep decrease occurs at larger tilt angles. This can perhaps be explained by saying that it is known that the film area is split into domains by the pulse previously applied near to the hard direction when the tilt angle is small, in the form of a very fine network pattern. Thus to saturate the film in the easy direction from this state is not difficult since the wall does not have far to move and the domain is already nucleated. Hoffman *et al*[10] have described a storage device exploiting this property of the film.

The tolerances in the system to angle can be worked out from these curves. It can be seen for this specimen that tilt angles varying from 2 deg to 8 deg over the plate would be acceptable and would still leave considerable tolerances in the digit drive currents. Any reduction in I_{dd} not coupled with a corresponding reduction in I_{dt} would reduce these tolerances. Such a situation occurs if the film thickness is increased and it has been found that the maximum thickness is about 2000 Å.

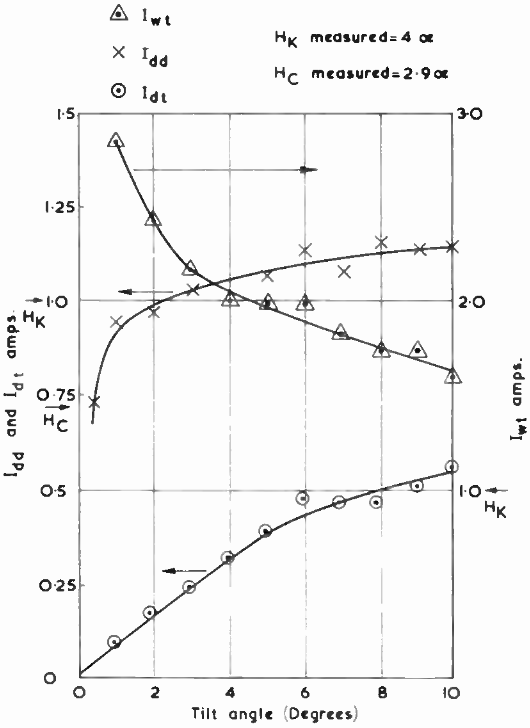


Fig. 12. Variation of the threshold parameters with tilt angle for a "Gyralloy I" film 1200 Å thick.

4.6. *Conclusions*

It has been shown by these experiments that it is possible to make a large area magnetic film which has sufficiently uniform properties to make the construction of a very fast store a practical possibility.

A pattern of discrete dots gives much poorer rotational performance than selection of discrete elementary areas by means of defined magnetic fields. However, it is clear that although the magnetization rotates with a good approximation to the simple theory, the magnetic fields which are required to achieve this are higher than might be expected. The mechanism must be complex and requires further study.

5. Scaling and Packing Density Experiments

5.1. *Experimental Arrangement*

Experiments have been described using a film area of 2·5 mm × 2·5 mm for an individual storage element. It was required to find if this could be reduced and also to find the smallest spacing between elements which could be used without introducing interference between elements. An experiment was designed for this purpose in which two sets of strip lines were made by electroplating copper onto a thin layer of "Melinex" which had first been made conductive by depositing a layer of copper onto it by vacuum evaporation.

Figure 13 shows the arrangement used. Each strip was 0·5 mm wide with 0·1 mm spacing between them; 16 strips in all were used in each set. The two sets were placed at right angles to one another and on top of an aluminium plate coated with film; the tilt angle was set at 5 deg. One sense line only was used; this was made 0·5 mm wide plated on thin "Melinex" and stuck with impact adhesive to the aluminium plate.

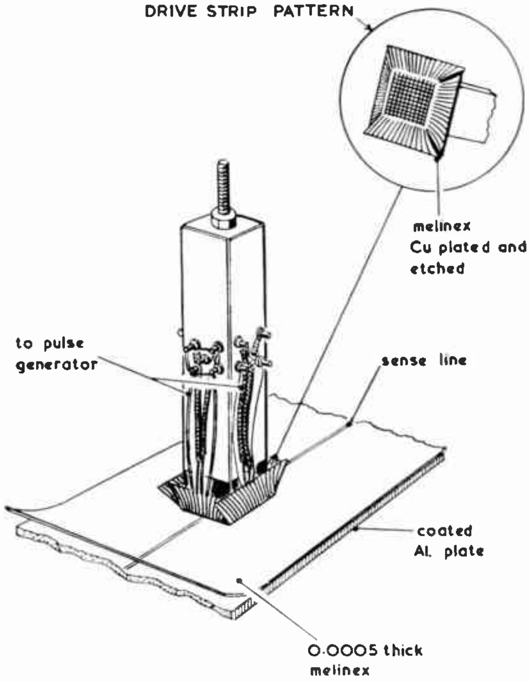


Fig. 13. Experimental arrangement used in scaling and packing density experiments.

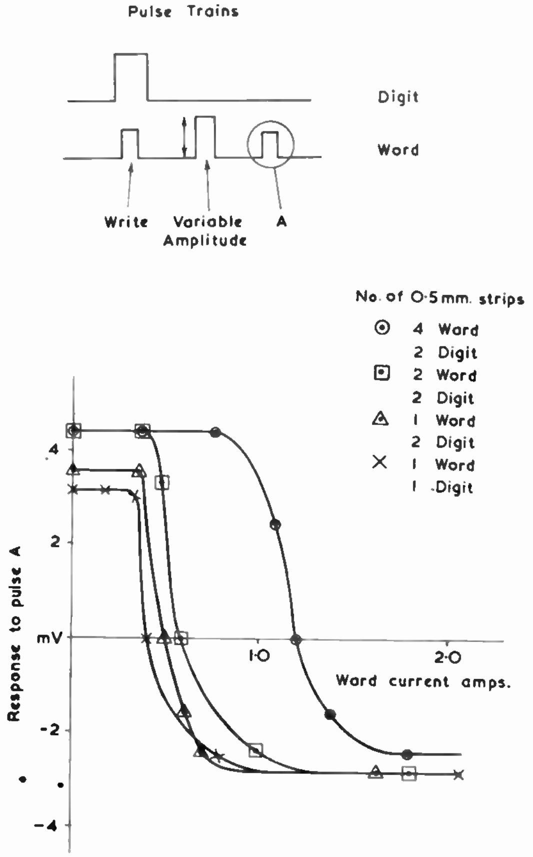


Fig. 14. Curves of response versus word current for drive strips of various widths

It can be seen that the spacing between the drive strip and the plate was very small since the Melinex layers were only 0·01 mm thick and hence that the horizontal magnetic field at the film due to the current passing through a strip would not extend much beyond the width of the strip. The effective areas of and spacing between elements could thus be altered at will by passing the drive currents through the appropriate strips.

5.2. *Performance of Element as a Function of Width of Drive Strips*

Experiments were made using various numbers of the drive strips 0·5 mm wide in parallel. The fixed sense wire was always in the centre of the digit drive line used.

A more complicated pulse generator was used in these tests enabling I_{wt} to be measured more easily. The pulse train applied is shown in Fig. 14. Curves were plotted of the voltage induced in the sense line in response to the front edge of the second read out word pulse (whose amplitude was maintained constant) as a function of the amplitude of the first read out word pulse. The threshold value, I_{wt} is that word current which causes zero output at the leading edge of the second pulse.

Figure 14 shows the results obtained using a film again of Gyralloy I of approximately 1200 Å thickness with $H_k = 5$ oersteds and $H_c = 2{\cdot}1$ oersteds. The parameters refer to the number of word and digit strips used in the experiment. It is seen that reducing the number of word strips from 4 to 2 reduces by about 2 times the value of I_{wt}, i.e. H_{wt} is the same. There is not, however, a corresponding reduction in I_{wt} when the number is reduced from 2 to 1 strips, similarly reducing number of digit strips from 2 to 1 has a small effect. There was no change in I_{wt} on increasing digit strips from 2 to 4. (The output voltage is not reduced since the read out current was kept constant; the amount of flux must change of course, hence the duration of the spike is changed since the rise time to the threshold value is reduced with the reduction in the threshold.)

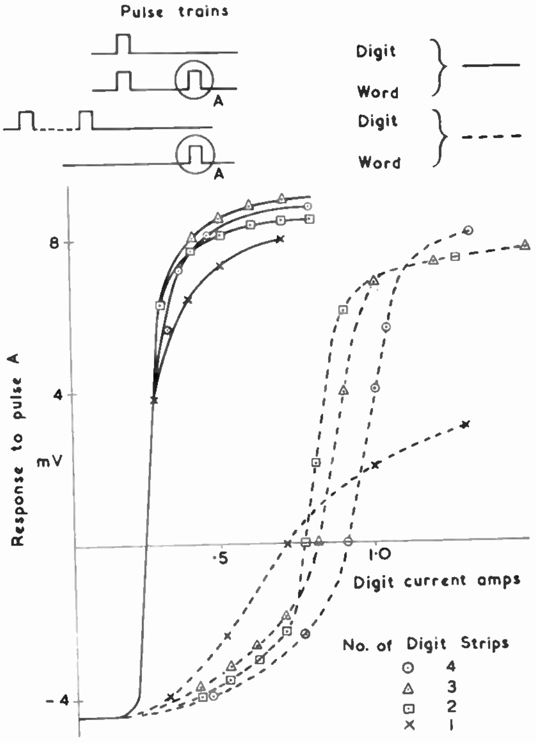


Fig. 15. Curves of response versus digit current for drive strips of various widths.

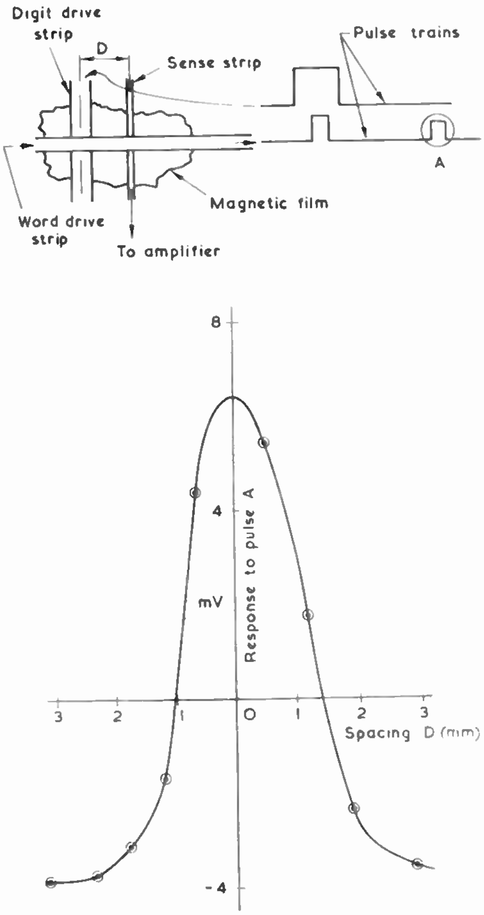


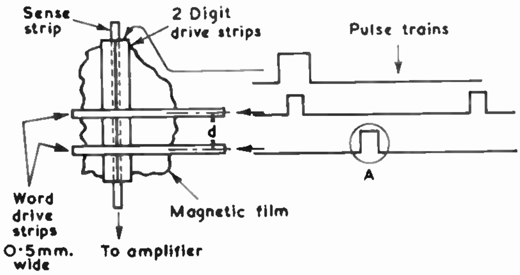
Fig. 16. Results of experiment to determine least spacing without interference between digit strips.

Figure 15 shows the effect on I_{wt} and I_{dd} values of altering the effective width of the drive strips. It should be noted that I_{dt} hardly changes at all but that the I_{dd} value changes slightly so that reducing the width of the strip will alter the available tolerances slightly.

5.3. *Element-to-element Interference*

It was necessary to determine the minimum spacing between digit drive strips and between word drive strips. Since the magnetic material is anisotropic, it was thought possible that these two would be different. In the first experiment spacing between digit strips was investigated by connecting to various digit drive strips in the pattern and observing the output in the sense line as shown in Fig. 16. It can be seen that a spacing of 2 strips is adequate (1·2 mm).

In the second experiment the spacing between word drive strips was investigated as shown in Fig. 17. It can be seen that when using word strip a spacing of 0·7 mm is adequate.



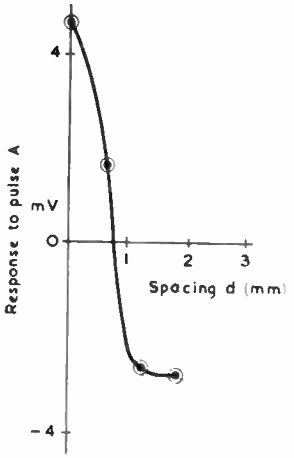


Fig. 17. Results of experiment to determine least spacing without interference between word strips.

5.4. *Conclusions*

It has been shown that it is possible to reduce width of word drive strip to 0·5 mm with about 0·7 mm spacing between word strips and that it is possible to reduce width of digit drive strip to 0·5 mm with 1·2 mm spacing between them.

In the final design 1 mm word drive strips were used since it was thought that this would provide a very good compromise between output flux and packing density; similarly, 1 mm wide digit drive strips were used since this would appear to give a larger difference between the I_{wt} and I_{dd} values than 0·5 mm strips without a proportionate increase in packing density since the spacing had to be 1·2 mm. It has been shown that the pitch of the word lines can be 1·2 mm and the pitch of the digit lines 2·4 mm thus giving an overall packing density of 230 bits per square inch. This packing density is higher than the highest that can be achieved using ferrite storage cores that are presently available.

6. Design and Performance of Practical Matrix

It has been shown that magnetic films can be made which can be selected by the technique proposed and which are sufficiently uniform over an area 4 in. × 4 in. or 16 in^2.

It has been shown how the width of the drive strips and the spacing between them affects the performance of the storage device.

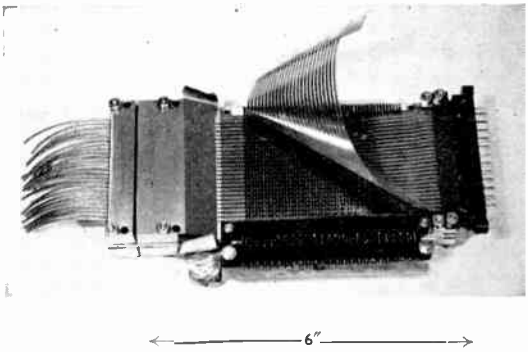


Fig. 18. A storage matrix containing 50 words each of 50 bits. The digit drive strip pattern has been lifted to show details of the construction.

These experiments then have yielded the information on which the design of a practical device can be based.

It was decided that the storage device required should have a cycle time in range 0·5–1 microsec; it should have a 50 bit word; it should have 50 words using all the available 4 in. length of the plate.

6.1. *Construction*

The final design is shown in Fig. 18.

The magnetic film was of the "Gyralloy I" material of about 1200 Å thick. It was used in the form of the complete sheet and was tested before assembly for spread of the preferred direction over the plate. Plates which were shown to have the preferred axis lying at 5 deg ± 3 deg to the edge of the plate were accepted for assembly.

After testing, the plate was coated with a layer of cellulose lacquer by dipping and was allowed to dry. The lacquer was then coated by vacuum deposition with a layer of copper a few thousand angstrom units thick. The thin copper layer was used as a conducting base which was built up by electroplating to a layer 0·001 in. thick. The desired sense line pattern was then etched out using the conventional printed circuit techniques.

Two of these plates were bolted to a $\frac{1}{8}$ in. thick brass plate with an insulated copper sheet, which acted as the earth return for the digit drive current pulses, placed between the aluminium plate and the brass plate. The sense lines were lifted from the lacquer at the end and soldered to the inner conductors of a miniature 50-ohm coaxial cable. The junction was of course screened by the brass connector at the end of the plate.

The word drive lines were then wound over the aluminium plates. Each word line consisted of a coil of enamelled copper strip 0·002 in. × 0·010 in. The coil had four turns and was slightly larger than 1·0 mm wide. The spacing between the coils is 0·5 mm or equivalent to two turns of the strip. The ends of the word coils are soldered to the pins of the plug.

The digit drive line was etched by the standard printed circuit techniques from sheet composed of 0·001 in. copper bonded to 0·005 in. polyurethane plastic backing (Foilex). Each digit strip was 1 mm wide and has one slot 0·007 in. (0·178 mm) wide etched in the middle. The spacing between the strips was 1·5 mm, thus the pitch was 2·5 mm or 0·100 in. This pitch was convenient for connection to a standard printed circuit socket which was provided at the end of the matrix away from the sense output. The other end was cold joined using a gold-indium pressure seal to the return copper sheet placed underneath the aluminium plate.

6.2. *Performance*

The performance of this storage device can best be summarized by the following measured characteristics:

	Threshold Value	*Working Range*
Word Drive	$I_{wt} = 0{\cdot}25\text{A}$ max.	$0{\cdot}3\text{A} < I_w < 3\text{A}$ (not tested above this value)
Digit Drive	I_{dt} max. $= 0{\cdot}5\text{A}$ I_{dd} min. $= 0{\cdot}9\text{A}$	$0{\cdot}6\text{A} < I_d < 0{\cdot}8\text{A}$

Drive Inductance (Word Coil): 0·6 μH at 0·5A of which 0·2 μH is contributed by the film. This means that for a pulse of rise time 100 mμ sec, back voltage generated is 6 volts at I_w = 0·5 A.

It should be noted that the back voltage appearing in the word drive coil generated by the film is not dependent on the direction of rotation and hence the pattern of the information stored does not affect drive impedance).

Digit Line: It is intended that in a large store the digit line would be terminated in its characteristic impedance of about 10Ω; this is not necessary for the small store described.

The digit pulse has to overlap word pulse by at most 20 mμsec to achieve write "1" operation.

Output: Switching time response does not lag behind pulse having rise and fall time 40 mμ sec. No increase was observed in I_{wt} using pulses of duration 100 mμsec measured at base.

Signal output voltage 3 mV for word pulse having 40 mμsec rise time.

Noise Output: (a) due to word pulse was not measurable.

(b) due to digit pulse (mutual inductance between sense line and digit drive line) 12 mV for centre I_d value with digit pulse having rise time of 40 mμsec. (Lacquer layer 0·0004 in. thick.)

The cycle time of the store will be limited rather by the circuits associated with the store than the response of the magnetic material. The measured characteristics show that a small store of 50 words should easily have a cycle time of 0·3 microsec.

7. Conclusions

The storage device described has exploited the fast mode of coherent rotational reversal. It is shown that the problem of reproducibility of the required magnetic properties of the magnetic film can be solved. The process of manufacture of the film is relatively simple and hence cheap since it does not involve very critical processing.

The method of construction of the storage device allows the very small flux change to be observed without being swamped by interfering signals and conversely the drive power required is very low.

It should be possible easily to extend the size of the store to that approaching all but the largest ferrite core stores in use today. The cost of the storage elements should be lower and the speed of operation much higher.

8. Acknowledgments

The author would like to thank his colleagues for their very enthusiastic support during the investigations leading to the store design. In particular he would like to thank Mr. P. Astwood who has taken charge of the development of the magnetic film manufacturing process and Mr. M. C. Kearton who has made most of pulse response measurements leading to the store design and has developed most of the electronic test gear.

The author would like to thank the Directors of International Computers and Tabulators Limited for permission to publish this paper.

9. References

1. M. S. Blois, "Preparation of thin magnetic films and their properties," *J. Appl. Phys.*, **26**, p. 975, 1955.
2. J. W. Forrester, "Digital information storage in three dimensions using magnetic cores," *J. Appl. Phys.*, **22**, p. 44, 1951.
3. J. A. Rajchman, "A myriabit magnetic core matrix memory," *Proc. Inst. Radio Engrs*, **41**, p. 1,407, 1953.
4. E. C. Stoner and E. P. Wohlfarth, "A mechanism for magnetic hysteresis in heterogeneous alloys," *Proc. Roy. Soc. A.*, **240**, p. 74, 1948.
5. E. M. Bradley and M. Prutton, "Magnetization reversal by rotation and wall motion in thin films of nickel-iron alloys," *J. Electronics and Control*, **6**, p. 81, 1959.
6. E. M. Bradley and M. Prutton, "Magnetization reversal uniaxial films near to the preferred direction," *J. Appl. Phys.*, **31**, *Suppl.*, p. 285S, 1960.
7. D. O. Smith, "Magnetization reversal and thin films," *J. Appl. Phys.*, **29**, p. 264, 1958.
8. C. D. Olson and A. V. Pohm, "Flux reversal in thin films of 82% Ni: 18% Fe," *J. Appl. Phys.*, **29**, p. 274, 1958.
9. W. Dietrich and W. E. Proebster, "Millimicrosecond magnetization reversal in thin magnetic films," *I.B.M. J. Res. & Dev.*, **3**, 375, 1959.
10. G. R. Hoffman, J. A. Turner & T. Kilburn, "High speed digital storage using cylindrical magnetic films," *J. Brit.I.R.E.*, **20**, p. 31, 1960.
11. A. V. Pohm and S. M. Rubens, "A compact coincident current memory," *Proc. Eastern Joint Computer Conference*, p. 120, 1956.
12. W. R. Smythe, "Static and Dynamic Electricity," p. 390, et seq. (Mc-Graw-Hill, New York, 1950.
13. M. Williams, Private Communication.
14. M. Prutton and E. M. Bradley, "The induced magnetic anisotropy in evaporated films of nickel-iron alloys," *Proc. Phys. Soc.*, **75**, p. 557, 1960

An Experimental Comparison between a Pulse and a Frequency-Modulation Echo-Ranging System†

by

L. KAY, B.SC. ‡

Summary : Experiments designed to study the operation of a frequency-modulation echo-ranging system and compare this with a pulse system are described. The results show that a previous theoretical study by the author[1] can be used as the basis of the design of a frequency-modulation system which may compare very favourably with a pulse system designed for the same purpose. When the bandwidth of the pulse system is limited, as it sometimes is in underwater sound systems, the frequency-modulation system can give much superior results. On the other hand, the pulse system can provide a much higher resolution in range if the bandwidth of the system is restricted only by that of the transducer arrays.

1. Introduction

A recent theoretical comparison between pulse and frequency-modulation echo-ranging systems[1] showed that under certain circumstances there could be a marked difference in the information provided by the two systems. For example, if the bandwidth of transmission of one system were greater than that of the other —say the pulse system used a bandwidth greater than the f.m. system, the pulse system would provide higher resolution in range. This is because the range resolution (i.e. the number of objects which can be resolved in a given range) in a pulse system is proportional to the bandwidth required to pass the pulse. On the other hand if the f.m. bandwidth were the greater of the two, the f.m. system would in all probability (because of practical limitations) provide a higher rate of information rather than a high degree of resolution. This is based on the assumption that the background produced by the f.m. transmission is very similar to "noise" having a uniform spectrum over the bandwidth being considered. The output, due to an f.m. transmission, from an analyser filter covering a range element equal to $1/N$th the maximum range would then be similar to noise from a filter having the same bandwidth as the analyser. A target on the other hand would appear as a steady tone, and the difference between this and the background, which varies rapidly, will be quickly obvious to an operator. Arranging the analyser bandwidth to be wider, following an increase in f.m. transmission bandwidth, the rate of change of the output due to the background will increase in proportion. The time required to observe the variation—as compared with a steady tone—is thus shortened, and the information is obtained more rapidly than in the pulse system.

The experiments described here were designed to verify this, and at the same time lead to a clearer understanding of the behaviour of an f.m. system. Pulse systems are relatively easy to comprehend as the information is received as a two-dimensional sequence of events (i.e. as an amplitude/time variation). This is not so in the f.m. case as signals are received from all ranges simultaneously and the presentation of the information can be difficult to visualize. The author believes this work can remove that difficulty and even encourage a study of f.m. systems as an alternative to pulse systems.

---

† Manuscript received 8th December 1959. Sponsored by the Radar and Navigational Aids Group. (Paper No. 589.)

‡ Department of Electrical Engineering, University of Birmingham; formerly of the Royal Naval Scientific Service.

U.D.C. No. 621.396.962.25:621.396.962.3

2. Requirements of the Experimental Equipment

Ideally, a comparison between two echo-ranging systems should be conducted simultaneously, since generally there are many variables present in the medium which cause continuous variation in the results obtained. Both systems should also have similar parameters (e.g. frequency of transmission, acoustic beam width, etc.) when a simultaneous comparison becomes impossible as a continuous f.m. transmission will mask completely a pulse transmission having the same frequency as the mean of the f.m. transmission.

The ideal conditions are therefore not practical and some time must elapse between the operation of the two systems. As conditions vary, a variable is introduced into the results and account must be taken of this when making any comparison. Fortunately it was found there were periods when the apparent rate at which changes occurred was such that sections of the recordings could be taken under conditions approaching the ideal.

The tests were conducted using underwater sound and both a pulse and a frequency modulation equipment were constructed using common underwater arrays so that acoustically the systems were identical. Schematic diagrams of the two equipments are given in Figs. 1 and 2.

It was shown in reference 1 that a multi-pulse system would be more comparable with an f.m. system than a single pulse system, and should therefore have been used in the tests. A multi-pulse system is one which transmits r.f. pulses, each of a different frequency, in the transmission interval of a single pulse system. The frequency difference between two consecutive pulses is equal to the bandwidth required to pass the pulse envelope, and is usually taken as the reciprocal of the pulse duration. The total bandwidth of the system is thus the number of pulses × the bandwidth of each pulse. The returning signals of several frequencies are then amplified in their respective channels and delayed so that on adding later, an echo in the different channels due to a common target will coincide in time. Complexity of equipment ruled out the use of a multiple system, however, as it is readily seen that many channels (60 in the case described) would have been required. In any case single pulse systems are by far the most common in echo-ranging, so that it is with these that a relationship should be established.

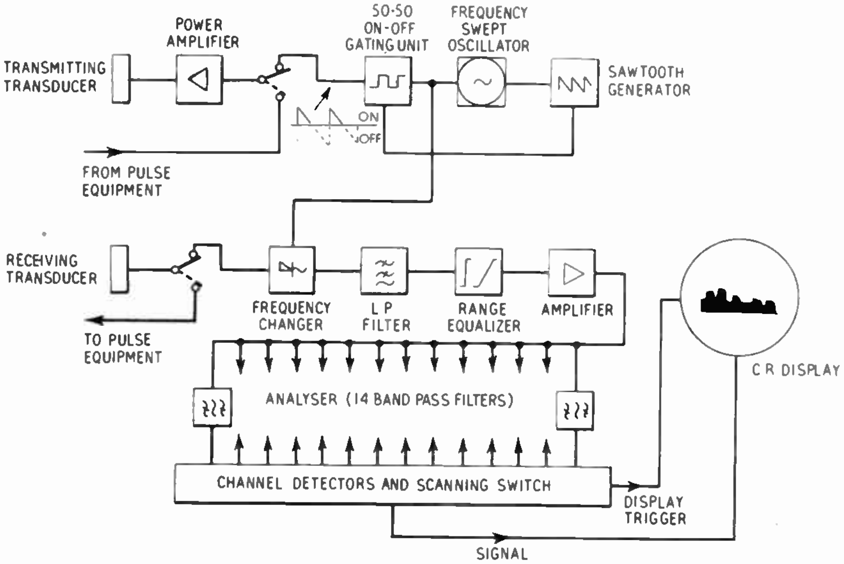


Fig. 1. Schematic of experimental f.m. equipment.

In order to compare two systems, some, if not

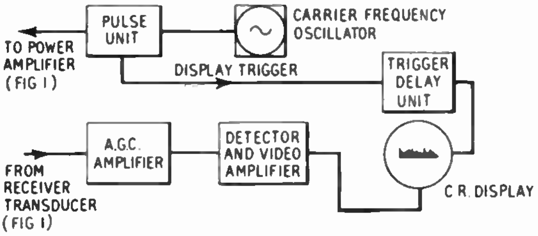


Fig. 2. Schematic of experimental pulse equipment.

all of the parameters such as range resolution, bandwidth of transmission, transmission interval, etc. should be the same for both equipments. The maximum range and hence the transmission interval for both equipments are naturally made the same. Transmission interval in the case of a continuous f.m. transmission simply refers to the time taken to sweep through the frequency band which covers the range from zero to maximum (see Fig. 3). Because of the relationship

$$\text{range resolution} \propto \frac{\text{f.m. transmission band}}{\text{analyser band}}$$

in the f.m. system, and—

$$\text{range resolution} \propto \text{bandwidth}$$

in the pulse system the design of the f.m. system has, in effect, an additional degree of freedom over the pulse system. The f.m. resolution can be chosen independently of the transmission bandwidth by a suitable choice of analyser bandwidth, with the limitation that the analyser bandwidth must not be less than 1/(transmission interval).

The bandwidth of the available underwater transducers was 5 kc/s, and this was fully employed by the f.m. system without appreciable change taking place in the acoustic beam-width during the frequency sweep. Full use of this bandwidth by a pulse system would have entailed transmitting pulses of 0·2 msec duration with a resultant high resolution in range of six inches (velocity of propagation taken to be 5,000 ft/sec). To achieve this resolution would have been difficult—if not a practical impossibility—with an f.m. system, as there would have been 600 analyser filters per 100 yd range. Since one of the parameters (e.g. range resolution or bandwidth of transmission) must be different for the two systems, range resolution governed by a practical f.m. system—was therefore chosen as being the common factor rather than bandwidth. In order to keep the number of analyser filters to a minimum without too serious a loss in performance a range resolution of 10 yd was chosen when working with a maximum range of 500 yd thus making the analyser bandwidth 100 c/s from[1]

$$\text{analyser bandwidth } (B_a) = \frac{\text{transmission bandwidth } (B_{(FM)})}{\text{units of range resolution } (N)} = 5000/50 \text{ c/s.}$$

The frequency sweep actually used is shown in Figs. 1 and 3 where it will be seen that the transmission was on for a period T of 0·6 sec from

$$T = 2R_m/C$$

where R_m = maximum range

C = velocity of sound in the medium

and off for a similar period T. The f.m. oscillator continued with the sweep during this period, but was fed to the frequency changer only.

This avoided the possibility of serious ambiguity due to echoes from objects at more than the maximum range appearing in the output at the same frequency as echoes from less than the maximum range of 500 yd, as can occur with a fully continuous transmission, and in addition, signals from any range appeared in the output

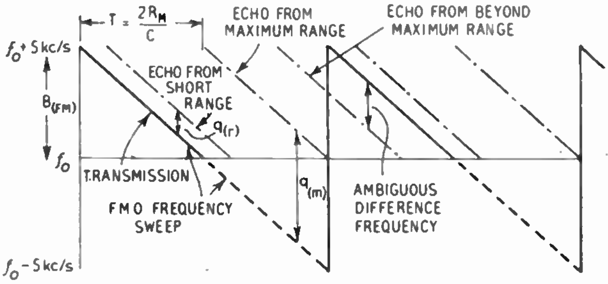


Fig. 3. Frequency/time graph of transmission and reception of f.m. system.

for the same period of time T sec. Ambiguity could still occur but was no worse than that experienced in a pulse system.

Nevertheless, half the operable period was lost and such a method of transmission would not be of great value in an operational equipment as compared with an experimental equipment.

For simplicity, only 14 analyser filters were used covering a range interval of 140 yd from 125 to 265 yd. The pulse system of course covered the whole range of 500 yd but the cathode-ray display was arranged only to cover approximately the same range interval as the f.m. system.

The pulse equipment was designed to transmit every interval of 0·6 sec a pulse of 12 msec duration (corresponding to a range resolution of 10 yd) with an effective bandwidth of only 83·3 c/s. The actual bandwidth of the pulse system has only a second-order effect on the performance of the system provided the signal always exceeds thermal agitation noise by a good margin, and the bandwidth is greater than the reciprocal of the pulse duration.

Making the range resolution of the two systems the same resulted in their bandwidths being different by a factor of

$$\frac{\text{f.m. bandwidth } (B_{FM})}{\text{pulse bandwidth } (B_P)} = \frac{5000}{83\cdot 3} = 60$$

The effect of this is to introduce a difference in time interval between independent samples of information from any one annulus of range. The time interval between samples of information in the pulse system is T sec (in this case 0·6 sec) since only one sample per 10 yd annulus of range is obtained in each transmission interval. The f.m. system on the other hand provides an average of one independent sample of information every 10 msec (i.e. the reciprocal of the analyser bandwidth) and hence in the interval T sec the number of independent samples received is 60.

It is well known that, in the sea, successive transmissions result in different background returns such that the cross correlation factor is almost zero, provided the interval is not too short. For an interval of 0·6 sec the background returns were for all practical purposes uncorrelated from "ping to ping" yet over quite long periods of time (1 or 2 min) the mean level remained unchanged. No satisfactory explanation can be offered for this phenomenon, but advantage was taken of it to simulate a multi-pulse system as is explained in Section 3·4. The difference in the bandwidth of the two systems was in fact largely eliminated by this means.

3. Experimental Tests

Tests were made in a depth of water of about 50 feet over a sea-bed which was found to give a uniform background of reverberation after allowance had been made for attenuation. This was done using a short pulse transmission of 2 msec. No discrete echo was in evidence within the range covered by the f.m. display (125 to

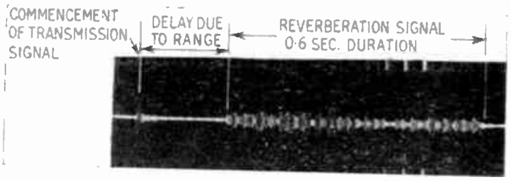


Fig. 4 (a). Typical output from one 100 c/s filter due to reverberation.

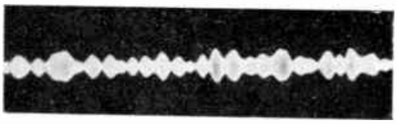


Fig. 4 (b). Typical reverberation signal with expanded time scale.

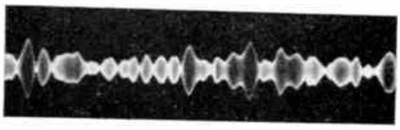


Fig. 5. Noise from 100 c/s filter with same time scale as Fig. 4(b).

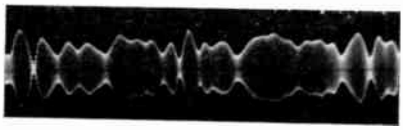


Fig. 6. Reverberation plus a single target echo at the output of 100 c/s filter.

265 yd). Physical "sampling" of the sea-bed showed it to consist of sand and small stones.

3.1. *The Nature of F.M. Signal Returns*

To determine the nature of the received signal resulting from an f.m. transmission, the output of an analyser channel was photographed during a succession of f.m. transmissions. A typical trace and an expanded section of this is shown in Figs. 4(a) and (b). These should be compared with Fig. 5 which is a section of a record of the output from the same analyser filter having an input signal of wide band noise. By visual inspection there appears to be no noticeable difference, statistically, between the two traces although they are quite independent.

Since the recording of Fig. 5 is due to an input signal of wideband noise having a Gaussian distribution we know certain facts about it. The autocorrelation function given by[2]

$$R\tau = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x(t)\,x(t+\tau)\,dt \quad \ldots(1)$$

is determined from the spectral density of the output signal $x(t)$ from the analyser filter by the relation

$$R\tau = \int_0^\infty \overline{G(f)}\cos 2\pi f\tau\, df \quad \ldots\ldots\ldots(2)$$

i.e. the autocorrelation is the Fourier cosine transform of the spectral density $G(f)$. The spectral density of the output signal is determined only by the filter for a wide band noise input and hence an analysis of the waveform to determine the autocorrelation will only provide confirmation of an established fact.

Because the transfer function of the filter is linear the probability distribution $W(x)$ of the output signal $x(t)$ will be the same as the input, i.e. a Gaussian distribution given by

$$W(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(\frac{-x^2}{2\sigma^2}\right) \quad \ldots\ldots\ldots(3)$$

where σ = r.m.s. value of the "carrier."

The envelope of this noise signal such as will appear at the output of a linear detector, follows a Rayleigh distribution given by

$$W(X) = \frac{X}{\sigma^2}\exp\left(\frac{-X^2}{2\sigma^2}\right) \quad \ldots\ldots\ldots(4)$$

where X is the envelope amplitude.

We wish to determine the nature of the reverberation and check that it is the same as noise. From the foregoing it is clear that, provided the spectrum at the input is uniform over the bandwidth of an analyser filter, the output spectral density and the autocorrelation factor of the output signal will be determined by the filter characteristic, as in the case of noise. We do not however know the probability distribution of the output envelope amplitude nor can we be certain about the input spectrum. It is clear though that the probability distribution of the output will indicate that of the input because of the linear transfer function of the filter.

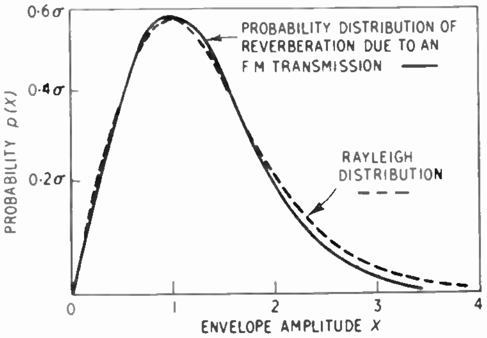


Fig. 7. Probability distribution of reverberation.

Numerical analysis of the reverberation waveform from five transmission sweeps showed that the probability distribution of the envelope amplitude was in fact very nearly of Rayleigh type as seen from Fig. 7, and in any case only an approximation was possible from this limited sample. Analysis of more than five consecutive transmission sweeps could introduce errors due to changes taking place in the medium. Of those examined, it was found that the mean level remained constant. A magnetic tape recording of the received signals was replayed several times whilst the input spectrum was explored by a wave analyser having an effective bandwidth of 4 c/s. The mean power was found to be constant over the range of frequencies covered by the filter. This is considered sufficient evidence that for all practical purposes the reverberation signal input can be assumed equivalent to wide band noise. Under nearly ideal conditions all the analyser filters had the same mean output, but of course this cannot be expected in general and the mean background level will vary with range in any echo-ranging system.

3.2. *Target Echo*

Having established the similarity which can exist between reverberation and noise the next step was to confirm that a target echo (from a simple or point target) can be considered as a tone. This is difficult to determine because of two factors; in the first place, reverberation is always present causing the echo amplitude to fluctuate, and it was observed that the modulation on the signal was sometimes more than could be accounted for by reverberation background alone. When the target echo was large compared with the background it was found that the echo often fluctuated slowly and quite unrelated to the filter response-time. No satisfactory explanation has yet been found for this, but it is known that echoes from pulse transmissions also may vary in amplitude from transmission to transmission. It is believed the variation was due to changes in the medium rather than to the frequency sweep.

Clearly, the echo was not a pure tone but as will be seen in the next section the relation between the pulse system and the f.m. system is not greatly affected since both systems may suffer the same variations in echo amplitude. There was, nevertheless, sufficient evidence to suggest that to a first-order approximation the target echo can be considered as a single tone provided the target itself is not complex, i.e. producing two or more discrete echoes. Figure 6 shows a section of a recording of the output from a 100 c/s filter containing both reverberation and an echo from a spherical target. The difference between this and reverberation alone is easily seen.

The characteristic of an echo signal can best be observed from Fig. 8 which shows the difference in distribution of a target echo plus reverberation and reverberation alone. Rice[3] has shown that the distribution of the envelope amplitude of

$$I = \varnothing \cos pt + I_N \qquad \text{.........(5)}$$

where $I_N = \Sigma^m C_n \cos(\omega_n t - \theta_n)$ as $m \to \infty$ that is, a tone pulse noise, is given by

$$W(X) = \frac{X}{\sigma} \exp\left(\frac{-X^2+\varnothing^2}{2\sigma^2}\right) I_0\left(\frac{X\varnothing}{\sigma}\right) \quad \text{...(6)}$$

where $X^2 = (\varnothing + I_c)^2 + I_s$

I_c = component of I_N in phase with cos pt.

I_s = component of I_N in phase with sin pt.

$\sigma = \overline{I_N^2}$

$I_0\left(\frac{X\varnothing}{\sigma}\right)$ is the Bessel function of zero order.

$W(X)$ is plotted against $X/\sqrt{\sigma}$ in Fig. 8 for values of $\varnothing/\sqrt{\sigma} = 0$ (Rayleigh distribution) and 3; i.e. signal/noise ratio of 0 and $3/\sqrt{2}$ respectively. These are then compared with $\varnothing/\sqrt{\sigma'} = 0$ and $\sqrt{3}$ where σ' is such that the "mode" of the tone plus noise (N_1) is the same as noise N_2 ($= 3\ N_1$) alone.

It was not possible to separate the noise (or reverberation) and the tone (or target echo) and thence plot the distributions obtained from the experimental results, as in the case of reverberation alone. To isolate the echo signal by a very narrow band filter (minimum bandwidth = 1/sweep interval) of say 3 or 4 cycles bandwidth the linearity of sweep must be better than 3 or 4 parts in 10,000. This was more than could be expected of the system used, the linearity of which was estimated at about 0·5 per cent., i.e. 50 c/s. The 100-c/s bandwidth filters were thus

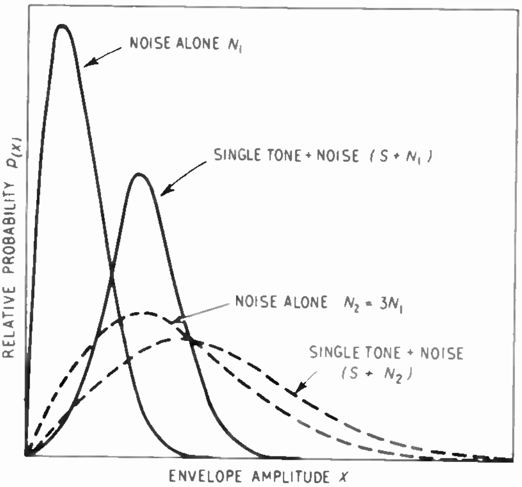
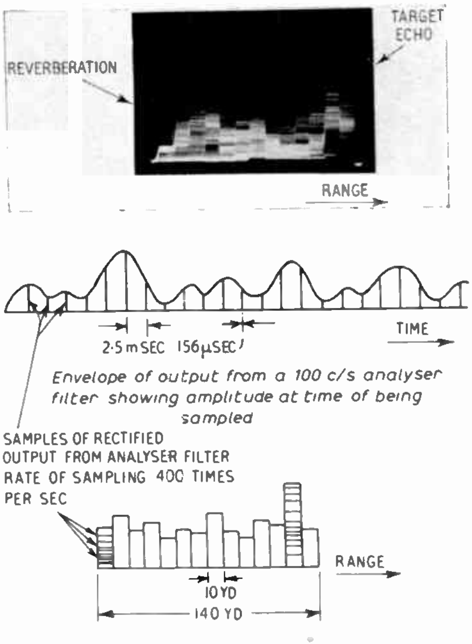


Fig. 8. Comparison between distributions for noise and noise + single tone.

about the minimum which could be used with this particular system. The linearity of frequency sweep required is of course a serious practical disadvantage of f.m. echo ranging systems.

Thus we can only compare the form of distribution obtained in practice with the distribution which can be calculated theoretically for similar (though not exactly the same) conditions. The immediately obvious difference between the two theoretical curves of "noise" and "noise plus tone" of Fig. 8 is the well-known fact that the mean value of X is different and it is usually because of this that a target is detected[4]. Two other features are of importance however. The peaks of amplitude for "noise" and "noise plus tone" follow curves which are very similar in shape although the probability of a peak of signal plus noise being greater than noise alone may be considerable, depending upon the signal/noise ratio. Because of this, the only information which can be obtained from an observation of the peaks of the envelope is that one channel may have a larger signal than the other. This could be due to either the presence of a tone or a higher level of reverberation compared with other channels—which is not unusual.

Comparing now the two curves for signal amplitudes less than the mean, it will be seen that their shape is quite different provided the signal to noise ratio is moderately large. This difference is most noticeable in the f.m. display picture of Fig. 9. A reverberation signal produces a column, corresponding to each analyser channel which tends to be filled to the bottom showing there is a high probability of a signal falling to very low values (c.f. distribution for noise alone in Fig. 8). When a target echo is present however, the change in distribution is more marked for the amplitudes which are less than the mean value than for those which are greater than the mean. The detection of an echo signal in a "noise" background can thus be made either by the change in the mean level (normal method for pulse systems), the increase in the peak signals, or the decrease in the number of low level signal amplitudes—depending upon the number of independent samples of information available. There is no special significance in the change in the mean level for different points in range nor for the change in the peak amplitudes; these could be due to either a target echo or a higher level of reverberation. To distinguish one from the other requires additional information not always available. On the other hand, a change in the low level probability is significant, being due only to the presence of an echo.



Envelope of output from a 100 c/s analyser filter showing amplitude at time of being sampled

SAMPLES OF RECTIFIED OUTPUT FROM ANALYSER FILTER RATE OF SAMPLING 400 TIMES PER SEC

Illustration of the formation of the f.m. display

Fig. 9. Example of f.m. display.

Figures 10 and 11 illustrate these points. Let us first consider Fig. 10, where it will be seen that an echo is present, indicated quite clearly by the large amplitude signal in one channel as compared with the others. The three pictures are of the same echo, but the degree of smoothing of the output from the detectors in the scanning switch is different in each case. To obtain these photographs, the tape recording of the signal from the output of the range equalizer (Fig. 1) was replayed into the analyser filters, after modifications were made to the detector circuit. In Fig. 10(a) the output of the detector was shunted by an R-C network having a low-pass cut-off frequency of 2 c/s; in Fig.

10(b) the cut-off frequency was 20 c/s and in Fig. 10(c) was 100 c/s. Alternatively, one can look upon the network as having a time constant of 80 msec, 8 msec and 1·6 msec respectively.

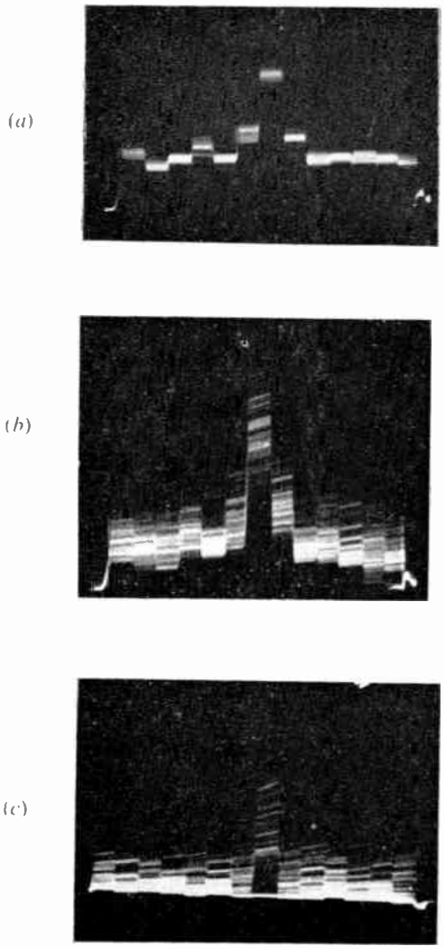


Fig. 10. F.m. display showing the effect of smoothing —large signal/background ratio. (a) $R.C = 80$ msec. approx. 0·6 sec exposure; (b) $R.C = 8$ msec, 0·6 sec exposure; (c) $R.C = 1{\cdot}6$ msec, 0·6 sec exposure.

Thus the output from the detector was almost completely smoothed in (a) when the *mean* signal level was presented; partially smoothed in (b) when the spread of amplitudes about the mean was small; and in (c) there was no smoothing (other than the rejection of the "carrier") when the fluctuation in the amplitude was unrestricted by the electrical networks.

The echo is clearly seen in each of the photographs because of its amplitude relative to the background level in the other channels, and consequently it cannot be said that one form of presentation is better than the other from the pictures alone. This is because the integration effect of the photography is such that even the unsmoothed display is excellent. Yet, at the time the photographs were taken it was evident that the smoothed display (a) was best because the transient nature of the display and the inferior integration of the long persistence screen reduced the detectability of the unsmoothed echo. In fact, detection was generally made by observing the base line in the latter case to note if the line was broken—as in (b) and (c)—due to the difference in the probability distribution. The conclusion was that when the echo/background ratio was good the smoothed display was the best form of presentation.

It was also noted that when the echo/background ratio was small and the variation in the background with range also small, the smoothed display gave better results. This was rare however, because the background generally varied considerably with range. (See Fig. 11.)

Here the echo/background ratio is small and if only Fig. 11(a) were available one could not be certain that a target echo were present because of the variation in the output level from channel to channel. Observing now Figs. 11(b) and (c) there is noticed a difference in channel 11, where the probability of a low level signal is less than the probability of the same amplitude occurring in the other channels. (Those adjacent to channel 11 suffer slightly from the overlap of the filter responses). From the theoretical probability curves of Fig. 8, this could only be due to a target echo as already discussed. Thus we see that under such circumstances, a high degree of smoothing destroys valuable information in the form of a probability distribution. These circumstances are of course the ones existing at the stages of initial detection in any system. Again, one should remember that the photographic integration is superior to that of a display, particularly when the picture can only be viewed for a fraction of a second rather than several seconds or longer. At the time of taking these latter records the unsmoothed display was in fact superior; this is the reverse of the case when the echo/background ratio was large.

Since subjective results are being discussed it must be emphasized that insufficient subjective tests were made to substantiate fully the conclusions given, but it is not difficult to see the trends from the photographs.

Thus, although the general theory of reference 1 suggests that an integrated display, obtained by using a smoothing filter, will improve detection of a target echo, in practice, one has to be careful in choosing the type of integration.

3.3. *Rate of Receiving Information*

It was shown in reference 1, and discussed in Section 2 of this paper, that independent samples of information are obtained on the average once in every time interval of the reciprocal of the analyser bandwidth. In this case, the time is 10 milliseconds which is 1/60th of the sweep time. Because the range resolution of the pulse system was arranged to be the same as that of the f.m. system, each independent sample of information from an analyser filter was equivalent in the pulse system to one sample obtained from the same range element during each transmission interval of 0·6 seconds, i.e. the f.m. system received the same information as the pulse system but in 1/60th of the time.

To show this, the same tape recording as used for obtaining Fig. 10 was replayed and the unsmoothed display photographed. This time however, it was photographed for intervals of 10, 40, 100 and 600 msec. These photographs can be seen in Fig. 12. During a 10 msec exposure one should obtain on the average four samples from the scanning switch but only one sample of information. It will be seen that the echo is detectable in the photograph (specially chosen) but other photographs having a 10 msec exposure show that this is not always the case; sometimes one can get four samples of a low echo amplitude at the same time as four samples of a high level of reverberation are obtained from another channel. This is a random process as in a pulse system.

Since the pulse and f.m. equipments were designed so that either could be selected from a two-way switch, the performance of the pulse system was regularly monitored. On such occasions it was found that a single transmission gave the same unreliable results as one single sample of information from each analyser in the f.m. system. The comparison with the pulse system is discussed in the Section 3.4.

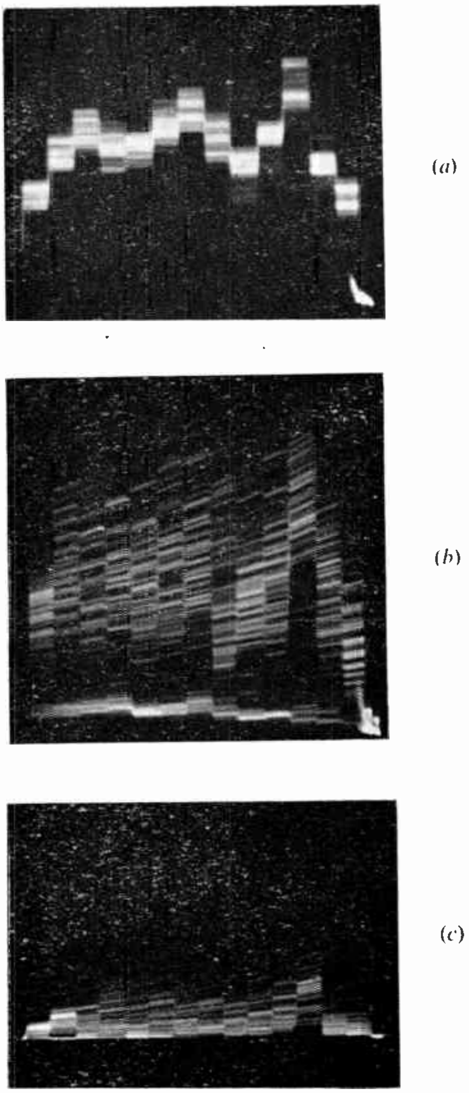


Fig. 11. F.m. display showing the effect of smoothing —small signal/background ratio. (a) $R.C = 80$ msec, approx. 0·6 sec exposure; (b) $R.C = 8$ msec, 0·6 sec exposure; (c) $R.C = 1{\cdot}6$ msec, 0·6 sec exposure.

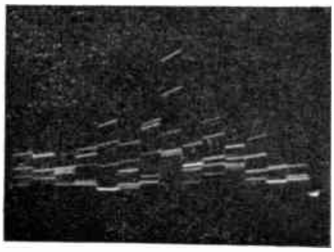
The photograph having an exposure of 40 msec, corresponding approximately to four consecutive pulse transmissions, shows the echo more definitely, and here each randomly chosen "40 msec" photograph showed a clearly defined echo. This was expected as the echo/background ratio is high. The effect of integration for 100 msec and then 600 msec is obvious. The big gap at the bottom of the echo in the 40 msec exposure picture was obtained by chance as can be seen from the longer exposures of the same echo.

The information received from one f.m. sweep of 0·6 sec was thus equivalent to that obtained from 60 uncorrelated pulse transmissions covering a period of 36 sec.

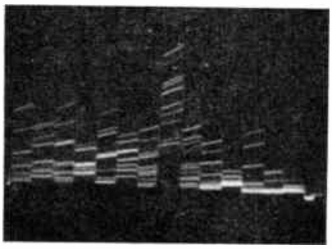
duce a variation in the mean background level nor a variation in the echo amplitude. Many attempts were made before this was approached.

A recording of 30 pulse transmissions superimposed on each other is shown in Fig. 13 (approximately the same range bracket as for the f.m. system is used) and these should be compared with the f.m. recording of Fig. 10 made immediately after the pulse transmissions.

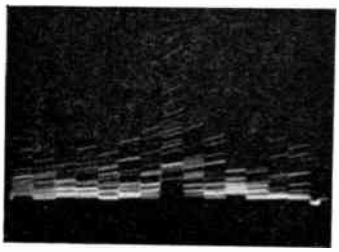
The ratio of echo level to the mean background level in the pulse system is not easy to determine, but having taken 30 traces the mean level of both the background and that of the pulse are more readily estimated than for one trace alone. Remembering that the distribution of amplitudes due to reverberation only, taken at any one point in range, is approximately of Rayleigh type, the mean of all the background levels obtained can be estimated from Fig. 13 (2 kc/s bandwidth). Calling this 1 unit, the mean echo level is measured as 3·5 from which the mean echo/mean background ratio is 3·5. This method is chosen as it can now be compared easily with the ratio of mean echo level/mean background level for the f.m. system shown in Fig. 10(a). The amplitudes shown are mean values and the ratio is found to be 3·3. The difference between 3·5 and 3·3 is not considered significant, and it can be fairly safely



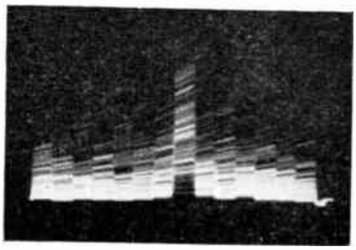
(a)
Exposure 10 msec, i.e. obtained in 1/60th of sweep time and is equivalent to one 12 msec pulse transmission.



(b)
Exposure 40 msec, i.e. obtained in 1/15th of sweep time and is equivalent to four 12 msec pulse transmissions.



(c)
Exposure 100 msec, i.e. obtained in 1/6th of the sweep time and is equivalent to ten 12 msec pulse transmissions.



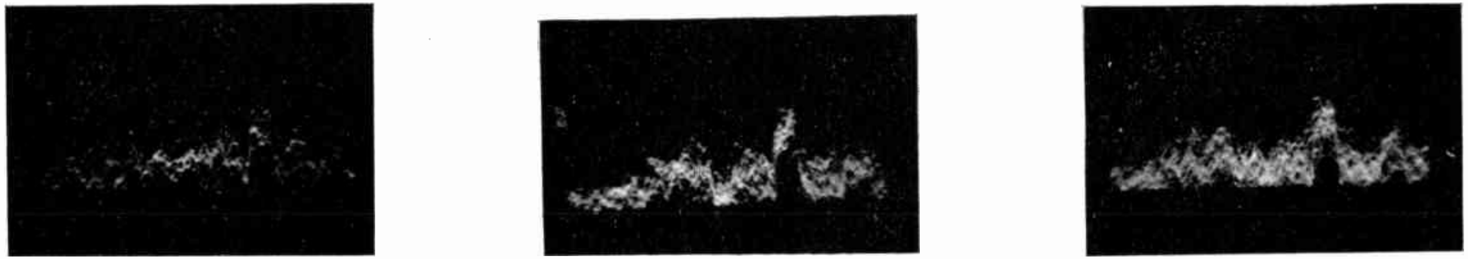
(d)
Exposure 600 msec, i.e. obtained during one complete sweep and is equivalent to sixty 12 msec pulse transmissions.

Fig. 12. Illustration of the rate at which information is received.

3.4. *Comparison with the Pulse System*

In comparing now the f.m. results with those of the pulse system it is first necessary to establish that both systems gave the same echo/reverberation ratio. This was thought to be the best method of determining the ratio of the background returns from the two systems rather than attempt to obtain absolute levels. The target, provided it is completely "illuminated" by the pulse and frequency independent, will give the same echo return irrespective of the system.

Because the two systems could not be operated simultaneously, the recordings had to be taken under conditions which did not pro-

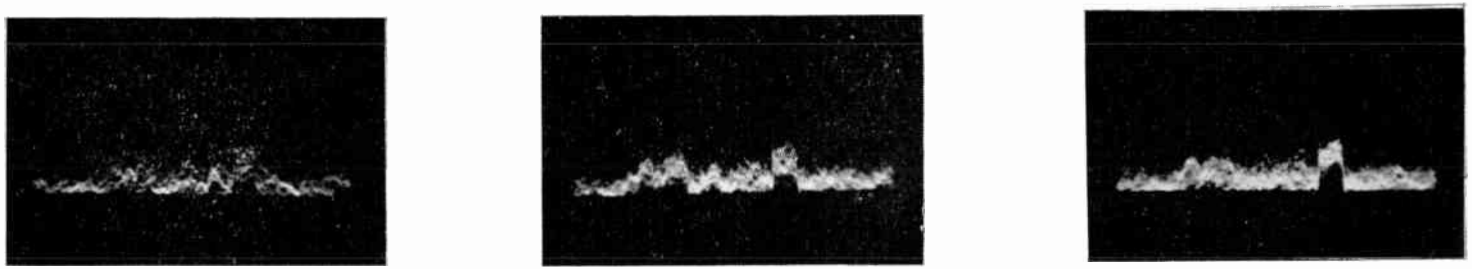


10 consecutive transmissions obtained in 6 sec.

20 consecutive transmissions obtained in 12 sec.

30 consecutive transmissions obtained in 18 sec.

12 msec pulse; receiver bandwidth 200 c/s.



12 msec pulse; receiver bandwidth 2 kc/s.

Fig. 13. Improvement in the certainty of detection with increase in the number of pulse transmissions.

assumed that the two systems had the same echo/background ratio within the limit of the design parameters. The f.m. filters were to some extent accepting reverberation from the adjacent channels and thus should have a poorer echo/background ratio.

The build-up of information concerning a target echo is clearly seen from the 10, 20 and 30 consecutive pulse transmissions. Correlation between consecutive traces was found to be almost zero, and since the target echo remained at the same range the effect is very similar to what would have been obtained from the addition to 30 pulse transmission returns, each of a different frequency, as in a multi-pulse system, but all transmitted at the same time. In the latter case the result would have resembled the mean amplitude of the 30 superpositions and it is this which one observes when detecting a target echo.

The similarity between the presentation and build-up of information in the two systems is thus shown to be in keeping with the theoretical treatment. Other forms of presentation could have been used but perhaps not with the same degree of flexibility. Had a shorter pulse been used, thus employing a wide bandwidth and providing a higher degree of resolution, the reverberation level would have been reduced accordingly. This would have increased the echo-reverberation ratio and the system would have given comparable results with fewer transmissions. As these features of the pulse system are well known, experimental results obtained along with those described are not discussed.

4. Conclusion

Although the tests carried out still leave much to be desired, the results obtained are considered sufficient to justify the assumptions made in the theoretical discussion of the author's earlier paper. The presentation of the experiments has been designed to improve the understanding of an f.m. system and link it more closely to the pulse system, so that critical comparisons can easily be made.

In practice there are bound to be discrepancies, and these were certainly present in the results obtained, but generally they were of a second-order nature and could be neglected when compared with the unpredictable variations which are constantly taking place in any echo-ranging system. Complex targets which produce two or more discrete echoes will not appear in the output as a single tone, nor will an echo pulse appear as a single rectangular pulse. Interference due to overlapping echoes will be just as detrimental to the pulse system as will multi-tone echoes in the f.m. system. In fact, neither system behaves in an ideal manner and this should always be remembered.

It is thought that the experimental results clearly establish that (i) for a given range resolution, the f.m. system can give equally good detection information at a much faster rate than the pulse system, (ii) for a given range resolution and time of observation, the f.m. system can give a much more certain detection. The improved performance of the f.m. system is obtained because it can normally have a much wider frequency band; if however the pulse system also has a wide band (and therefore either a very short pulse, or multiple pulse channels) its detection performance over a period of time at least equal to one pulse repetition period should equal that of the f.m. system.

5. Acknowledgments

The author wishes to acknowledge permission by the Admiralty to publish this paper, and is indebted to Mr. G. J. S. Hart and Mr. J. E. L. Sothcott for their valuable assistance in building some of the electronic equipment and support during uncomfortable moments at sea.

6. References

1. L. Kay, "A comparison between pulse and frequency-modulation echo-ranging systems," *J. Brit.I.R.E.*, **19**, p. 105, 1959.
2. W. R. Bennett, "Methods of solving noise problems," *Proc. Inst. Radio Engrs*, **44**, p. 622, 1956.
3. S. O. Rice, "Mathematical analysis of random noise," *Bell Syst. Tech. J.*, **24**, p. 46. 1945.
4. D. G. Tucker and J. W. R. Griffiths, "Detection of pulse signals in noise," *Wireless Engineer*, **30**, p. 264. 1953.

NATIONAL AND INTERNATIONAL ORGANIZATIONS

Valve and Semi-conductor Manufacturers' Organizations

An announcement from V.A.S.C.A.—the Electronic Valve and Semi-Conductor Manufacturers' Association formed last year (see *Journal* for November 1959, page 678)—indicates that the Association now has 15 members. The Association has taken over from B.V.A. (the British Radio Valve Manufacturers' Association) responsibilities for semi-conductors and industrial valves and tubes, the B.V.A. continuing its separate interest in domestic valves and television tubes. The first Chairman of the Association is Mr. G. A. Marriott, Immediate Past President of the Institution.

The British Electrical & Allied Manufacturers' Association has established a Semi-Conductor Devices Section in recognition of the rapid technical advance in semi-conductors and their increasing application for power and industrial purposes. The formation of this Section will provide within the Association an expert body to guide manufacturers of semi-conductor devices on matters of industrial policy. The Section will co-operate closely with V.A.S.C.A., and among its important objectives will be the work of fostering standardization of semi-conductor devices, both on a national and international basis.

New Chairman for the Frequency Advisory Committee

The Postmaster General has accepted the resignation of Sir Lawrence Bragg, O.B.E., M.C., F.R.S., from the Chairmanship of the Post Office Frequency Advisory Committee. Sir Lawrence, the Resident Professor and Director of the Davy Faraday Laboratory of the Royal Institution, has been Chairman of the Committee since it was first set up in 1958*, and he is retiring from the appointment because of his many other commitments.

In his stead, the Postmaster General has appointed Dr. R. L. Smith-Rose, C.B.E., who retired from the position of Director of the D.S.I.R. Radio Research Station at the end of September.

The present membership of the Frequency Advisory Committee includes Captain F. J. Wylie, R.N. (Retd.) (Member), nominated by the Chamber of Shipping and Liverpool Steam Ship Owners' Association, and Mr. J. R. Brinkley (Member) who represents the Electronic Engineering Association.

Fourth Report of Mobile Radio Committee

Recommendations for increasing the number of v.h.f. channels for mobile radio users have again been made by the Mobile Radio Committee in its Fourth Report, recently approved by the Postmaster General. Last year the Committee drew up a programme for reducing the width of channels in the low band (approximately 70-88 Mc/s) to 25 kc/s; now the same channel width is to be adopted as standard for the high band (165-173 Mc/s). This will produce 90 more channels in the high band during the five-year changeover period specified in the Fourth Report. The changeover to the narrower channels begins on the 1st January 1961. Thereafter, all new land-mobile systems in the high band will have to use equipment meeting the 25 kc/s specification.

International Co-ordination of Time and Frequency Services

Co-ordination was begun early this year between the United Kingdom and the United States in order to help provide a uniform system of time and frequency transmissions, which is needed in the solution of many scientific and technical problems in such fields as radio communications, geodesy, and the tracking of artificial satellites. Participating in the project are the Royal Greenwich Observatory, the National Physical Laboratory, and the General Post Office in the U.K. and, in the U.S.A., the U.S. Naval Observatory, the Naval Research Laboratory, and the National Bureau of Standards.

The transmitting stations which are included in the co-ordination plan are GBR and MSF at Rugby, England, NBA, Canal Zone, WWV, Beltsville, Maryland and WWVH, Hawaii. It is expected that by the end of 1960 the time signals from all the participating stations will be emitted in synchronism to the thousandth of a second. Such accuracy has been needed for some time in tracking artificial satellites on a world-wide basis.

---

* See *J. Brit.I.R.E.*, **18**, page 6, January 1958.

Radio Engineering Overseas . . .

The following abstracts are taken from Commonwealth, European and Asian journals received by the Institution's Library. Members who wish to consult any of these papers should apply to the Librarian, giving full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the journal unless otherwise stated. The Institution regrets that translations cannot be supplied; information on translating services will be found in the publication "Library Services and Technical Information."

RECEIVER FOR A RADIO TELESCOPE

A simple superheterodyne receiver which has been developed for use with a radio telescope in Holland, operates at frequencies between 200 and 500 Mc/s and which has a noise factor of only $F = 2{\cdot}5$ at 400 Mc/s. The high frequency amplifier contains two disc-seal triodes in cascode, which provide a very high gain, and the noise contribution from the second valve is virtually eliminated. The detector is a constant-impedance type; the local oscillator is stabilized at 400 Mc/s with a quartz crystal. These and other measures make the receiver so stable that its sensitivity is stated to remain constant for weeks on end. The receiver has an optional bandwidth of 10 Mc/s or 1 Mc/s and the time constant is variable between 0·1 and 10 sec. The methods used to determine the noise factor and calibrate the detector and antenna are described. Finally, various radio-astronomical observations are discussed, mostly carried out with the 25 m parabolic reflector at Dwingeloo. The isophot chart of the sky, reproduced in the paper, provides the most detailed available information on the structure of our Galaxy at 400 Mc/s.

"A 75 cm receiver for radio astronomy and some observational results," C. L. Seeger, F. L. H. M. Stumpers and N. van Hurck. *Philips Technical Review*, **21**, No. 11, pp. 317-33, 1959-60. (In English.)

INTERFEROMETER RADIO TELESCOPE

The Radio and Electrical Engineering Division of the National Research Council of Canada has constructed a radio telescope which has a single-lobed, fan-shaped receiving pattern formed by combining several individual interference patterns. The aerial is 600 feet long and has a pattern which is 2 degrees N-S by 1·2 minutes E-W at an operating wavelength of 10 centimetres. It is used for solar noise observations at the N.R.C.'s radio astronomy observatory at Goth Hill, near Ottawa. Preliminary interpretations of some of the scanning curves of the solar disk suggest that the E-W extent of the radio emissive regions associated with the sun-spots is seldom smaller than 1·5 minutes of arc.

"A compound interferometer," A. E. Covington, *Journal of the Royal Astronomical Society of Canada*, **54**, pp. 17-28, 58-68, February and April, 1960.

WAVEGUIDE FILTERS

The problems in the construction and in the design of tuneable cavities made from obstructions in homogeneous rectangular waveguides for low power transmissions and medium bandwidth requirements have been investigated at the University of Tübingen. Design charts were derived from the equivalent parallel-tuned circuit of capacitively tuned cavities. The use of conventional obstructions for the design of tuneable cavities results in substantial bandwidth variations caused by the frequency response of the admittance values of the obstructions. The bandwidth variations occurring during a capacitive tuning and obtained from cavities made from inductive posts were investigated with the aid of these charts and the results confirmed by series of measurements.

"Matched and tuneable cavities as circuit elements for waveguide filters," H. Urbarz, *Nachrichtentechnische Zeitschrift*, **13**, pp. 383-91, August, 1960.

GAS DISCHARGE INDICATOR TUBE

For the read-out of transistor scaling circuits there is a need for indicator tubes (which do not themselves count) capable of being operated by low-energy signals of a few volts. The tube described in a recent Dutch paper has a flat annular cathode whose surface is divided into ten sectors, and a ring-shaped anode; the tube is filled with neon + 0·1 per cent. argon at a pressure of about 15 cm Hg. A gas discharge (anomalous glow discharge) is initiated at the desired place in the tube by means of one of ten auxiliary electrodes (triggers). The control signals supplied by the transistor circuit need only make the potential of the relevant trigger differ by 5 V from that of the (earthed) anode. The current of the auxiliary discharge required to initiate the main discharge is 50 microamps. The displacement of the main discharge to any desired position, corresponding to a given count, is made possible by the periodic extinction of the discharge. To this end the tube is fed with an unsmoothed, rectified alternating voltage, obtainable, for instance, from the mains.

"A gas-discharge indicator tube for transistorized decade counting circuits." *Philips Technical Review*, **21**, No. 9, pp. 267-75, 1959-60.

HELICAL TRANSMISSION LINES

Theoretical investigations are described in a German paper on waveguide modes in helical transmission lines with any type of external medium and with a consideration of a finite wire thickness of the helix. It has been assumed that in all cases the wavelength in the guide is much larger than the axial distance between the centres of adjacent wires. Points of discussion are: the effect of the external medium on the application of the helical line as a waveguide, the performance as a mode filter in the transmission of an H_{01}-mode wave and the rotation of the plane of polarization of linearly polarized waves. Waveguides consisting of axially assembled, mutually insulated metal rings, and metal tube waveguides provided with a helically cut groove on the inner surface, are treated as special forms of helical waveguides.

"Helices as transmission lines for waveguide modes," G. Piefke. *Nachrichtentechnische Zeitschrift*, **13**, pp. 335-41, July, 1960.

A WIDE-BAND DISTRIBUTED AMPLIFIER

A paper from the Hamburg Institute of Broadcasting Techniques describes a distributed amplifier, the frequency characteristic of which is dimensioned according to Tschebyscheff behaviour and a set of equations is obtained for a two-valve distributed amplifier, for which an approximate solution is given. For a limiting frequency of 300 Mc/s the paper subsequently calculates the various components of the amplifier, its frequency characteristic as well as the frequency characteristics of the grid and anode chains alone. General formulae are found for distributed amplifiers with any given number of valves, and the possibilities of zero compensation are discussed. A two-valve distributed amplifier was constructed for the purpose of verifying the theoretical results. The frequency characteristics of the grid and anode chains followed in the main the calculated curves. On the experimental frequency characteristic of the overall amplifier, which shows the expected Tschebyscheff fluctuation, there is initially superimposed an increase in amplification with frequency, which, however, may be considerably reduced by suitable measures. The remaining increase is explained theoretically. A comparison of the Tschebyscheff amplifier with the usual type of distributed amplifiers shows an amplification that is greater by the factor 1·84. The paper concludes with a discussion of the cascading of several distributed-amplifier stages.

"Increasing the gain of wide-band distributed amplifiers by compensation of its null point and arrangement of the remaining poles of a Tschebyscheff ellipse," V. J. Koch, *Archiv der Electrischen Ubertragung*, **14**, pp. 348-60, August, 1960.

THE TRIANGULAR "V" AERIAL

An aerial has been described by the Professor of Electrical Engineering at Adelaide University which consists of a transmission line uniformity expanded in cross-section, of constant characteristic impedance and whose open end is a large aperture. It has a frequency range of 3-4:1, with good matching, no beam splitting and gains at the high-frequency end of the order of 18 db. With a square aperture either singly or in groups of four it forms a useful u.h.f. beacon aerial; with apertures of large width to height ratio it forms a good substitute for the rhombic aerial.

"The triangular 'V' aerial," E. O. Willoughby. *Proceedings of the Institution of Radio Engineers, Australia*, **21**, No. 8, pp. 517-23, August, 1960.

DIRECT FREQUENCY MODULATION OF A TRANSMITTER BY MICROPHONE

A device is described in a German paper in which a capacitor microphone used for the frequency modulation of a high frequency oscillator is simultaneously employed as an electrostatic control element for maintaining a constant mean frequency of oscillation. With the aid of theoretical investigations and measurements on a small commercial v.h.f. transmitter it is shown that this arrangement may be used with particular advantage in the case of miniature transmitters and radio-microphones and that this can be achieved with little effort. A control ratio of 1:30 is possible.

"Improvement of the frequency stability of a high frequency oscillator frequency modulated by means of a capacitor microphone," H. Maier, *Nachrichtentechnische Zeitschrift*, **13**, pp. 436-40, September 1960.

MULTI-CHANNEL TRANSMISSION

A French engineer has described a newly designed equipment for the transmission of binary data, on a time-division basis, upon one telegraph channel. This fully transistorized equipment makes it possible to transmit sequentially either 12 telemetering signals with an accuracy better than 1 per cent., or 12 groups of 6 remote-indications of the make-and-break type, or any combination of both signals, within the limits of the capacity of the system. Taking into account the signals used for synchronization, information is sampled every two seconds. However, if a channel bandwidth higher than 120 c/s is available, the transmission speeds can be significantly increased. The same system can handle remote control signals in the reverse direction when it is supplemented by checking devices intended to provide a very high reliability of operation.

"A new multi-channel system for data transmission," M. Soubies-Camy. *Onde Electrique*, **40**, pp. 525-42, July-August, 1960.

TRANSIENT BEHAVIOUR OF TRANSISTORS

A member of the Institution working in Holland has recently published a detailed analysis of the transient behaviour of alloy junction transistors both when switching on and switching off. The approach to the investigation of the inherent problems is via an extensive study of concentration patterns, thus allowing a qualitative and in many cases a semi-quantitative analysis of the transient behaviour. Detailed discussion of this behaviour is preceded by an analysis of the steady-state conditions. The consequences of voltage feed, current feed and quasi-voltage feed are dealt with at some length. Subsequently the relation of the transistor switching parameters to the more conventional parameters are discussed. Finally, the influence of transistor symmetry is investigated and an electrical equivalent circuit is given for large-signal operation. Junction diode "reverse recovery" is also dealt with, thus explaining similar phenomena occurring in transistors for switching purposes.

"Transient behaviour and fundamental transistor parameters." C. J. le Can. *Electronic Applications, Eindhoven*, **20**, No. 2, pp. 56-83, 1960.

TELEVISION PICK-UP DEVICES

The April 1960 issue of the French journal *Acta Electronica* is devoted to a series of papers on multiple-beam cameras and transistorized video frequency equipments.

The titles are:

"Television pick-up devices: multiple-beam cameras and transistorized equipments." R. Geneve.

"Multiple-beam cameras. The main problems encountered with these pick-up devices." P. Billard.

"Optical combinations with a constant extension. Their application in multiple-image cameras," P. Billard and M. Oliffson.

"The computation of transistorized video amplifiers." M. Audebert.

"Transistorized preamplifier for television cameras," L. Enselme.

"Transistorized generator of television synchronization and blanking signals," J. Borne.

"A transistorized portable television camera." J. M. Fournol and L. Enselme.

"An electronic view-finder for motion-picture cameras." P. Billard and J. Maillard.

"A double standard television camera," P. Billard, L. Enselme, J. M. Fournol and M. Oliffson.

The authors are all members of the staff of the Laboratories d'Electrique et de Physique Appliquée of Paris.

Acta Electronica, **4**, No. 2, pp. 127-314, April, 1960.

AUTOMATIC CHARACTER RECOGNITION

Automatic character recognition is mainly applied at present to number processing. The reason for this is that on the one hand the number of the different characters is small and that on the other hand large quantities of information are available which have to be processed quickly and reliably. In this case the character reading device serves as an input unit for the data processing equipment. General considerations of the requirements which a character reading device has to fulfil are discussed in a recent German paper using an example of cashless financial transactions. A character reading device for typewritten figures is described which scans the figures by an optical method and stores these figures in their natural form. A shift register, which automatically feeds the figure information during the shift process correctly into the subsequent recognition circuit, is used as a store.

"A character reading device for typewritten figures." W. Dietrich. *Nachrichtentechnische Zeitschrift*, **13**, pp. 317-20, July, 1960.

MEDICAL AND BIOLOGICAL ELECTRONICS

In the July 1960 issue of the *Proceedings of the Institution* of Radio Engineers, Australia, a group of five short papers is published which formed a symposium on medical electronics at the I.R.E. Radio Engineering Convention in Melbourne last year:

"Electronics in electrophysiology." Mollie E. Holman. (A brief introductory review is given of the use of electronics in the study of nerve and muscle cells.)

"Isolation of output of a pulse generator." I. D. Pugsley and B. M. Johnstone. (Shielded r.f. coupling to an isolated probe permits pulse stimulation of biological tissue without coupling to the pick up electrodes. Pulse amplitude up to 50 V and durations between 10 microsec and 100 millisecs are available.)

"A precision constant current supply." J. Filshie. (A unit has been developed with an output current of 1-10 ma constant to better than 1 per cent. for periods of up to one hour.)

"The design of direct coupled pre-amplifiers," L. Dally, B. M. Johnstone and I. D. Pugsley. (Two hybrid (electrometer) triode-transistor amplifiers are discussed. Positive feedback effectively reduces the input capacitance of one amplifier. The analysis of this feedback is given.)

"Measurement of arterial blood pressure," J. R. Goding. (Arterial blood flow is described in terms of an electrical analogue. It may be measured by a small transducer consisting of a moving ferrite core which varies the coupling between two coils.)

Proceedings of the Institution of Radio Engineers, Australia, **21**, No. 7, pp. 457-69. July, 1960.