*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 NOVEMBER 1960 NUMBER 11

## NOTICE OF THE THIRTY-FIFTH ANNUAL GENERAL MEETING

NOTICE IS HEREBY GIVEN that the THIRTY-FIFTH ANNUAL GENERAL MEETING (the twenty-seventh since Incorporation) of the Institution will be held on WEDNESDAY, 11th JANUARY, 1961, at 6 p.m. at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1.

### AGENDA

1. **To confirm the Minutes of the 34th Annual General Meeting held on 2nd December 1959.** (Reported on pages 737-739 of Volume 19 of the *Journal* dated December 1959).

2. **To receive the Annual Report of the Council.** (To be published in the December issue of the *Journal*).

3. **To elect the President.***

4. **To elect the Vice-Presidents of the Institution.***

5. **To elect the Ordinary Members of the Council.***

6. **To elect the Honorary Treasurer.***

7. **To receive the Auditors' Report, Accounts and Balance Sheets for the year ended 31st March 1960.**

   The Accounts for the General and other Funds of the Institution are to be published in the December issue of the *Journal*.

8. **To appoint Auditors and to agree their remuneration.**

   Council recommends the re-appointment of Gladstone, Jenkins & Co., 42 Bedford Avenue, London, W.C.1.

9. **To appoint Solicitors.**

   Council recommends the re-appointment of Braund & Hill, 6 Gray's Inn Square, London, W.C.1.

10. **Awards to Premium and Prize Winners.**

11. **Any other business.** *Notice of any other business must reach the Secretary 40 days before the meeting.*

* For the reasons outlined in the Annual Report, Council has not proposed the election of new Officers or members of Council. The President, Vice-Presidents, Honorary Treasurer and ordinary members of Council are prepared to continue in office in accordance with Article 29.

# INSTITUTION NOTICES

### The Pilkington Committee on Broadcasting

The Institution has accepted an invitation to give evidence to the Committee on Broadcasting which has been set up by the Postmaster General under the Chairmanship of Sir Harry Pilkington. The terms of reference of the (Pilkington) Committee are:—

> "To consider the future of the broadcasting services in the United Kingdom, the dissemination by wire of broadcasting and other programmes, and the possibility of television for public showing, to advise on the services which should in future be provided in the United Kingdom by the B.B.C. and the I.T.A.; to recommend whether additional services should be provided by any other organization, and to propose what financial and other conditions should apply to the conduct of all these services."

On behalf of the Council, reports are being prepared jointly by the Technical and Television Group Committees. Note has been taken of observations submitted by individual members and it is hoped to be able to make reference in the *Brit.I.R.E. Journal* to the evidence submitted to the General Council.

### Mr. L. G. Brough

Members of the North Eastern Section of the Institution, and many others, will learn with interest that Mr. Leonard G. Brough (Associate Member) has recently retired from his appointment as Engineer with the North Eastern Electricity Board. Mr. Brough has served on the Section Committee for over ten years, the past eight as its Treasurer. He has also taken a keen interest in the Section's support of the Brit.I.R.E. Benevolent Fund.

Although born in London, Mr. Brough obtained his technical education in Crewe and Manchester, gaining his A.M.C.T. in 1923 after part-time study. He was apprenticed to the London & North Western Railway Company in 1910 as an electrical instrument maker and after war service with the Army Ordnance Corps he joined the Company's Signals and Telegraphs Department. In 1924 Mr. Brough was appointed an engineer in the telecommunication section of the Operations Department of the North Eastern Electric Supply Co. In this capacity he was closely concerned with the extension of the use of carrier-wave telephony and supervisory control over high-voltage lines. This work formed the subject of a paper which he read before the North Eastern and Scottish Sections of the Institution in 1948.

Mr. Brough has been an Associate Member of the Institution since 1944 and members will wish him a long and happy retirement.

### Physical Society Exhibition

The 1961 Physical Society Exhibition will be held at the Royal Horticultural Society's Halls, Westminster, London, S.W.1, from Monday, 16th January, to Friday, 20th January, 1961.

As in previous years, the Physical Society kindly offers special admission tickets to enable Brit.I.R.E. members to visit the Exhibition on the morning of Monday, 16th January. Members who wish to take advantage of this offer should write to the Institution without delay; requests for general tickets admitting at other times may also be made now. Tickets *will not be despatched* until a few days before the Exhibition.

### Civilian Scholarships: Royal Military College of Science

The War Office has announced its intention to award further scholarships tenable at the Royal Military College of Science, Shrivenham, for civilian students. The courses, of three years' duration, are for London University external degrees and the scholarships are designed for the training of young scientists for Government research establishments.

The scholarships carry exemption from tuition and examination fees and the student receives a maintenance allowance of £355 per year which is not subject to tax or means test. Applicants must be under 22 years of age on 1st October, 1961 or, if they have completed National Service, under 24 years of age.

Application forms and further information may be obtained from the War Office, C.13(c)3. Room 338, The Adelphi, John Adam Street, London, W.C.2.

# Silicon Photo-voltaic Cells for Instrumentation and Control Applications†

*by*

V. MAGEE, B.SC., PH.D. ‡ and A. A. SHEPHERD, M.SC., PH.D. §

*A paper read before the Institution in London on 30th March 1960.*

*In the Chair:* Dr. T. B. Tomlinson (*Associate Member*).

**Summary:** The paper describes the operation of silicon *p-n* junction photo-voltaic cells as detectors of visible and near infra-red illumination. A brief account is given of the detection mechanism, with references to earlier papers, and the processes used in the fabrication of this type of cell are described. Several applications of silicon photocells which make use of their particular advantages are considered.

## 1. The Photo-voltaic Effect in Silicon

If one face of a single crystal plate of silicon is illuminated by light in the wavelength range 0·3 to 1·2 microns, the incident photons can create charge carriers in the silicon crystal at a small distance below the surface. These carriers are formed in pairs, one positive and one negative carrier per pair, due to the removal of an outer valence electron from the silicon atom by the incident photon, leaving behind a positively charged site or positive "hole."

If a *p-n* junction is introduced into such a silicon plate at a sufficiently small distance below the surface, the pairs of carriers may be separated, allowing useful work to be performed in an external circuit. Figure 1 shows a cross-section through such a *p-n* junction, together with the corresponding energy band configuration in the semi-conductor. Under equilibrium conditions the *p*-type region contains a high density of positive holes and the *n*-type region a high density of electrons. A potential gradient as shown in Fig. 1(b) exists between the *p* and *n* regions, in which the free carrier density is low. This region is referred to as the charge depletion layer in Fig. 1(a) and has a width $W$ given by the expression

$$W = W_p + W_n$$

where $$W_p \cong \left(\frac{KV}{2\pi e N_p}\right)^{\frac{1}{2}}$$

and $$W_n \cong \left(\frac{KV}{2\pi e N_n}\right)^{\frac{1}{2}}$$

$K$ = dielectric constant of silicon

$V$ = contact potential at junction

$N_p$ = number of positive holes per cm$^3$ in *p*-region.

$N_n$ = number of electrons per cm$^3$ in *n*-region.

When illumination falls on the silicon surface, it will penetrate the bulk material to a depth depending on its wavelength. The short wavelength light will be absorbed within a very small distance of the surface, and the longer wavelength light will penetrate a greater distance.

In the absorption process, hole electron pairs will be formed; excess electrons (i.e. minority carriers) will be present in the *p*-type layer and excess holes in the *n*-type layer. After formation, these excess carriers will diffuse through the material, and any carriers reaching the depletion layer will flow across it under the influence of the potential gradient, the electrons

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† Manuscript received 24th February 1960. (Paper No. 590.)

‡ Formerly with Ferranti Ltd., now with the Plessey Co. Ltd., Towcester, Northants.

§ Ferranti Ltd., Semi-conductor Research and Development Division, Wythenshawe, Manchester 22.

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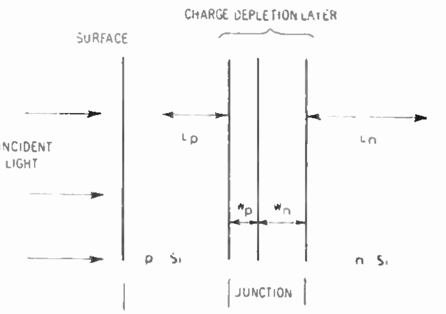
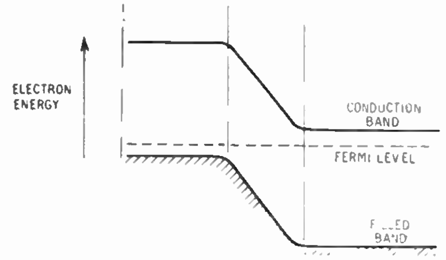


(a) Cross-section of silicon photocell



(b) Energy level diagram for silicon photocell

**Fig. 1.** Schematic diagram of silicon photocell cross section showing the electron energy levels in the $p$ and $n$ type regions.

moving to the right in Fig. 1 and the holes moving to the left. These active carriers will be collected from a region of the material bounded by the carrier diffusion lengths, the mean values of these lengths being $L_n$ and $L_p$. Excess carriers formed outside this region will not be effective.

The collection of carriers by the junction will give rise to a current if the cell is connected to an external circuit. A simplified equivalent circuit of the photocell under these conditions is as shown in Fig. 2. It consists of a current generator supplying current $I_S$, which is proportional to the light intensity, into the $p$-$n$ junction impedance in parallel with the external load $R_L$. Thus, if $I_J$ is the current in the $p$-$n$ junction and $I_L$ the load current,

$$I_S = I_J + I_L \qquad \ldots\ldots\ldots(1)$$

The junction current $I_J$ is given by[1]

$$I_J = I_0 \left[ \exp\left(\frac{eV}{kT}\right) - 1 \right] \qquad \ldots\ldots\ldots(2)$$

$I_0$ is the reverse saturation current of the junction, and $V$ is the voltage across it, including the built-in potential. From eqns. (1) and (2) it can be seen that the form of the voltage-current characteristic of the photocell is as shown in Fig. 3. The maximum voltage is obtained under open circuit conditions, when $I_L = 0$, and is given by

$$V_{0c} = \frac{kT}{e} \log\left[\frac{I_S}{I_0} + 1\right] \qquad \ldots\ldots\ldots(3)$$

The maximum, or short circuit current is $I_S$, which is proportional to light intensity.

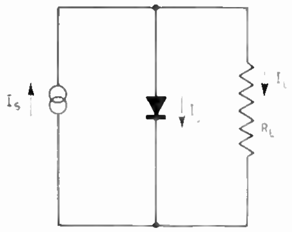


**Fig. 2.** Equivalent circuit of silicon photocell.

During the past few years, much attention has been devoted to the use of this type of photocell as a power converter for changing solar energy to electrical power[2, 3, 4]. If the generated power in the load is plotted as a function of load resistance from Fig. 3, it will have the form shown in Fig. 4, where the power available exhibits a maximum value at a particular value of load resistance $R_{\text{opt}}$. Under these conditions, a silicon cell should theoretically have a power conversion efficiency of about 22 per cent. for solar radiation[5]. In practice, however, losses occur due to

(a) Reflection of light at the silicon surface.

(b) Recombination of excess carriers in the silicon before collection by the junction.

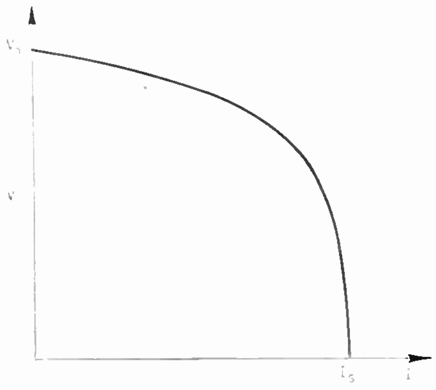


**Fig. 3.** Voltage/current characteristic of silicon photocell.

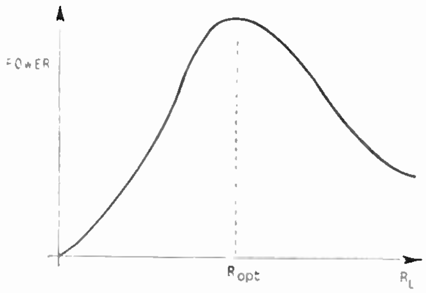


**Fig. 4.** Power/load curve for silicon photocell.

(c) Internal resistance of the cell.

These losses are, of course, also of considerable importance for silicon photocells used as sensing devices when maximum sensitivity is required.

## 2. The Fabrication of Silicon Photocells

The primary requirements in preparing *p-n* junctions in silicon for photocells are as follows:

(i) The junction should be planar, and formed at a small distance (about 0·0001 in.) below the surface exposed to light.

(ii) The surface should reflect as little light as possible.

(iii) The potential barrier at the *p-n* junction should be as high as possible, to give a high value of $V_{oc}$. This implies a high doping level of impurities on both sides of the junction.

(iv) The diffusion lengths $L_p$ and $L_n$ for the excess carriers in the silicon should be as long as possible. This implies a high value of minority carrier lifetime in both *p* and *n* regions.

(v) The series resistance of the surface layer should be low.

(vi) The resistance in the contacts to the silicon surfaces should be low.

These requirements can most easily be met by a process involving formation of the *p-n* junction by solid state diffusion. In a typical schedule for preparation of silicon photocells, *n*-type slices of silicon of low resistivity are loaded into a furnace at a temperature in the region of 1200°C, and a layer of boron is deposited on the surface of the slices from a boron compound. The slices are held at the high temperature for a time sufficient to allow the boron to diffuse into the silicon and form a *p*-type skin about 0·0001 in. deep (condition (i)). The surface skin has a low resistance due to the high concentration of boron impurity, which fulfils conditions (iii) and (v). Also during this process, a surface film of low reflectivity can be formed, satisfying condition (ii). If the diffusion temperature is raised, the concentration of impurities in the *p*-type skin is increased, lowering the resistance of the surface layer. The high processing temperature, however, leads to a reduction in minority carrier lifetimes in the material. This effect can be counteracted to some degree by slow cooling after diffusion. A low value of lifetime leads directly to a reduced value of $I_s$ in the completed cell. After diffusion, the silicon slice is cut into separate cells of the required area, and the junction is removed from all surfaces except the active surface, by lapping and etching away the unwanted material. Contacts are then attached to the two sides of the junction by plating and firing, or alloying, the process being chosen to provide contacts of resistance as low as possible.

Multiple cells may be formed on a single slice of material by this process, for example, by grooving the sensitive surface of the silicon to form several cells on a common base. Figure 5 shows the construction of a MS1/9 type silicon multiple photocell for reading nine-hole punched tape as used in computer tape readers, and Fig. 6 shows a range of photocells of various sizes produced by the solid-state diffusion process.

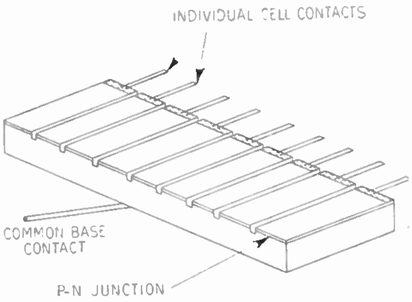


**Fig. 5.** Construction of MS1/9 silicon photocell for punched tape reading.

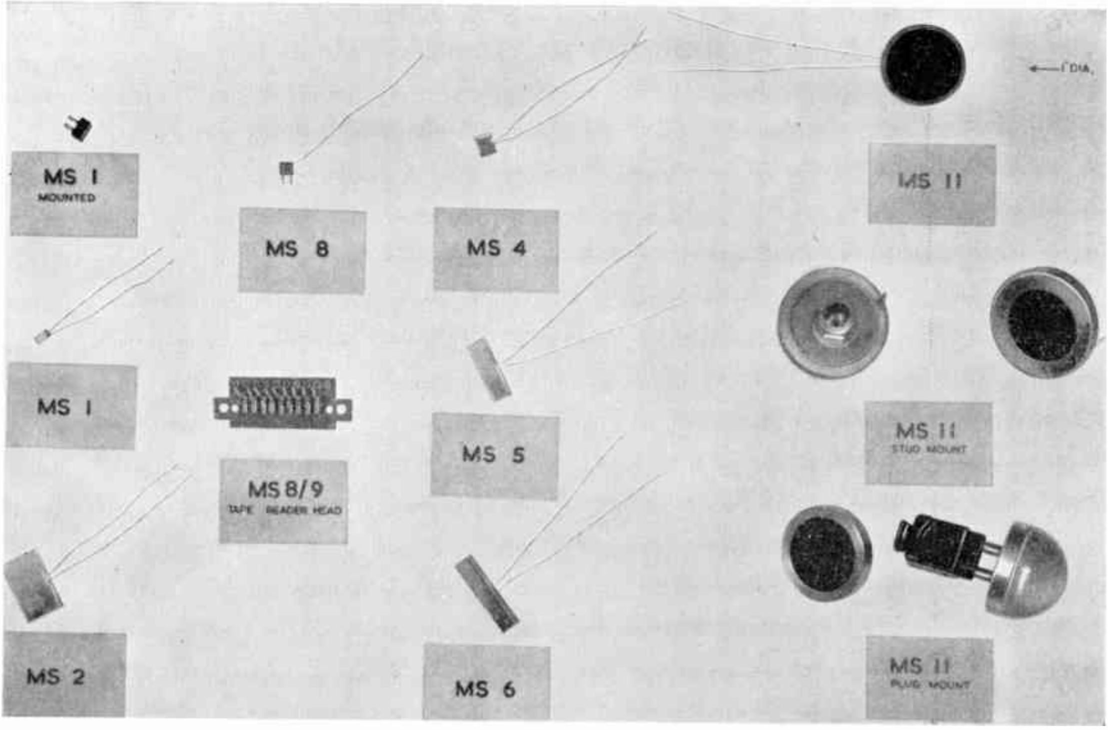


Fig. 6. Range of silicon photocells available for control and instrumentation purposes.

Although the construction described above uses *n*-type base material, cells may also be made by diffusion of an *n*-type impurity, for example phosphorus, into a *p*-type silicon slice. It is often convenient to use such an arrangement for multiple cells on a common base when negative going output signals are required from the cells

### 3. The Use of Silicon Photocells as Circuit Elements

When silicon photocells are to be used as detecting elements, many of their circuit properties may be deduced from the characteristic voltage-current output curves. In Fig. 7 typical curves are shown for several illumination levels for a small area cell (Ferranti MS1) and a large area cell (Ferranti MS11). Figure 7(b) also shows for comparison purposes the output characteristics of a typical selenium barrier layer cell having an area of 0·78 in.$^2$. Curves are given for illumination levels of 100 ft. cd. and 1000 ft. cd. and it will be seen that although

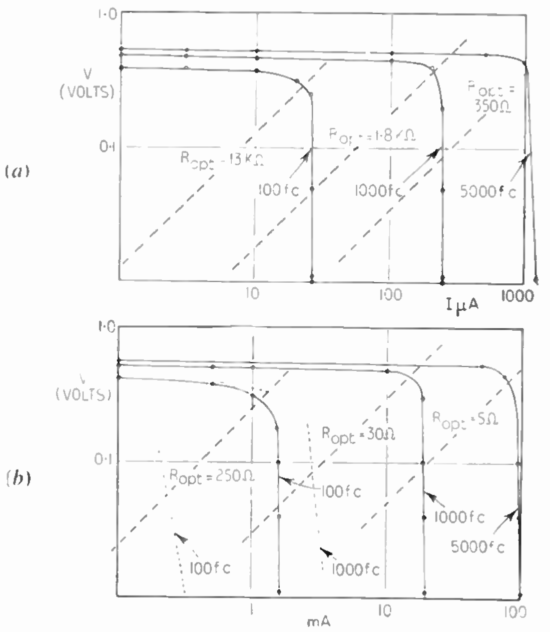


Fig. 7. Typical voltage current characteristics. (a) MS11 silicon photocell. (Active area 0·72 in.$^2$ C.T. 2854°K.) (b) MS1 silicon photocell. (Active area 0·135 in.$^2$ C.T. 2854°K.)

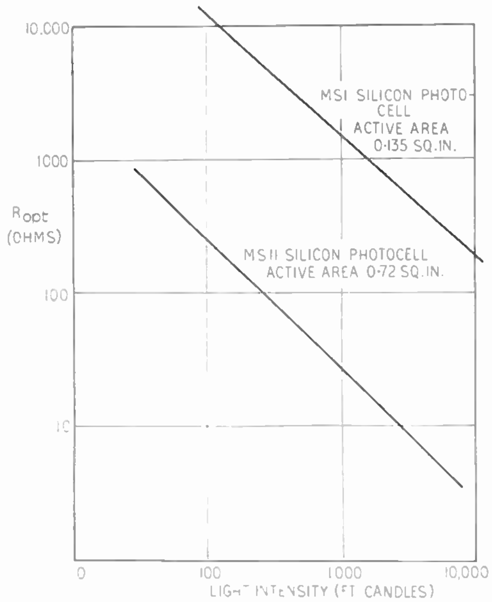


**Fig. 8.** $R_{opt}$ as a function of illumination intensity.

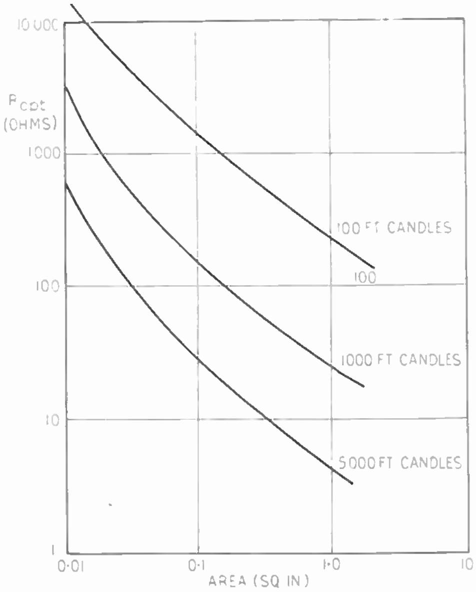


**Fig. 9.** $R_{opt}$ as a function of cell area.

similar open circuit voltage can be achieved with selenium at high light levels, the short circuit current is much lower than that for the silicon cell, giving a power conversion efficiency of only about 2 per cent.

From the square shape of the output curves for silicon cells, it is clear that two types of operation are possible, as follows.

### 3.1. *Operation into a High Impedance Load*

In this condition the load impedance is higher than that for maximum power output, and the output voltage varies only slightly over a wide range of load impedance. It will be seen that for a given cell area, the value of $R_{opt}$ is dependent on the level of illumination to be used, and a typical plot of $R_{opt}$ as a function of illumination intensity is given in Fig. 8. In Fig. 9 a plot is given of $R_{opt}$ as a function of cell area for illumination levels of 100, 1000 and 5000 ft. candles. When operated into a high impedance load, the voltage output approximates to $V_{oc}$ and is logarithmically dependent on light intensity according to eqn. (3), since $I_s$ is proportional to light intensity.

### 3.2. *Operation into a Low Impedance Load*

In this condition, the cell is operating into a load impedance lower than that for maximum power output, and the output current varies only slightly as the load impedance changes. Under these conditions, the output current approximates to the short circuit value $I_s$ and is directly proportional to illumination intensity and to cell area.

It must be noted that as the temperature of the cell rises during operation, the output characteristics will change somewhat, the value of $I_s$ increasing by about 0·3 per cent. per degree C temperature rise, and the value of $V_{oc}$ decreasing by about 2mV per degree C temperature rise. It will be apparent from these values that the cells can usefully be operated up to temperatures in excess of 100°C, and this implies that high intensities of illumination may be used without the need for cooling the cells.

As has been stated in Section 1, the silicon photo-voltaic cell is sensitive to radiation in the wavelength range 0·3 to 1·2 microns. A typical plot of spectral sensitivity of a silicon cell in terms of short circuit current vs. wavelength has

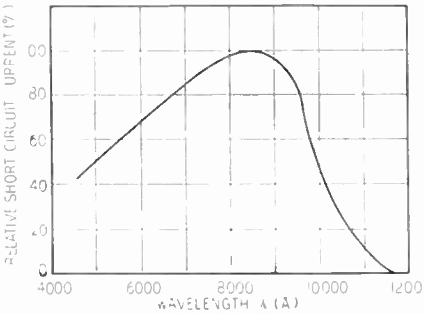


**Fig. 10.** Spectral response of silicon photocell (after Prince and Wolf[4]).

been given by Prince and Wolf[4] and is shown in Fig. 10. A curve of this type may be used when selecting a light source to operate the cell with maximum sensitivity. It will be seen that the cell response in the near infra-red is high, and if it is to be used as a detector for visible light only, as for example in a film exposure meter, some efficiency must be sacrificed by including a filter which cuts off the infra-red illumination.

## 4. Applications

### 4.1. *Relay Systems*

The first application of silicon photocells in control and instrumentation to be discussed is that of direct operation of a relay.

The relay selected will have two major design specifications of importance to the silicon photocell. These are the power required to operate it ($P$) and the range of coil resistances in which it can be supplied. From the above description of the theory of silicon photocells it will be clear that the choice of coil resistance is a critical factor in providing a maximum efficiency cell relay system. A major requirement of the coil is that the voltage required to operate the relay should not exceed 0·5V. The resistance should also be as near as possible to the value of $R_{opt}$ for the silicon photocell. The corresponding voltage under these conditions is about 0·4V in most cases. Therefore for an optimum case we can say that

$$\sqrt{PR} = 0{\cdot}4 \qquad \ldots\ldots\ldots(4)$$

and that

$$R \ngtr \frac{0{\cdot}67}{P} \qquad \ldots\ldots\ldots(5)$$

where $P$ is the power required by the relay and $R$ is the coil resistance.

The remaining parameters of interest in specifying the cell relay system are the level of illumination necessary to actuate the system ($F$) and the area of cell ($A$).

In considering the possible systems one may presuppose a level of illumination and an available relay, and calculate the area of cell required. Alternatively, the light level may be fixed, together with a decision to use the largest silicon photocell available in which case one may calculate a design target for the relay.

The relations given earlier, together with eqns. (4) and (5), may be used in carrying out such design calculations.

The number of possible variations of design are quite large. In most cases the optimum course would be to approach the relay designer with the above type of data. However, we will describe one case as an example.

It is required to provide a system which will operate at an illumination of 1000 ft. candles using the largest area cell available, thus enabling the most robust and presumably economical relay to be selected with maximum efficiency.

The largest area cell currently available has an area of approximately 5 cm$^2$. From Figs. 7(a), 8 and 9 the maximum output power of the cell would be 5mW, and this would be obtained when operating into a load of 30 ohms. The relays available must now be examined to select one with the following design criteria: minimum coil energizing power not greater than say 3mW and a coil resistance not greater than 35 ohms and not less than 25 ohms.

Relays are currently available with operating power requirements ranging from 0·005 to 350mW and coil resistances ranging from 0·1 ohms to 20000 ohms. However the relays available do not provide a continuous variation over these ranges. In certain cases therefore it will not be possible to provide a suitable combination probably due to lack of power output even under optimum conditions to actuate the available relay. Also in many cases the fragility and cost of a relay suitable for the cell power output available will be prohibitive. In any event, it is unlikely that the maximum output, under matching load conditions, from the maximum area cell, under maximum illumination levels, will exceed 30mW. In these cases, a further possibility is economically to increase the sensitivity by incorporating a transistor amplifying stage into the system. This type of system is already manufactured as an integral unit using a d.c. input. The combination of a silicon photocell d.c. input with this arrangement approaches fairly closely the ideal photoelectric relay for use in electronic equipment, i.e. consumes negligible power in operation, is capable of switching loads of 5A at 250V a.c. and is small in size, fast operating, robust and economic. This rating of relay system can be achieved with input powers of the order of 0·1mW, using a transistor, compared with an operating power requirement of 100mW in the case of a directly operated relay.

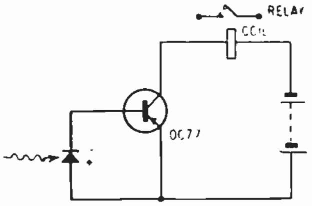


**Fig. 11.** Photocell transistor relay system—basic circuit.

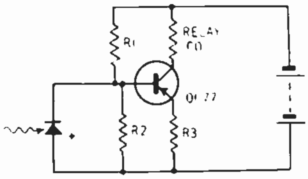


**Fig. 12.** Photocell transistor relay system with stabilized and adjustable bias circuit.

Typical circuits for this type of transistorised relay unit are illustrated in Figs. 11 and 12. The values of R1 and R2 and R3 are adjusted to bias the transistor correctly in terms of the current output available from the silicon photocell actuated by the light available together with the nature of the d.c. operating supply available. The characteristics of the transistor are not critical. It is only necessary to ensure that the selected transistor has a suitably rated maximum collector voltage value, and a current gain in the common emitter connection in the range 30 to 80. The current amplification is such that quite small photocells will deliver sufficient current output to operate the system in the case of light levels greater than 200 ft. candles. In calculating the area of cell required the basic design parameter is that the cell should be capable of delivering 100 microamps into a load of 2000 ohms with the operating light level available. A major point to realize in designing this type of system is that the transistor is a current-operated device and therefore it is of advantage to arrange for the photocell to be operating under short circuit conditions. Since the effective photocell load in the case of a transistor input is of the order of 2000 ohms or greater, it therefore follows that the smaller area cells with their higher matching load values are much more efficient for a given light level than the bigger area cells.

Again it would perhaps be helpful to describe an actual application. Referring to Fig. 11 a light flux of 300 ft. candles on a MS4 silicon photocell will actuate a relay requiring 50mW coil energy with a d.c. bias of 20V and a transistor with a common emitter current gain of 30. The coil resistance required in this case will be 5,400 ohms.

All the components involved in the transistor photo relay system are small and the possibilities of combining all three into a suitable design of hermetically sealed composite unit are very attractive.

Mention may be made here of a general point concerning the above types of relay system. Relays are often involved as vitally important components in safety circuits of electronic systems. In view of this, considerable importance attaches to the "fail safe" mode of operation involved in the systems in which the direct photo-voltaic output of a silicon photocell is used to trigger the relay.

It is of course possible to switch a relay using a photo-transistor. The advantages offered here in favour of joint use of a silicon photocell and the normal transistor are the increased degree of stability and design versatility obtained.

### 4.2. *Light Measurement*

Silicon photocells have many applications in the field of light measurement instrumentation.

A wide range of meter movement design and silicon photocell combinations can be used. Again a major design point is the impedance of the meter movement. Two major cases exist : logarithmic indication of light output and linear indication. The design criteria involved are that for logarithmic indication the meter load should be not less than 30 per cent. greater than the matching load of the proposed cell and illumination combination. For linear indication the meter load should be not greater than 70 per cent. of the matching load.

In addition to powering light measuring instruments silicon cells are very suitable, because of their high efficiency, for operating light proportional control mechanisms, such as those involved in automatic camera lens stop control. In the case of the camera application, difficulties are presented by the wide divergence of the silicon photocell from "eye corrected response", particularly in the far red and near infra-red regions of the spectrum. Filters, which will correct this deficiency, at the expense of about 50 per cent. of the potential cell output, are available.

### 4.3. *Data Reading and Automation with Silicon Photocells*

The use of silicon photocells in their miniature mounted forms, such as MS1 and MS8 cells, for a variety of electronic data reading applications, is one of the more novel applications. It is one which offers some attractive solutions to problems being encountered in the ever expanding field of electronics in automation and computation. In the present paper we will describe in varying detail work which has been conducted in the fields of tape reading, punched card reading, optical digitization of angular movement to high accuracy, automatic machine tool control, high speed counting, and film reading.

A typical tape reading system is that used in the Ferranti TR5 tape reader. The object in this tape reader is to present digital information arranged in a binary pattern. This is achieved by translating rows of punched holes in paper tape which represent the binary digits. The individual digits are converted into electrical signals for presentation to the computer in the following manner.

A continuous line of light produced from a tungsten filament and a cylindrical lens is arranged to fall across the width of the tape, the width of the beam being adjusted to dimensions commensurate with the diameter of the punched holes. Directly under the tape a mechanical masking plate containing suitably sized holes together with a row of individual miniature silicon photocells are provided. These components are arranged so that the active areas of the silicon photocells, the holes in the lower masking plate and the holes in the punched tape are all in register at the time of reading of a single character. Figure 13 illustrates a diagrammatic view of this arrangement.

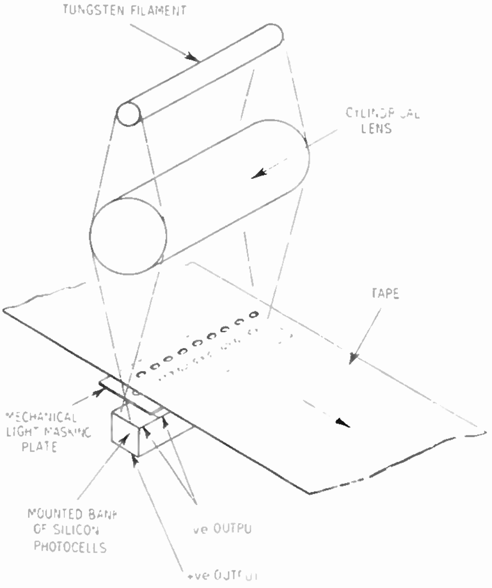


Fig. 13. Tape reader system.

A specialized unit containing the requisite number of silicon photocells suitable for use with eight channel tape is now in production. This consists of a rectangle of single crystal silicon, the active surface of which is mechanically divided into nine equal areas. Electrical contacts are provided to the individual areas, which produce negative-going signals. A connection is also made to the base of the rectangle which forms a common positive return. Figure 5 is a diagrammatic illustration of this specialized type of silicon multi-element photocell. Figure 14 illustrates the unit in its assembled form ready for mounting in the tape reader. Figure 15 shows the actual reading head in a TR5 tape reader.

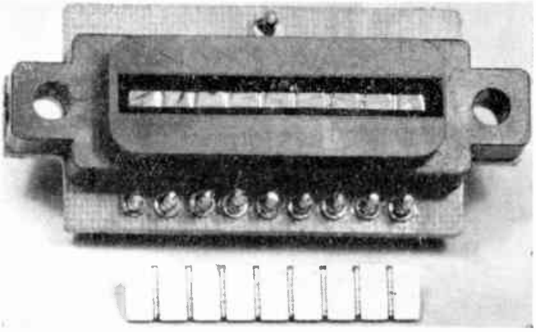


**Fig. 14.** Photograph of an MS1/9 silicon photocell.

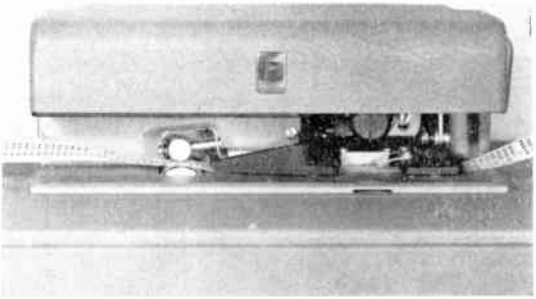


**Fig. 15.** TR5 reading head.

From the above description it follows that a given pattern of holes in the paper tape representing one character will result in a corresponding pattern of electrical signals from the bank of silicon photocells. These signals consist of constant current pulses, each of which is fed into the base of a germanium transistor, and associated biasing circuitry to switch a digit store. Figure 16 shows the complete circuit for one channel.

It is a primary requirement that transistor VT1 should remain switched off when the silicon photocell is illuminated through the blank tape. The resistor R1 and associated potentiometer enables the output current of the photocell in this condition to be backed off for this purpose. A useful design feature of the silicon photocells in this connection is that the individual outputs of any of the nine photocells are sufficiently uniform to enable a single common biasing network to serve all nine channels. The contrast ratio for a typical tape provided by this arrangement is of the order of seven to one. The output signal current level from the silicon photocell under illumination conditions corresponding to a hole in the tape is sufficiently in excess of the 50 microamps required to switch VT1 on, to ensure reliable switching in every instance. The further amplification in the digit store amplifier chain results in an output signal at point C of 5V at 2mA.

Two very useful characteristics of silicon photocells in this type of application are the fast response time, which is many times that feasible in tape reader apparatus from the mechanical standpoint, and, perhaps more important, the stability of the cell output characteristics. This is particularly marked in comparison with other

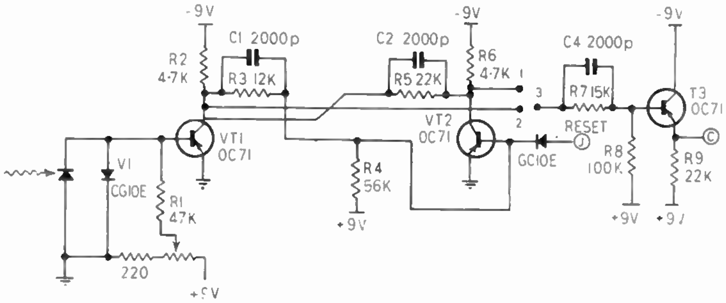


**Fig. 16.** TR5 circuit diagram.

types of photo-conductive reading elements. The very good stability of silicon photocells arises from the fact that they are operated with the internal $p$–$n$ junction biased in the forward mode, and as such are relatively immune from surface effects. These surface effects are the predominant factor in determining stability characteristics of reverse biased junctions as operating in photo-conductive devices.

Finally, mention must be made of the fact that the use of silicon photocells in this type of tape reader applications permits operating ambient temperature rises within the equipment of up to 60°C. This enables relatively more powerful light sources to be employed. In the TR5 equipment a 10W lamp is used.

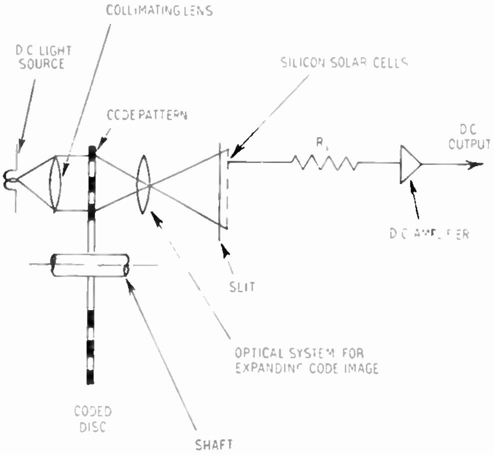


**Fig. 17.** Basic arrangement of angular position optical digitizer system.

Several other systems similar to the TR5 tape reader system have recently been developed using the miniature mounted MS8 photocells. These cells present a fairly idealized miniature unit for stacking in row and matrix systems. This cell is 0·060 in. wide by 0·120 in. long, end viewing, and mounted on a precision dimensioned heat sink, containing two accurately placed locating pins. These pins also serve to mount the units on printed circuit boards. Particular examples of the use of MS8 cells in this manner are represented by an optical digitizer unit, a complete reading system containing built-in light source for reading punched cards, a reading head for translating coded information presented as line patterns on cinéfilm, and finally a new design of tape reader in which four lines of information are read simultaneously.

The optical digitizer is a system for presenting a measurement of the position of a rotating shaft with an accuracy of 1 minute of arc, and presenting the information as a digital signal to a computer. Again the fast response speed of silicon photocells allows high speeds of shaft rotation to be employed. Figure 17 is a diagrammatic illustration of such a system. A collimated light beam passes through a radial code pattern, produced by a combination of photographic and mechanical technique, situated on a disc which is rotated by the shaft to be monitored. The emergent image passes through an optical system which expands the image of the code into a thirteen-position light pattern arranged in two adjacent rows containing seven and six points respectively. A matrix of thirteen silicon MS8 photocells is provided in register with this pattern. As the disc rotates, a pattern of current signals containing sufficient permutations to present digitally the angular position of the shaft to the above accuracy is obtained. These signals are handled by similar transistor amplifiers to those used in the TR5 tape reader system. Further developments employ a coarse and a fine disc. These have improved the resolution to the order of two seconds of arc.

By combining silicon photocells with the coded discs, it is possible to design a complete system within a cylinder 6 in. diameter 6 in. deep, containing coded disc, photocell matrix, light source and optical system, with a single cable loom carrying the complete information to the digit store and channel transistor amplifier box.

The electronic reading of punched cards with MS8 photocells is readily accomplished with a row of eighty or twelve MS8 photocells mounted to register suitably with the punched holes in the card. An interesting development here is a new compact form of light source and reading system. In this, eighty MS8 photocells are arranged in a row pitched at 0·080 inches. A perspex rod is positioned above the cells. Suitably shaped grooves are provided in the

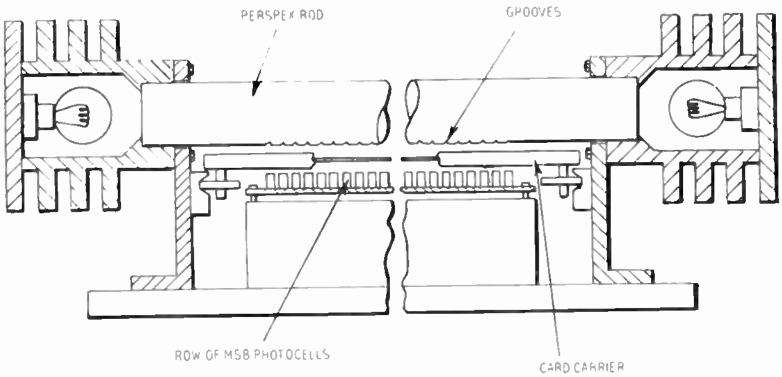


**Fig. 18.** Schematic illustration of the punched card reading system.

perspex rod in register with the photocells. Light sources are positioned at the ends of the perspex rod. The rod acts as a light pipe, the light leaving the rod only at the grooves. These in turn constitute eighty individual light sources each in register with its own photocell. Figure 18 is a diagrammatic illustration of this system which is the subject of a current patent application.

### 4.4. *Automatic Machine Tool Control with Silicon Photocells*

A new system for automatic machine tool control has been developed based on the moiré fringe technique[6]. The use of precision diffraction gratings to generate these fringe patterns formed the basis of the original work in this field, and considerable help was provided by the improved and extensive ranges of diffraction gratings now available[7,8]. In the present paper we will briefly describe the basic principles of this new system in sufficient detail to point out the role now being played by silicon photocells, and the special type of characteristics required by the silicon photo-electric cells.

The basic mode of operation of the moiré fringe system is as follows. Referring to Fig. 19 two diffraction gratings are positioned directly over one another. When a collimated beam of light falls vertically on this system, the transmitted light contains a fringe pattern. Figure 20 illustrates a vertical view very much enlarged of the relative arrangement used with two linear diffraction gratings. The two identical gratings are arranged to be at a slight angle $\theta$ to one another; $\delta l$ is the line spacing. Alongside the representation of the grating lines in Fig. 20, a graphical representation is shown of the manner in which the light intensity varies along the fringe pattern. When the line width is appreciable compared with the spacing a more triangular output is obtained. Lines AB and CD represent the positions of fringes which occur at the minima of light intensity across the fringe pattern. This fringe separation is deter-

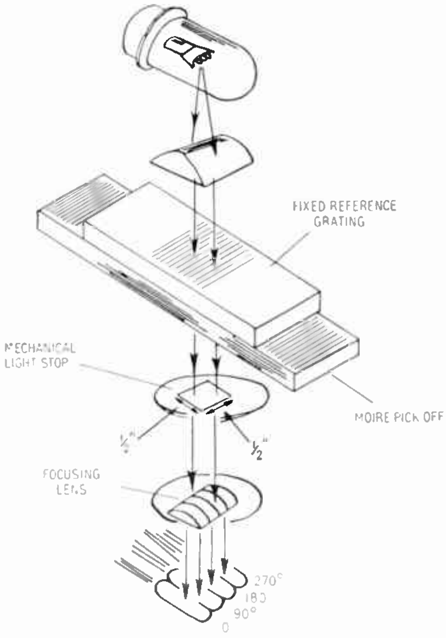


**Fig. 19.** Diagrammatic illustration of the moiré fringe system for machine tool control using silicon photocells.

mined by the value of the angle $\theta$, i.e. the angle at which the lines of the two fringe patterns are set relative to each other. In practice the angle $\theta$ is usually adjusted so that the fringe width is of the order of 0·5 in.

The next fact to realize in understanding the system is that when the diffraction gratings are moved relative to one another through a distance $\delta l$, maintaining the angle $\theta$ constant, the fringe pattern also moves by one fringe width. This means that a mechanical movement of the order of 0·0005 in. of one diffraction grating results in a light pattern 0·5 in. long going through one complete cycle of intensity variation. Again referring to Fig. 20, movement of the grating through a distance $\delta l$ means that the intensity of light at any point along the direction of the grating lines goes through a complete cycle of intensity according to the section ABCDE. The phase angle points such as 0 deg, 90 deg, 180 deg and 270 deg serve to identify the position of any one point in this cycle at any one point of time or total distance moved.

Figure 19 illustrates how the silicon photocell can be utilized with the above optical system to control machine tools. The collimated light beam containing the fringe pattern is passed through a mechanical stop on to a bank of four silicon photocells arranged in line. The cells are small enough to be accommodated in a width of 0·5 in. The angle between the grating is now set so that the centre lines of the four photocells correspond to the 0 deg, 90 deg, 180 deg and 270 deg points in the fringe pattern. By this means therefore one obtains a system where when one grating moves relative to the other, the four photocells generate current outputs which depend on the position of the moving grating. Each of the outputs is 90 deg out phase relative to its neighbour.

Since effective intensities of the order of 100 ft. candles correspond to the peak of this varying illumination intensity at any one point, each cell acts as a source of two current pulses, one negative going and one positive going, each of the order of 30 microamps, for a relative movement of $\delta l$.

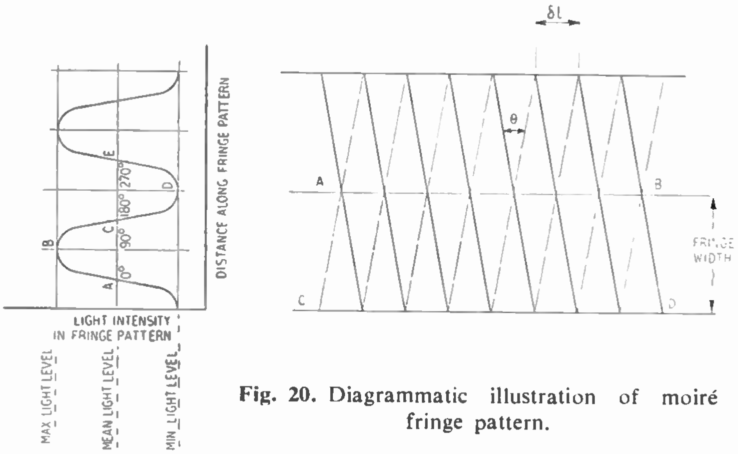


**Fig. 20.** Diagrammatic illustration of moiré fringe pattern.

These pulses can be handled in suitable electronic circuitry now fully transistorized in a manner which enables digital electrical signals representative of (a) the direction of movement of the grating, from a fixed reference point, and (b) the total distance moved from a reference point to an extremely high accuracy to be generated. In controlling machines one grating is attached to the moving part of the machine, generally the worktable, and a fixed reference grating is suitably located on the machine. By this means, systems have been developed whereby the complete movements of machines can be programmed and controlled by electronic computers.

It is clear that rather special silicon photocell characteristics are required for this application. A major requirement is that the cell outputs should be very accurately linearly related to varying light level, and that a high degree of matching in this relationship between light intensity and cell current output for groups of not less than four cells must be available. Also stability of the light intensity cell output relationship under wide conditions of ambient temperature and light intensity are required. A further important requirement is that a constant ratio of the cell output to the light intensity must be maintained even when the load into which the cell operates covers the widely varying range represented by the input of a germanium transistor in the common emitter connection, into which the base current flowing covers the range 5 to 30 microamps.

Silicon photocell development has succeeded in meeting all these requirements. It is perhaps of interest to quote the specification of MS1C silicon photocells. These are specially produced versions involving modified manufacturing and testing procedures of the MS1A cell to which they are identical in geometry.

### *Silicon Photocell MS1C Specification*

(1) With an illumination intensity of 200 ft. candles from a tungsten filament (C.T. 2854) and a load of 500 ohms, the current delivered by the cell should be not less than 45 microamps.

(2) With a load of 2500 ohms and an illumination intensity as specified below, the current delivered by the cell should be not less than 90 per cent. of the current delivered into a 500 ohm load. The illumination for this test may be anywhere between the limits of 200 ft. candles, and that illumination equivalent to a current output of 45 microamps through a 500 ohm load by the test cell.

(3) The cells are to be supplied in matched sets of four, so that the outputs of a group of four cells into a 500 ohm load shall be within ± 5 per cent. for any test illumination in the range of 30 to 200 ft. candles.

### 4.5. *Fast Photo-electric Binary Counter*

The fast response characteristics of silicon photocells and their high stability voltage outputs enables a very fast compact and efficient transistorized electronic counting unit to be constructed. As an example of this we will describe a special demonstration unit shown at the 1960 Physical Society Exhibition in London. This

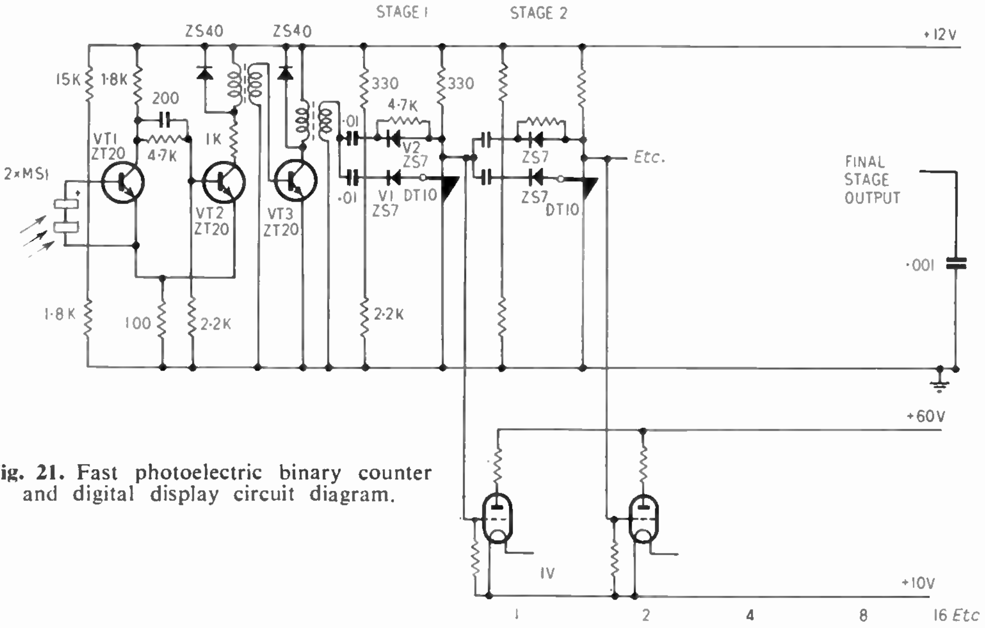


**Fig. 21.** Fast photoelectric binary counter and digital display circuit diagram.

system demonstrated a unit which would detect and present in a total count, according to the binary system, the number of interruptions occurring in the light beam at rates up to 500 kc/s. In the demonstration the number of teeth in a revolving wheel passing a given reference point over a period of time was computed. Many other similar cases with more practical outlets may be envisaged. The circuit makes considerable use of the fast switching components now becoming available. The complete circuit diagram is shown in Fig. 21. Note should be taken of the direct switching of a silicon transistor by two silicon photocells connected in series. This is necessary because of the higher input voltages required in the case of the silicon transistors employed.

Light pulses are applied to two MS1 solar cells connected in series, the resultant positive output pulses being fed into a Schmitt trigger circuit.

With no input, VT2 is conducting and the voltage developed across the common emitter load of 100 ohms holds VT1 in the off condition. When a positive voltage is applied from the solar cells, VT1 collector current starts to increase, with a resultant fall in collector voltage. This in turn causes a fall in base voltage and current of VT2. VT2 collector current decreases, the bias voltage across the common 100-ohm resistor decreases tending to increase the collector current of VT1. This effect avalanches and VT1 is switched rapidly "on" and VT2 switched "off". Thus a rapid change in collector voltage and current of either transistor can be obtained from an input which may be increasing relatively slowly. This change occurs as soon as the solar cell output is sufficient to overcome the standing bias. This condition will last until the light pulse ends when the trigger circuit will switch back to its original state.

A pulse transformer in the collector of VT2 differentiates the square pulse appearing at the collector and the transistor VT3 amplifies only the resultant positive pulses. The fast diodes ZS40 prevent voltage overshoots due to the transformer inductance. Thus sharp negative-going pulses are applied to the first counter stage, by suitable connection of the transformer windings.

On application of the h.t. voltage the *p-n-p-n* switches (DT10) are in the off condition, the 12V h.t. voltage being well below trigger voltage. A small gate current bias is flowing through diode D1 due to the potential divider across the h.t. supply, biasing the gate negative with respect to the positive side of the switch.

Application of a negative pulse causes current to flow through both diodes D1 and D2. The current through D2 causes a small decrease in voltage across the switch due to the series load resistor. The current through D1 is sufficient to increase the total gate current to a value that will fire the switch. The switch changes to its "on" condition and the voltage at the positive side of the switch falls rapidly to approximately zero.

In this "on" state D1 is reverse biased and the application of a second negative pulse has little effect on the gate terminal. This second pulse forward biases diode D2 and the current flowing through the switch is momentarily diverted through D2. When this current through the switch falls below the sustaining value the switch again reverts to the "off" condition. Thus repetitive input pulses switch the *p-n-p-n* sequentially from one state to the other. Due to the bias current the switch voltage is a little below 12V in the "off" condition and approximately 1V in the "on" condition.

Due to the use of diode gates D1 and D2 the circuit responds only to negative-going pulses and thus when stages are connected in cascade Stage 2 will only change condition when Stage 1 switches to the "on" condition. This results in a count down of 2 per stage.

Visual indication can be provided by subminiature voltage indicators (DM160) which light when the grid is at cathode potential and extinguish when the grid is 3 to 4 volts negative to cathode. Thus with the cathode held at +10V when the *p-n-p-n*'s are in the off condition the indicators light and go out when the *p-n-p-n*'s switch on and their voltage falls.

It will be noted that on application of the 12V h.t. all indicators will light and the first applied pulse will switch them off. Thus to find the total count at any instant the indicated value is one less than the true value. This could be overcome by means of a reset switch which would apply an initial pulse before the true count commences.

### 4.6. *Temperature Indication*

Because of their far red and near infra-red sensitivity, silicon photocells can be used in constructing very compact and economical remote temperature measuring devices. They are able to cover the range 350 to 2000°C with appropriate detection arrangements. Their compact, robust construction and high ambient temperature working properties offers many advantages over currently used thermopile and optical pyrometer equipment. It is necessary to ensure correct calibration of the silicon photocell in terms of the spectral distribution of the radiation source being used. A very useful feature of silicon photocells in this application is that larger outputs are obtained than is the case with thermopiles. Coupling of the detector element with associated temperature controlling and indicating instruments is therefore much more economically and easily accomplished.

A current application in this field which may develop is the use of silicon photocells as detectors in control units for use with oil fired boiler systems.

## 5. Conclusions

A survey of the basic theory of silicon photocells has been presented. This survey has deliberately been kept brief in order that the main relationships between the cell characteristics and practical operation of the cells in control and instrumentation applications could be described.

In the final section of the paper we have described the application of silicon photocells in a wide range of control and instrumentation uses. These range from simple relay and light metering systems to complicated computation applications. In all cases we have endeavoured to describe the basic design concepts involved in the applications. In some cases we have included factual design details.

## 6. Acknowledgments

The authors would like to acknowledge with gratitude the contribution of other members of the Semiconductor Research and Development Staff of Ferranti Ltd. whose individual work has contributed to many of the cell developments described and their application. They would also like to thank Mr. R. Vogel of the Ferranti Computer Division, Mr. A. T. Shepherd of the Edinburgh Division and Mr. J. Walker of the Semiconductor Applications Laboratory for contributing details of the TR5 tape reader, automatic machine tool control and binary counting systems respectively.

Thanks are due to Mr. J. R. Pickin, Manager of the Electronics Department, Ferranti Ltd., for permission to present the paper.

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## DISCUSSION

**Mr. J. M. Waddell:** I should like to ask the authors why they chose to operate these photocells in the photo-voltaic mode rather than in the photo-conductive mode. Photo-voltaic cells have advantages in that they require no external power supply and retain their calibration better than do photo-conductive type cells, although this latter is a matter of degree. They therefore find great application in portable instruments for measuring light intensity e.g. exposure meters. For obvious reasons they also provide an ideal source of power in artificial satellites. However, if a silicon junction is operated in the photo-conductive mode very considerable advantages can be obtained merely by adding an external source of power. The current obtained is the same as in the photo-voltaic short circuited case (or it may be increased up to 50 or more times if a photo-transistor is used), and the output voltage is multiplied by anything from 20 to 200 times. The output power is therefore increased by anything from 20 to 4000 times that obtainable from the equivalent area photo-voltaic cell. The authors seem to pay relatively little attention to the use of their photocells without an external supply, and practically all the applications they have described involve a power supply for a subsequent amplifier, an amplifier which probably would not be required if photo-conductive operation has been used, especially if a photo-transistor is employed.

Until recently the only photocells intended for this mode of operation available in this country (either of the diode or the triode variety) were made of germanium, with its inherent temperature limitations, particularly with regard to dark current. It may be that this feature of the existing biased type cell has made them unpopular. If, however, such cells are made from silicon they have the advantages of large power output, high sensitivity, wide temperature range, and low dark current, thus combining the best features of the various types. In particular silicon photo-transistors (which are now available in this country) have a dark current not greatly in excess of that of the corresponding diodes, although their current output under operating conditions is much greater than that of the corresponding diodes. This is because the current gain of the transistor is low for small currents of the order of the dark current (which is in any case low for a silicon device) but rises rapidly as the current increases when the cell is illuminated. Thus the ratio of the light current to the dark current (the important factor in a conductive type cell) is a maximum.

**Dr. Shepherd** (*in reply*): There are certain advantages in operating cells in the photo-voltaic mode even when a voltage supply is used for subsequent amplification. The photo-voltaic mode of operation is inherently more stable than the photo-conductive mode, which is affected much more by less controllable parameters such as surface leakage currents. In addition, the photo-voltaic mode of operation is "fail-safe," in that no output signal is produced in the event of cell failure, whereas if a photo-transistor fails, an output signal is immediately produced for no input signal. Since the photo-voltaic cell is a very simple device, the combination of such a cell with a standard transistor could well be more economic than the use of the more complex and expensive photo-transistor.

**Mr. H. C. Bertoya** (Associate Member): What is the frequency characteristic of the cell? I have in mind an application calling for a cell which responds to a light source modulated at 500 kc/s.

**Dr. Shepherd** (*in reply*): Unless the value of load resistance is considerably lower than $R_{opt}$, the rate of change of output voltage is limited by the cell capacitance. This is of the order of 15,000 pF per cm$^2$.

**Dr. L. R. Baker:** I would like to ask Dr. Shepherd two questions.—Firstly, can the silicon photocell be used in precision photometry? Secondly, what factors limit the sensitivity of the photo-cell to 0·3 microns in the blue end of the spectrum?

**Dr. Shepherd** (*in reply*): The cells should be useful in precision photometry, since the stability of characteristics appears to be much better than that of selenium cells. Because of the low output currents at intensities below about 10 ft candles, it is difficult to use them in this region. It is, however, possible to design special cells for operation at these low light levels. These cells would have somewhat reduced performance at high intensity.

The high frequency cut-off of the cell is determined by the energy step from the bottom of the valence band to the top of the conduction band. For silicon, this leads to a cut-off at about 0·3 microns in the blue end of the spectrum.

**Mr. D. S. Evans:** In the manufacture of high resolution optical digitizers we use Schwarz photoconductive cells, which are about one thousand times more sensitive than the silicon cells. Unfortunately, these and photo-transistor types are temperature sensitive and drift badly. They are therefore best used on an a.c. system using a flash tube such as a neon for illumination.

In digitizers we are having to pack as much light as possible through a 0·010 in. or 0·005 in. slit. In a d.c. system this means almost certainly the use of a filament light source of fairly high intensity. As a result the cells are subjected to both heat from the lamp and ambient temperature. Only the silicon cells so far can remain stable under these conditions and are thus chosen because of their high temperature range, rapid response and uniformity.

I would be interested to know what proportion of the manufactured cells are acceptable and whether the process is fully controlled and predictable. Further, in chopping up a block into sections is any single section likely to become a casualty? Similarly, what degree of uniformity is there over the detecting surface if, for example, a very narrow beam of light is passed over the cell?

Lastly, when shall we see more sensitive silicon cells? It would be interesting to know the authors' views on the possibility of making a silicon photomultiplier. Perhaps, however, one would be just as well off with a single cell and amplifier.

**Dr. Shepherd** (*in reply*): Since the manufacturing process for photo-voltaic cells is a simple one, a high yield of acceptable cells can be obtained. In making multi-element cells it is always of course possible for one or more elements to become a casualty. This, however, is almost invariably due to mechanical processing damage rather than an inherent fault in the cell itself. Somewhat greater sensitivity is usually exhibited in the central area than at the edges of the cell. This can be as great as 20 per cent. difference in short circuit current.

It is of course possible to obtain gain by constructing a photo-transistor type structure in silicon, but these devices are much more sensitive to ambient conditions and are less controllable in manufacture by virtue of the leakage currents encountered in the reverse biased junction.

**Mr. B. L. H. Wilson**: Dr. Prince has pointed out in his paper[4] theoretical reasons (connected with minority carrier diffusion length and majority carrier mobility) for preferring cells made with a diffused $p$-type layer on $n$-type base material for high level operation in the visible part of the spectrum. Is this prediction borne out in practice?

**Dr. Shepherd** (*in reply*): Slightly higher efficiencies have been obtained with $n$-based cells than with $p$-based cells to date. In some cases, for example, multi-element cells, it is an advantage to be able to make cells of either polarity. In solar batteries to be used outside the atmosphere, $p$-based cells also have the advantage of reduced sensitivity to high energy radiation.

**Mr. J. Cunningham-Sands** (Associate Member): Does the silicon photo-voltaic cell suffer from any fatigue effect during or after being subjected to either continuous or intermittent high intensity illumination?

**Dr. Shepherd** (*in reply*): No fatigue effects of the type associated with selenium cells have been discovered with silicon photo-voltaic cells to date.

**Mr. M. L. N. Forrest**: I would like to raise certain practical points concerning the method of specifying the performance of silicon photo-voltaic cells, particularly for their use in data reading applications.

At present a two-part specification seems to be employed. The first part sets the current which a minimum limit cell will provide into a specified load at a specified light level. The second part stipulates that the current from all the cells supplied as a group will have a certain specified spread under the same conditions.

Excluding discussion of the most appropriate load and illumination conditions under which to specify performance there is a fundamental difficulty in that such a specification is essentially open ended at the top limit. This implies at least the necessity to provide a setting-up control common to the group of cells in one piece equipment. In practice the situation may be more difficult than this because of the possible necessity to replace a faulty cell in service with one not from the original group. This leads inevitably to the provision of a separate setting-up control for each cell. Such a situation is considered unsatisfactory. What prospects are there of a specification for these cells having both upper and lower limits so that batching and the use of setting-up controls can be dispensed with? The spread desired on the cell current is relatively narrow because the recording media under consideration, principally punched cards and punched paper tape, have a considerable transparency in the absence of a punching.

**Dr. Shepherd** (*in reply*): Although the present specifications are, as Mr. Forrest points out, essentially open-ended at the top limit, in practice the maximum difference between the lower limit of the specification and the maximum current obtainable with the present technology is quite small. If cells are required with an even smaller spread of characteristics, it is of course possible to supply specially selected cells for particular applications.

# APPLICANTS FOR ELECTION AND TRANSFER

As a result of its October 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.

## Transfer from Associate Member to Member

ELLORY, Frederick Ronald. *Hillingdon, Middlesex.*
KASON, John. *London, N.W.2.*
STEVENS, Gp. Capt. John H., O.B.E., B.Sc., R.A.F. *Henlow, Beds.*
YARDLEY, Frederick Richard. *Malta G.C.*

## Direct Election to Associate Member

GEORGE, Reginald Eric. *Ilford, Essex.*
GIBNEY, Frederick George. *Chelmsford, Essex.*
GOWER, Cdr. Albert Charles Stephen, R.N. *Malta G.C.*
MORLING, Kenneth Frank. *London, N.W.10.*
OAKLEY, Ronald Herbert. *Bourne End, Buckinghamshire.*
SHORT, Ronald Luther, B.Sc. *Portsmouth, Hampshire.*
STONE, Geoffrey Malcolm Cecil. *London, S.E.23.*
TUCK, Archibald, B.Sc. *Greenford, Middlesex.*
WARDEN, Peter William. *Romford, Essex.*
ZARIEFF, Cdr. Mohamed, B.A., R.N. *Karachi.*

## Transfer from Associate to Associate Member

CHILD, Cecil. *Ashtead, Surrey.*
CRIMP, John. *Dartford, Kent.*
REID, Terence Patrick. *Great Bookham, Surrey.*

## Transfer from Graduate to Associate Member

BARCLAY, Leslie William, B.Sc. *Leigh-on-Sea, Essex.*
HARRIS, Ernest Jack. *Greenford, Middlesex.*
HIGGINS, John C., M.A.(Cantab.), M.Sc.(Lond.). *London, N.7.*
HUTCHINS, Wilfred Horace. *Woodbridge, Suffolk.*
JAMES, James Roderick. *Swindon, Wilts.*
JASTRZEMBSKI, Jerzy Andrzej. *London, S.W.19.*
KARTAR SINGH, Capt. Ind. Sigs. *Mhow, India.*
KRAICER, Alec. *London, N.W.3.*
NEWMAN, Henry John. *Great Bookham, Surrey.*
STEELE, Capt. Peter Michael, B.Sc.(Eng.), R. Sigs. *Lechlade, Gloucestershire.*

## Transfer from Student to Associate Member

BRIGHT, Norman Harry. *Stafford.*
FERNANDO, Lt. Cdr. Ira Barry Evertsz, R.Cy.N. *Colombo.*
GARRAD, Terence Victor. *Leatherhead, Surrey.*

## Direct Election to Associate

BISHOP, Frank Roland Gold. *Peterborough, Northampton.*
BLACH, Robert. *Dar Es Salaam, Tanganyika.*
CARTER, Donald John. *Southall, Middlesex.*
GYLES, Anthony Courtier. *Nakuru, Kenya.*
HAWKINS, Alan Joseph. *New Malden, Surrey.*
LEVER, Robert Charles. *London, W.6.*
SWAIN, Reginald William. *Twickenham.*

## Direct Election to Graduate

ACKROYD, Brian Robert. *London, S.W.16.*
AKKA, Ezouri Fuad. *Manchester.*
ASHWORTH, Nevil Dootson, Dip. El. *Rochdale.*
ATKINSON, Geoffrey Harrison. *New Malden, Surrey.*
BALL, Thomas Michael. *London, W.6.*
BARR, William Patrick. *Letchworth, Hertfordshire.*
BOAST, Alan Walter. *London, N.W.9.*
BROWN, Peter Douglas. *Southend-on-Sea.*
BURTON, Royston Alfred. *London, S.W.18.*
CATTLE, Brian. *Reading, Berkshire.*
CUNNINGHAM, Robert Alexander. *Gainsborough, Lincs.*
DREW, Ralph Francis. *London, S.W.14.*
EASON, Ronald Charles. *Stoneleigh, Surrey.*
FAIRCHILD, Victor. *Stevenage, Hertfordshire.*
GEDGE, John Lewis, B.Sc. *Bath, Somerset.*
HATLEY, Derek John. *Farnborough, Hampshire.*
HEATH, Reginald Walter. *London, E.4.*
HICKS, Gordon Graham. *Basingstoke.*
HUDSON, Walter Hilton. *Salford, Lancashire.*
HUGHES, Gwilym. *Llangefni, Anglesey.*
JOHNSON, Michael David. *Frimley, Surrey.*
JONES, David Llewellyn. *Totnes, South Devon.*
KENNY, Ernest Moston. *Newcastle-on-Tyne.*
LEWIS, Henry Norman. *London, N.W.2.*
LOVEDAY, George Christopher. *Westcliff-on-Sea.*
MANGRU, Soney James. *Trinidad, B.W.I.*
MARSH, Colin. *Wigan, Lancashire.*
MARTIN-ROYCE, Robert Dennis. *London, S.E.18.*
MAYNE, Alfred George. *Barnstable, N. Devon.*
MEEK, Neil. *Isleworth, Middlesex.*
*MILLS, Jacob Lamquaye, B.Sc.(Hons.). *Accra.*
MORGAN, Harold Ramsay Victor. *London, S.E.9.*
PAGE, Donald Stephen. *Timperley, Cheshire.*
PAYNE, Robert William. *Hayes, Middlesex.*
PHILPOTT, Michael James. *St. Paul's Cray, Kent.*
RICHMOND, Michael. *Witham, Essex.*
ROBINS, Michael John. *Cheltenham, Gloucestershire.*
ROBINSON, Alan John. *Malvern, Worcestershire.*
ROOKS, Leslie David. *Cambridge.*
SMITH, Frank Bernard, B.Sc. *Wigan.*
SQUIBB, Sidney Leonard. *Orpington, Kent.*
THOMAS, Clive Corbet. *Hamble, Hampshire.*
WADE, John. *Harlow, Essex.*
WARD, James Trevor. *Weston-Super-Mare.*
WHEELER, Rodney Edward. *Erith, Kent.*
WOOD, Clive Allan. *London, S.E.9.*
WOTHERSPOON, Ronald R. *Old Coulsdon, Surrey.*
*ZAHEDY, Javad. *Ilford, Essex.*

## Transfer from Associate to Graduate

LETT, William Frederick. *Malvern Link, Worcs.*

## Transfer from Student to Graduate

ALLINSON, Peter Michael. *Chelmsford, Essex.*
BARNETT, Christopher Frank. *Chelmsford, Essex.*
BHAT, Manohar Ganesh, B.Sc. *Bombay.*
BLYTH, John Robert Davison. *Colchester.*
BOCKING, Colin Stanley. *Colchester.*
BREARLEY, Harry. *Pudsey, Yorks.*
BREARLEY, Malcolm. *Pudsey, Yorks.*
CHAN, Peter Kiu. *San Francisco.*
CHAN, Tai-Yuen. *Harlow, Essex.*
DEAKIN, William John. *Newport, Mon.*
DILLIWAY, Roy Pinder. *Tadley, Hampshire.*
FORD, Hugh Dermot. *London, W.4.*
FULLICK, Peter Ernest. *London, E.6.*
HALPIN, Robert Joseph. *London, N.8.*
HIND, Robert William. *London, E.12.*
HOOTON, Arthur. *Surbiton, Surrey.*
JOHN, Kannampuzha Pavanny, B.Sc. *Trichur, India.*
JOYCE, Arthur. *Kingsbridge, S. Devon.*
LEVELL, Roy William. *Bournemouth.*
MAY, David Harold. *Plymouth.*
NARAYANA MENON, Pottekkat. *Bangalore.*
SANDERS, Thomas Gerald. *Malvern, Worcestershire.*
SOUTHWELL, Capt. Barry, R.E.M.E. *Reading.*
STEVENS, Colin Leonard. *Ilford, Essex.*
VASUDEVAN, V. *Kanpur, India.*

# STUDENTSHIP REGISTRATIONS

The names of 70 students registered at the October meeting of the Committee will be published later.

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* Reinstatements.

# Training for Operating and Maintaining Television Studio Broadcasting Equipment †

*by*

K. R. STURLEY, PH.D., B.SC. ‡ and A. E. ROBERTSON, B.SC. §

*A paper read before a meeting of the Institution in London on 27th January 1960.*

*In the Chair :* Mr. V. J. Cooper, B.Sc.(Eng.) (*Member*).

**Summary :** The B.B.C.'s pioneering work in the training of staff for operating and maintaining television studio equipment is described. A general discussion on training policy and recruitment is followed by an outline of the training schedule and training techniques. A detailed survey is given of the methods used for training technical assistants and technical operators in the B.B.C. Television Service. The standard which must be reached by the new recruit if he is to continue in the Corporation's service is indicated, and courses provided for technical assistants and operators worthy of promotion are described.

## 1. Introduction

During the last war the B.B.C. lost a considerable number of its skilled technical staff to the armed services and these had to be replaced by relatively unskilled people, who required training before they could be used to operate or maintain broadcasting equipment. Early *ad hoc* training arrangements were co-ordinated in 1941 into a Training Section, which at the end of the war was converted into a Training Department, centralized in residential accommodation at Wood Norton Hall, near Evesham. At first staff were only trained in sound broadcasting techniques but soon after the B.B.C. public television service was reopened in 1946 it became clear that additional staff would have to be trained for television. Plans for technical training in television were formulated in 1946 and the first courses began in 1947. The early recruits to television came from the Sound Service so that the Training Department could assume that their students would have a basic knowledge of sound broadcasting technique and would only require to learn the fundamentals of television and the general principles of its techniques. It was not possible at that time to give practical experience on a complete camera channel for these were in short supply and could not be released for training purposes. Lectures were supplemented by laboratory work on such parts of a camera channel as could easily be constructed, for example, video frequency amplifiers, synchronizing-pulse generators, etc. The main object of this conversion course was to produce staff who could service rather than operate the equipment, and it was not until 1952 that planning for operational training was initiated, and culminated in 1954 in the first technical operators' course in television. It is symptomatic of the steady growth of television training that the Department dealt with a total of 200 students, all intended for the Sound Service, in its first full year of operation (1946), whereas last year (1959) 716 students, of whom 335 were for television studio work, passed through its hands.

The B.B.C. Training Department is responsible for all technical staff training, which it provides at five levels: new entry, promotion (after about four years' service), conversion (sound to television), refresher (bringing up-to-date) and

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U.D.C. No. 621.397:654.197:371.3

specialist (f.m. transmission, colour television, etc.). This paper will however concern itself only with the technical training of television staff at two levels, namely new recruits and promotion. Training and recruitment policy will first be considered, then follows a discussion of the general principles and techniques of training, and finally a detailed survey is given of the syllabuses and methods used in the training of staff to operate and maintain television studio broadcasting equipment. Staff are also trained for operating and maintaining television transmitter equipment but this type of training is not considered here.

## 2. Training Policy

The aims of any training department can generally be defined as:

(1) To improve the efficiency of the individual and the organization.
(2) To avoid the wastage of trial-and-error learning.
(3) To overcome resistance to new ideas.

Since maintenance work is essentially an individual contribution, the importance to the organization of high individual efficiency is obvious. In operational work team efficiency is all important and the individual must not only develop his own skill but must be encouraged to co-operate with others and to appreciate how his own actions can influence those of the other team members.

The value of the second aim needs little emphasis. Trial-and-error learning on the job is quite unacceptable in broadcasting since mistakes may completely ruin the artistic effect towards which a producer is striving. If trial-and-error methods are unsuccessful they generally produce bad habits that are difficult to eradicate later or when successful encourage secretiveness about the hard-won technique. One of the tasks of an operational training section is to be on the lookout for improvements in technique and to see that the new knowledge is spread over as large a number of students as possible.

The third aim is very important in an organization like the B.B.C. which is constantly seeking for and testing new ideas in presentation, such as inlay-overlay and magnetic tape video recording and reproduction.

## 3. Recruitment

Training must be closely associated with recruitment policy and this is secured in the B.B.C. Engineering Division by a close liaison between the Training Department and the Establishment Department, which actually undertakes recruitment. In addition senior training staff attend recruitment boards to check the technical standards and general suitability of new recruits. The board must try to judge the potentialities of a candidate because one who reaches the limits of his capacity in the early stages of his career is likely to become an establishment problem when changes of technique require staff to be retrained. Even when techniques are relatively static, age may early take its toll and make such staff a liability.

It has been found readily possible in the majority of applicants to distinguish between the technical operator and technical assistant (maintainer) type. The characteristics of a good technical operator are a satisfactory personality, an interest in people, some artistic appreciation particularly of television production, a good memory for procedure and quick reactions to an emergency.

It is less necessary for the technical assistant to be a good mixer, but he should have a satisfactory personality. He should be able to work on his own, and be capable of logical analysis as well as of acquiring skill with basic hand tools and soldering. He should possess a better initial technical knowledge than the operator but in either case, provided the minimum of technical knowledge is shown, personality and teachability are ranked higher than present technical knowledge at a recruitment board.

A recruitment board generally consists of a half-hour's interview during which general and technical questions are put to the candidate to discover his interests and his present technical knowledge.

The technical operator is expected to have some knowledge of simultaneous and quadratic equations, logarithms, and trigonometrical functions as well as simple electrical theory such as Ohm's law. He should have some interest in broadcasting programme material with (possibly) photography or high fidelity reproduction as a hobby. His background understanding of his hobby is usually explored and his reactions to current affairs are noted.

The technical assistant is required to have a wider and deeper technical knowledge particularly in electronics, and he should know what valves and transformers can do, and what reactance means. He, too, is expected to show a lively interest in current affairs, and sound and television broadcasting. The recruitment board awards marks under four main headings of:

(i) qualifications (G.C.E., City and Guilds Certificate, or Ordinary National Certificate),
(ii) experience (relevant to the work done in broadcasting),
(iii) technical ability (how he answers the questions put by the Training Department representative), and
(iv) personality.

To be acceptable a candidate must score an overall total of 50 per cent. but any serious failure in personality would outweigh high scoring under the other headings. The recruitment board is briefed on where vacancies exist and so far as possible candidates are chosen with these requirements in mind. Any expressed preferences are noted and, when possible, fulfilled. No recruiting procedure however well organized can be infallible and a comprehensive quarterly reporting system has been instituted during the recruit's first year in order to bring to light square pegs in round holes. The main headings of the report include personality, cooperativeness, general progress, application and practical skill. When failure is due to unsatisfactory personal traits or to technical incompetence termination follows if transfer to other work is not expected to produce any improvement.

As long as National Service continued the B.B.C. was able to recruit almost all the technical staff it required from those who had served in the technical branches of the armed forces and the average age of recruits was about 21. With the cessation of national service the B.B.C. has necessarily had to reconsider its minimum age of entry and this has been lowered to 18 years of age. Shift working, the high sense of responsibility which must be shown by staff working anywhere in the broadcasting chain, and the complexity of the technical and operational problems, have precluded recruitment at an earlier age or with lower qualifications than G.C.E. at advanced level in Mathematics or General Science. Recruitment boards take a different form because technical knowledge cannot be very great and educational standards are fixed by the G.C.E. qualification.

## 4. The Training Schedule

All new recruits are first given a three-day induction course, during which information is presented on B.B.C. organization, with particular reference to the Engineering Division, and conducted tours are made of studios and recording centres in London. They are then posted to the Lime Grove Studios, to the television Outside Broadcasting Department at Wembley or to a regional centre, and for the next three months the engineer-in-charge is responsible for introducing them to the broadcasting system and for trying them out on the more elementary and routine tasks. He then has to fill in a comprehensive report which is a preliminary assessment of the new recruit's probable usefulness in the operating or maintenance field. The next stage is a new entry course of 14 weeks' duration at Wood Norton. Particulars of the instruction given to the technical operator and to the technical assistant are outlined in Sections 7 and 8. A practical and written examination is given at the end of the 14 weeks' training and an overall pass standard must be reached. Each case of failure is carefully considered in conjunction with reports on class and laboratory work from about four lecturers or assistant lecturers who have been most closely associated with the particular student. If no extenuating circumstances come to light a recommendation for termination is made.

Successful completion of the course is followed by a final six months' "polishing" period during which the recruit is widening his experience and gradually accepting his full share of the load.

The responsibility of the organization does not cease when the member of staff has been launched on his career, and after an adequate period of practical experience (from 2½ to 4 years), and aided possibly by private or organized study, he can apply for a 14 weeks' promotion course, which aims at further increasing technical and practical competence in his own field. Candidates in operations or maintenance work are required to satisfy a selection board, consisting of a representative from Training Department and one from Establishment Department. that they are ready to undertake the promotion course. Operators are asked a series of questions on operational problems and the principles of lighting; emphasis is placed on technical knowledge with the maintenance man who is expected to reach a standard about equal to the City and Guilds Intermediate Certificate (pre-1958) in Telecommunications. A special correspondence course has been organized to bring technical assistants up to this standard because shift working makes attendance at a technical college normally very difficult.

Developments in television techniques are constantly occurring and provision is made for senior staff to return to the Training Department for refresher or specialist courses. These are generally of short duration ranging from 1 to 2 weeks.

## 5. Training Technique

Even with ideal recruitment conditions a fairly wide variation in the standards of a given class is to be expected and the problem is to bring the average to a satisfactory standard while permitting the below-average to progress as far as their capacity allows and the above-average to "stretch" themselves. This requires a strict adherence to the lecture pattern but permits latitude in laboratory work and tutorial. The "end-product" must always be kept in mind; in broadcasting it is an artistic production and the work of all staff must be directed to helping the producer achieve the results he desires. The operator's role in this is obvious but the technical assistant could, by shoddy repair or failure to clear a fault completely, also ruin the artistic effect. Both types of staff need to realize that interpretation is by means of the eye and ear and in any conflict between objective measurement and subjective sensation, the latter must be the deciding factor.

However specialized a course may be there will be fundamental principles on which it rests, and a decision must be taken whether to deal with principles before specialized applications or whether to deal with them as the need arises. From a teaching point of view there are advantages in the second method but its application may be uneconomic. Thus a new recruit to sound or television studios for transmitters requires to know certain fundamental principles which are common to all three specialized activities and they can be dealt with most economically by providing a common course for all such students. This common course has the psychological advantage that it helps to impress their interdependence on members who are part of the same team. The B.B.C. Engineering Training Department divides new recruit and promotion courses into two almost equal parts, and during the first part, dealing with fundamentals, all students work together. In addition to other advantages this preserves a steadier load on the departmental staff because when new recruits are in Part I of their course, promotion staff are in Part II and vice versa.

Mornings are normally given over to lectures and afternoons to practical work in laboratories or workshop, or to exercise classes and tutorials. A subject taking the whole of one morning is divided into three almost equal parts of an hour's duration with a break of at least five minutes between each. The first 20 minutes of every morning is given over to a question period by the previous day's lecturer. This enables him to check the success of his lecturing and also gives the student an indication of the important features of the previous day's work. The problem of recording the information given in lectures is not easy to solve; duplicated notes are of value for senior staff on short courses and are useful when descriptions of apparatus are involved. Their indiscriminate use can encourage a high speed of lecturing and insufficient consolidation. A satisfactory compromise is for the lecture to be divided into convenient sections which, after thorough discussion, are committed to the blackboard in concise note form. The act of writing is good for the lecturer because it aids orderliness and lucidity, and also for the student because it slows up the flow of new ideas and helps to fix the discussion in the student's mind. Copies of complicated diagrams are provided for each student.

Even though the mathematical standard of the technical assistant is generally superior to that of the operator, it is well below that of the professional engineer, and pictorial presentation must play a greater part than mathematical analysis. The development of demonstration apparatus is an important part of the Training Department's work.

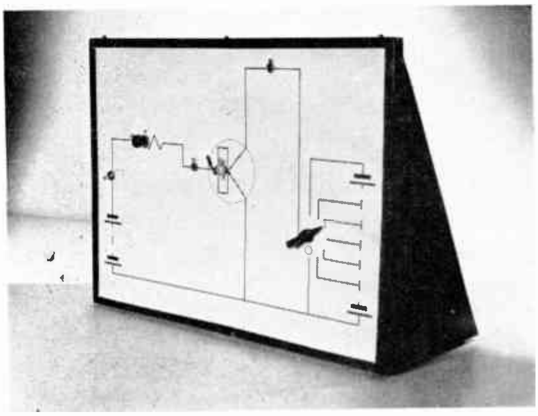

**Fig. 1.** A demonstration board for transistor characteristics.

Figure 1 shows an example of relatively simple equipment for demonstrating transistor characteristics whereas Fig. 2 gives the block diagram of more complicated apparatus that has been constructed for displaying the effect of noise, interference, distortion and changes of gamma on television pictures. The vision signal is derived either from a vidicon camera (2) or a step-wedge generator (5), and it is passed through a distortion/interference unit (6) before being finally viewed on picture monitors. Altogether the equipment comprises 13 units made up as follows:

(1) Oscilloscope for displaying the vision signal waveforms in front of the vidicon camera, X deflection being obtained from (8) and Y from (6).

(2) Vidicon camera for viewing
  (a) Oscilloscope (1)
  (b) Test Card C
  or (c) Scene.

(3) Camera control unit supplying basic waveforms to vidicon from synchronizing pulse generator (4) and processing the vidicon output for transmission to the switching unit (7).

(4) Synchronizing pulse generator supplying control signals to the camera control unit (3), the step-wedge generator (5), and the sawtooth generator (8), and driven either from its internal master oscillator (free-running or locked to the 50 c/s mains) or from twice line frequency derived from the sub-carrier oscillator (10).

(5) Step-wedge generator providing a variable number of steps when driven by an internal multivibrator locked to line frequency, or eight steps when driven from (10).

(6) Unit containing distorting networks giving low or high frequency attenuation, clamp or d.c. restorer, three circuits of high, normal and low gamma, interference and noise mixer, and a synchronizing pulse amplitude control. The desired type of distortion or interference is selected by operation of a switch on the front panel.

(7) Source and output switching unit connecting step-wedge or camera output direct or through (6) to the distribution amplifier (12) for the picture monitors.

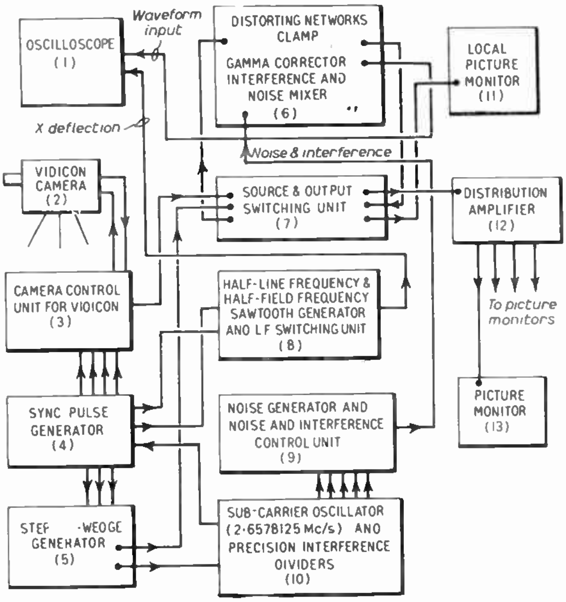

**Fig. 2.** Block diagram of equipment used for displaying noise, interference, distortion and gamma changes on television pictures.

(8) Sawtooth generator synchronized to half-line or half-field frequency to provide the X deflection for oscilloscope (1). This allows the waveform of two lines or two fields to be displayed.

(9) Noise generator with frequency spectrum and level control, and also selector for interference from sub-carrier oscillator (10) and hum.

(10) Sub-carrier crystal oscillator and dividers to show the effect of incorrect colour sub-carrier frequency and of off-set carriers with co-channel transmission. Outputs are provided to the synchronizing pulse generator (4) and step-wedge generator (5) for locking of line frequency to the sub-carrier.

(11) Local picture monitor to assist demonstrator.

(12) Distribution amplifier to (13).

(13) Picture monitors distributed round the classroom.

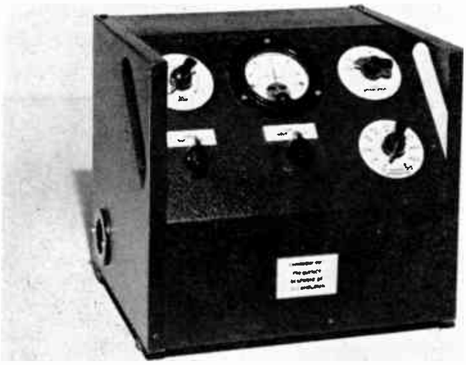

Fig. 3. A standard chassis.

In the laboratory students work in pairs except when they have to produce a mock programme. The ideal organization would keep laboratory work in step with lectures and this is approached in Part I but is not realizable in Part II because expensive manufactured apparatus is involved. In the early stages of practical operational training, confidence and skill must be built up gradually and a complicated procedure needs to be broken down into a number of smaller self-contained procedures. In order to save time students are given loose-leaf sheets of instructions which can be inserted in their laboratory notebooks. For Part I laboratory units are small and self-contained; in their standard chassis (Fig. 3) they are easily inspected and as well-finished as the manufactured products used in Part II. Exercise classes and tutorials, which occupy about one-third of the available afternoons, are used to give practice in handling simple calculations and to increase an appreciation of circuit values for amplifiers, meter shunts, etc. An occasional timed question and descriptive question are inserted to give practice in examination technique.

### 6. Training Staff Organization

The Training Department is organized into three instructional sections, each in charge of a senior lecturer who is entirely responsible for the work of his section, for the reporting procedure on students, and for the setting of examination questions, moderated by the head and assistant head of the department. The three sections deal with fundamentals, maintenance and operations. The staff/student ratio is 1 to 30 for lectures, and normally 1 to 10 for laboratory and tutorial work, but for certain types of work, e.g. complete camera channel operation or maintenance, it falls to 1 to 6. Laboratory technicians are used for servicing and setting-out (when necessary) the apparatus and for building demonstration equipment.

### 7. Television Technical Assistant Training

#### 7.1. *The Training Schedule for the New Recruit*

The essential differences between the new entry and promotion courses will be evident from the two syllabuses given in Appendices 1(a) and 2(a). The new entry course is introductory, giving the fundamentals of television and providing the student with sufficient background knowledge and experience to be able to carry out correctly the setting-up procedure and routine maintenance tests. He should be able to diagnose and repair the simple faults. The promotion course, on the other hand, gives a more detailed insight into circuitry, helps to develop rapid and accurate fault-finding and fault clearance, and encourages the student to display a responsible attitude so that eventually he can be trusted to supervise others.

Referring to the Part I new entry syllabus it will be seen that general workshop practice and safety measures have early place in the lectures. Both are backed up by practical work; time in the workshop is limited to five afternoons and no more than a basic skill in soldering and the handling of simple tools can be instilled. Additional experience is gained because in the laboratory all students must wire a simple amplifier and power supply, which are then tested for gain and regulation. The department also runs some specialized six-week Workshop courses for selected candidates. The Holger-Nielson method of resuscitation is taught and all students have to practise on a "live" body under supervision before they complete the course. Part I is of necessity general because it is taken by all types of technical assistant.

The right and wrong uses of instruments and the effect of source internal resistance are shown in laboratory experiments, and the possibilities of the television technician's most important tool, the cathode-ray oscilloscope, are fully explored. Tests on charge and discharge circuits introduce the subject of television waveforms, and impedance and valve characteristics are studied and measured. Figure 4 shows an amplifier with component values that can be switched so that the student can easily study their effect.

The syllabus for Part II starts where Part I leaves off and extends television fundamentals to consider the whole chain and vestigial-side-band transmission. The significance of the d.c. component and its preservation are followed by a discussion of the types of distortion that can affect vision signals. After a descriptive treatment of video amplifiers there is a series of introductory lectures on fault location, the type of question to put, and on how to interpret the information obtained. Then begins a survey of the television broadcasting chain from the optical system through the camera, synchronizing-pulse generator and mixer to the monitor. Block diagrams are used to teach the student what a piece of apparatus does rather than how it does it. The procedures for routine maintenance tests on camera channels precede explanatory lectures on telecine, telerecording, inlay and overlay and the action of lines carrying video signals.

The practical work deals with pulse amplitude and duration measurements using a cathode-ray oscilloscope designed for this work, with video amplifiers and pulse generators containing simple faults, with component and input and output impedance measurements, and with setting-up procedure on image-orthicon and vidicon camera channels.

The final week is devoted to practical tests and also to revision in preparation for a written paper of three hours' duration requiring two questions on Part I and three questions on Part II to be answered. Three practical tests, each of approximately 20 minutes' duration, have to be undertaken. Marks are deducted when the set time is exceeded and when adjustments are made in random fashion or scales misread. Another cause of lost marks is a lack of regard for personal safety or a lack of care in handling the equipment. One test involves fault-finding and correction on, for example, a video amplifier with unbalanced input and balanced output; the faults, generally four in number, vary from blown fuses to faulty components. Expertise in the use of the cathode-ray oscilloscope for the measurement of amplitude, frequency and rise-time, and for displaying a single line of the video signal is also tested. All students must show that they can set-up a camera channel to obtain a satisfactory picture and a check is made to see that they deal logically with the controls,

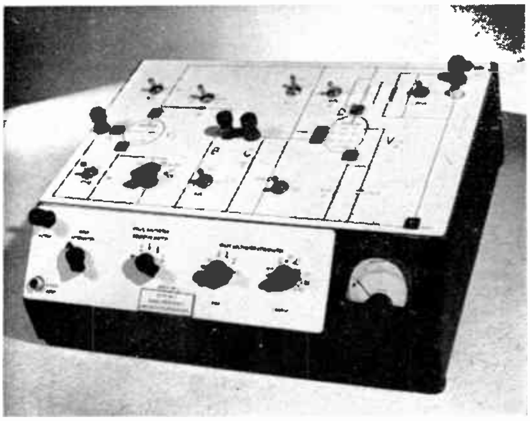

**Fig. 4.** A two-stage amplifier with switched components.

observe the safety precautions and are able to explain satisfactorily their actions.

Over the past five years the number of Probationary Technical Assistants trained for television is 360, of whom about five per cent. have failed in the examination.

Though the successful candidate may be regarded as trained at the end of his new-entry course, he has yet to gain further experience on the job before he can be regarded as fully conversant with all his duties and able to deal effectively with possible technical emergencies. During the next six months he is gradually bringing himself up to full proficiency in the post in which he will eventually be confirmed as an established member of staff.

### 7.2. *The Promotion Course for Technical Assistants*

As indicated in Section 4, a technical assistant is given an opportunity of acquiring the technical background essential for promotion after he has satisfactorily completed about four years' service. Technical knowledge will have to be accompanied by an ability to supervise the work of others, and for the higher posts a capacity for leadership must be shown. These characteristics cannot be taught but rather have to be cultivated, and attempts are made in the laboratory and tutorial periods of the promotion course to present the student with alternative choices and situations in which discrimination, judgement and initiative must be exercized.

The syllabuses for the fundamental Part I and specialized Part II of the course are given in Appendix 2(a). It will be noted that Part I is not merely an extension of the new entry course; there is a gap which must be filled in by the candidate with the aid of a correspondence or technical college course. The selection board must be satisfied that this has been done before he is accepted. A good knowledge of methods for representing alternating voltages and currents by vectors, j notation and polar notation is expected, and some familiarity with calculus is looked for. The candidate is also questioned on coupled-circuit theory, valve parameters and non-linear operation. Some revision of these subjects is carried out in Part I of the course and in addition the student is given insight into methods of solution for the specialized problems he will meet in Part II. Exercise classes involving calculations on typical active and passive networks are held and tutorials are used to strengthen the weakpoints in his technical armoury.

The laboratory experiments follow the general headings of the lectures, i.e. there are experiments to illustrate the network theorems, resonance conditions, etc., and valve input damping (including that due to the diode detector) is explored. The frequency response of amplifiers and the pass and attenuation characteristics of filters are measured and calculated, and the effect of negative feedback is studied. The behaviour of pulse generators and of transistor amplifiers is also examined.

Part II starts with a general revision of television principles and passes quickly to a detailed study of the essential components of a television system, e.g. d.c. restoration and clamping, video amplifier characteristics and gamma control. A short review of lighting problems and terminology are included because the maintenance technician must be able to confer with the lighting specialist, whose work can be so affected by the initial setting-up of the camera channel. The survey of the television broadcast chain follows the same general pattern as that for the new entry course but it goes into much greater detail, circuit diagrams and performance being closely analysed rather than qualitatively studied as in the earlier course.

The laboratory work allows a full practical examination of the component parts of the television channel, such as master oscillator and dividers, synchronizing-pulse generator, line and field scan amplifiers, delay networks, distribution amplifiers, and stabilized power supplies. Practice is given in the setting-up and routine maintenance procedure for all types of camera channel used by the B.B.C. and this is followed by fault location and correction. The associated exercise class helps the student to acquire examination technique.

The course finishes with two three-hour written papers, one concerned with Part I and the other with Part II. A choice of five questions out of eight is given and both papers are arranged to devote about 50 per cent. to calculation and 50 per cent. to description. Attempts are made to frame the descriptive questions in such a way that the student with a good memory gains little advantage, and the maximum mark for each part of a question is indicated so as to encourage the student to show discrimination in the way he distributes his time.

As would be expected of a promotion course, the failure rate amongst the 320 students accepted over the past five years has been relatively high at about 25 per cent.

## 8. Television Technical Operator Training

### 8.1. *The Training Schedule for the New Recruit*

The technical operator functions as a member of a highly organized and integrated team whose diverse skills are directed towards the production of a programme. Thus programme sense as well as operational ability is essential in a technical operator if he is to prove a worthwhile member of the team. Hence his initial training must emphasize both aspects and be as broadly based as possible, covering broadcasting techniques in sound and vision and introducing him to the artistic as well as operational aspects of programme presentation.

Although the technical operator has some knowledge of mathematics and electrical theory, he lacks the technical vocabulary and background of the technical assistant, and the five-week Part I course has to be devoted to making good this deficiency. The syllabus (Appendix 1(b)) bears some resemblance to that for the probationary technical assistant (it is placed in the same appendix to facilitate comparison) but the treatment of subjects that are listed in both is completely different. Thus engineering detail is suppressed in favour of a general understanding of the television system and its strength and weaknesses as a presentation medium. Of the subjects not common to both syllabuses, sound and optics are the most important because the microphone and lens are the starting points in the television chain; the technical operator must have an adequate understanding of both, and further work on optics is continued in Part II.

Maximum opportunity must be given to acquiring experience in the handling of a wide variety of equipment in order to increase manual dexterity and to encourage co-ordination between hand, eye and ear. The ratio of practical work to lecture instruction is therefore maintained at about 60 to 40 throughout the course, and during Part I two weeks are devoted to simple electronics experiments and three weeks to photometry and sound.

The syllabus for Part II, which lasts nine weeks, is also given in Appendix 1(b). The coverage of the syllabus has to be wide because the operator may be engaged in sound or vision control, and in order to perform satisfactorily as a member of a team he should know something of the work of those engaged in other parts of the vision chain such as lighting, telecine, telerecording and also of those engaged in the distribution of the associated sound programme via the Sound Service Network. Pictorial composition and lighting occur early in the syllabus because they are the corner stones of television technique. Time does not allow treatment in the traditional way and the subjects are explored in an analytical manner, which brings out the general principles of artistic appeal. Lack of television experience on the part of the new recruit makes the discussion of production techniques of little value and this subject is reserved for the more advanced promotion course. When dealing with apparatus, block diagrams are extensively used and if more detail is required emphasis is on the operational controls and their effect on picture or sound quality. Experience in training operators shows that it is occasionally necessary to proceed beyond the block diagram and seek a more detailed understanding of how the controls perform. Care is exercised to see that this engineering aspect is not over-stressed. In the section of the syllabus devoted to sound, the basic principles upon which microphones depend are examined and the factors which affect directivity pattern are discussed.

The practical work in Part II is partly directed to discovering the student's ability in the operational field and partly to giving him practice in handling the controls of apparatus he will later use. Most recruits to technical operations show some signs of artistic appreciation and ability, and given training and opportunity they can produce a picture that is balanced, well-composed and pleasing, i.e. they can be-

Fig. 5. Registering light and shade due to the key-light.

come competent craftsmen. Only a few possess an innate perception for form and balance, and sufficient freedom is given in the practical work to allow these potentially-valuable recruits to demonstrate their creative capabilities. The kind of artistic training given is illustrated in Figs. 5 and 6. Figure 5 shows the student sketching in the patterns of light and shade on an illuminated model head; he is able to move the key-light source to different positions and study its effect on the face. The outlines of the head and face are indicated on the sheet and only the shading has to be performed. This trains the student in making full use of his eyes. The next two illustrations (Fig. 6(a) and (b)) show how experience is gained in studio problems with the aid of a model set. Figure 6(a) shows the initial stages of the special effects lighting with the lamps in position and Fig. 6(b) is a photograph of the model set when the lighting has been completed. From this the students graduate to work on full-scale sets using television cameras and in Fig. 7 students are at work on two television sets in the Training Department's television studio. The subject in the right-hand corner is supposed to be in a dimly-lit hut having unplastered brickwork. A simple lighting control console can be seen at his right and is not visible to the camera in the foreground. A lighting unit is placed on the floor to give some idea of rigging problems. Two students, one measuring light intensity and the other adjusting one of the lights, are preparing the second set. The second camera seen in Fig. 7 is of the two-man type, and a student acts as the dolly operator when it is in full operational use. Since no programme responsibilities are involved the students can be allowed to carry through the engineering line-up procedure and after achieving a good picture can observe the effects of incorrect control settings. This leads to a better understanding of the equipment and contributes to a closer liaison between technical assistant and operator. Practical work is performed on the directivity patterns of microphones using "dead" room and duct techniques. and opportunity is given for the acoustic

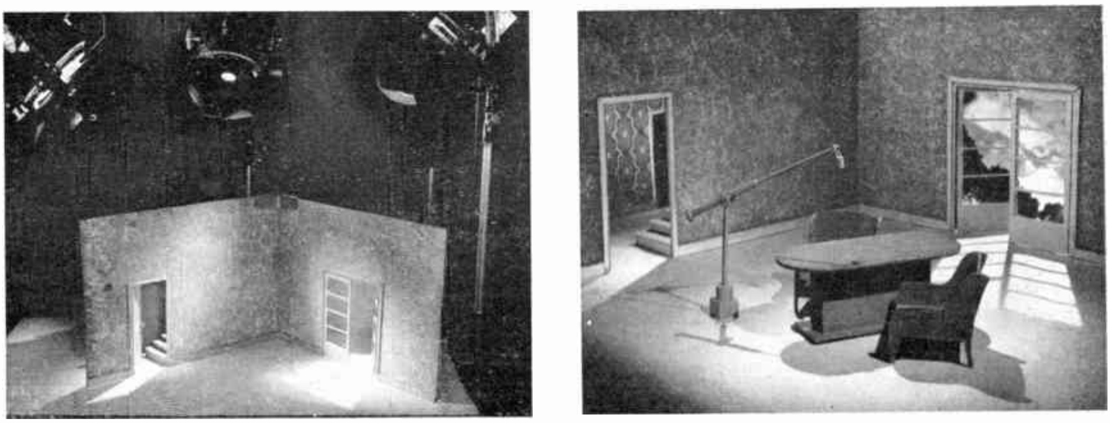

Fig. 6. (a) Special lighting for a model set. (b) The model set after lighting has been completed.

treatment of a small studio using tape recordings to demonstrate progress.

The technical operator, like the technical assistant, must face a practical test and written paper, in both of which he must be successful if his appointment is to be confirmed. The written paper is of two hours' duration with two out of three questions on Part I and four out of six questions on Part II to be answered. The practical tests usually last a little over the hour and may involve the correction of bad lighting on a television set, the setting-up of a camera channel whose controls have been misaligned, the construction of an optical system such as a telephoto lens and simple editing of a magnetic tape recording.

This course is a relatively new one and 99 students have been accepted since the beginning of 1958; four per cent. have failed to reach the required standard.

### 8.2. *The Promotion Course for Technical Operators*

The purpose of the promotion course is to fit the technical operator for taking charge of a special section of the operating crew, as lighting supervisor, vision control supervisor, or sound control supervisor, and eventually as Technical Operations Manager, for directing the activities of the whole crew. Because the operator's day-to-day work makes many demands on his attention, he rarely has sufficient time for keeping abreast of developments in his own field and has even fewer opportunities of knowing about developments in overall crew technique. The course tries to correct this by giving him time to look more critically at his own contribution as well as by introducing him to the work of others in the operational crew, thus giving him a better understanding of the overall production problem and enhancing his chance of promotion.

The duration of the course is 12 weeks and it is divided into two parts, one, five weeks long, dealing with fundamental principles, and the other (seven weeks) with techniques. The syllabuses for both parts are given in Appendix 2(b). Part I syllabus is an extension of the probationary technical operator's syllabus (Appendix 1(b)) and of necessity a proportion of the time has to be spent on revision. It will be noted that Part I is given a marked practical slant; for example, the section on optics is leading towards a full understanding of the action of the lens types used in television, and in general electrical theory the microphone is treated as a source of e.m.f.

The laboratory work preserves this same bias and includes the construction of a telephoto lens from its constituent parts, lighting measurements using standard light meters and the S.E.I. photometer, and distortion measurements on valve amplifiers.

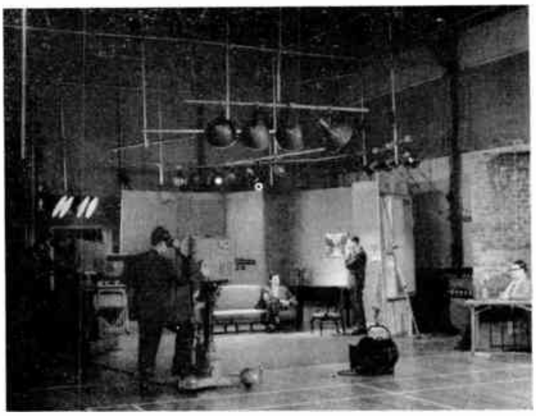

**Fig. 7.** The television training studio.

The syllabus for Part II shows that it is divided according to the three categories of staff making up the production crew, and its aim is to extend the student's knowledge and to provide him with opportunities of practical experience in the part of the operational field with which he is less familiar. In the new-entry course only the basic principles of lighting are studied but in the promotion course they are directly related to the contrast ratio and gamma of the camera tube, the colour and reflectivity of the scenery, and the position and movement of camera and microphone. Lighting plots are analysed and lighting control systems discussed. Similarly vision control involves a close study of the variations in technique demanded by the available types of camera tube applied to the very different problems created by the studio production as compared with the outside broadcast. Under the section concerned with sound control, the acoustic problems of the television studios and methods of providing artificial reverberation are discussed. Microphones and the control equipment are given detailed consideration from an operational point of view, with special reference to balance techniques with dance bands and light orchestras.

A particular feature of the course is the use of guest lecturers from the production side to discuss their problems in drama and light entertainment in relation to the work of the technical operator. Directors, producers, scene designers and staff in make-up and wardrobe all contribute.

The practical work is sectionalized in the same way as the lectures. Thus for lighting there is a series of experiments of gradually increasing complexity starting from simple facial shots and progressing to full-scale sets. Later the student is expected to plan the lighting and prepare a plot for a specific lighting level and contrast ratio before the scene is actually set up. Initially very close supervision is exercised and the student has to justify his choice of type and placing of the lights, but as skill and experience increases he is permitted greater freedom. The lecturer offers a critical appraisal of the work but students are also encouraged to express their views of each other's work. In this way it is hoped to develop a critical faculty which will still function long after the technical operator has returned to his studio work.

The final test of success in lighting is the scene as viewed on a picture monitor, and the complementary nature of vision control becomes apparent during periods when practical experience is being obtained on the operation of all the controls between camera tube and picture monitor.

Training in sound control presents more practical difficulties than training in the other two techniques because it is almost impossible without the aid of actors or orchestra to create the complex problems which a sound supervisor may meet on a production. The layouts of dance bands and orchestras are studied and recordings of programmes for which different balance techniques were used, are criticized and analysed. The sound requirements for complicated productions and the necessary facilities, such as public address, two-way working, "clean" feeds, and artificial reverberation, are examined in detail.

Those members of the course who in their normal work have spent much of their time in one operating position are given full opportunity of concentrating on gaining practical experience in other positions.

The course ends with two two-hour written papers, one concerning Part I and the other Part II. In the Part I paper four questions have to be attempted out of eight, ranging over such subjects as factors controlling photo-cathode image illumination, hyper-focal distance and depth of field, the action of a vacuum photocell and the production of sound shadows and standing waves.

The Part II paper offers a choice of four questions out of nine, each of the main sections, lighting, vision control and sound control being allocated three questions. As an example the three questions on lighting might ask for a lighting plot for a drama production using $4\frac{1}{2}$ in. image-orthicon camera tubes, a description of the facilities provided on a lighting console, or criticism of the lighting in photographic prints provided. The questions on vision control might require a description of the functions of the camera control unit, or of the resolution and colour charts, whereas the sound control section could include questions on sound balance in a light entertainment production before an audience, or a question on the talk-back system used in a complex studio production.

This course has been in action since 1955 and a total of 84 students have been trained but no pass/fail mark has been in operation.

## 9. Conclusions and Acknowledgments

This description of the methods developed for the training of technical assistants and technical operators for the B.B.C. Television Service represents the results of over 12 years' experience in maintenance staff training and about five years in operations training. During the period many developments and some changes in training methods have been necessary to accommodate advances in technique brought about by new ideas from the production and engineering sides of the service, and this has only been possible through the close liaison at all levels between Engineering Training Department and the Television Operations and Maintenance Departments. Staff from the Training Department are released to spend a fortnight each year or when necessary longer periods to keep abreast of developments in the television field.

The authors gratefully acknowledge the ready assistance they have received from their colleagues in Operations and Maintenance Departments, the willing and enthusiastic co-operation of the training staff in finding satisfactory ways of presenting the new techniques, and the permission given by the Director of Engineering, B.B.C., to publish the work.

## 10. Appendix 1: New Entry Course Syllabus (14 weeks)

### Part 1: Fundamental Principles (5 weeks)

(*a*) PROBATIONARY TECHNICAL ASSISTANTS

*General Workshop Practice:* soldering, filing, action of cutting tools, the drill: hardening and tempering.
Safety precautions, electrical and mechanical, Holger-Nielson resuscitation methods.

*Wave Motion:* types of wave motion, sound, the e.m. spectrum: velocity, frequency, wavelength, relationship; complex waves, harmonics; the response of the ear, the phon.

*General Electrical Theory:* potential and current division; pads and faders, balanced and unbalanced circuits; the decibel, resistor colour code, preferred values; plugs and jacks, connections and simple applications.

*Electromagnetism:* generation of e.m.f., application in the telephone, loudspeaker, relay. Inductance; time constant, integrating and differentiating circuits, energy of magnetic field; reactance, vector representation, L and R in an a.c. circuit. Iron cored coils; the transformer, voltage ratio, matching, balance to unbalance connection.

*Capacitors:* types, relation of capacitance to physical dimensions, electric field: time constant, integrating and differentiating circuits, energy storage. Reactance, vector diagrams, resonance.

*Meters:* moving coil, moving iron, thermocouple. Shunts and multipliers.

*Valve Theory:* the diode; mains units, smoothing circuits; the triode; characteristic curves, load line, biasing; the pentode, characteristics.

*A.F. and R.F. Amplification:* coupling and decoupling circuits, frequency response, attenuation and non-linear distortion; negative feedback, effect on gain and distortion; basic oscillator circuits.

*Modulation:* amplitude and frequency modulation, bandwidth requirements; block schematics of transmitter and receiver.

*The Cathode-ray Tube:* construction and operation; magnetic and electrostatic focusing and deflection, e.h.t. supply; as a measuring device and as a picture tube.

*Television Fundamentals:* formation of the television picture; aspect ratio, interlace, synchronization; the video waveform, bandwidth.

(*b*) PROBATIONARY TECHNICAL OPERATORS

*General Safety Precautions (electrical):* Holger-Nielson method of artificial respiration.

*Sound:* velocity, frequency wavelength relationship: complex waves, harmonics, the response of the ear, the phon. Refraction and reflection, standing waves; pressure doubling.

*Optics:* fundamental behaviour of simple lenses and mirrors; angle of view. Units of photometry.

*General Electrical Theory:* revision of elementary d.c. theory, application to pads and faders, balanced and unbalanced circuits; the decibel; plugs and jacks, simple applications. Operation of relay, telephone, loud-speaker; the transformer, voltage ratio, use for matching, balance to unbalance conection. Capacitive and inductive reactance. Tone correction using L, C and R circuits.

*Meters:* moving coil, thermocouple. Shunts and multipliers.

*Valve Theory:* the diode, use as a rectifier; the triode and pentode; characteristic curves; use as an a.f. amplifier. Frequency response related to attenuation distortion. Non-linear distortion, effect on sound programme quality. Effects of distortion on pulses; correction circuits. Simple treatment of a.f. and r.f. oscillators. Comparison of a.m. and f.m. sound.

*The Cathode-ray Tube:* principles of operation; electrostatic and electromagnetic scanning arrangements. Synchronization.

*Television Fundamentals:* formation of the television picture; aspect ratio, interlace, synchronizing pulses, the video waveform.

**Appendix 1 (cont.)**

### Part II (9 weeks)

(*a*) PROBATIONARY TECHNICAL ASSISTANTS

*Television Standards:* interlacing, derivation of line and field timing, vestigial sideband operation, co-channel working.
Block schematics of the television system.

*Charge and Discharge Circuits:* frequency and pulse response of simple C.R. and L.R. circuits, time constants for coupling, differentiation and integration.

*D.C. Component:* problems in transmitting the d.c. component, simple d.c. restoring circuits; the principles of clamping, simple clamping circuits.

*Distortion:* attenuation; non-linear, the significance of "gamma," gamma correction; time delay, phase distortion.

*Video Frequency Amplifiers:* distortion produced by shunt and series capacitance, simple explanation of correction circuits, the uses of cathode followers, simple typical circuits.

*Principles of Fault Location:* methods and procedures, correct use of instruments in collecting information, logical deduction, typical component and valve faults.

*Optics:* plane mirrors, total internal reflection, convex lens, formation of image, angle of view, the eye, the projector, units of photometry, luminous efficiency.

*Camera Tubes:* photo-electric effects, secondary emission, target potential stabilization, principle of electron multipliers, charge storage principles, orthogonal scanning, beam focusing, target and photocathode construction; signal generation and transfer characteristics of C.P.S. Emitron, image orthicon and Vidicon tubes.

*Sync-pulse Generators:* frequencies and waveforms involved, block schematic diagrams of Pye and Marconi sync-pulse generators.

*Camera Channels:* general requirements, block schematics and typical waveforms of a representative channel, aperture correction, gain control, limiters and clippers, picture blanking and picture-sync mixers, schematic diagrams of camera body, control circuits and waveforms, camera tube protection, shading signal and clamp pulse generation.

*H.T. Stabilizers:* general principles of operation.

*Television Monitors:* block diagrams and typical circuits.

*Television Maintenance:* logical fault finding on camera channels, principles and operation of sweep alignment equipment.

*Telecine and Telerecording:* technical considerations, systems used by the B.B.C.

*Inlay and Overlay:* general principles.

*Video Lines:* the effects of correct and incorrect terminations.

(*b*) PROBATIONARY TECHNICAL OPERATORS

*Pictorial Composition:* television problems, camera framing, angle and movement, choice of lens, wide and narrow angles and perspective.

*Lighting:* key, filler, back and background lighting; lighting equipment and lighting plot symbols; contrast ratio and the television camera, significance of gamma; light meters.

*Applied Optics:* eye and camera tube response to light; television camera lens types, focus, depth of field and resolution; special optical systems, back projection, teleprompter, caption machines.

*Camera Tubes:* basic requirements, photo-electric and photo-conductive effects, charge storage and target potential stabilization; review of tubes in use.

*Vision Equipment:* function of, and facilities provided by camera control unit, vision mixing unit and picture monitor.

*Telerecording and Telecine:* film response, sensitometry and densitometry; systems used for recording on film; recording on magnetic tape; reproduction and use of films in television.

*Programme Distribution:* the vision and sound simultaneous broadcast systems; distribution and contribution; line problems with vision and sound signals, control circuits; control room operations in London and the Regions.

*Acoustics:* sound insulation problems, reverberation, problems in television studios.

*Microphones and Loudspeakers:* basic requirements: types in use for television.

*Sound Equipment:* facilities required, peak programme meter, dynamic range and volume compression, the B.B.C. Type A and B studio equipments.

*Sound Recording:* disk recording and reproducing facilities; magnetic tape operation.

## 11. Appendix 2: Promotion Course Syllabus

### Part I: Fundamental Principles

(*a*) TECHNICAL ASSISTANTS (7 WEEKS)

*General Electrical Theory:* network theorems, and their applications, exponential character of currents and voltages in pulse transmission; relationships in a magnetic circuit, effect of ferromagnetic materials on current and voltage waveforms, the magnetic amplifier. Sinusoidal analysis; vector representation and operator j analysis, polar co-ordinates.

Series-parallel conversion, resonance, coupled circuits; transformer equivalent circuits applied to amplifiers and power circuits; attenuators and filters.

*Power Supplies:* single and three-phase applications; simple treatment of the synchronous motor, the induction motor, single and bi-phase rectifier circuits, smoothing circuits.

*Measuring Instruments:* revision of basic types, special application, valve voltmeter, wattmeter, Megger.

*Valve Theory:* revision of valve types and their characteristics; equivalent circuits; class A, B and C operation, push pull: effect of interelectrode capacitance; non-linear operation, modulation, frequency-changing and detection; oscillators, r.f. and a.f. types; frequency modulation, reactance valve, frequency-to-amplitude conversion.

*Negative Feedback:* general principles, gain, distortion, methods of applying feedback, input and output impedances.

*Transistors:* characteristics of junction diodes and transistors, choice of working point, biasing methods, application of negative feedback.

*Cathode-ray Oscilloscope:* revision of basic principles; time bases, gas-filled and vacuum types.

(*b*) TECHNICAL OPERATORS (5 WEEKS)

*Sound:* general revision of nature and production of sound; intensity-loudness relationship; radiation of sound, effect of obstacles in sound field, resonance.

*Optics:* general revision of behaviour of lenses and mirrors; critical angle, dispersion, total internal reflection; the projector; telephoto and reverse telephoto lens, zoom lens system; optical system of colour television camera.

*Photometry:* intensity of light sources, luminance; types of photometer; lens testing, abberrations.

*General Electrical Theory:* revision of units; sources of e.m.f., microphone, current changes in inductance, flyback e.h.t.; resonance effects in LCR networks; complex wave synthesis; the magnetic amplifier.

*Valve Theory:* revision of valve characteristics; complex waves and distortion; secondary emission; photo-cells, characteristics of amplitude and frequency modulation.

### Part II (7 weeks)

(*a*) TECHNICAL ASSISTANTS

**Television Maintenance**

*Television Principles:* general revision.

*Black Level Control:* d.c. restoration: effects of charge and discharge time constants, source and diode resistance, practical circuits and tolerances.

Clamping: two diode and four diode clamp switches, effects of clamp switch resistance, clamp pulse generators, nature and location of clamp faults.

*Video Frequency Amplifiers:* general response of RC coupled amplifiers: effect of shunt capacitance and coupling capacitance on frequency and pulse response, shunt inductance and cathode correction at high frequencies, low frequency correction by decoupling and negative feedback, d.c. coupling.

Cathode followers: amplification, input and output impedances, cut-off distortion, load lines.

*Gamma and Gamma Control:* effects on picture quality and noise, practical circuits for camera and film channels.

*Lighting:* general problems, units and terminology.

*Camera Tubes:* revision of principles, transfer characteristics, aperture distortion, shading and spurious signals, electron optics, scanning and focusing, noise in camera tubes and the first valve of the head amplifier.

*Sync-pulse Generators:* typical circuits and waveforms, frequency dividers, delay lines, master oscillators, mains-hold circuits, typical circuits and waveforms, master and slave locking units.

*Camera Channels:* supply and control circuits, pulse timing and waveforms: camera control unit input circuits, aperture distortion and spurious shading signal correction, gain control methods, cable compensation, circuits for picture signal and blanking mixers, peak white and black level clippers, special circuits.

*H.T. Stabilizers:* series and shunt stabilizers.

*Television Monitors and Receivers:* amplification at v.h.f., wide-band i.f. circuits, vision detectors, sync separation, scanning generators and amplifiers, e.h.t. generators.

*Telecine:* intermittent and continuous motion systems.

*Telerecording:* Film: practical details of stored field, suppressed field and fast pull-down systems.

Magnetic tape: problems involved, the Ampex system of recording and reproduction.

*General and Specialized Maintenance:* Vision equipment: routine maintenance tests, square wave and sine-squared pulse testing, adjustment of frequency response.

Sound equipment: performance testing of amplifiers, microphones, loudspeakers, studio consoles and reproducing desks.

*S.B. System:* S.B. channels for sound and vision, testing and equalization of line links.

### (*b*) TECHNICAL OPERATORS

### Television Operations

#### Lighting

*Technical requirements:* lighting level, contrast ratio, tonal range, colour range and Munsell values; colour temperature.

*Sources:* tungsten filament, gas discharge and flourescent types; hard and soft lighting, optical and mechanical features, directivity pattern.

*Lighting techniques:* high and low tonal key, interior, exterior, cyclorama, backcloth; outside broadcast problems.

*Facilities:* dimming control by resistance, reactance or thyratron; the lighting console; lighting plots, rigging methods; still and moving back projection, front and shadow projection.

#### Vision Control

*Camera tubes:* sensitivity, acceptable contrast ratio, colour response light/signal characteristics, gamma; Emitron, image orthicon and Vidicon types; resolution and colour test charts.

*Equipment and techniques:* general studio schematic diagrams, elements of pulse generation; multi-source working, O.B. sources and genlock; inlay and overlay effects on lighting, camera movement and scene design: outline of telecine and telerecording features and problems.

#### Sound Control

*Acoustics:* the television studio; artificial reverberation.

*Microphones:* frequency response, directivity pattern, output; balance techniques with dance bands and light orchestras.

*Equipment:* type A and B studio apparatus, layout and operational facilities, schematic diagram, talk-back arrangements; public address systems and effect on studio and O.B. balance technique; disk reproducing desks: magnetic tape recording and reproduction.

#### General

*Technical operations manager:* duties, relationship to crew and production, make-up and wardrobe staff.

*Production problems:* in drama and light entertainment; set design.

# DISCUSSION

**Mr. B. D. Gardner:** I understand that before the rapid expansion of the television industry about 1955, the B.B.C. training and operational policy was to have engineers operating and maintaining their own equipment—this particularly applied to the staff operating outside broadcasts, central control, the smaller Regional studios, racks and telecine. In these departments I would have thought that engineers operating this equipment, and therefore having greater local knowledge of faults and performance, would both save time and expense in locating and rectifying faults. During fault conditions some of the operating staff are idle, and at times during operations the maintenance staff allocated to that area would be unable to do much work since not all the equipment and services can be duplicated.

If this assumption is correct, then was the division into separate units of the engineering and operational staff due to experience indicating that efficiency would be increased? Or was it due to the difficulties in obtaining sufficient staff of the calibre suitable for training in the dual role, coupled with the economic necessity created by the rapid expanse of the industry?

**Mr. W. D. Kemp:** Can Dr. Sturley give us any idea of the percentage of candidates completing the training courses who stay with the B.B.C. and rise to senior positions? I would also like to know whether the B.B.C. enters into any agreement with staff selected for such courses in order to ensure that they do not leave the Corporation shortly after completing the course. I have in the past been approached by people seeking posts in Independent Television who have taken B.B.C. courses, which has seemed to me to be rather an unprincipled action.

**Mr. R. C. Harman:** Dr. Sturley has described two courses, one for new entrants and one for more advanced personnel. As the two courses are separated by a gap of some 4½ years, will Dr. Sturley tell us of any measures taken to ensure that the growth of knowledge is maintained during this considerable period.

Secondly, Dr. Sturley has demonstrated how his students are taught to recognize the various forms of waveform degradation by observation of Test Card "C." It would seem to me that he has in fact made a very strong case for the speedy introduction of vertical interval test signals which may more easily be observed for any departure from normal working.

Finally, the point has been made by Dr. Sturley that any worthwhile training scheme costs a great deal of money. This is true, and one of the most important features of these costly schemes is the lecturer. Would Dr. Sturley describe what qualities he seeks in a lecturer, apart from competence? My thoughts on this problem are centred on the belief that a good lecturer has to be something of an actor in order to get the "feel" of his audience.

**Mr. N. Hughes** (Associate Member): It seems that the training given at Evesham tends to produce specialists and thus restricts the interchangeability of operational staff. Operating conditions with programme contractors occasionally necessitate a greater degree of interchangeability, in order that a person should be able to do more than one job, e.g. camera control operator should during holiday or sickness relief periods be able to operate other equipment such as telecine or video tape. This is surely more useful to a broadcasting organization than the specialist. Could we have Dr. Sturley's views, please?

**Mr. B. Marsden** (Member): Dr. Sturley said that new entrants to the B.B.C. spent three months in studios before proceeding to Evesham for a formal training course. I think that, unless precautions are taken in this first three months, a new entrant can receive very incorrect impressions of the principles and techniques involved in picture generation without the correct basic knowledge to guide him. Can Dr. Sturley tell us of any precautions which have been taken to ensure that the entrant receives the correct guidance?

**Mr. R. A. H. Gooday** (Associate Member): It would be interesting to learn if the Corporation holds special training courses for training operators and engineers in new equipment, e.g. video tape and colour equipment.

*Communicated*: Before the advent of commercial television broadcasting on 22nd September, 1955, it was necessary for the commercial programme companies to locate and train sufficient staff to enable programmes of up to ten hours per day to be maintained from the first day.

As senior engineer in charge of a studio and technical facilities centre, it was necessary for me to find and train a technical staff of some sixty technical operators and engineers. Training courses were arranged with the co-operation of Marconi College, but these were only of three or four weeks' duration and were directed towards operators on one course and engineers on the other.

The majority of operators and engineers had no experience of television broadcasting equipment (it being impossible to obtain such engineers without taking them from the B.B.C.); in fact, at this Centre only two operators had previous experience with the B.B.C. and they were promptly located in Master Control. Camera operators were trained by the production department but camera control operators, telecine operators, master control operators and maintenance engineers had to be trained by Engineering. Camera control and master control operators were selected from applicants with television servicing background or from technical assistants in industry. Telecine operators were selected from cinema projectionists who had some basic knowledge of television principles.

Each unit and shift of operators was strengthened by the permanent location of one or more maintenance engineers to that unit. Thus maintenance engineers also took part in operation, supplying the necessary technical knowledge, especially during the early days. It was found much easier to train maintenance engineers, despite the wide range of equipment (British, French and American), than to train the technical operators. Also it was found that several more senior maintenance engineers approached the problem with a fresh mind and incorporated comprehensive tube-replacement and preventive maintenance schemes before transmissions commenced (even completed maintenance stores with rapid-find systems and immediate spares locations in each facility area were established before transmissions commenced).

The first engineer for this Centre was engaged in April 1955, the Centre went on the air (together with another programme company) on 22nd September, 1955). The incidence of break-down from the first day was very low, and the picture quality rapidly improved after transmissions commenced. During this period the building in which the Centre was located, including all studios, etc., were being completely rebuilt (alarm systems informed the builders when to stop hammering during programme times).

Does Dr. Sturley consider that compared with these conditions the B.B.C. trainees are a little "feather-bedded"?

## AUTHORS' REPLY

Mr. Gardner raises a matter of considerable importance to broadcasting authorities, namely, whether to aim at using engineer-operators everywhere or to separate the tasks of maintenance and operations. There is no doubt that the engineer who also possesses operating ability of a high order is a valuable man and particularly is this true of outside broadcast work, which may have to be undertaken in isolated spots under unfavourable conditions and with a strictly limited amount of spare equipment.

The situation is different in television studios where adequate spares can be made available. Under these circumstances the work becomes entirely operational and it is more efficient to recruit operators, and have relatively few engineers (who are admittedly in short supply) to deal with the breakdown by replacement followed by diagnosis and repair.

Short of undertaking considerable research it is not possible to answer Mr. Kemp's first question. It is true that B.B.C.-trained staff appear to have considerable market value not only in commercial television but also in the electronics industry generally, and a number have been attracted outside the organization. At the same time it is gratifying to note that many of those judged by the Training Department to be of outstanding quality during their training period are now occupying the middle-senior positions in the Operations and Maintenance Departments. The B.B.C. has not made any attempt to bind staff for a given period after they have completed any of its training courses. The moral obligation has been ignored by some but the numbers have not been excessive.

The ideal method of increasing technical knowledge during the three to four year gap between new entry and promotion course would be to provide opportunities for attending courses at technical colleges leading to the Final or Full Technological Certificate in Telecommunications (City and Guilds) or to a Higher National Certificate. As Mr. Harman probably well knows, the shift system and the isolated position of some of the places of work make this difficult to achieve. The B.B.C. has made arrangements for a correspondence school to provide a course in mathematics and radio, and this method of self-training is being used by many of the staff. Close liaison has been established between the correspondence school and the B.B.C. Engineering Training

Department, who provided the syllabus and were consulted on the material and presentation.

A good lecturer certainly needs to be something of an actor but the following qualities are also essential:

(a) A lucid delivery, an analytical mind, a considerable store of patience, and a sense of humour.
(b) A flair for presenting difficult problems in the simplest manner and obvious enthusiasm for his subject.
(c) Ability to assess objectively the merits of others, and to compose a satisfactory report.
(d) The capacity for working as a member of a team.
(e) Experimental and practical ability.

Except for the division between operators and maintainers, the training is non-specialist. The syllabuses given in the appendices show that all aspects of television operations are dealt with, including telecine and telerecording. Furthermore new-entry staff are given a period of crew training in London during which they are tried out in the various positions. Naturally some show greater aptitude at certain tasks than others, and good staff management will see that as far as possible "square pegs go into square holes." There are points for and against the versatility Mr. Hughes recommends; the jack of all trades may well be master of none and the B.B.C. values the reputation it has built up for a polished engineering and operational performance, which can be more easily maintained through specialization of tasks.

Mr. Marsden spotlights one of the dangers of letting new recruits loose in a large organization, namely that they may pick up wrong ideas. The Training Department does not have direct supervision of the first three months but through close contacts with the Regional Engineers and the local engineers-in-charge, every effort has been made to ensure that the period is used to good advantage. A personal interest in each recruit by the local senior engineer, and attachment of the recruit to a member of the staff who has some understanding of his problems are two important ways of securing proper integration into the organization.

B.B.C. Engineering Division policy is to give whenever possible special training to staff who have to undertake responsibility for operating new techniques, and the Training Department organized courses on colour television to help those engaged in the B.B.C. experimental transmissions and latterly has been giving instruction on videotape recording.

Mr. Gooday paints an exciting picture of the start of his own technical organization and it takes the mind back to the early B.B.C. pioneering days of the first public television service. By comparison with their forerunners of 1936, the 1959 B.B.C. trainees would appear to be feather-bedded but each generation will always be able to say this of the next. When Mr. Gooday has been "on the air" for as long as the B.B.C.'s present record he will look back on his early days with nostalgia but will probably admit that, when there is time for it, training pays very good dividends and can increase the value of subsequent experience.

# News from the Sections . . .

## North Western Section

The North Western Section held its first meeting of the session on 6th October at the Reynolds Hall, College of Technology, Manchester, when Mr. L. E. Jansson gave a very interesting paper on "V.H.F. F.M./A.M. Transistor Receivers."

The transistor portable receiver for medium and long wave reception has now been established for about three years, the transistors used in these receivers being made by means of the well-known alloy technique. New methods of transistor manufacture such as the alloy-diffusion technique allow base widths as little as 1 micron to be achieved. Transistors of this type which are already available give good performance at a frequency of 100 Mc/s, so the advantages of f.m. reception can now be combined with the low battery consumption of transistor receivers. To ensure reliable reception in the many possible places where transistor receivers might be used a sensitivity of a few microvolts is required. This performance can be easily achieved using a total of nine transistors, stated Mr. Jansson and he then discussed the detailed design considerations of a portable receiver.

The first of the nine transistors is used in the r.f. stage and is operated in the grounded base mode. The choice of the grounded base configuration is dictated by the high operating frequency and the internal phase relationships within the transistor at this frequency. They cause the internal feedback in grounded base to be positive, so giving increased gain. The magnitude of the internal positive feedback is limited, however, by the design of the transistor collector circuit—after the input circuit has been designed for optimum noise performance—so as to ensure that the amplifier remains stable under all conditions. A wide-band coupling transformer is used between the f.m. aerial attached to the receiver and the first transistor input but the r.f. stage collector circuit is tuned to obtain the desired second channel rejection.

The second transistor is used in a self-oscillating mixer stage. In this stage the phase lag of approximately 90 deg in the transistor at 100 Mc/s causes the adoption of an oscillator circuit in which the feedback from the collector to the emitter is taken via a small capacitance which gives a 90 deg phase lead and so ensures that the oscillator tuned circuit operates at its own resonant frequency, so giving the best possible frequency stability.

The f.m. i.f. amplifier includes three alloy diffused transistors operating in the grounded emitter mode. The i.f. frequency is 10·7 Mc/s. To achieve the desired bandwidth of ±100 kc/s at 3db and ±300 kc/s at 40db, three double-tuned coupling transformers are employed. Neutralization is not employed because the phase relations within the transistor cause the overall internal feedback to be slightly negative; this improves the amplifier stability. Furthermore, the small advantage to be gained by neutralization has to be weighed against the difficulties of obtaining accurate neutralization at a frequency of 10·7 Mc/s.

A conventional unbalanced ratio detector re-designed to suit the requirements of transistors and semi-conductor diodes feeds the four-stage audio amplifier.

For medium and long wave reception a normal ferrite rod aerial is used. This is coupled into a self-oscillating mixer stage. The transistor for this stage is the same one as that employed as the first i.f. amplifier at 10·7 Mc/s. The remaining two 10·7 Mc/s i.f. amplifier transistors then act as i.f. amplifiers at 470 kc/s and a normal diode detector feeds the same audio amplifier as was used for f.m. reception. The number of transistors used for a.m. reception is, therefore, only seven. This gives adequate sensitivity for a.m. reception and, since the f.m. r.f. amplifier and f.m. mixer transistors are not needed for medium wave operation, the complications of switching in the 100 Mc/s front end unit are avoided.

The rapid development of new techniques in device fabrication shows promise of producing transistors for operation at still higher frequencies in the future and Mr. Jansson suggested that such improvements would lead to modifications in the design of individual stages and possibly to a reduction in the number of transistors required.

F. J. G. P.

# The Development of a High-performance Tape Handler†

*by*

H. M. HARRISON, ASSOCIATE ‡

*A paper read at a Symposium on Magnetic Recording Techniques held in London on 15th December 1960.*

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

**Summary:** Modern data processing systems are limited by the low input and output repetition rates of the electromechanical devices available. A number of forms of storage devices exist, but the greatest attraction of magnetic tape is the capacity of storage and the price per bit of stored information. This paper describes one way of achieving the development of a high-performance tape handler designed to reduce the severity of the problem of input and output rates. The main points of interest are: (1) The 1 in. wide tape is handled completely out of contact at 200 in./sec.; (2) Vacuum techniques are employed for tension control, drive and braking of the tape; (3) Start/stop and reverse times are better than 5 msec.

## 1. Introduction

Magnetic tape as a data storage medium owes its attractiveness to its compactness and cheapness when compared with other forms of data storage. For example, the cost per "bit" has been estimated to be about £2 stored electronically, 2s. 6d. by magnetic cores, 4d. on magnetic drums, and between 0·001 and 0·3 pence on magnetic tape. A spool of tape 2,400 ft long will store in excess of 60 million bits. A drum will store about one tenth of this and a large core store about one twentieth. Access times, however, usually vary inversely as the amount of stored information. It is therefore necessary for the data to be arranged in a logical order and access time of the tape is then less of a problem.

One role of the tape handler is similar to that of the "jotting" pad which is used for quick notes and calculations, crossings out and general tidying up of all sorts of information from peripheral equipment ready for presentation to the computer. It is also used to take processed information from the computer as quickly as possible and then to distribute it at a pace more suited to the capabilities of peripheral equipments. Other duties include the presentation to the computer on demand of information from, for example, pay rolls, price lists, stock records, tax tables and control programmes. A computer exists to save time. If the property is not to be wasted, it is necessary that it has the attendance of efficient and fast tape handlers.

In the specifications of tape handlers, emphasis has rightly been put on the start/stop times. Time spent in starting and stopping can waste some tape, but in many machines not all of the start and stop times are occupied in accelerating and decelerating the tape. Most mechanisms have inertia and some time elapses before drive is imparted to the tape itself. A notable exception is the electrostatic type of drive in which the only significant inertia is that of the tape.

However, any time wasted starting is computer time, which is expensive and requires a "buffer" in the computer to store information until the tape is up to speed, and ready to accept it. The faster the starting of the tape, the less "buffering" is required.

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The tape has to be stopped after the computer has finished with it. The computer, therefore, is not very interested in how long it takes to stop the tape. What does matter, is the waste of tape which results from a long stopping time. It is becoming common to-day to see specifications of less than 10 millisec for start and stop times at tape speeds of over 100 in./sec for tapes as wide as 1 in. or more.

High tape speed is a valuable feature since this obviously steps up the data handling rate in input and output stages where magnetic tape is commonly employed. In the past, tape speeds tended to be multiples of the audio standard of 15 in./sec, e.g. 30 in., 60 in., 75 in., 150 in., but there is little reason for this to be rigidly adhered to. Speeds of 100 in./sec, 150 in./sec and 200 in./sec are in use.

Tape speed is not the only factor influencing the data rate. The number of separate tracks and the number of "bits" per inch of track are directly relevant.

These two factors have limiting conditions which are imposed by the magnetic tape itself. Digital data, unlike analogue data, must be exact and whereas in an analogue recording a few lost cycles due to dirt or tape imperfections are of little consequence, in digital recording it could result in a gross error. It is for this reason that the number of "bits" (or in some systems, cycles) per inch in digital magnetic recording has usually been of the order of 100 or 200 per inch in order to keep the ratio of wavelength to flaw as high as possible. New techniques[1] are being developed to overcome this limitation but are not yet in general use.

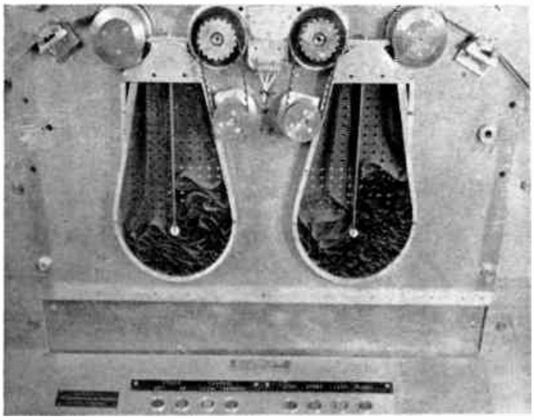


**Fig. 2.** Experimental tape handler with bin covers removed.

Practically without exception the various designs of fast data tape handler follow the same basic pattern[2, 6]. Fast start/stop specifications imply that the smaller the amount of tape to be accelerated the better.

A spool of tape $10\frac{1}{2}$ in. dia. and 1 in. wide weighs 5-6 lb, and has a moment of inertia of some 1200 oz-in.$^2$. A piece of 1 in. tape 4 ft long only weighs $\frac{1}{10}$th oz. Clearly some reservoir of tape, not on a spool, is required between the cumbersome spool and that piece of tape which we require to accelerate rapidly. This in turn requires means of measuring and monitoring the amount of tape in the reservoir which is then used to control the winding and unwinding of the spools to maintain this level between limits. It is the precise way in which this basic system is achieved which varies from equipment

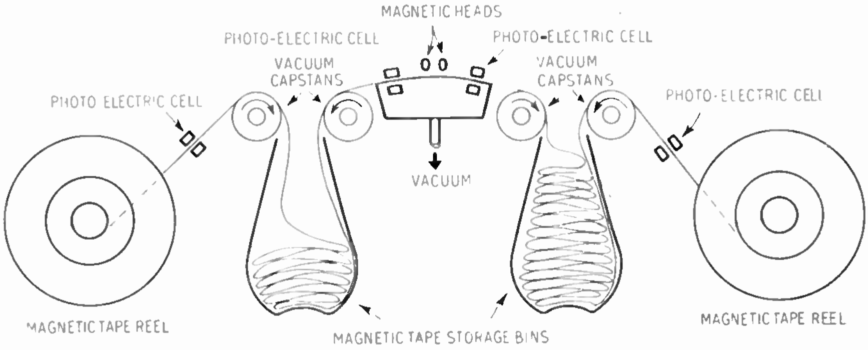


**Fig. 1.** Layout of tape deck.

to equipment depending on the prime requirements.

The particular tape handler to be described meets certain prime requirements which are worthy of mention at this point:

(1) The oxide coating of the tape must be handled with the greatest possible care.
(2) The tape must be wound on to and off the spool under controlled tension.
(3) Tape speed to be 200 in./sec in both directions.
(4) Packing density 200 flux reversals per inch.
(5) Tape width 1 in.
(6) Tape length 2,400 ft minimum.
(7) Start/stop times less than five millisec.
(8) Reverse time less than seven millisec.
(9) Heads—two channels interleaved, each of 12 tracks, i.e. 24 tracks on 1 in. tape.

The tape handler and its associated equipment use no thermionic valves. All the electronic units employ transistors and although, at present, the motor control is by contactors, this is scheduled to be replaced by a magnetic control.

The essential components of the tape transport are as follows (see Figs. 1 and 2).

Tape bridge and magnetic heads.
Main tape drive capstans.
Tape bins and sensing circuits.
Binning capstans.
Spools drive.

Housed in the cabinet are:

Power supplies.
Read/write amplifiers.
Vacuum pumps, etc.
Cooling and pressurizing fan.
Contactors and starters.

## 2. Tape Drive General Description

The tape drive is a dual vacuum capstan assembly with a tape guiding bridge carrying the magnetic heads, mounted between the drive capstans. A vacuum drive was chosen on account of the need to avoid "handling" the oxide surface[2]. These capstans drive on the backing of the tape and 200 in./sec is achieved with 3 in. dia. shell at about 1270 rev/min. These are driven via timing belts from $\frac{1}{8}$ h.p. two-pole three-phase induction motors. This gives a range of tape speed with no belt slip by choosing the timing pulley ratios to suit. The tape was originally brought to rest by means of a high-speed vacuum valve connected to rows of holes in the bridge. In the course of development however, it was found that the valve could be dispensed with and the holes left permanently connected to the vacuum supply, which is at about − 12 in. mercury. This obviated the need for a valve and got over a difficult valve timing problem. The ratio of driving area on the capstan to brake area on the bridge is about 4:1.

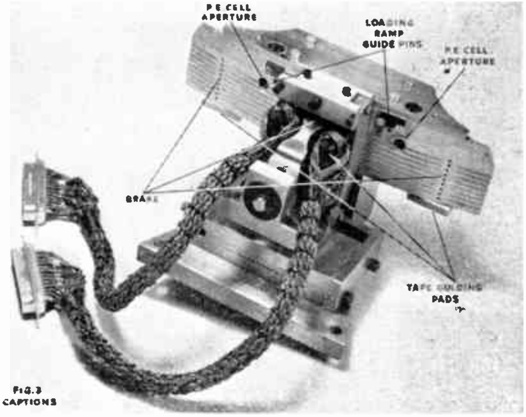


Fig. 3. Tape bridge and head mounting with heads.

Guiding of the tape is provided by three pads of hard material on the rear of the bridge (see Fig. 3). These give control of the tape over the whole of the bridge which is some 6 in. long. Two round pins at the front of the bridge keep the reference edge of the tape against the three rear pads. The capstan shells are stainless steel and incorporate flywheels. The capstan bodies which are inside the rotating shells also house the high speed vacuum valves which are driven by moving coil actuators.[3]

Magnetic tape reservoir storage is provided by two bin assemblies located between the main capstans and the binning capstans. The amount of tape accommodated in them can be up to 50 ft and is measured in the manner described in section 2.3.

The binning capstans revolve inwards to the tape bins and are vacuum slipping drives which strip off the tape from the spools as they unwind and maintain tension as the spools wind up.

The spool drive uses three-phase motors, geared to give a spool hub peripheral speed slightly in excess of 200 in./sec.

### 2.1. *Start and Stop Mechanism*

The start/stop and reverse times of the specification are comfortably met, with a safety margin, under all combinations and rates of command signals.

The control uses a three-wire system in which the command "go" is +3V and "stop" is −3V. Similarly, "right" is +3V and "left" is −3V.

The signal is fed to the transistor controls which produce a pulse of 3·5 amps peak in the 5 ohm coil of the moving coil valve. In order to achieve maximum performance, the following factors are relevant.

(a) High vacuum (10−12 in. Hg).
(b) Small space to exhaust.
(c) Low impedance air passages.
(d) Lightweight moving parts (under 7 grammes).
(e) Large magnet (8000 gauss on 1 in. pole).
(f) Long coil.
(g) Freedom from bounce (magnetic and pneumatic damping).

The valve itself (Fig. 4) is a piston type, 0·32 in. dia. and 1 in. long in which the plunger is integral with the moving coil. The piston has a series of annular grooves which can be positioned opposite to one or other of two sets of matching grooves in a sleeve. The sets of slots are staggered relative to the grooves. Thus the capstan chamber immediately under the tape can be connected to one or the other of the two reservoirs inside the capstan body. These reservoirs are in turn connected to pipes leading out to larger reservoirs and pumps. One of these reservoirs is kept at −12 in. mercury and the other at −6 in. water pressure. The −12 in. mercury is the drive vacuum and the −6 in. water is the slip, or non-drive vacuum.[4]

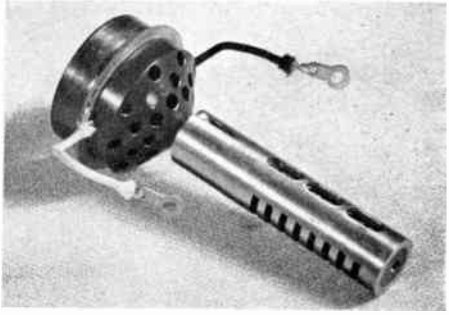


**Fig. 4.** High-speed air valve and sleeve assembly.

The purpose of the non-drive vacuum is to ensure that the tape is always wrapped round the capstan and therefore "available" for a "start" (see Fig. 5).

The valve completes its stroke in under two millisec. The tape starts to move after two millisec, and is up to 200 in./sec by three millisec.

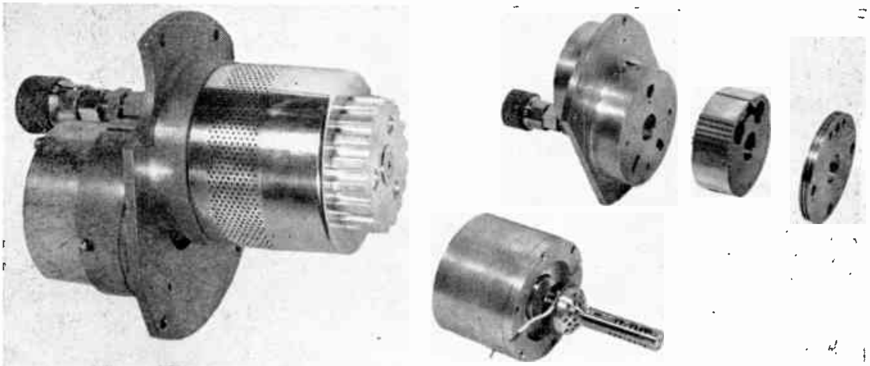


**Fig. 5.** Drive capstan exploded showing internal reservoirs.

A photograph of the start/stop pattern is shown in Fig. 6. This was taken from the screen of a double-beam oscilloscope. One set of Y plates display the timing waves and the other Y plates display the signal from the tape. The large timing wave is also used to command the tape unit to "go" and "stop." A 1 kc/s sine wave, superimposed on the "command," gives 1 millisec markers. The tape signal for this purpose was pre-recorded with continuous digits at 20 kc/s to enable the acceleration of the tape to be seen. Since the output from the head is a function of the rate of change of flux it can be assumed that the tape is up to speed when the signal level ceases to increase. Reverse is achieved by signalling both valves together and it is completed in four millisec (Fig. 7(a)). It is interesting to superimpose a "start" and a "stop" pattern as in Fig. 7(b). The similarity of (a) to (b) is obvious and illustrates the fact that there is no "tug of war" between the capstans when reversing, although the overall time is less than the sum of start and stop times. The tape is in fact brought to rest in about three millisec during a reversal.

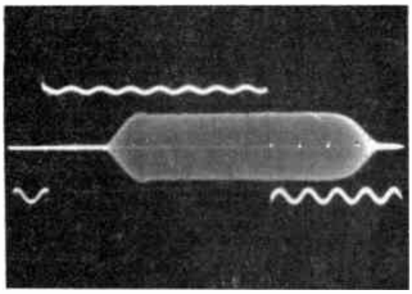
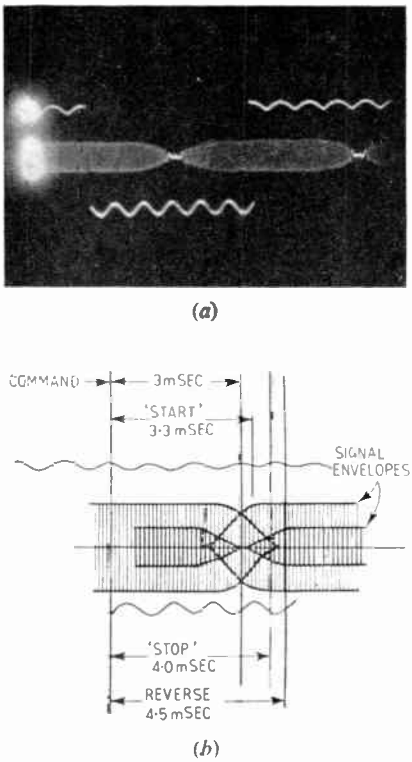


**Fig. 6.** Start-stop timing pattern at about 50 per second (experimental model).

The drive pulse for the valve is produced by the charge and discharge current of a 500 μF capacitor. OC16 transistors connect the capacitor to +20V or 0V via the moving coil of the valve. A small "hold-on" current is also provided by R1 and R2. (Fig. 8(a) and (b)).

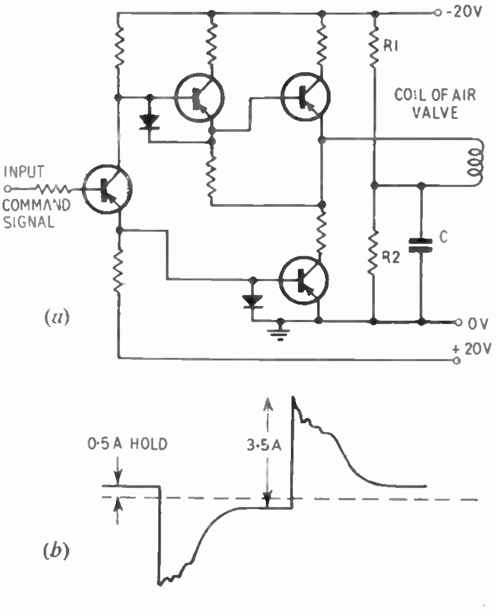
The tape is accelerated to 200 in./sec in 1 millisec. Thus the start distance is $\left(\frac{200}{2}\times\frac{1\cdot0}{1000}\right)$ inches = 0·1 in. (0·254 cm) assuming the



(a)

(b)

**Fig. 7.**(a) Reverse timing pattern at about 50 per second (experimental model) (b) Composite start-stop and reverse patterns.



(a)

(b)

**Fig. 8.**(a) Air valve drive circuit (b) Typical current waveform of valve drive.

acceleration $f$ to be uniform. Since $f = \frac{v}{2t}$, then $f = \frac{200}{12 \times 0{\cdot}001 \times 32} = 518g$. This means that the force on the tape is approximately one kilogramme.

A similar calculation for the valve reveals that it is subjected to a force of $98g$ and completes its stroke in 1·83 millisec.

Looking at the timing pattern (Fig. 6) this gives reasonable agreement. No allowance has been made for the effects of

(i) Damping produced by the aluminium former which acts as a "shorted" turn.

(ii) The pneumatic damping produced by the piston end of the valve and the small hole down the centre of the stem (Fig. 5).

(iii) The "build-up" time of the current in the coil.

Under the effects of $98g$ an asymmetrical valve would be subjected to severe out-of-balance forces, which would soon result in failure. For this reason the symmetrical construction of the valve and coil is valuable.

It is interesting to consider what the start time would be if the tape speed were doubled. Since acceleration takes place *after* two millisec the overall time would be extended from 2 + 1 msec (= 3 msec at 200 in./sec) to 2+2 msec (= 4 msec at 400 in./sec).

Therefore start distance =
(2 msec at $\frac{1}{2} \times 400$ in./sec) = 0·4 in.

### 2.1.1. Stop mechanism

The tape is brought to rest by the three rows of vacuum holes which are provided on the bridge. This is somewhat like "driving with the brake on" but, since the ratio of the driving area to braking area is so large, together with the fact that the weight of tape to be brought to rest is only 2 grammes, this is sufficient to decelerate the tape in about 1 millisec. The delay of about 2·5 – 3 millisec is due to the time it takes to close the valve plus the time it takes the vacuum to disperse to a level where drive is lost. The vacuum on the bridge also maintains the tension in the tape necessary for stable running under the heads.

The stopping distance at 200 in./sec is thus 0·6 in. (3 msec at 200 in./sec) plus 0·1 in. (1·0 msec at 200 in./sec). Total = 0·7 in. But at 400 in./sec the stopping distance would be 1·2 in. (3msec at 400 in./sec) plus 0·4 in. (2 msec at $\frac{1}{2} \times 400$ in./sec) Total = 1·6 in.

The calculated figure at 200 in./sec agrees very closely with the measured distance, but an interesting fact was discovered during the early experiments. It was found that if the "open" or "atmosphere" ports of the two capstans were coupled closely together and not to atmosphere[4], the timing pattern changed, suggesting that the tape was moving again for a short distance after the initial stop. It was reasoned that this movement must be in the reverse direction and be due to the momentary "leak" of vacuum from the valve which was being switched off. This "leak" would enter the other chamber and be carried to the non-driving capstan where the transient drop in pressure would move the tape a short distance. This would have the useful effect of shortening the stopping distance. The length of the pipe connecting the two chambers is about 12 in. Since sound travels at about 1 ft/millisec the "leak" pulse should arrive at the "non"-driving capstan 1 millisec after the other valve has operated.

In order to prove that this was in fact happening, the tape was recorded while at rest with single pulses, which also coincided with pencil marks drawn on the tape alongside the head block. The tape was then set running and the pulses used to trigger a pulse generator with a variable time delay. The leading edge of the pulse from the generator produced a "stop" signal and the trailing edge produced a "go" signal. This enabled the pencil mark to be seen during the "stopped" period and the stopping distance to be measured. When the connecting pipe between the capstans was removed, the stopping distance was lengthened and vice versa.

### 2.1.2. Start/stop repetition frequency

The specification called for rates of up to 40 per second and it was found that rates in excess of 100 per second could be achieved without any resonance effect.

The tape signals indicated that it was reaching 200 in./sec during these intervals and prolonged periods at high rates appear to be permissible. Valves have undergone over 12 million operations without deterioration.

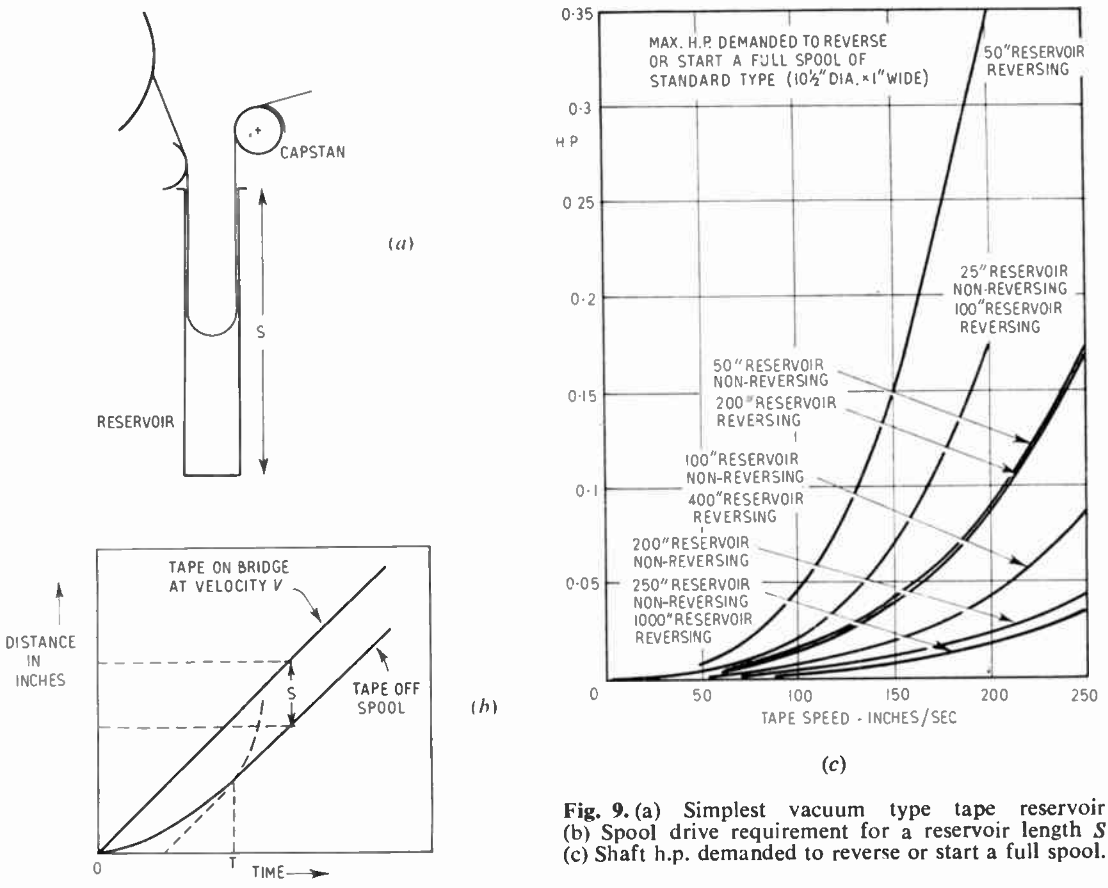


**Fig. 9.** (a) Simplest vacuum type tape reservoir (b) Spool drive requirement for a reservoir length $S$ (c) Shaft h.p. demanded to reverse or start a full spool.

### 2.2. *Spool Servo*

In deciding on the type of spool drive and tape reservoir, many factors had to be considered.

Single or even double loop vacuum type tape reservoirs cannot accommodate more than a few feet of tape without becoming embarrassingly large. Restricting the size of tape loop puts up the torque requirement of the spool motor. This in turn increases the danger of tape slipping on the spool under high acceleration and deceleration, unless high winding tensions are employed. Excessive winding tension will damage the tape!

When these points had been carefully considered it was calculated that the relationship between spool shaft horsepower and steady tape speed was a cubic law.

Consider a single loop reservoir of capacity $2S$ (i.e. length of reservoir $= S$) and a capstan capable of either filling or emptying the reservoir at velocity $v$. If the tape is at rest with the loop at the centre of the reservoir (Fig. 9(a)) and tape is then put in at a speed $v$ (step function) then the spool must be accelerated in a time $T$ such that the speed of tape reaches $v$ just as the tape is about to touch the bottom of the reservoir. This assumes constant acceleration $f$ (from Fig. 9(b)). The capstan drive is applied virtually instantaneously (the straight line) and the spool drive requires some time to catch up (the curved line).

An alternative way of considering the acceleration is to say that initially the relative velocity between tape entering and tape leaving the reservoir is $v$ and finally it is zero (where the two curves become parallel).

$$\text{The filling speed} = v - \frac{vt}{T}$$

Increase of content =

$$\int_0^T \left( v - v\frac{t}{T} \right) \mathrm{d}t = v \left[ t - \frac{t^2}{2T} \right]_0^T = \frac{vT}{2}$$

Thus $\frac{S}{2} > \frac{vT}{2}$

or $T < \frac{S}{v}$

For a spool of given size, the rotational energy will be proportional to the square of angular velocity, which in turn will be proportional to $v$. This has to be provided in less than $S/v$ seconds so that power $P \propto v^3 . S^{-1}$.

Taking a practical case of a tape unit designed to reverse at 150 in./second with reservoirs capable of accommodating 50 in. of tape, increasing the tape speed to 200 in./sec (a factor of 4/3) demands an increase in motor power of approximately 2·4. Doubling the reservoir loop would halve this figure.

The curves of Fig. 9(c) show the relationship of motor power, tape speed (steady) and reservoir length.

In the case of a reversing drive the velocity change is $2v$.

The torque $T = 4 \times$ non-reversing case.

Thus power is 4 × non-reversing case (assuming that we re-set to the centre of the reservoir).

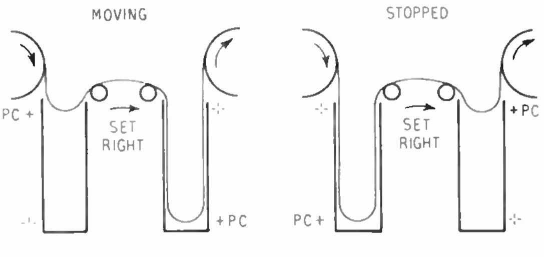


**Fig. 10.** Use of multiple reset points to increase effective length of reservoir.

By resetting towards one end of the reservoir, depending on the direction of tape travel, it would be possible to reduce the factor of 4, at the expense of more complex re-set arrangements. (Fig. 10.)

The limit would be when the re-set points are right at the ends of the reservoir when the factor becomes two. This means that, considering tape entering a reservoir, the tape loop is maintained just at the bottom of the reservoir. Hence when the tape reverses, the full length of the reservoir is available before the spool need have reached maximum speed in the opposite direction.

The value chosen for $I$ (moment of inertia) to derive the curves of Fig. 9(c) is that of a full 10½ in. dia. spool of 1 in. wide tape, and does not include any allowance for spool carrier, gears and motor armature.

Motor characteristics vary with type, and there are also working safety factors to consider to avoid emptying the reservoir under marginal conditions. Judging by the ratings of motors used by various manufacturers in their tape units and the performances achieved and fitting them on the appropriate curves it was evident that a factor of about seven related the shaft horsepower of the curves to the motor required. This, for the 200 in./sec case using a 50 in. reservoir, indicates a motor horsepower of about 2·5!

As mentioned earlier, there is a marked danger of the tape slipping on the hub under high torque. In view of this it was decided that larger reservoir storage of tape was essential. Accordingly these reservoirs were planned to accommodate an average length of 40 feet of tape and to hold the tape loosely folded and tensionless. This allowed the use of a smaller motor in the ¼ h.p. class and reservoirs of small volume. The time scale for development was such that elegant servo drives with or without clutches were not likely to be ready in time. The simplest and cheapest system of switched a.c. motors was chosen, since it was also readily available. Electrical interference was troublesome but it was largely overcome by filtering the lines to and from the contactors.[5]

The spool servo is a simple "bang-bang" or "two state" type. The motors are ¼ h.p. three-phase a.c. squirrel cage type with electromagnetic brakes connected to one phase of the supply. Three-phase motors were chosen on account of their good starting torque. A gear ratio of 1·5 : 1 is employed to give increased torque and a suitable spool speed. The supply is made and broken by a contactor whose coil is driven via a relay which in turn is driven by the transistors of the bin sensing unit.

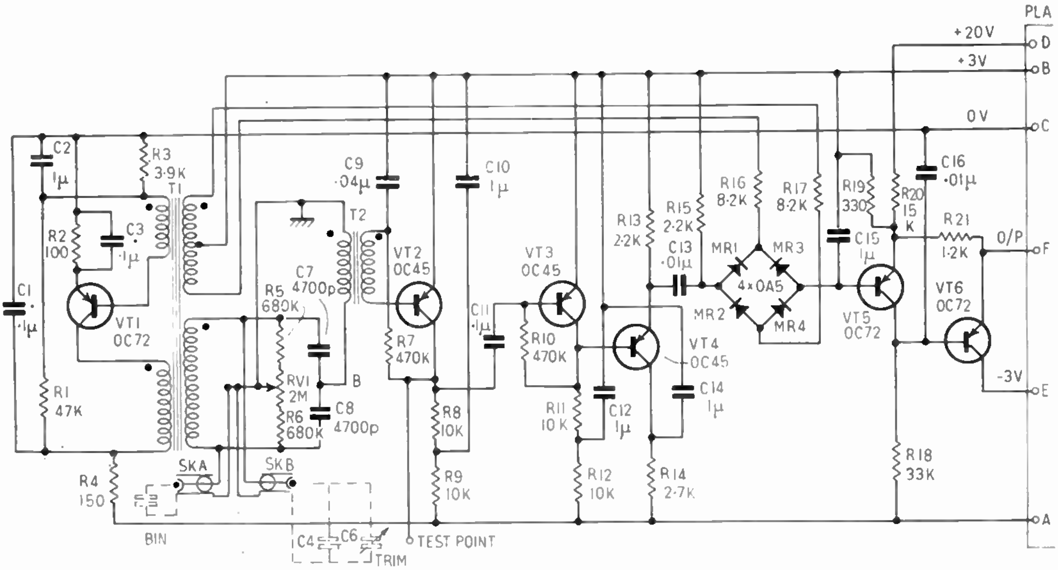


Fig. 11. Circuit of bin sensing method.[4]

### 2.3. *Bin Sensing*

A number of methods of measuring the length of a loosely folded tape in a bin are known. The tape can be weighed[6] or made to cast a shadow on photo-sensitive elements using oblique light.[18] A further method, which has proved satisfactory and is now in use, is that of sensing the amount of tape by measuring the change in capacitance which the dielectric properties of the tape will produce when lying between the two plates of an air spaced capacitor. The bin is made so that the front and back form the plates of a capacitor and, in order to be able to see the tape in the bins, the front is actually plate glass with an evaporated layer of chromium on one surface. The film is thin enough to be transparent and the sensing circuit is sensitive to changes of as little as six inches of tape.

The change of capacitance is very small but the sensing circuit is made sufficiently drift free by the choice of components with suitable temperature coefficients. Changes in level are by no means as critical as they would be in vacuum loop reservoirs.

The diagram of the sensing circuit is shown in Fig. 11.

The capacitance bridge B has the bin as one of its limbs and is energized by a transistor oscillator at 50 – 100 kc/s. An adjustable reference capacitor provides the means of capacitance balancing and setting the tape level in the bin. The bridge is balanced for other losses by a resistance potentiometer and the subsequent unbalance voltage produced by the tape is amplified to bring it to a suitable level to drive a synchronous, diode, demodulator. The output from the demodulator is then put through a low pass filter. The output stage employs positive feedback to introduce some "hysteresis" into the sensing and eliminate the jitter which would result when just on the point of balance.

The "trip" level is normally set to about 40 ft and the unit produces a binary output of +3V for over 40 ft and – 3V for under 30 ft.

The spool servo circuits are pre-set left or right from the command signals so that the control, from the bin contents, is also "binary," i.e. it has only two states—run and stop.

#### 2.3.1. High rates of reversal

It is undesirable and unnecessary for the spool drives to attempt to follow very high rates of reversal. The control logic is so arranged that the spool drive completes one command (i.e. it fills or empties to the bin "trip" level) before accepting another (see appendix and ref. 20).

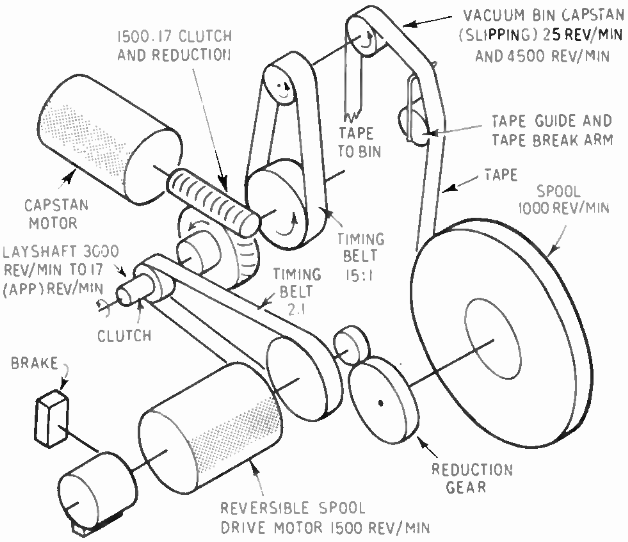


**Fig. 12.** Binning capstan drive.[7] Both free wheels drive the same way (i.e. anti-clockwise in this case), bin capstan always drives inwards (i.e. anti-clockwise in this case). Shaft speeds nominal.

The spool drives thus settle down to a natural low frequency of operation governed by the amount of tape on the spool. The left/right ratio of the drives is determined by the mark/space ratio of the reverse command signals.

Since the motors are of standard construction it will be obvious that additional cooling is required for the reverse case owing to the fact that they do not run fast enough or for a long enough period for self cooling to be effective.

### 2.4. *Tension Control*[7]

The early experiments met some difficulty to trying to make the tape run out of the bin onto the spools under controlled tension without handling the oxide. Systems using vacuum loops do not have this problem since the tape is already in tension while in the loop reservoir. The bin system however allows the tape to lie in loose folds.

Tape under no tension will not run round a normal guide. To overcome this the guide was made in the form of a cylinder with a shallow groove 1 in. wide. The bottom of this groove was perforated and a little vacuum applied. The drag so produced kept the tape in tension on its way out of the bin and the winding tension was proportional to the vacuum level.

This overcame the winding-up problem but there was still that of unwinding the tape into the bin. Accordingly it was arranged to rotate the vacuum "guide" towards the bin and to drive it via a "free wheel" (or sprag clutch) from the spool drive. A second "free wheel" prevented the "guide" from being pulled backwards when the tape was being wound up. As long as the peripheral speed of the "guide" (or binning capstan as it is called) is higher than the speed of the tape unwinding from the spool, the tension is maintained. Figure 12 shows the drive mechanism for the binning capstans and Figs. 13 and 14 show the relationship between vacuum, and tension and capstan speed.

The tension is sensed by a simple device which stops the drive on main capstans and spools in the event of incorrect tension. (Fig. 15.)

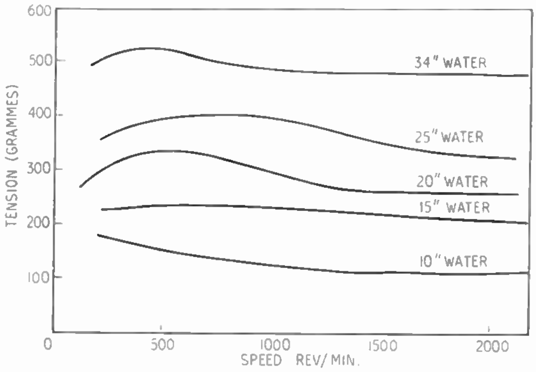


**Fig. 13.** Graphs of speed/tension for various vacuum levels on binning capstan. Mylar-based tape.

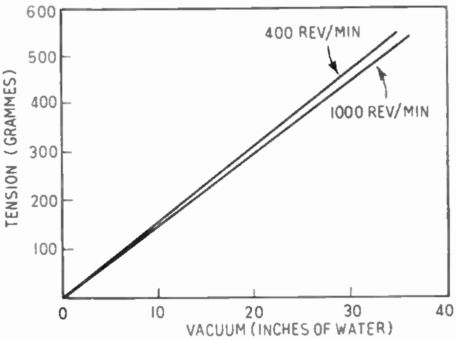


**Fig. 14.** Graphs of tension vacuum for various speeds of binning capstan. Mylar-based tape.

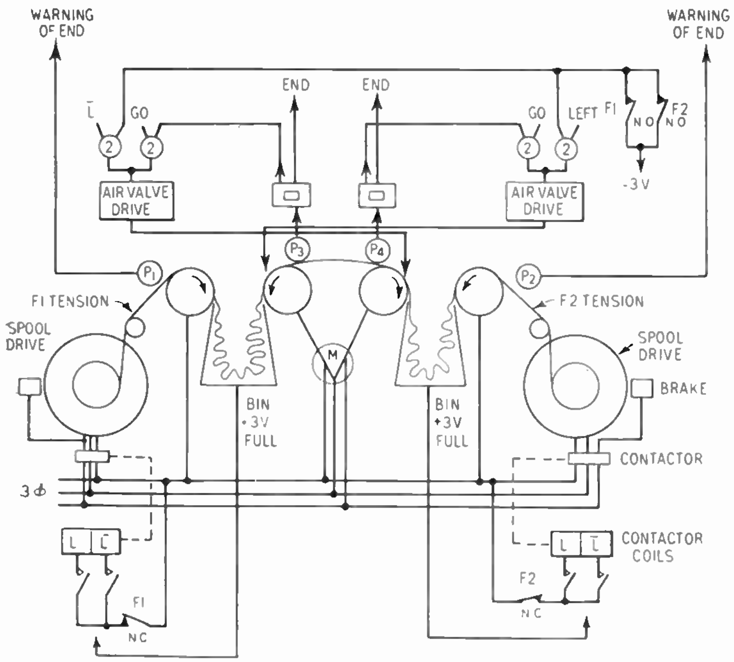


**Fig. 15.** "Logic" of tape END and tension sensing.

## 2.5. *Interlocks, Loading and Unloading*

Interlocks fall broadly into two categories (a) Those which are required to ensure correct sequences of operation and (b) those which monitor the states of various parts of the tape unit.

In (a) for example we have the "switch-on" sequence. Pressing the ON button switches on the transistor power supplies. These are monitored by a safety circuit so that if any of the various "rails" are not available for any reason the machine is immediately shut down. Thus the transistor section is protected both during "switch on" and when running. If no fault is present, the air blower is started and its air flow is monitored to give warning of a choked filter. This, however, is only a warning, since failure of the cooling air is not of vital nature and the tape unit could be allowed to complete a spool of tape before it was necessary to switch off for investigation. Failure of a supply rail, however, could damage a large number of transistors, and requires rapid action.

Following on the switch-on sequence, the next stages can only take place if the tape compartment doors are closed. Pumps and capstans will then start up. Here it is important to start up the main vacuum pump before the drive capstans are allowed to revolve in order to enable the tape brake, on the bridge, to clamp the tape and prevent it moving. It is also essential to clamp the tape when switching off and this is done by having a vacuum reservoir to maintain braking until the capstans have stopped. Similarly all capstans and vacuum supplies must be "on" before the spools can be revolved so that tape is not thrown off the spools and damaged. The lids of the tape bins also must be down before this happens.

In the second category (b) are tape tension alarms, auto/manual interlock, auto reverse interlock, and those controls that may be used in "manual" but must be re-set before the machine can be operated in "auto" (i.e. with the computer).

It is always a problem deciding on which interlocks are essential and which are merely useful. Too many interlocks may result in the unit being less reliable than it was without them.

For normal use it is customary in most tape units to have some means of stopping the tape before the end runs off the spool. This can be done with metallic contact strips, or mechanical holes to operate pneumatic trips, or optical holes (windows) to operate photo-electric trips. Naturally, magnetic markers on the tape would also do, but they are not visible nor, in the strictest sense, permanent, since they could be accidentally erased. In a unit using vacuum drive a mechanical hole would be an embarrassment. An optical window was therefore chosen; another advantage of this is that unlike the conventional magnetic marker, the system is a d.c. one and its output is not dependent on the speed of tape.

"End of tape" is thus signalled by a window ¼ in. wide by 2 in. long at the outer (front) edge of the tape. The drive is automatically stopped by the exposure of the appropriate bridge phototransistor (Figs. 15 and 3) and a signal sent out of the machine.

Warning of the approach of the end of tape is extremely useful and, when using tape bins of the kind described, can be obtained some 30-40 ft in advance. This is done by detecting the end of tape before it enters the bin. There will usually be 30-40 ft in the bin and this gives a few seconds advance warning.

In order that the warning signal should be steady (d.c.) and not fleeting, the ends of the length of tape are prepared as clear, full width, leader and trailer some 6-12 ft in length. When this was first tried it was found that the dielectric effect of clear uncoated polyester base was about one-fifth that of oxide coated base. This implied a length of $5 \times 40 = 200$ ft of leader and trailer in the bins to operate the sensing unit and stop the spool drive! Leaders with ¼ in. windows some feet long were found to be less different dielectrically from normal tape but presented a problem of manufacture.

A simple solution was adopted. The tape was prepared with 6-12 ft of clear leader and trailer, followed, 2 ft later, by a 2 in. long ¼ in. window. The early warning cells were positioned so as not to detect the small edge window, which therefore entered the bin. The logical circuits were arranged so that exposure of the early warning cells stopped the spool drive. Tape was then driven over the bridge until the edge window reached the "stop" cell The bin then had only 2-3 feet of tape in it.

To load and unload a spool of tape it is obvious that some interlocks must be overridden. The machine is loaded by pushing the leader, held between the hands, into a guide slot and trapping the end, round the take up spool. Both brakes are released for this by either of two switches. The doors are then shut, and (if the ON has already been pressed) the machine switches on. Completion of this is indicated by the illumination of lamps STOP and RIGHT. The LOAD button is then pressed. The left bin and then the right bin are filled, drive is then automatically reversed and the tape comes to rest with the START window on the right-hand photocell and loading is complete. This takes about 10 seconds from pressing the LOAD button.

*Unloading* can be initiated anywhere on the tape. The tape immediately runs left until the leader runs off the right hand spool. The right hand bin is emptied and the end driven over the bridge. This causes a vacuum failure which is used to allow the left-hand spool to wind out all the tape up to the leader. This exposes the left-hand early warning cell which stops the spool. The spool thus comes to rest with a foot or two of tape in the bin and with the end still under tension. The doors can then be opened and the machine shuts down automatically.

### 3. Magnetic Heads

The merits of, and design criteria for heads used out of contact have been well covered in available literature[2, 9, 10, 12, 13, 15]. The additional requirements for multi-track use with interchangeability between headblocks and tapes call for close tolerances in manufacture to obtain accurate alignment of both tracks and gaps.[17]

The heads employed in this application are E.M.I. type B and have track alignments of ±0·001 in. and gap scatter of 0·0005 in. total. Two 12-track blocks are mounted (at a distance of 1 in. between gaps) so as to interleave their tracks. The tracks are 0·026 in. wide and pitched on the tape at 0·040 in. Safety lanes are thus 0·014 in. wide and adequate to ensure low crosstalk at the bit packing of 200 reversals per inch.[8]

The use of two blocks, has the advantage of permitting wider head to head separation than would be the case if all 24 were mounted in one block. There is also more room for screens and windings. Since the heads are read/write units, the inter-head screens are made as a sandwich of copper-mumetal, copper. giving electrical and magnetic screening.

The gap spacer is of 0·002 in. copper and is made as large as possible to give maximum writing sensitivity consistent with maximum reading sensitivity.[14] The reading output is of the order of six millivolts for a writing current of 140mA peak-to-peak. The spacing from the tape surface is 0·001 in. (See Fig. 16).

The cores of the heads are solid permalloy B strips 0·030 in. wide by 0·015 in. thick by

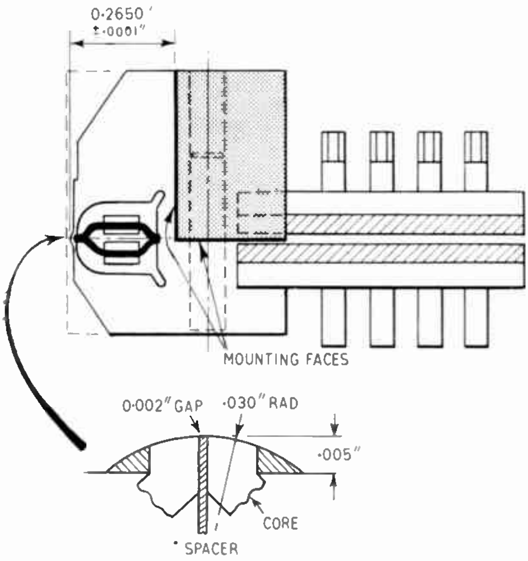


**Fig. 16.** Magnetic head construction.

0·25 in. long (See Fig. 16). The construction is that commonly employed where precision gap alignment is paramount, the blocks being made in two 12-track halves, encapsulated, ground and finally clamped together. A feature of this design is the use of one long and one short block to make the complete unit. The protruding ends of the long block are ground at the same time as the pole faces of the half heads and these become the datum edge of the head gaps and the head mounting. After assembly the complete block is track-dressed to 0·026 in. to take out any slight misalignments and finally form-ground to a radius of 0·030 in.

This small radius removes the corners from the head faces which would otherwise give a secondary gap effect.[15] In pulse recording this gives rise to pre-pulses of reverse polarity which cannot be tolerated.

## 4. Reading and Writing Arrangement

Since only one headblock is used when going left and the other when going right there is no need for very high accuracy of spacing of the two rows of gaps. It is also only necessary to provide writing and reading amplifiers for 12 tracks. The amplifiers are switched from one head to the other by the "left/right" signal and each headblock can be switched to read or write.

The phase modulation system of recording[16] allows the use of transformers for writing and reading via the magnetic heads and a two way switch unit, employing transformers, is used as shown in Fig. 17.

The tracks are used in the following manner: 6 for data, 1 for parity, 2 for semi-parity, 2 for clock, 1 for block marking.

## 5. Circuit Elements and Power Supplies

The control system uses units from a range of standard panels designed for the EMIDEC 2400 computer. This is a very flexible way of satisfying any requirement of a system involving binary logic.

Panels of circuit elements are assembled on printed circuit boards 7½ in. × 3½ in. These boards are equipped with a plug and are assembled into a frame in the tape unit which can carry 50 boards. Besides carrying groups of simple logical functions, e.g. two AND circuits

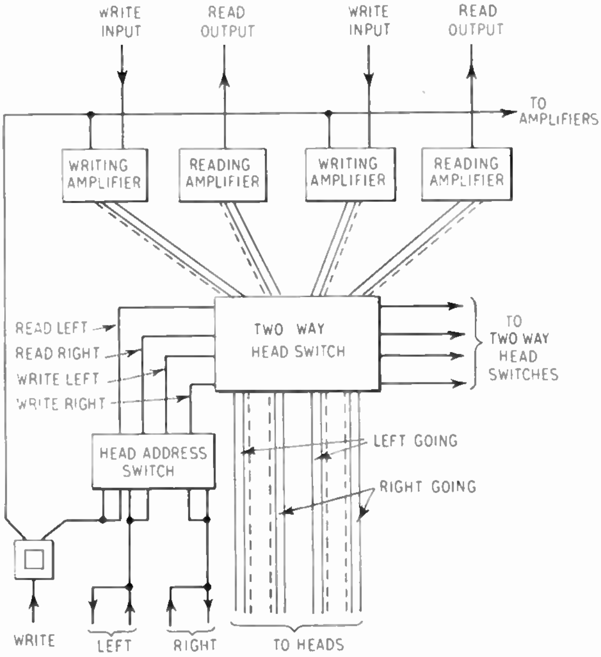


**Fig. 17.** Basic read/write system.

and two OR circuits, they can also carry writing amplifiers, reading amplifiers monostable and bistable elements, reshapers, squarers, relay drivers, etc.

In the logical circuits so far given, the elements which have been used are shown in Fig. 18 together with their functions.

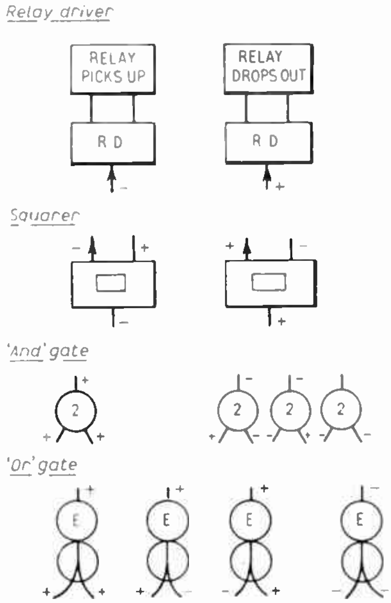


**Fig. 18.** Basic logical elements.

Standard levels of +3V and −3V are used for interconnection of functions. Power rails are fixed at +20, +3, 0, −3, −20 volts, the +20 and −20 volt supplies being unstabilized and the +3V and −3V stabilized with transistor shunt stabilizer panels. The reference voltages for the stabilizers are obtained from Zener diodes.

The 220V 50 c/s a.c. supply to the transistor power units is stabilized and filtered from interference. Power to the rest of the tape unit is 400V three-phase 50 c/s a.c. and where 230V single phase is required this is taken between one phase and neutral. These supplies are filtered against interference and miniature circuit breakers are used as a safety precaution.

The tape unit is switched on and off by a 24V pulse, locally or remotely controlled.

## 6. Spools

These are special precision spools, designed to run accurately and be strong enough to withstand normal treatment without permanent bending. The material used is magnesium alloy to keep the moment of inertia as low as possible. Two diameters are in use on this tape unit, namely

10½ in. for 3,600 ft of 0·001 in. base tape or 2,400 ft of 0·0015 in. base tape.

9½ in. for 2,400 ft of 0·001 in. base tape.

The spool is securely held on the carrier by a simple quick action twist lock, which keeps the hub against the platform datum. This precision spool is interchangeable with those in use in the U.S.A.[19] Its prime function is to protect the tape at all times and ensure that, when unwinding, the tape is guided into the tape path of the machine in an accurate manner without misalignment. For this last reason the total nominal clearance between flange and tape is 0·030 in. Since the tape is also accurately guided onto the spool from the machine this is still a working clearance and the 0·090 in. spool flanges do not touch the tape and are amply strong enough to withstand handling (Fig. 19).

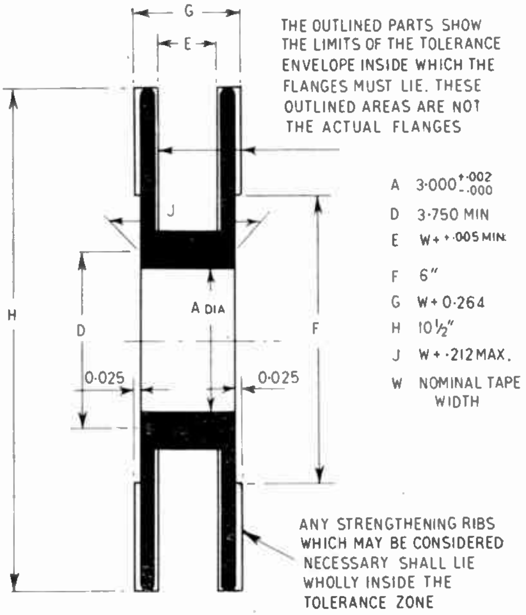


**Fig. 19.** Precision spool tolerances.

## 7. Conclusions

Two hundred inches per second is probably the highest tape speed actually in use with a computer. This basic design of tape handler will allow further exploitation in terms of speed. The other aspect of bit packing will depend on tape quality and durability. In this respect sandwich tapes are of particular interest, since they will allow "in contact" working without the penalty of severe wear of both tape and heads.

## 8. Acknowledgments

Permission and encouragement to present this paper have been given by the Directors of E.M.I. Electronics Limited.

It was the writer's pleasure and good fortune to lead a highly enthusiastic development team whose efforts brought about the completion of eight "first generation" prototypes within two years.

The writer has tried not to re-state what is available in current literature and wishes particularly to draw readers' attention to the paper entitled "Factors influencing the application of magnetic tape recording to digital computers" written by his colleague Mr. D. P. Franklin.[12]

**Fig. 20.** Prototype tape unit with lower doors removed.

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## 10. Appendix: Spool Drive Memory Logic (Fig. 21)

Take the case where the spools are at rest.

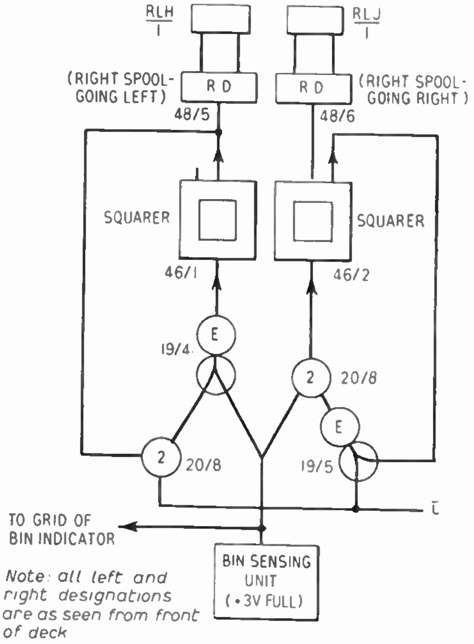
Two events can cause the motors to run:—

(a) A change on the left/right line.

(b) A change in the bin contents.

If (a) occurs, only (b) can cancel it and vice versa. During this process any reversions of the initiator signal are ignored until the complementary state is achieved.

For explanations of the logical symbols used in Figs. 15 and 20, see Fig. 18.



*Note: all left and right designations are as seen from front of deck*

**Fig. 21.** Spool drive memory.

# A Fast Start/Stop Machine for Handling Magnetic Tape †

*by*

W. C. R. WITHERS, ASSOCIATE MEMBER‡

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

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

**Summary :** Some of the requirements for a fast start/stop digital tape recorder are considered. A prototype machine is described, which operates with ½ in. wide tape at a speed of 100 in./sec., and has start and stop times of 3 millisec (to 90 per cent. of final value).

## 1. Introduction

### 1.1. *Requirement*

The fundamental requirement of a fast start/stop machine is to provide a high capacity store for a digital computer. Using a 10 kc/s signal at 100 in./sec on 3,600 ft of half-inch wide tape with return-to-zero signals working with the heads out of contact a total of three million bits is possible. By using read and write heads in contact with the tape and a 25 kc/s signal, a total of about fifteen million bits is possible.

Having written a block of digits of from one to four inches long on the tape, it may be necessary to reverse the tape motion rapidly and to check the accuracy of the information just recorded by reading it back into the computer. For this reason it is necessary to have two capstans rotating in opposite directions with some means of rapid engagement so that the checking process can be carried out with the minimum waste of time and tape. A tape brake is also necessary to stop the tape while it waits for the arrival of the next block of information from the computer. Since the acceleration imparted to the tape is extremely high (of the order of 300 *g*) and since the inertia of a spool of half inch tape is high, some form of reservoir or tape store must be provided between the capstan assembly and the spools of tape. In the machine to be described the reservoirs consist of a pair of metal tubes 4 ft in length into which the tape is drawn by means of suction. Error detectors at the centre of each reservoir are used to control spool servo motors which in turn drive tape into or extract tape from the reservoirs according to the direction in which the tape is being driven by the capstans.

### 1.2. *Control*

The machine is switched on in the "stop" state by applying a.c. mains to a control line from the computer. The equipment is so arranged that if this control line is broken it will unload all tape on to the left hand spool before disconnecting itself from the mains.

The operation of the pinch rollers, tape brake and rewind is effected by means of pulses from the computer.

Local control is available to the operator who can, by means of push buttons :

(i) STOP the machine;

(ii) LOAD the machine with tape from either spool;

(iii) UNLOAD the machine in either direction (i.e. run all the tape off at high speed on to either spool.)

For test purposes a set of controls is available to an engineer enabling him to control the operation of the machine in place of the computer.

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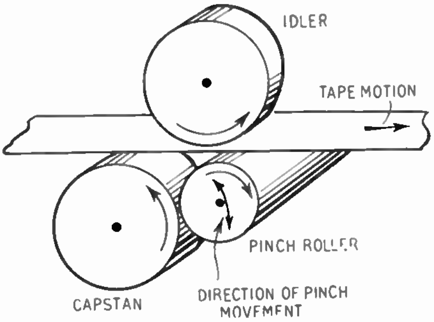
U.D.C. No. 621.395.625.3 : 681.142.

The engineer is also able to operate a number of marginal checks so that failure of any of the control electronics, power supply, lamps, etc., may be anticipated as far as possible.

## 2. Detailed Description of the Machine

### 2.1. *The Capstan Drive System*

In order to get the tape up to speed quickly the capstan, pinch roller and idler (see Fig. 1) are all continuously driven, so that energy has only to be imparted to the short length of tape lying across the tape guide bridge. The capstan is driven from a synchronous motor at 1,500 rev/min. via a flexible coupling and flywheel. The pinch roller is rubber covered and is driven by friction from the capstan. The idler is driven by means of a rubber-tyred pulley wheel at, or very near to, the speed of the capstan.



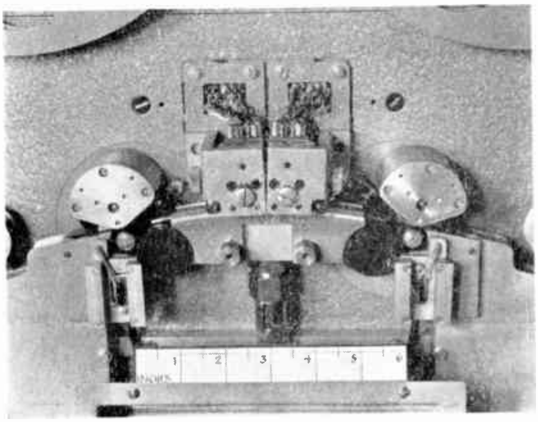


Fig. 1. Capstan system.

To drive the tape an electro-magnetic actuator moves the pinch roller up radially about the capstan centre and pinches the tape against the idler. The pinch roller compresses slightly and thus imparts drive to the tape. An important feature of the design is the angle between idler and capstan centres referred to the pinch roller centre. This is arranged so that once the actuator moves the pinch roller into engagement with the tape the rotation of the capstan provides a wedging action tending to hold the pinch roller in against the tape. In this way the pinch roller only strikes the tape with a force of one pound—considerably less than that required in a direct pinch system design—and drives it at a speed of 100 in./sec.

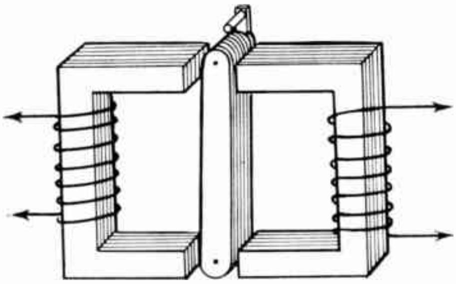


Fig. 2. Pinch roller actuator.

### 2.2. *The Actuator*

The actuator is shown in Fig. 2 and the power transistor driving stage in Fig. 3. The power stages are driven from a trigger circuit controlled by the computer, so that the actuator is always powered "in" or "out". The pin on the armature of the actuator rotates a collar which is concentric with the capstan driving shaft. An arm on the collar carries the pinch roller which moves round the capstan in order to drive the tape, as already shown in Fig. 1.

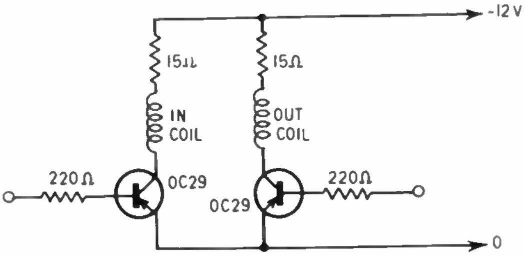


Fig. 3. Actuator driving stage.

### 2.3. *The Tape Brake*

The tape brake consists of two rubber rollers mounted above the tape guide block, one on either side of the read/write heads. The actuator is similar to that used for operating the pinch rollers. When the tape brake is to be applied the actuator "in" coil is energized and the tape brakes press the tape against the tape guide block (see Fig. 4). The tape brakes are coupled to their actuator by small links.

### 2.4. *The Tape Control Unit*

Figure 5 shows the block diagram of a tape control system. The circuit is direct coupled throughout so that it can be operated either from pulses of greater than 25 microseconds or from direct voltages, provided that they exceed +10 volts in amplitude.

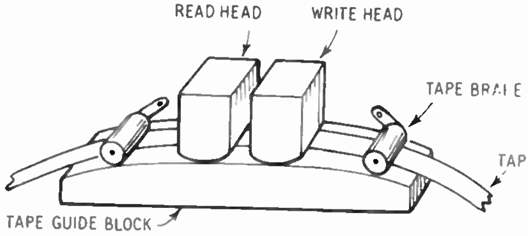


**Fig. 4.** Tape brake.

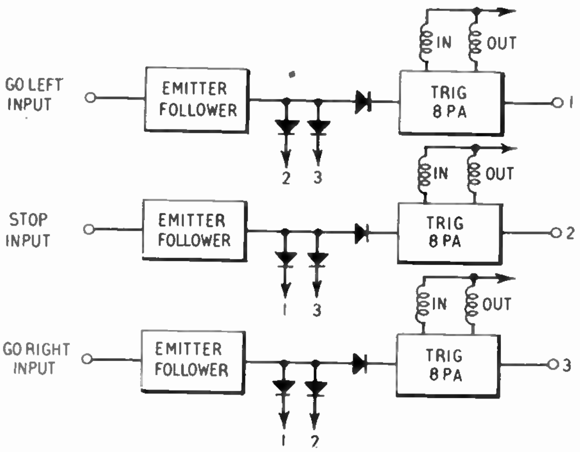


**Fig. 5.** Tape control unit block diagram.

One of the three identical circuits is shown in Fig. 6. VT1 is an emitter follower and is normally bottomed by means of R1 so that the anode of D1 is normally held one volt negative and is cut off. On receipt of a positive pulse of greater than 10 volts VT1 is switched off, the anode of D1 goes positive, transistor VT3 is switched off and VT4 switched on (transistor VT3 and VT4 forming an Eccles-Jordan trigger circuit). The collector of VT3 goes negative passing base current from the power transistor VT2 turning it on and passing 1·6 amps through the "in" coil of the solenoid, operating that actuator. At the same time VT4 of the other two units is switched off thus passing 1·6 amps through the "out" coils of the remaining pair of actuators and cancelling any previous command.

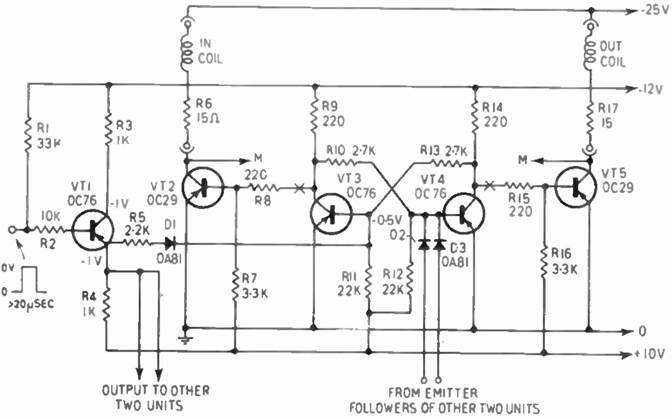


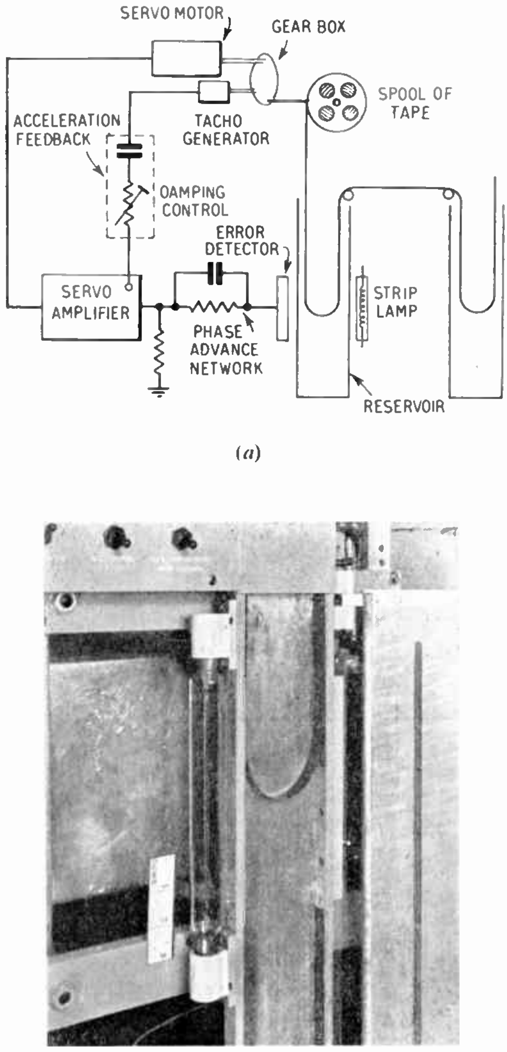
**Fig. 6.** Tape control unit circuit diagram.

Using the system described the following times are obtained:

(a) Start time (time taken from the issue of a command until the tape is up to 90% of its final speed)—3 millisec.

(b) Stop time (time taken for speed to fall to 10% of its initial value)—2 millisec.

(c) Reverse time (time taken from full speed in one direction to 90% of full speed in the opposite direction)—6 millisec.



(*a*)

(*b*)

Fig. 7. (a) Servo system; (b) Tape reservoir.

## 3. The Spooling Drive System

The servo controlled spool drive system has been briefly mentioned in the Introduction and is shown in Fig. 7.

In order to keep the tape reservoirs half filled with tape a proportional servo system is used, the servo motor being a 100-W d.c. model. A substantially constant armature current of 3 amps is provided by a metal rectifier and 48 microfarads capacitor fed from the a.c. mains supply (Fig. 8).

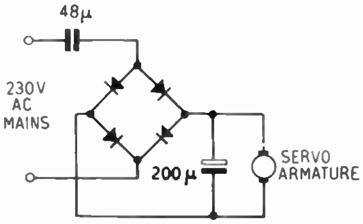


Fig. 8. Servo armature supply.

The field coils are specially wound for operation from a transistor amplifier which is shown in Fig. 9.

### 3.1. *Operation during a 100 in/sec. Capstan Tape Demand (Fig. 9)*

The amplifier supplies a push-pull output of up to 0·5 amps into either of the servo motor field windings. The output stage consists of a balanced pair of OC28 transistors, VT2 and VT3, driven from a "long tailed" pair VT1 and VT4. The error signal derived from the photo-transistor error detector is passed through a phase advance network C3, R11, R12 in order to feed an error plus error-rate signal to the amplifier input. Since the signal provided by the error detector varies between 0 and −12 V a balancing −6 V signal is provided by R1 and R2. This is necessary to ensure that the servo keeps the error detector only half covered with tape. The emitter resistor common to VT1 and VT4 is selected to provide a satisfactory amplifier balance with the error detector half covered. For additional stability a tacho generator is coupled to the servo gearbox and a capacitor C1 is used to provide acceleration feedback to the base of transistor VT1. The preset control RV1 is used to set the damping of the servo system. Acceleration rather than velocity feedback is necessary here to eliminate the velocity following error which would otherwise exist on demand for a continuous supply of tape by the capstan system.

In order to run the tape from one spool to the other without using the pinch roller drive (loading and unloading) the servo system on one side is connected so as to provide a constant speed drive. For spooling tape to the right, for example, the right-hand servo tacho generator is connected to provide speed control, while the reservoir error detector is disconnected. The left-hand servo system functions normally to maintain a loop of tape in the reservoir. When the operator presses the UNLOAD button the right-hand servo runs slowly for about 5 sec to allow the tape to be drawn from the reservoir. After this period RLJ (Fig. 9) operates, connecting a larger speed controlling signal into the servo amplifier. The servo system is arranged to speed up gradually to avoid snatching all the tape out of the reservoir on the trailing side. On detecting the left-hand end of tape mark, the spooling process is slowed down to allow the tape end to pass slowly through the machine. When both end of tape detectors are exposed the machine reverts to the STOP state (see below).

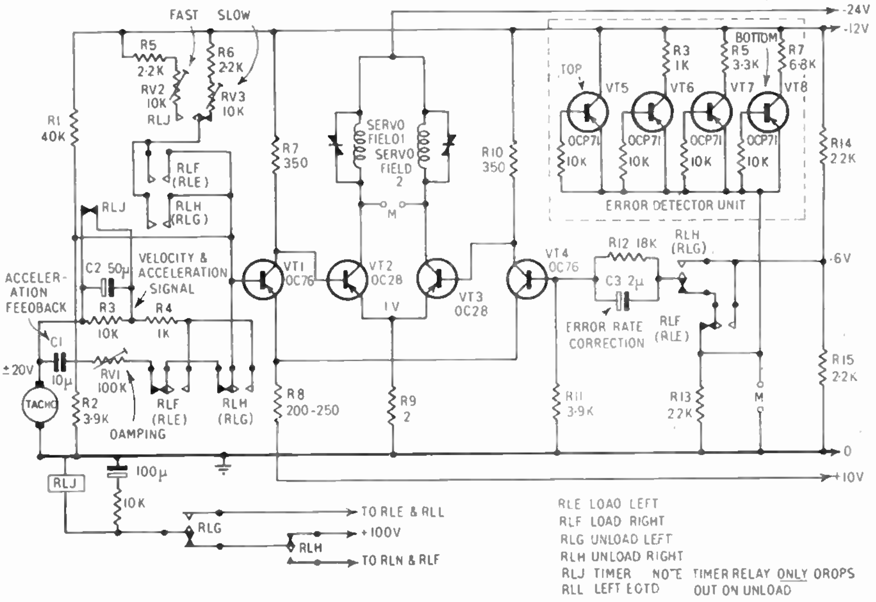


**Fig. 9.** Servo amplifier circuit. (The relay contacts used in the left-hand servo amplifier are shown in brackets.)

### 3.2. *The Servo Error Detectors*

The servo error detectors consist of four photo-transistors mounted in an aluminium block, 6½ in. long, which acts as a heat sink. The error detector is mounted on one side of the tape reservoir and a 30 W 25 V strip lamp is mounted on the other side (Fig. 7). A perspex window on each side allows light to pass from the lamp to the error detector. Reference to the circuit diagram of Fig. 9 shows the way in which the photo-transistors are connected. The photo-transistors feed current into an emitter resistor common to all four. Suppose the error detector is obscured from the strip lamp by tape, as tape is withdrawn from the reservoir the photo-transistors are uncovered one at a time starting with the bottom one. The collector resistors are so arranged that as each photo-transistor "bottoms" on being uncovered the voltage developed across the common load resistor (R13) increases by 3 volts, reaching a maximum of almost −12 volts. It might be

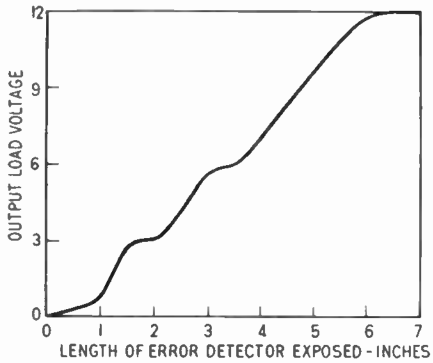


**Fig. 10.** Graph of error detector output.

thought that the output from the error detector would consist of four discrete steps but this is not so since the reservoir is 3½ in. wide and the amount of light falling on the photo-transistors does not change very abruptly. A graph of the voltage actually developed across R13 is shown in Fig. 10. Photo-transistors were used because of their rapid response and large output.

### 4. End of Tape Detection

Twenty feet from each end of the tape a length of tape of approximately one inch is cleared of oxide. Two "end of tape" detecting stations are provided, one each side of the head assembly. Each end of tape detector consists of a pillar lamp above the tape and a photo-transistor mounted below the tape. The photo-transistors are connected to a transistor relay operating unit.

When the machine is to be threaded with tape the operator presses the STOP button and opens the tape compartment door, disconnecting the capstan and servo motors from their supply. The operator then places a new spool of tape on the right-hand spool of the machine and presses the LOAD LEFT button which releases the spool brakes allowing the machine to be threaded with tape. On closing the tape compartment door the machine runs tape slowly through as for spooling until the end of tape mark is sensed by the left-hand end of tape detector. When this happens the left-hand servo fills the reservoir with tape. The machine is then automatically switched into REMOTE and the computer is signalled that the tape unit is awaiting control signals.

When nearly all the tape has been processed the right-hand end of tape mark is sensed at the right-hand station and the computer is signalled that this has occurred. If the computer fails to apply the tape brake the machine does so itself when the right-hand end of tape mark appears at the left-hand end of tape station.

The end of tape detectors have one other important function and that is during rewind. When the machine is being controlled by the computer (remote phase) and has partly processed the spool of tape it may be required to rewind all the tape on to the right-hand side. To do this the computer emits a 100 microsec pulse, a relay is operated in the tape machine causing it to empty the right-hand reservoir and speed up as for spooling. However, when the *left-hand* end of tape mark passes the *right-hand* end of tape detector the machine is reversed until the mark is sensed by the left-hand detector, when the left-hand reservoir is refilled with tape and the computer signalled that the machine is ready for further service, i.e. the machine goes into the REMOTE state.

The circuit of one end of tape detector is shown in Fig. 11. The detector has to operate at tape speeds of 5 in./sec., 100 in./sec. and 200-300 in./sec. during loading, running and unloading (spooling) respectively. With a one inch length of cleared tape as an end of tape mark this gives pulses of 200 millisec, 10 millisec and 3-5 millisec duration, and in addition these pulses all have different rise times associated with them. In order to operate a relay from any one of these inputs for a fixed period of 100 millisec a level sensing and time delay circuit is used.

The photo-transistor is illuminated from a distance of about ¼ in. so no lens system is necessary. On a passage of the end of tape mark an output of −12 volts is obtained from the photo-transistor. To allow for any d.c. zero drift this signal is a.c.-coupled to the "Schmitt trigger" circuit VT1 and VT2. When the input signal passes through approximately −2 V the trigger is operated producing a positive going output. This signal is fed via C2 to VT3, the first transistor in a "flip flop" circuit. The signal turns off VT3 which in its turn switches on VT4. VT4 powers the relay in for about 100 millisec by which time C3 has discharged sufficiently to allow VT3 to come back on again, the circuit then having reverted to its initial state. Under high speed spooling conditions "hold in" contacts on the relay are used to earth the collector of VT4, holding the relay in and causing the machine to run the last 20 ft. of tape out slowly to avoid damage.

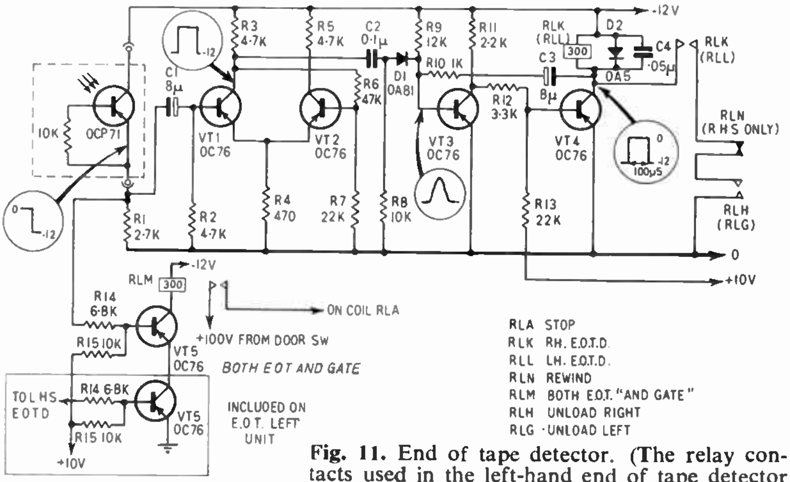


**Fig. 11.** End of tape detector. (The relay contacts used in the left-hand end of tape detector are shown in brackets.)

4.1. *Both End of Tape Detector* "AND *Gate*"

As mentioned before, if both end of tape detectors are exposed simultaneously due to a break in the tape or to running all the tape out of the machine a transistor "AND gate" is used to operate a relay putting the machine on STOP. This circuit is also shown in Fig. 11.

### 5. Fifty-microsecond Pulse Generators

When the machine switches from LOCAL to REMOTE a pair of contacts operate the pulse generator shown in Fig. 12, signalling the computer that operation under computer control may commence. An identical pulse generator is operated when the machine is running under computer control and the right-hand end of tape mark passes under the right-hand end of tape detector: this signals the computer to apply the tape brake.

### 6. Rewind Circuit

In order to initiate the rewind operation it is necessary to operate a relay from a 50-microsecond pulse from the computer. This is accomplished by means of the circuit shown in Fig. 13. An emitter follower VT1 is used to operate a trigger circuit VT2, VT3 similar to the one used to operate the pinch roller actuators. Transistor VT4 is used to actuate relay RLN which sets the conditions for rewind to commence. On completion of the fast rewind operation the machine reverts to "REMOTE" when RLB connects a 25-microfarad capacitor part way up the collector load of VT2. This momentarily removes its collector supply voltage which re-sets the trigger and hence RLN.

### 7. Spool Interlock

Each spool carries a special handle coloured red or green. In making a recording a spool of unused tape has a red handle attached and is fitted to the right-hand side of the machine. An empty spool with a green handle is fitted to the left-hand side. A micro-switch with a star

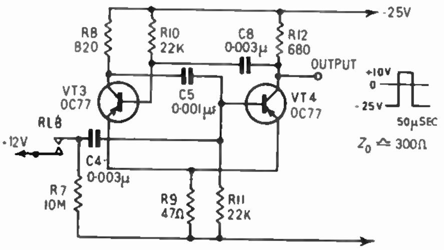


**Fig. 12.** 50 microsecond pulse generator.

wheel attachment is mounted behind the spool hub of both spools. These are based on the N.A.B. spool but have additional holes in them to allow attachment of the spool handle. The red handles have three pins set at a diameter of 4¼ in. and the green ones three pins on a 3⅞ in. diameter. The pins project through the hub when the spool is mounted and when rotating during threading of the machine set the star wheel in either of two positions by means of the pins projecting from the spool handle. Rotation of the spool after the micro-switch has been set has no further effect; thus only a red handled spool allows writing currents to be switched on. Fitting green handled spools to either side of the machine lights green lamps beside the appropriate spool. The spool interlock is shown in Fig. 14.

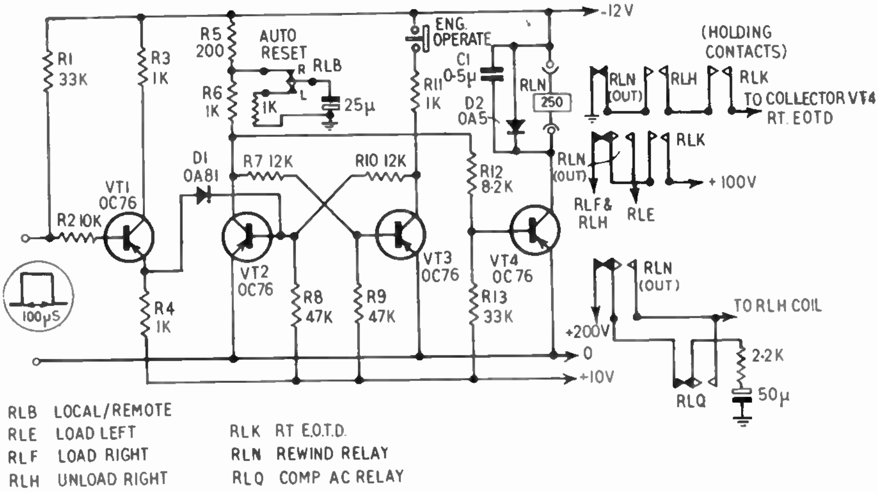


**Fig. 13.** Rewind circuit.

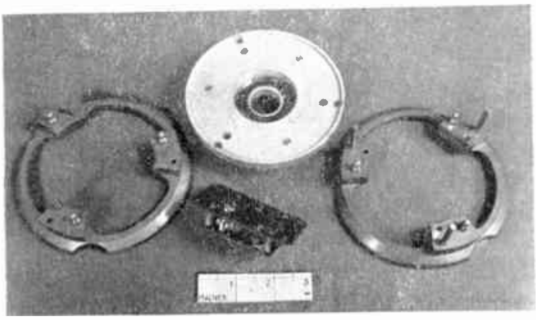


**Fig. 14.** Spool interlock.

## 8. Checking Facilities

The engineer has various facilities available to him on his own control panel. These are:

(i) Independent fuses for all the power supply units.

(ii) A LOCAL/REMOTE switch to disconnect the machine from the computer control lines and to control the machine by means of push buttons in order to test the performance of the machine. Push buttons make the machine GO LEFT, GO RIGHT (engaging the appropriate pinch roller) and REWIND by setting the rewind controlling trigger circuit.

(iii) A tape compartment door interlock override switch to run the machine with the tape compartment door open.

(iv) A computer a.c. control line override switch to simulate a shut down of the computer, which it will be remembered causes the machine to unload all the tape on to the left hand spool before disconnecting itself from the mains supply.

(v) Lamp dimming push buttons to allow a marginal test to be carried out on the performance of:

  (a) The servo system with reduced error detector illumination.
  (b) The end of tape detectors—also with reduced illumination.

(vi) Metering facilities for all the supply voltages for checking and for setting up (see also (ix) below).

(vii) Metering the output of the servo amplifiers and actuator trigger circuit power amplifiers (as explained in (ix) below).

(viii) Metering the tacho generator outputs during LOADING (slow run) and UNLOADING (fast run) to allow setting of the correct spooling speed and to check that these speeds are maintained during service.

(ix) The meter is 0–100 microamp with an internal metal rectifier so that the deflection is in the same direction regardless of the polarity of the voltage connected to it. This is particularly useful in checking the trigger circuits and servo amplifiers where the meter is connected from collector to collector of the power output stages. It will read correctly regardless of which stage is cut off and which is bottomed. All the meter series resistors were chosen to give half-scale deflection at the correct applied voltage so that the engineer has only to note readings which deviate from half scale by more than ±5 per cent.

## 9. The Relay Unit

### 9.1. *Control Relays*

One chassis houses all the relays and contactors for the machine. The relays, actuated by the operator's push buttons, are of the "remanent" pattern† and are so arranged that operation of one relay re-sets any relay which may already be engaged, as shown in Fig. 15.

Each relay carries two coils wound on a remanent core. Energizing one coil magnetizes the core which pulls the relay armature in and operates the set of contacts. At the same time the release coils are operated by 100 volts connected to the re-set line via a metal rectifier, demagnetizing the cores of any relays previously operated.

The STOP relay is also of the remanent pattern and since it is operated when the machine is switched off it will remain operated, setting the machine to STOP when the supply is reconnected.

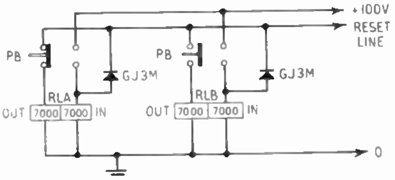


Fig. 15. Remanent relay system.

### 9.2. *Protective Devices*

In order to protect the machine from power supply failures each power supply unit has a relay across its output to switch the machine into the STOP state should a unit fail. The spool brakes are arranged to operate on removal of their supply (fail safe). The lamps for the end of tape detectors and the servo error detectors are provided with series relays which also put the machine on STOP if a lamp fails.

## 10. The Transistor Control Unit

The transistor circuits which control the machine are mounted on plug-in circuit boards and are accessible from the back of the machine.

## 11. The Power Supply Unit

This unit is accessible from the rear of the machine and carries the power supplies for the transistor unit, servos, relays, and lamps.

## 12. Read and Write Heads

The reading and writing heads provide eight tracks on half inch wide tape. Both heads are on adjustable mountings to permit alignment of the tracks on reading and writing and also from machine to machine. The heads are mounted a nominal 0·001 in. away from the upper surface (oxide) of the tape to give out-of-contact operation. One advantage of this is the reduced head wear obtained. A disadvantage, however,

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† "The Design of Remanent Relays" (The Telephone Manufacturing Co. Ltd., London, 1959).

is the tendency of the tape to 'flutter' beneath the heads, particularly just after engagement of the pinch roller. To minimize this effect air is drawn through a series of small holes in the tape guide block beneath the heads pulling the tape down on to the guide. One blower unit is used to do this, to draw the tape into the reservoirs, and to cool the servo motors.

### 13. Electrostatic Attraction

Another effect which can be troublesome in a machine of this kind is the electrostatic attraction set up between the tape, the sides of the tape reservoir and the tape guide block due to a frictionally induced charge on the tape. It was not found possible to eliminate the attraction so instead the frictional force necessary to pull the tape along these surfaces was greatly reduced by lining the reservoir sides and the tape guide block with p.t.f.e. steel backed strips half an inch wide. A further reduction was obtained by placing two small rollers just inside the top of each reservoir—the tape then being drawn down inside in the form of a long loop touching the sides of the reservoirs only where the loop bulges out at the bottom. No further static trouble has been experienced.

### 14. Read and Write Amplifiers

Space is provided within the unit to allow for the fitting of customers' read and write amplifiers. Multi-way plugs and sockets are provided at the rear of the instrument for the connection of power supply, control lines, signal inputs and signal outputs. Transistor reading and writing amplifiers are being developed for the machine.

### 15. Acknowledgments

The author is most indebted to his colleagues at Data Recording Instrument Co. Ltd. for their valuable assistance in the development of this equipment and to the Director, Mr. C. Hardy, for his early suggestions of the mechanical system and also for permission to publish this paper.

# Some Engineering Aspects of Magnetic Tape System Design†

by

D. W. WILLIS, M.A.‡ and P. SKINNER, GRADUATE‡

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

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

**Summary:** The design of a digital magnetic tape system requires a detailed knowledge of many effects, some of which by their random and transient nature are difficult to evaluate. Proposals are made for the evaluation of many of these effects in terms of specific measurements on waveforms generated by standard tapes, rather than in terms of dimensional tolerances. Suitable standard tapes are defined in the appendices, together with description of some methods by which they might be prepared; some selected definitions of related terms are also given. By adopting the technique of worst-case design, specifications can be placed on the performance parameters of the system and its components, which are consistent with design for the standard of reliability demanded of modern data processing systems. Such a technique necessarily leads to a modest system specification. Some of the factors described can be removed from the system by proper design, and the method described permits such improvements to be evaluated. In general the system performance is limited ultimately by noise and by random mechanical effects.

## 1. Introduction

It is usual when recording digital information to make use of two discrete levels of magnetization, for example a change from positive to negative saturation indicates a binary one and a change from negative to positive saturation indicates a binary zero. Other methods are in use, and many are described in the literature§. In a typical case eight tracks are used simultaneously on half inch wide tape, each row of flux reversals across the tape representing digits of a particular character, as shown in Fig. 1. This implies that in order to interpret successfully the signals from the tape, it is necessary to preserve the phase of the signals during the writing and reading processes. The current trend is to operate at increased packing density to give not only increased storage capacity on each reel of tape but also increased data rate for a given tape speed. As the digit density is increased, the phase variation of the signals becomes an increasing fraction of the interval between digits,

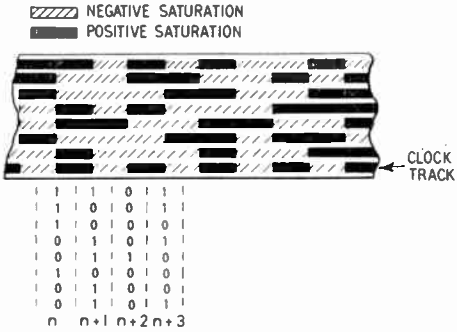

**Fig. 1.** Showing successive characters written across the tape.

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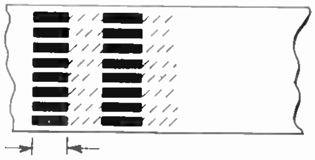
† Manuscript received 29th February 1960. (Paper No. 594.)

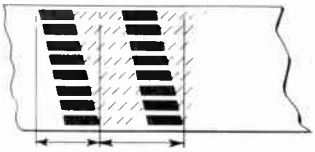
‡ Decca Radar Limited. Research Laboratory, Lyon Road. Walton-on-Thames, Surrey.

U.D.C. No. 621.395.625.3:681.142

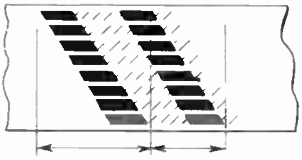
§ R. K. Richards, "Digital Computer Components and Circuits," pp. 314-336. (Van Nostrand, Princeton, New Jersey, 1957.)



CHARACTER WIDTH WITH NO PHASE DISPLACEMENT



DECREASED CHARACTER SEPARATION WITH PHASE DISPLACEMENT (SKEW)



OVER-LAPPING OF SUCCESSIVE CHARACTERS DUE TO INSUFFICIENT SEPARATION

Fig. 2. Effect of increasing digit density.

and ultimately the significance of each particular row of digits is lost (see Fig. 2).

Another important factor is noise, which in this context includes all extraneous signals. Since the reading system responds to changes of magnetic flux it is necessary to ensure that random flux changes at the head produce signals at the discriminator below a known threshold and are consequently ignored. It follows from this that the flux changes representing information must produce signals above this threshold. Thus the essential parameters of a successful digital recording system are the signal amplitude and the noise level, which describe the dynamic range, and the phase of signals on different tracks which together make up a character.

The degree of control that can be exerted over these factors determines the density at which digits may be spaced along the tape consistent with a given rate of error. The engineering problem is to obtain a realistic appreciation of the magnitude of the variation of these parameters in the circumstances in which operation is demanded.

For example it is relatively easy to assess the dynamic range and signal phase variation if a particular tape is always associated with a particular tape mechanism, reading and writing heads, and set of circuits. The problem becomes much more difficult where in a typical data handling system there may be tens of tape mechanisms and thousands of tapes, and complete interchangeability is demanded. Further it is an obvious advantage in the maintenance of a large system if heads and circuits can be interchanged.

In systems which typically handle pay roll and similar commercial accounting operations, absolute accuracy is demanded of the digital recording. This paper describes a method of worst-case design which determines the overall performance by assuming that all the components of the system are operating simultaneously at their most unfavourable extreme deviations from nominal performance. This method of design is thought to be essential if the standard of performance demanded is to be achieved.

## 2. A Typical Recording System

A typical digital recording and reading arrangement is shown in Fig. 3, in which the various components whose effects are to be discussed are identified.

The signals usually appear on several parallel channels corresponding to the number of tracks in use. They pass to the writing circuits, one to

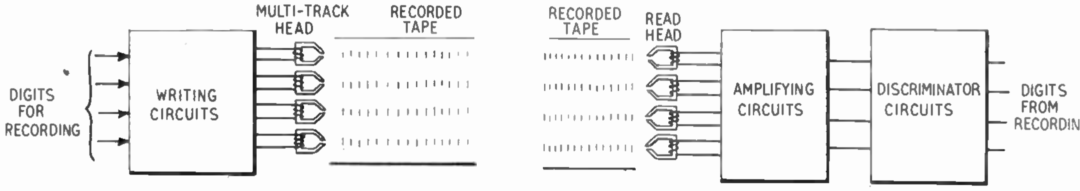


Fig. 3. A typical recording system.

each track, which convert the input signals into current signals to drive the recording head. A recorded tape is passed over a similar reading head, each track of which is connected to a reading amplifier. Here the signal level is raised to the level of a few volts and passed to the discriminator at the end of the chain. The discriminator applies certain criteria to the signal, for example that the signal must be greater than the threshold and have a particular phase with respect to a clock signal, and so decides whether the signal represents a one or a zero or noise.

Table 1 shows how the signal amplitude, the noise level and the signal phase can be influenced by the components of the recording system.

## 3. Determination of the Minimum Signal Amplitude

### 3.1. *Drop-outs*

Imperfections in the magnetic coating reduce the signal amplitude, and dust particles can have a similar effect by momentarily separating the head from the tape.† Tapes are commonly supplied tested to be free of drop-outs below 50 per cent. of the reference signal level; this implies of course that allowance must be made for some signals to fall to 50 per cent. of the reference level.

### 3.2. *Mean Average Level*

There will be a variation in the average signal level between tapes due to variations in the magnetic oxide dispersion. Another factor encountered in out-of-contact systems is the variation in head to tape spacing caused by overall thickness tolerances.

A typical figure for mean average level variation would be +30 −10 per cent. of the reference level.

It should be noted however that the mean average level does not enter directly into the

**Table 1**

| | PULSE AMPLITUDE | NOISE LEVEL | PULSE PHASE |
|---|---|---|---|
| TAPE | Drop outs<br>Mean average level | Drop ins | Signal displacement |
| TRANSPORT | Dynamic registration variation | Dynamic registration noise | Dynamic skew |
| | Static registration variation | Static registration noise | Static skew |
| HEADS | Amplitude scatter<br>Overwriting noise<br>Writing crosstalk<br>Reading crosstalk<br>Read/write crosstalk | Overwriting noise<br>Writing crosstalk<br>Reading crosstalk<br>Read/write crosstalk | Static skew<br>Reading phase error<br>Writing phase error |
| CIRCUITS | Gain stability | Gain stability<br>Thermal noise<br>Hum<br>Interference | Amplifier delay variation<br>Discriminator phase variation<br>Logical time variation |
| PULSE PACKING DENSITY | Pulse crowding<br>Shrinkage | | Pulse crowding |

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† C. D. Mee, "Magnetic tape for data recording," *Proc. Instn Elect. Engrs,* **105B**, pp. 373-382, July 1958.

consideration of minimum signal amplitude since the drop-out performance is defined in terms of the reference level and not with respect to the average signal level of the tape in use. The mean average level tolerance will indicate the margin between the actual signal level and the drop-out signal level.

### 3.3. *Dynamic Variation*

The tape speed variations caused by the transport mechanism can be measured by observing the minimum signal amplitude when playing back the *sensitivity calibrating tape,* T.5 (Appendix 1).

Movement of the tape sideways under the head due to variations in the path of the tape can be measured by using the *dynamic registration amplitude calibrating tape,* T.2, and noting the minimum signal over the length of tape.

### 3.4. *Static Registration Variation*

Variations of amplitude due to the transport and not due to the tape motion are caused by registration errors in the recorded tracks of information. The effect is caused by either or both the reading and writing tracks not being in the nominal positions with respect to the guide datum of the mechanism. It is not easy to separate the static and random variations if a calibrating tape is used. A more satisfactory method is to use the mechanical tolerances of track width and position with respect to the guide datum, and to compute the static registration variation from the known relation between track displacement and signal reduction. The *static registration calibrating tape,* T.6, is used in a system in which an adjustment is provided for registration.

### 3.5. *Head Effects*

There are several effects which may cause unwanted flux changes in the head. If they produce components in phase with the signal. the amplitude is increased, and if the components are out of phase, the signal amplitude is reduced.

Thus there may be residual signals on the tape, caused by imperfect erasure of previously recorded information, occurring coherently with new information. The electromagnetic interaction between various tracks within the head can give rise to cross-talk both when writing and when reading; these cross-talk signals are usually synchronous with the information signal. The interaction occurring when the writing head induces signals into the reading head, is synchronous.

### 3.6. *Amplitude Scatter*

Reading heads in particular usually vary in sensitivity, and it is common practice to use an attenuator pad to bring the sensitivity of each track down to that of the least sensitive track expected. Such a pad often has finite steps and so on allowance is made for the variation in sensitivity even after compensation.

### 3.7. *Gain Stability*

On account of the threshold concept introduced earlier, it is necessary that the amplifiers used between the reading head and the discriminator have a known gain. Head signals are usually in the millivolt range and the discriminator will require a level of several volts. Because a bandwidth of some 50 kc/s is required, several stages of amplification are used and gain stabilization by negative feedback is necessary. Further, the amplifier is usually a plug-in replaceable item and ideally the gain should not require adjustment for any particular channel. The gain variation between amplifiers should allow for drift, component ageing, change in heater and high tension supplies and so on.

### 3.8. *Pulse Crowding*

If the longitudinal packing density is increased, the magnetic cells formed on the tape ultimately interact and the signal amplitude is reduced as a result of self-demagnetization. This effect can give rise to variation in amplitude depending upon the information pattern.

When the increase in packing density is produced by recording on a low-speed limit transport, the effect is known as shrinkage. It is even more marked if data is read from a high-speed transport giving an artificially high data rate and then recorded directly on to a slow-speed machine, without being re-clocked to achieve the nominal signal rate.

### 3.9. *The Minimum Playback Signal Amplitude*

It is now necessary to evaluate the minimum amplitude of signals at the discriminator resulting from the erasing of previously recorded information on that track, and the recording of the most unfavourable combination of signals on the other tracks.

The effects of dynamic registration variation will be operative both in the recording and in the playback process, as will also the effects of static registration variation if a tape is played back on a different transport or head; for this reason these effects must be taken into account twice.

Supposing the reference signal level measured at the discriminator, is $V$ volts, and the following effects are measured as fractions of the reference signal level:

Fractional reduction due to drop-outs $= A$
Fractional reduction due to dynamic registration variation $= B$
Fractional reduction due to static registration variation $= C$
Noise contribution due to residual signals from the tape $= x$
Noise contribution due to extraneous signals $= y$
Fractional reduction due to amplitude scatter $= D$
Fractional reduction due to amplifier gain variation $= E$
Fractional reduction due to pulse crowding effect $= F$

The minimum signal at the head derived from the tape is

$$VA\ (B^2 \cdot C^2 \cdot F - x)$$

The minimum signal entering the amplifier is therefore

$$V\,[A\ (B^2 \cdot C^2 \cdot F - x) - y]$$

and the minimum playback signal amplitude is given by

$$V_n = V\ [A\ (B^2 \cdot C^2 \cdot F - x) - y]\ D.\ E.$$

It will be seen when the factors contributing to noise are developed, that in terms of factors listed in section 4.9:

$$x = 2b + 2c + d + e$$
$$y = f + g + h$$

## 4. Determination of the Maximum Noise Level

### 4.1. *Drop-ins*

In most systems of digital representation the tape is saturated over relatively long lengths, for example in the system described if the data is a series of zeros. The same imperfections in the tape that cause drop-outs give rise to non-uniform fields at the surface of the tape leading to spurious pulse signals known as drop-ins. Tapes are commonly supplied with noise signals of this nature below a specified level.

### 4.2. *Registration Noise*

Variations in registration between the track on the tape and the head give residual signals due to failure to erase previously written data. Similarly constant registration errors due to mechanical tolerances in the position of the head mounting datum and the mean path of the tape produce the static noise signal. The *dynamic registration noise calibrating tape,* T.3, may be used to evaluate the dynamic effect and a similar proportional method to that used for the signal variation is used for determining the maximum static noise level.

### 4.3. *Overwriting Noise*

This is due to failure to saturate the tape adequately when recording new information over previously recorded signals. It is measured by overwriting with a normal width track recording head and reading the residual signal with a reading head of specially narrow track-width, and scaling the results to the reading track-width in use. This precaution is necessary to eliminate dynamic and static registration effects.

### 4.4. *Writing Cross Talk*

This describes the interaction between tracks in a writing head. The effect is usually small if saturation techniques are used. The writing cross-talk in a particular track is taken as that value under the worst combination of signals on all other tracks.

### 4.5. *Reading Cross Talk*

There is usually some coupling between tracks in the reading head and this produces cross-talk when the other tracks in the head are reading information. Again it is necessary to find the maximum value of the cross-talk, under various combinations of signals from the other tracks.

### 4.6. *Read/Write Cross-talk*

It is not uncommon to be reading from the tape for the purpose of checking while the writing head is recording new data. On account of the very large difference between the recording field from the write head and the field strength from the tape, such an arrangement almost inevitably leads to spurious signals being induced in the read head.

### 4.7. *Gain Stability*

The same considerations apply here as for the signal amplitude. The amplifier channel gain directly affects the discriminating level, although since the amplifier is substantially linear, the dynamic range is not affected. Thus an increase in gain will increase the magnitude of all signals including the noise, and can make the noise level approach the discriminator level.

### 4.8. *Thermal Noise, Hum and Interference*

These factors are well known and it is only necessary to point out that in determining the maximum interference level, it is necessary to ensure that all pieces of equipment that can produce interference have in fact been included.

### 4.9. *The Maximum Playback Noise Level*

It is also necessary to evaluate the maximum noise level which may appear at the discriminator. Unlike the case of the signal, most of the factors contributing to the noise level are additive and not multiplicative.

Again the effects of dynamic and static registration variation will be operative both in the recording and in the playback process and must be taken into account twice.

Noise contribution due to drop-ins $= a$
Noise contribution due to dynamic registration variation $= b$
Noise contribution due to static registration variation $= c$
Noise contribution due to overwriting noise $= d$
Noise contribution due to writing cross-talk $= e$
Noise contribution due to reading cross-talk $= f$
Noise contribution due to read/write cross-talk $= g$
Fractional increase due to amplifier gain variation $= E$
Noise contribution from thermal noise, hum, interference $= h$

Thus the maximum playback noise level is

$$V_n = V\,(a+2b+2c+d+e+f+g+h)\,E$$

### 4.10 *The Significance of the Minimum Signal and the Maximum Noise Level*

It is now possible to formulate the first requirement for a successful magnetic tape recording system.

This is $V_s > V_n$

## 5. Determination of the Maximum Playback Phase Displacement

### 5.1. *Signal Displacement*

It has been seen that imperfections in the coating of the tape can lead to the generation of spurious flux patterns at the surface, which induce voltages in the play-back head. These imperfections have already been taken account of in their effects on signal amplitude and noise, but their presence in the neighbourhood of authentic flux changes may lead to a change in the shape of the induced voltages and a displacement in the time at which the discriminator is actuated.

### 5.2. *Dynamic Random Skew*

Variations in the path of the tape from the mean path produce time displacements between signals from the various tracks. The effect is measured with the *dynamic skew calibrating tape*, T.4, by displaying signals from the track in question on a time-base started by a signal derived from a reference track. It is necessary to record the maximum deviation of the signal pulse throughout the length of the tape.

### 5.3. *Static Skew*

On account of mechanical tolerances and setting up errors in the head mount, the mounting plane locating the head may not be parallel to the mean path of the tape. The *static skew calibrating tape* is used to evaluate the magnitude of this effect.

### 5.4. *Track Scatter*

The gaps in a particular head may not be in line, so even although the azimuth of the head is reduced to zero, there will be a phase error between signals from different tracks.

Another cause of phase error in a reading head is the variation in the gap-width. To a first order of approximation the head will write about the trailing edge of the gap and read about the centre of the gap, giving a read-to-write variation equivalent to half the gap width tolerance.

The effect for a write head is defined as the *writing phase error*, and for the read head as the *reading phase error* (see Appendix 2, 3.4 and

### 5.5. *Amplifier Delay Variation*

This describes the phase delay variation in the read signal channel. In a gain stabilized amplifier the effect is usually small.

### 5.6. *Discriminator Phase Variation*

This describes the accuracy with which the discriminator gives an output corresponding to the part of the waveform which represents the position of flux reversal. For example, with an amplitude discriminator, the phase variation of the output is a function of the signal amplitude. since the signal has a finite rise-time. In the case of a peak-detector, the phase variation is much less for change in input amplitude, but must still be taken into account.

### 5.7. *Logical Time Variations*

Once the discriminator circuit has determined that a particular signal represents a digit, this information is usually staticized in a bi-stable or similar circuit. It is then examined by a narrow strobe pulse derived from the clock channel when all the digits of a particular character have arrived. The timing of this pulse is initiated by one or more signals from the tape and is synchronized with the main clock pulses of the central computer. The variation of the time interval in this synchronizing process must be accounted for.

### 5.8. *Pulse Crowding*

The bandwidth of the recording system is determined by such characteristics as the magnetic properties of the tape, the effective gap-width of the head and the degree of contact between head and tape. Bandwidth restriction leads to interaction between neighbouring flux reversals on the tape, and when the digit interval approaches the pulse width, the interaction causes displacements in phase as well as in amplitude, which are dependent on the pulse pattern.

### 5.9. *Evaluation of the Maximum Playback Phase Variation*

The effects of dynamic skew will be operative both in the recording and in the playback process, as will also the effects of static skew if a tape is played back on a different transport or head; for this reason these effects must be taken into account twice.

The maximum playback phase variation $T_p$ is therefore the sum of the following effects:

Tape signal displacement $= t_1$
Dynamic skew $= t_2$
Static skew $= t_3$
Reading phase error $= t_4$
Writing phase error $= t_5$
Amplifier delay variation $= t_6$
Discriminator phase variation $= t_7$
Logical time variation $= t_8$
Pulse crowding variation $= t_9$

So $T_p = t_1 + 2t_2 + 2t_3 + t_4 + t_5 + t_6 + t_7 + t_8 + t_9$.

The significance of the *maximum playback phase variation* will be clear from Fig. 2 which shows that if the packing density results in a pulse displacement which approaches $2T_p$ then the significance of digits in a particular character will be lost.

## 6. Conclusions

It has been shown that the design of a digital magnetic tape system is a formidable task in that it requires a detailed knowledge of many effects, some of which by their random and transient nature are difficult to evaluate. Proposals are made for the evaluation of many of these effects in terms of specific measurements on waveforms generated by standard tapes, rather than in terms of dimensional tolerances, which

o

are sometimes difficult to interpret. Suitable standard tapes are defined in the appendices, together with description of some methods by which they might be prepared; some selected definitions of related terms are also given.

By adopting the technique of worst-case design, specifications can be placed on the performance parameters of the system and its components, which are consistent with design for the standard of reliability demand of modern data processing systems. Such a technique necessarily leads to a system specification which at first appears modest against the performance obtainable from any single component, for example the resolving power of a typical head. Some of the factors described can be tuned out of the system by proper design, and the method described permits such improvements to be evaluated. In general the system performance is limited ultimately by noise and by random mechanical effects.

## 7. Acknowledgment

The authors are pleased to make acknowledgments to the Board of Directors of Decca Radar Limited for permission to publish this paper.

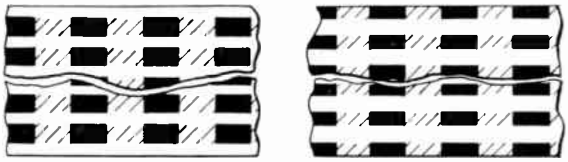
## 8. Appendix 1:
## Definition of Standard Tapes

T.1 *Guiding calibrating tape* is a tape or set of tapes chosen to give rise to the worst conditions of guiding, which may be expected on a transport to a given specification.

T.2 *Dynamic registration amplitude calibrating tape* is a drop-out free *guiding calibrating tape* which is erased with an alternating field and then recorded at nominal density on all tracks in positions displaced from the nominal by an amount just greater than the dynamic registration variation.

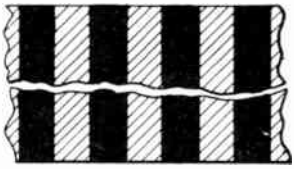
T.3 *Dynamic registration noise calibrating tape* is a *guiding calibrating tape* which has been recorded at nominal density across its full width, and then erased with an alternating demagnetizing field on all tracks in positions displaced from the nominal by an amount just greater than the dynamic registration variation.

T.4 *Dynamic skew calibrating tape* is a *guiding calibrating tape* recorded at nominal density on all tracks.



DYNAMIC REGISTRATION AMPLITUDE CALIBRATING TAPE

STATIC REGISTRATION CALIBRATING TAPE



SENSITIVITY CALIBRATING TAPE

Fig. 4. Some calibrating tapes.

T.5 *Sensitivity calibrating tape* is a tape recorded at nominal density across its full width, the mean average signal level of which is known in relation to the reference signal level.

T.6 *Static registration calibrating tape* is a tape of nominal dimensions which has been recorded at nominal density across its full width, and then erased with an alternating demagnetizing field on all tracks in their nominal positions.

T.7 *Static skew calibrating tape* is a tape of nominal dimensions recorded at nominal density on all tracks such that the points of maximum rate of change of surface induction lie on lines perpendicular to the mean path of the tape.

T.7.1 *Mean path of the tape* is the direction in which the tape is moving at times when the relative time displacement between the peaks of simultaneously recorded pulses has a value equal to the arithmetic mean of its peak values.

## 9. Appendix 2:
## Selected Definitions of Recording Parameters

1.1 *Mean average level* is the average peak value of pulse amplitude measured over 100 pulses played back from a track recorded with pulses at nominal density, measured in proportion to the reference signal level.

1.2 *Drop-out level* is the amplitude of the smallest pulse played back from a tape recorded with pulses at nominal density on all tracks, measured in proportion to the reference signal level.

1.3 *Drop-in level* is the amplitude of the largest spurious signal obtained from a tape which has been subjected to a unidirectional saturating field, measured in proportion to the reference signal level.

2.1 *Maximum dynamic registration amplitude variation* is the maximum peak-to-peak variation of mean average level measured at the output of a calibrated amplifier exhibited by a *dynamic registration amplitude calibrating tape.*

2.2 *Maximum dynamic registration noise amplitude* is the maximum peak-to-peak variation of mean average level of noise measured at the output of a calibrated amplifier exhibited by a *dynamic registration noise calibrating tape.*

2.3 *Maximum dynamic skew* is the maximum variation of relative time displacement between the pulses played back from different tracks of a *dynamic skew calibrating tape.*

3.1 *Minimum playback amplitude* is the minimum amplitude level measured at the output of a calibrated amplifier resulting from the erasing of a previously recorded signal on that track, and the recording of the most unfavourable combination of signals on the other tracks.

3.2 *Maximum playback noise* is the maximum noise level measured at the output of a calibrated amplifier resulting from the erasing of a previously recorded signal on that track, and the recording of the most unfavourable combination of signals on the other tracks.

3.3 *Maximum playback phase displacement* is the maximum time displacement between the peaks of simultaneously recorded signals on different tracks resulting from the most unfavourable combination of signals on all tracks.

3.4 *Reading phase error of head* is the time delay which must be added to the output of a head to bring the phase between that track and an outer track to zero when the reading azimuth of the head stack is zero.

3.5 *Writing phase error of head* is the time delay which must be added to the input of a head so that when a tape is recorded with simultaneous pulses on that track and an outer track with the reading azimuth of the head stack zero, the phase between pulses played back is the same as that from the *static skew calibrating tape.*

4.1 *Azimuth of head-stack* is the angle through which the head stack must be rotated in order to reduce the phase between the outer tracks of the *static skew calibrating tape* to zero.

4.1.1 *Phase between tracks* is the arithmetic mean of the peak values of the relative time displacement between the peaks of simultaneously recorded pulses played back from two tracks.

4.2 *Gap scatter* is the sum of the absolute values of the largest negative and positive values of the reading and writing phase error of the tracks making up a stack.

## 10. Appendix 3:

## Some Proposals on Methods of Preparing Standard Tapes

T.1 *Guiding calibrating tape*

This tape is by definition the one tape or tapes out of all those which will ever be used on the set of transports used in the system, which exhibit the largest value of dynamic registration and skew effects. If it is desirable that any of a set of tapes to a given specification should be used, it is the worst tape or tapes which will pass through the acceptance test defined by the specification. At the present stage of development it is probably impossible to prepare a guiding calibrating tape with the certain knowledge that it has the required properties.

The technique proposed is that tapes should be selected or prepared which have limit values of those parameters which are thought to have an effect on the quality of guiding. Tapes selected should include for example one of minimum specified width, one of maximum specified width and one with the maximum permitted value of weave (or one selected which is especially bad in this respect). Because it is unlikely that the tapes selected will be the worst that will be encountered, it is advisable to add a standard figure to all measurements as a margin of safety to cover this difference.

T.2, T3 *Dynamic registration calibrating tapes*

The design of the dynamic registration tapes must take account of the fact that the output from the playback amplifier gives an indication of the magnitude of the registration displacement, but not of its sign. The method of recording the tracks in displaced positions removes the need for the precision recording in nominal positions the tape or set of tapes constituting the guiding calibrating tape. If recording in the nominal positions were used, twice the displayed variation would have to be taken into account, and if the displacement were non-symmetrical, this would be worse than the true figure. If the relationship of playback amplitude to the registration displacement is known, one dynamic registration calibrating tape would be required, when the displacement used would conveniently be half a track width.

The mean average level is used since the effects of drop-outs is thus minimized, it being assumed that the length of tape required for the recording of 100 pulses at nominal density is sufficiently short for there to be any substantial change in registration when the tape moves by this amount. The effects of drop-ins may be eliminated by the use of a.c. erase, except those due to permanently magnetized particles in the tape.

T.4 *Dynamic skew calibrating tape*

It should be noted that the phase of a tape can be measured in both magnitude and sign, so the absolute value of the phase with respect to the static skew calibrating tape is unimportant.

T.5 *Sensitivity calibrating tape*

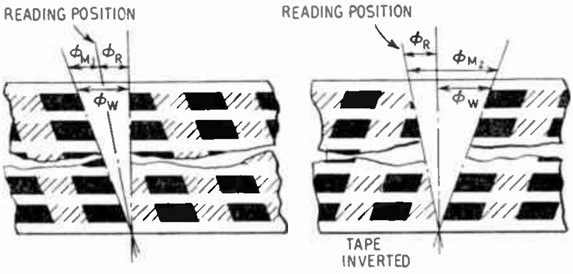
This is a tape recorded by a special head across the full width of the tape. The effects of registration errors may thus be separated out.

T.6 *Registration calibrating tape*

This tape is one selected to be good from the point of view of guiding and then recorded on a special transport constructed with the highest possible precision, and with the tracks in their nominal position. The effect of drop-ins is again eliminated by the use of erasure by means of an alternating field, and it should be noted that the technique for adjusting out registration errors becomes a null method.

T.7 *Static skew calibrating tape*

The task here is to record pulses across the tape such that the lines of the peaks lie perpendicular to the longitudinal axis of the tape. The proposed method makes use of the fact that the backing material currently available is sufficiently thin to allow the tapes to be played back upside down. If then a recording is assumed to be made with a perfect head (with no phase errors) then the tracks when replayed with the tape running in the normal manner, will be in phase. If now the tape is rotated about its transverse axis and replayed through the backing, the lines joining the peaks of pulses will now lie at an equal angle to the transverse axis of the tape, but of opposite sign. The phase of the playback signals now represents twice the error of the phase of the recording, and the head can be adjusted accordingly so that its azimuth is zero. The presence of writing and reading phase errors in the heads complicates the matter further, since it is not immediately obvious as to whether a phase error when the tape is being replayed in the same direction is due to a writing phase error or to a reading phase error. This can be resolved since in reading the tape in one direction the writing phase error, resulting in a displacement of the signal on the tape, is in the same direction as the reading phase error of the head, whereas in reading in the other direction, it is in opposition. Thus the required correction in writing phase corresponds to half the difference of the phase errors in each direction. This may be corrected initially by adjustment of the head in azimuth, and finally by the adjustment of electromagnetic delays on each track. The tape is now a correctly recorded static skew calibrating tape. The play-back should now show an equal phase error and of the same sign for replay in each direction. This residual is the reading phase error. (See Fig. 5.)



$\phi_W$ = WRITING PHASE ERROR

$\phi_R$ = READING PHASE ERROR

$\phi_{M_1}, \phi_{M_2}$ = MEASURED PHASE BETWEEN TRACKS

CORRECTION TO BE APPLIED TO RECORDING HEAD = $\phi = \frac{1}{2}[\phi_{M_1} + \phi_{M_2}]$

**Fig. 5.** Preparation of static skew calibrating tape.

# The Mechanical Considerations of Magnetic Recording Heads†

*by*

M. B. MARTIN, ASSOCIATE MEMBER ‡

*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 is confined to a discussion of the mechanical limits imposed on magnetic recording heads by the required performance specification. The performance criteria of a multi-track head are normally: sensitivity and the variation in sensitivity between tracks, the short wavelength response, high-frequency losses, bias sensitivity, and cross-talk between adjacent tracks. The manufacturing problems associated with multi-track heads are discussed in relation to the effects of mechanical variations on the head performance.

## 1. Introduction

One of the major problems which faces the designer of magnetic recording equipment is the manufacture of recording and reproducing heads to the mechanical standards made necessary by the performance demanded. The design of electromagnetic transducers for magnetic recording is largely a problem of manufacture, a situation brought about by the extreme accuracy required and small mechanical dimensions involved. It is hoped that this paper will have some interest to those who are engaged in the field of recording and help the users to understand why heads are so costly when the ultimate in performance is demanded.

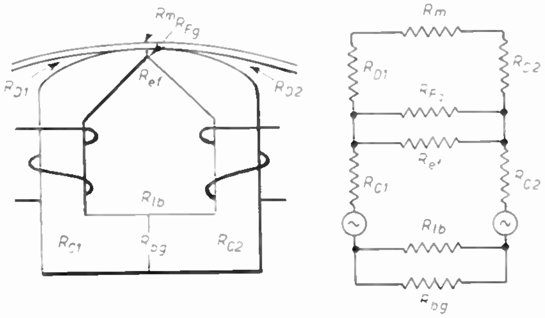


**Fig. 1.** Equivalent circuit of a recording head.

## 2. Recording Heads

### 2.1. *Sensitivity*

Figure 1 shows a simple equivalent circuit of a recording head.

$R_{C1}, R_{C2}$ = reluctance of the cores.

$R_{ef}$ = leakage reluctance of the front gap.

$R_{lb}$ = leakage reluctance of the back gap.

$R_{fg}$ = reluctance of the front gap.

$R_{bg}$ = reluctance of the back gap.

$R_{D1}, R_{D2}$ = reluctance of the path from head to tape.

$R_m$ = reluctance of the tape.

The reluctances external to the head, i.e. $R_{D1}$, $R_{D2}$ and $R_m$, are normally very large in comparison with the others which, with correctly annealed core material, are so low as to be negligible. The equivalent circuit shows that if this be the case, maximum sensitivity will be achieved when $R_{fg}$ and $R_{ef}$ are as high as possible and $R_{bg}$ is as low as possible. This is achieved by making the area of the back gap large compared with that of the front gap, and if the sensitivity of the head has to be within a tight tolerance—say 1 db—these areas have to be controlled accordingly.

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‡ Data Recording Instrument, 33 Woodthorpe Road, Ashford, Middlesex.

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In Fig. 2(a) the dimensions $d$ and $b$ are controlled by the lamination blanking tool and $s$ by the lamination stacking fixture. $b$ and $s$ will remain constant, but $d$ will be reduced by the grinding and lapping on the working face of the head, thus the final value of $R_{fg}$ is controlled by the amount of material removed in achieving a sharp, clean gap. Control of this dimension is simplified if the initial lamination shape is as shown in Fig. 2(b); this avoids $d$ being increased by lapping on the inside surface of the gap, otherwise an exact control of the amount of material removed in this operation would be necessary.

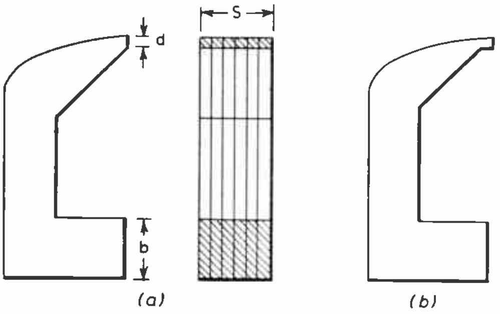

**Fig. 2.** Magnetic head lamination stack.

If the sensitivity of a recording head has to be controlled to ±1 db the reluctance of the front gap is the biggest single factor only if the other elements of the magnetic circuit can be ignored as stated above. To ensure this the areas $b \times s$ must meet exactly and the gap between them be accurately controlled. The dimension $s$ is determined by the track width and in the case of a 0·030 in. wide track can be controlled to ±0·0002 in. if necessary. The maximum value of $l$ is determined by the shortest wavelength to be recorded and the loss that can be tolerated due to the phase change of the recording signal in the time taken by an element of tape to pass over the recording gap. The minimum value of $d$ is determined by the expected useful life of the head, because this dimension will be reduced by wear causing the head sensitivity to increase to a maximum at the point where the head is worn out, i.e. $d = 0$. If the head is to be used for out of contact recording, for example recording on a drum, $d$ can be reduced to a few thousandths of an inch. If a life of two or three thousand hours running in contact is expected, $d$ must be somewhere in the region of 0·025 in. When this is the case a variation of ±0·0025 in. in $d$ will absorb the whole of a limit of ±1 db, in which case $l$ cannot be allowed to vary at all. In practice $d$ can be controlled to ±0·001 in. by the use of very accurate stacking fixtures and careful control of the amount of material removed in grinding and lapping the working face. This leaves approximately ±0·5 db to allow for the variations in gap length, windings, core reluctance and back gap reluctance. With correct annealing core reluctance can be ignored, careful assembly reduces variations in $R_{bg}$ to a very small amount, and the use of accurate spacer material allows $l$ to be controlled. Unfortunately, when dealing with foils of 0·001 in. thick and less, it is very difficult to obtain supplies controlled to much better than ±20 per cent. which is an impossibly wide variation for use as a gap spacer.

### 2.2. *Biasing Conditions*

The length of the recording gap must be such that the medium passes through several cycles of the bias frequency while crossing the gap: thus it is common for heads used only for recording to have gaps of 0·001 in. or greater. If the phase shift of the signal across the recording gap is of importance the gap length may be reduced to 0·0005 in. or even 0·00025 in. in which case the bias frequency may have to be raised. In order to minimize the losses due to capacitance and to keep the bias voltage down it is advisable to use a low impedance recording head wherever possible.

### 2.3. *Gap Irregularities*

The recording left on the medium depends on the shape of the trailing edge of the recording gap. This edge must be straight and free from irregularities caused by a poor lamination, burrs thrown up by the finishing process on the head face, rounding of the gap edge and spreading of the spacer material over the core. Burrs and "smeared" spacer can often be removed by "running in" on the tape, but this can only be effective if the basic gap formation is good. If it is required to record wavelengths of 0·0005 in. it is essential that the gap irregularities are kept to less than 50 microinches (the desirable figure is 5 microinches). In order to achieve this in the finished head the gap surface must be ground and lapped to an optical finish.

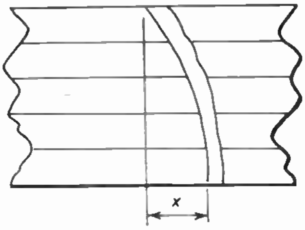

Fig. 3. Curved record head gap.

The straightness of the recording gap is of prime importance. The curvature of the gap should be such that $x$ in Fig. 3 is no greater than $\frac{1}{10}$th of the replay gap to be used, so that the phase shift across the gap and azimuth errors at the shortest wavelengths to be reproduced are negligible.

## 3. Reproducing Heads

### 3.1. *Sensitivity*

The equivalent circuit of a reproducing head (Fig. 4) is similar to that of the recording head, the recorded flux on the tape being represented by the generator in series with $R_m$. The conditions for the maximum flux through the core, and hence maximum voltage across the head

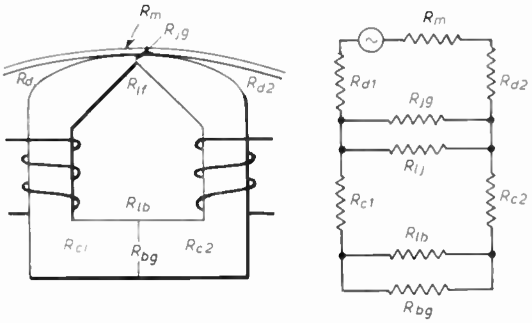

Fig. 4. Equivalent circuit of a replay head.

windings, are the same as those for the maximum sensitivity of a recording head. The overriding consideration in respect of the front gap length is the shortest wavelength that the head has to resolve which determines the reluctance of the gap for a given head life. As the sensitivity of the head is greater with a longer gap there is little point in using a gap shorter than necessary as the price paid in the loss of sensitivity is heavy.

### 3.2. *Short Wavelength Response*

It is a well known fact that the high frequency response of a replay head is limited by the effective length of the reproducing gap. This loss is given by the expression:

$$\text{gap loss} = 20 \log \left[ \frac{\sin (\pi\, l/\lambda)}{\pi\, l/\lambda} \right] \text{db}$$

where

$l$ = the effective gap length.
$\lambda$ = the wavelength of the recorded signal.

The gap length is determined by the gap spacer, the quality of the workmanship in forming the gap and the magnetic state of the poles immediately in the vicinity of the gap. For large gaps of 0·001 in. or greater the latter considerations become small: thus for a physical spacer of 0·001 in. it is reasonable to expect an effective gap of 0·0011 in. When the spacer is reduced to 0·00025 in. a typical effective gap is 0·00035 in. If the physical gap is 0·0001 in. the effective gap is often twice as great or more. With very careful lapping and a precise choice of gap spacer material it is possible to achieve smaller gaps, but the cost of doing so is prohibitive. In recent years the technique of vacuum deposition has been frequently used in achieving very thin gap spacers, physical gaps of 50-70 microinches having been made.

Figure 5 shows common forms of gap malformation.

Figure 5(a) represents a section through the gap showing rounding on the gap edges which can be caused by the spacer being softer than the pole pieces or by excessive finish lapping along the gap. As drawn the effective gap is about twice the spacer used, so if the spacer is 0·0002 in. the radius of the rounded corner is 0·0001 in. or less. It is desirable that this radius should be less than 10 microinches for such a gap and less than 5 microinches if the spacer is any thinner. A gap of this type must be "run in" before any equalization adjustments can be made as the performance of the head will improve as the poles wear down below the rounded corner.

Figure 5(b) shows a small portion of a gap where the edges of the poles are uneven. This can be caused by the edge crumbling or by scores on the inside face produced by lapping with too coarse or unclean grit. Ferrite cores exhibit crumbling to an extent that makes them unusable where very fine gaps are necessary. A ragged gap will not produce a sharp null when the recorded wavelength equals the effective gap length because the gap length is so variable. If the effective length of the gap is assumed to be the average the gap as drawn is nearly twice as long as the spacer is thick. In order to manufacture a good gap it is necessary that imperfections of this type are less than 1 per cent. or 2 per cent. of the spacer thickness—thus in the case of a gap of 0·00025 in. the flaws should be less than 2·5 microinches.

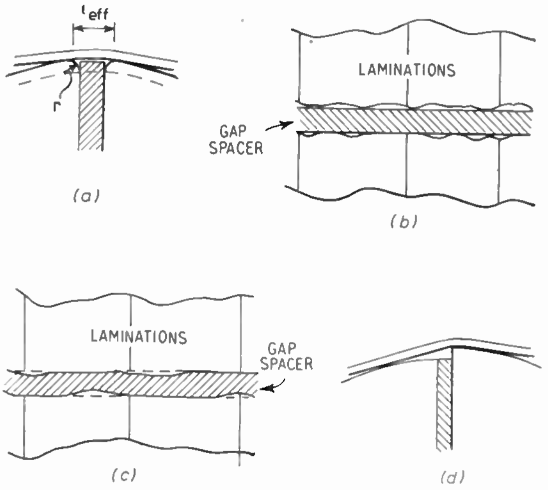

**Fig. 5.** Gap deformation.

The fault represented in Fig. 5(c) is the burring of the pole material over the gap spacer, usually caused by heavy lapping across the gap when the spacer is below the surface or when the spacer is friable or softer than the pole material.

Figure 5(d) exhibits a gap fault which gives poor short wavelength response. The step at the gap lifts the tape away from the opposite pole face thus causing a spacing loss. If the effective spacing is as small as 0·0001 in. the loss in output will be 5·5 db at a recorded wavelength of 0·001 in. Furthermore, if the step in the gap is 0·0001 in. for a physical gap of the same length the effective gap is increased to 0·00014 in.

Of all the problems of head manufacture, that of forming an accurate and small gap is probably the one which presents the most difficulty, and the labour involved in this operation represents a large part of the total cost of a head. Any grinding or lapping operations carried out on the pole faces must be controlled very carefully in order to avoid changing the magnetic properties of the material. If the tip is raised to local high temperatures by grinding or work hardened by physical distortion the permeability of the core is reduced locally, thus increasing the effective length of the gap.

### 3.3. *Azimuth*

If the replaying head gap is inaccurately "lined up" with the recorded signal the output is reduced by an amount given by:

$$\text{loss} = 30 \log \left[ \frac{\sin\left(\dfrac{\pi w \tan \alpha}{\lambda}\right)}{\dfrac{\pi w \tan \alpha}{\lambda}} \right] \text{db}$$

where

$w$ = width of the recorded track
$\alpha$ = angle of misalignment
$\lambda$ = recorded wavelength.

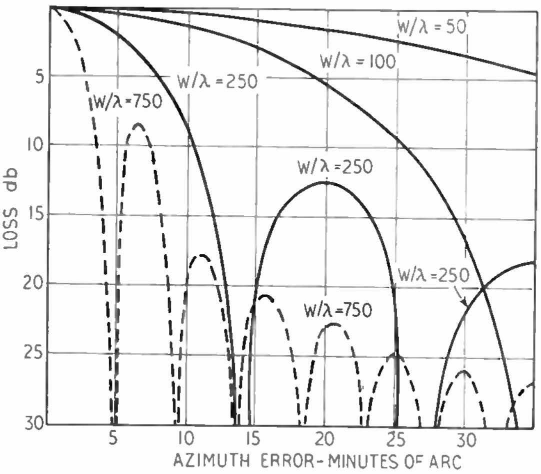

**Fig. 6.** Azimuth misalignment loss.

Figure 6 shows the losses plotted against $\alpha$ for different values of $w/\lambda$. From this it will be seen that a severe misalignment can align the head on a minor output peak.

If the gap is perfectly straight, azimuth loss is simply overcome by aligning the replay head to the recording head. If the gap is not straight this is not a simple matter; moreover when the head is set to give maximum output at the shortest wavelength there can be dips in the response curve at longer wavelengths, particularly if the record head has a gap curved in the opposite direction.

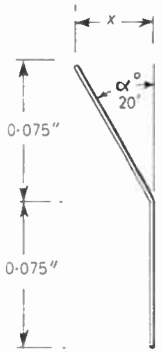

**Fig. 7.** Diagram representing gap azimuth errors.

For simplicity, consider a gap of the form shown in Fig. 7 where half the gap is at an angle of 20 min of arc to the other half. Such a gap will have two azimuth positions of equal output. Let us consider the case where one half is correctly in alignment and a wavelength where $w/\lambda = 100$ ($w$ here is half the total track width, i.e. 0·075 in.). The curve in Fig. 6 shows that the second half of the gap will have an output of half that of the other, thus the total output of the head is only three quarters of its correct output at a wavelength of 0·00075 in., which corresponds to 11,250 c/s at 7½ in./sec. In this example the dimension $x$ would be 0·0005 in., thus this end of the gap would be 240 deg out of phase with the correctly aligned half of this wavelength. A gap of this form is unlikely to occur in a single head, but it is quite likely that two tracks of a multi-track head could have this relationship.

### 3.4. *High Frequency Response*

The high frequency losses of a head are determined by the normal resistance, eddy-current and capacitance losses. A well-designed head having thin laminations which have been correctly annealed will have negligible losses up to a frequency of at least half a megacycle. The capacitance and resistance losses should also be negligible unless the head is wound with a large number of turns of fine wire.

### 3.5. *Long Wavelength Response*

When the recorded wavelengths become comparable with the pole length of the head or any screens or other leakage paths, the output of the head becomes modified. The response of a head designed without due regard for this effect can deviate from the 6 db per octave slope to a marked extent. These deviations are almost impossible to correct by circuitry, as can be seen from Fig. 8. Fortunately they can be avoided by careful head design.

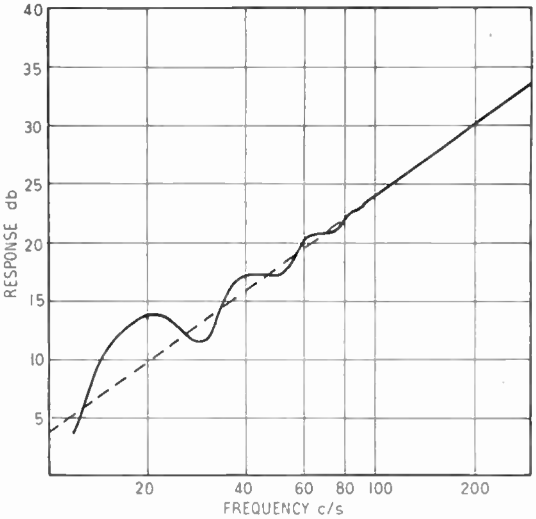

**Fig. 8.** Long wavelength deviation from normal response.

## 4. Multi-Track Heads

The problem of manufacture associated with all magnetic heads is magnified greatly when dealing with multi-track heads. In addition to the parameters discussed previously the designer now has to contend with cross-talk, the matching of performance between the units within a head and the physical positioning of the tracks in the head stack.

The sensitivity of an individual head is largely dependent on the depth of gap, as has been discussed. In order to maintain a close control on sensitivity the tracks have to be inserted in the main head body accurately in order to ensure that any further processes involving the removal of material from the front of the head results in all the tracks having as near an identical gap depth as possible. If the designed gap depth is 0·020 in. and an accuracy of 1 db is desired the manufacturing limits on this dimension can be no greater than ±0·002 in. It is not practical however to assume that the total sensitivity variation is due to this alone: normally one has to control to half this limit in order to achieve the desired result. Fortunately the grinding and lapping processes used on finishing the head face can be controlled to about ±0·0002 in. over a length of 1 in. leaving a tolerance of ±0·0008 in. which can be allowed for the less easily controlled job of siting the tracks in relation to each other and for variations in the stacking of laminations. These are not limits that can be casually accepted by any head manufacturer but they can be met by careful jig design and process control—at a price. It is therefore advisable for any prospective user to be certain that such a specification is necessary before laying it down—even a relaxation to ±1·5 db is worthwhile.

Another factor which affects sensitivity is the position of the replay head track in relation to the recorded track on the medium. If the replay track is misaligned with the recorded track by 10 per cent. of its total width a 1 db loss in output is the result. There is, therefore, little point in calling for tight limits on basic sensitivity and allowing the position of the head tracks in relation to the tape to vary. In an effort to overcome this difficulty it is accepted practice to record with a track width slightly greater than that of the replay head. This presents no difficulty in the case of the standard two tracks on ¼ in. tape where the record track is 0·110 in. wide and the replay head has tracks 0·090 in. wide. Multi-track heads are in common use with basic track widths of 0·020 in. and 0·030 in. i.e. five tracks and four tracks to a ¼ in. tape respectively. The recording widths for these heads are 0·024 in. and 0·034 in. which allows ±0·002 in. on track position assuming exact track widths. This means that each head, where separate recording and replaying heads are used, has a limit of ±0·001 in. on track position. Thus not only have the tracks to be within 0·001 in. in relation to each other but they have also to be within the same limit in relation to the mounting face of the head. The placing of head tracks to this accuracy over the length of a sixteen or twenty track head calls for a high degree of skill by the operators on any head machining or assembly operations which affect the track position.

In the ideal multi-track head the gaps are all perfectly in line in both azimuth and lateral positions. If the head is constructed by the stacking of a number of separate units it is possible for serious errors in alignment to be present in the final head. In considering azimuth errors earlier an example was used which was unrealistic for a single track head, but which could easily occur in the case of multi-units. An azimuth error that results in a variation of 6 db at a wavelength of 0·00075 in. is quite intolerable, and in practice the gaps must be within an angle of 5 min of arc of each other. This tolerance can be increased for tracks narrower than quoted and decreased for wider. It was also mentioned that the phase error produced at this wavelength by a gap displacement of 0·0005 in. was 240 deg which is far too great for any serious data analysis involving recording at this order of wavelength. If an allowable error of 20 deg in phase is acceptable the limit on gap displacement becomes about 42 micro-inches.

The problems of lining the gaps up to the necessary limits is largely overcome by making the heads in two halves as shown in Fig. 9. The two gap faces can then be optically lapped flat to an extremely high degree of accuracy. This method of construction is to be preferred, although it has its own difficulties but these are more easily solved than those associated with the stacking of separate tracks.

It is possible for heads made in two halves to exhibit "bow" along their length, as represented in Fig. 10. This can be caused by uneven

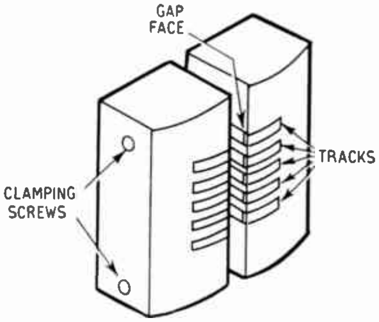

**Fig. 9.** Block type of multi-track head.

pressure by the clamping screws and by variation in thickness of the spacer material along the gap length. A variable bow can be caused by uneven thermal expansion of the materials used in the construction of the head. If the bow is of the form shown in Fig. 10 the gaps in the centre of the head will have a different effective length from those at the ends, so a gap intended to be 0·00025 in. is varied by a large percentage by a bow of as little as 0·0001 in. over an inch length, thus varying response and sensitivity.

The cross-talk performance of a multi-track head is largely out of the hands of a head production unit, and may therefore be considered to be outside the scope of this paper. The difficulties associated with the intertrack screens are purely the matters of placing the necessarily small components in position during assembly, and the tolerances on the thickness of commercially available screen materials.

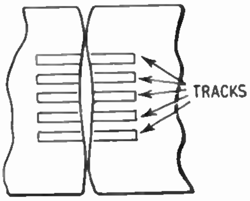

**Fig. 10.** Bowing of gap surfaces.

## 5. Acknowledgments

In conclusion the author wishes to thank Mr. C. Hardy, Director of the Data Recording Instrument Co. Ltd., for permission to publish this paper, and for his help in compiling it.

## 6. References

1. Otto Kornei, "Structure and performance of magnetic transducer heads," *J. Audio Engng Soc.*, **1**, p. 225, July 1953.
2. W. K. Westmijze, "Studies on magnetic recording," *Philips Research Reports*, **8**, pp. 148-57, 161-83, April and June 1953.
3. S. J. Begun, "Magnetic Recording." Chap. 4, p. 87 (Rinehart, New York, 1949).

# DISCUSSION
## on
# "Magnetic Recording Techniques"

**Mr. C. P. Gerrard:** In his paper† Dr. Noble derives an expression which contains the following variables: *the packing density, the discrimination level* and *the goodness factor.* The equation obtained gives *the number of drop-outs per unit length* at a function of these three variables, thus allowing a user to predict for a given reel of tape, the probable number of drop-outs for the different packing densities and discrimination levels, providing that he knows the goodness factor. The author also mentioned that he thought a high proportion of the drop-outs were due to nodules in the base material, pushing the tape away from the head and causing subsequent loss of signal.

In fairness to the author it must be admitted that he realistically took the view that perfect tapes would never be produced, and that it would always be a question of quoting an error probability figure. However, I would like to point out that the only point of interest to the user is the number of errors that his particular system of checking will allow to pass undetected. (The checking system used, and other relevant details could be supplied to the tape manufacturers, for study.) Errors due to nodules may well affect a group of digits, and in this case it is important to have a probability figure quoted, against a particular kind or group of errors, rather than the overall error figure used by Dr. Noble.

Now, as the tape must be tested at a particular *discrimination level* and *packing density* in order to establish the *goodness factor,* then it might be feasible to arrange for additional checks to be carried out. A separate checking channel could reject a tape if any two tracks gave a drop-out of more than say 10 per cent., during the same digit period (assuming the normal drop-out to be 50 per cent.). Tests for failures on longitudinally adjacent digits might be carried out by doing a special test run on higher packing densities than would normally be encountered.

In short, I feel that the information presented is not complete, in that it does not allow the designer to have absolute confidence in his checking or error correcting circuits, because of compensating errors occurring when a cluster of digits are altered to a nodule. I do think, however, that this might to a large extent be overcome by means of some additional tape testing by the manufacturer.

**Dr. R. Noble** (*in reply*): I would like to thank Mr. Gerrard for his comments and acknowledge that his point of view is essentially correct. When the work on drop-outs was undertaken most error correction seemed to consist of rewriting a complete information block, if the replay of a previous attempt to record it did not tally with the version held temporarily in a buffer store. Since, under these conditions, a drop-out of any kind would cause the rejection of the whole block of information, the overall error figure adopted seemed a reasonable criterion for assessing tapes. For many computers now in use the proposed method of assessment would be satisfactory. For the newer computers however, and from the point of view of the computer designer, the advent of error detecting and error correcting codes suggests that Mr. Gerrard's requirement of more information of a somewhat different nature has much to recommend it.

With regard to the occurrence of simultaneous drop-outs on adjacent tracks, my experience is that with present-day tapes, track-widths and track spacings, this type of error is a very rare one and not very important. With the decrease in track-spacing which the future will almost certainly bring however, this point of view may rapidly become untenable.

On the other hand, errors in longitudinally-adjacent digits are of immediate interest, and information on the number of pulses lost per drop-out would be useful. Some consolation is to be had from the fact that under typical operating conditions, over the past two years, the average number of pulses lost per drop-out has decreased from about 10 or 12 to about 2 or 3, a figure which many of the proposed codes seem able to handle. As pulse packing densities increase the situation will become worse once more and tapes will have to improve to meet the greater demand.

In general I feel that while the proposed testing method leaves something to be desired, it provides a start and in spite of shortcomings it does in actual practice permit tape grading in batches.

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† R. Noble, "The assessment of the reliability of magnetic tape for data processing," pp. 737-742 (October 1960).

Experience with a new testing machine built since the paper was written has shown that those tapes for which the overall drop-out counts are low are also those tapes in which the drop-outs are physically small. In other words when the overall drop-out count is low, the average number of pulses lost per drop-out is also low.

Experimental work is at present being undertaken along the lines suggested by Mr. Gerrard and I hope to have the continued opportunity to pursue the subject. I feel that it may be possible to arrive at a quality factor based on the probabilities of undesirable combinations of errors, but more experimental work is needed first. Whatever testing methods are developed, I feel that they should be relatively simple and of the widest possible application since behind them all will be the constant necessity to maintain the cost of computer tape at a reasonable level.

**Dr. B. J. Steptoe:** I would be interested to know from Mr. Harrison† whether his high speed tape deck has shown trouble due to electrostatic charging of magnetic tape hindering the starting process. This difficulty is reported in the paper by Mr. Willis.

**Mr. H. M. Harrison** (*in reply*): Difficulty was experienced in starting after a long stop period due to static attraction between the tape and the bridge, which was at that time smooth. Reducing the surface area in contact with the tape by putting grooves both on the bridge and on the sides of the bins greatly reduced this effect. The final cure was found to lie in coating the bin sides with p.t.f.e. We have reason to believe that the p.t.f.e. very gradually transfers and becomes deposited over all the tape bearing surfaces, and on the tape backing.

We also experienced difficulty which was due to static, in the form of sideways tilting of the tape in the bins. This of course can be disastrous if the tilt is not straightened out. The mechanism of this tilting was the adhesion of the electrostatically-charged edge of the tape to the glass front of the bins. Further filling of the bin tilted the tape edge remote from the glass.

The cure was to spoil the good "line contact" between the tape edge and front plate of the bin, by substituting resin bonded fibreglass sheet with an embossed pattern on its surface. It was necessary, of course, to perforate the sheet both in order to see the tape in the bin and to allow air to escape from between the folds of the tape.

**Mr. J. R. Herbert:** It is a common practice to record data on magnetic tape in blocks of about 80-100 characters, both for convenience in addressing and storing information from punched cards. This means that it is always the same portions of the tape, immediately in front of or behind each block, which are subjected to the high stresses required for rapid acceleration.

Under these circumstances it would be interesting to know if there is any evidence of excessive deformation occurring at these critical points, and whether, in particular, tape materials are known to exhibit a characteristic analogous to fatigue failure.

**Mr. H. M. Harrison** (*in reply*): This particular tape handler is used with the EMIDEC 2400 Computer. The block lengths here can vary from a few inches to a few feet in length and are not predetermined by block markers. We therefore have had no indication here of strain of the kind envisaged by Mr. Herbert.

With the EMIDEC 1100 Computer, however, the system employs fixed pre-marked blocks some two inches long. This computer uses the Ampex FR 300 tape handler which is pinch-roller driven. The accelerations imparted to the 1 in. wide tape are of similar order to those encountered in the vacuum-driven machine. It is true to say that we have had no indication of any deformation occurring or anything analogous to fatigue failure.

Mylar-based tape is extremely tough and resilient and the most significant observation we have made is that the magnetic heads wear off the oxide coating until the tracks become transparent. At this stage of course the tape is literally worn out as far as recording goes but not as far as the base itself is concerned. The yield point of 1 in. wide 0·001 in. base Mylar is 14 lb.; the tension produced by the tape handlers when accelerating is no more than 2 lb. approximately.

**Mr. W. C. R. Withers** (*in reply*): We have carried out a limited number of tests on tape stretch in which the machine was arranged to start 300,000 times from the same place on the tape: no tape stretch could, however, be detected. It would seem that this is not a problem provided the tension on the tape is kept low.

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† H. M. Harrison, "The development of a high-performance tape handler," pp. 841-56.

# THE SOUTH WESTERN SECTION'S CONVENTION

## "Aviation Electronics and its Industrial Applications"

The South Western Section of the Institution opened its 1960-61 session with a two-day Convention on "Aviation Electronics and its Industrial Applications." The Convention was held at the Bristol College of Science and Technology on 7th and 8th October, and was attended by some 70 full-time registered delegates: part-time attendances raised the peak audience to nearly 120.

The Convention was opened by the Principal of the College, Mr. G. H. Moore, M.Sc., F.P.S., F.R.I.C., who welcomed the Institution and the delegates to the College. The General Secretary, Mr. G. D. Clifford, then read a message from the President of the Institution, Professor E. E. Zepler, who was unfortunately unable to attend on account of illness. On behalf of the Section Committee, Mr. Clifford then invited Captain A. J. B. Naish, M.A., R.N. (Member) to take the Chair for the morning session.

In the first paper "System Engineering in Theory and Practice," the authors (M. James, Dip.El., M.Brit.I.R.E., and G. S. Evans, A.M.Brit.I.R.E.), discussed the functions of the systems engineer both in the aircraft and in the process industry and the applications of computers in solving system engineering problems. This was followed by a paper on "Spark Machining" by G. V. Smith, B.Sc. The second half of the morning session was devoted to circuit applications and papers were read by J. Evans, B.Sc., D. A. Gill, B.Sc., and B. R. Moffitt, B.Sc. (on Symmetrical Transistors) and by P. M. Thompson, M.A. (Graduate) on the "Tunnel Diode and its Applications."

At the afternoon session the Chair was taken by Mr. R. O. R. Chisholm, Chairman of the South Western Section Committee. The proceedings opened with a paper on the numerical control of machine tools by K. J. Coppin, B.Sc., A.R.C.S., (Associate Member) followed by a description of "Cavalcade" an analogue/digital converting system, by G. Henderson, M.A. After the tea interval, Dr. R. Cooper, B.Sc., Ph.D., in a paper on brain recordings discussed electroencephalograms made by pilots of high-speed aircraft during operational flights. Mr. G. B. Kent, B.Sc. (Associate Member) then described a high-speed graph plotter and the afternoon session concluded with a paper on "Analogue-Digital Computing Methods" by J. Archibald, B.Sc. (presented in the author's absence through illness by Messrs. T. E. Ivall and K. Firth).

For the final session of the Convention, the Chairman was Mr. H. H. Harper, Chairman of the Convention Sub-Committee. The general theme of the papers was predominantly analogue computing and its applications in the fields of simulation and flight control. The session was opened by Mr. C. Snowdon with a paper in which he described the use of electronic simulation techniques in the design of an automatic flight control system for aircraft and an auto-stabilizing system for v.t.o.l. aircraft. Mr. J. A. Plowman (Associate Member), in his paper "Electronic Flight Control" described an automatic attitude and height stabilization system for helicopters. Mr. T. V. Lawson discussed wind-tunnel simulation and flutter measurement, illustrating his lecture with a short film. By way of contrast, the subject of the paper read by Mr. W. A. Havranek dealt with an analogue computer for reactor engineering. The final paper of the Convention, "Microwave Thickness Measurement of Dielectrics" was presented by D. Whistlecroft, B.Sc., and described a technique evolved primarily for testing radomes.

An informal dinner was held on Friday, 7th October, under the presidency of Professor Emrys Williams, Ph.D. (a Vice-President of the Institution) at which the South Western Section entertained a number of distinguished guests, including the Principal of the College, Mr. G. H. Moore, Dr. A. E. Russell, C.B.E., D.Sc., F.R.Ae.S., F.I.Ae.S., Captain A. J. B. Naish, M.A., R.N., senior members of the College staff and the authors of papers.

An important feature of the Convention was an exhibition of electronic instruments held in rooms adjoining the lecture theatre. This provided both exhibitors and authors with an opportunity of demonstrating equipment to delegates, and also enabled delegates to have a pre-view of current developments in related fields. The exhibition was extremely well attended and proved to be a popular venue for informal discussions.

The South Western Section is deeply indebted to the Governors and Principal of the Bristol College of Science and Technology for permitting the use of the College and its admirable facilities which contributed so materially to the success of the Convention. The co-operation received from the University of Bristol, The Burden Neurological Institute, the Services and industrial organizations, also must be gratefully acknowledged.

G. F. N. K.

### The Convention Exhibition

Among the exhibits which featured equipment described in the papers, the demonstration of the eight-channel transistorized electro-encephalograph recorder for airborne "high g" work and the associated waveform analyser developed by the Burden Neurological Institute was particularly worthy of note. The production of delegates' electroencephalograms caused considerable interest and also some amusement! The spark machining equipment was shown in operation producing small, intricately-shaped piece-parts, a versatile technique which appeared to be comparatively unfamiliar to many engineers present.

The application of telemetry equipment developed originally for missile testing to industrial uses formed another interesting working display in which the signals from various transducers were telemetered over a short radio link (1 or 2 inches) to a 24-channel display (see photograph). Another piece of equipment, originally developed in connection with the processing of telemetry data which was shown in operation was an analogue-to-digital converter.

The control of gas turbines is a notable application of electronics in the aircraft industry and robust servo components developed for this purpose were shown. An engine condition analyser which displays temperature and vibration signals for four engines was demonstrated from simulated sources.

The autopilot and electronic control unit developed for helicopters could not have been easily demonstrated at the Convention but several of the units were shown. The equipment operates in conjunction with a Doppler drift indicator which produces an attitude correction for the autopilot in terms of pitch and roll.

A group of members discuss the industrial application of telemetry equipment.

*Left to right:* Mr. L. G. Coote (E.M.I. Electronics), Mr. H. H. Harper (Chairman of the Convention Committee). Mr. F. W. Sharp (Assistant Editor of Brit.I.R.E. Journal). Professor Emrys Williams (Vice-President).

### List of Exhibitors

Bristol Aircraft, Ltd.
Burden Neurological Institute.
Dawe Instruments, Ltd.
E.M.I. Electronics, Ltd.
Evershed & Vignoles, Ltd.
Miles Electronics, Ltd.
Newman Industries, Ltd.
Smith's Aircraft Instruments, Ltd.
Sparcatron, Ltd.
Ultra Electric, Ltd.
University of Bristol, Department of Aeronautical Engineering.
Westland Aircraft, Ltd.
Sir W. G. Armstrong Whitworth, Ltd.

# 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."*

## HELICAL DELAY LINES

In a recent German paper an account is given of theoretical investigations carried out on helices used as delay lines. The finite thickness of the wire is taken into consideration and an arbitrary external medium is assumed, and it is further presumed that the wavelength in the line is always very much greater than the axial distance between wire centres. The optimum wire diameter for a minimum attenuation is then determined and the properties of helices as directional couplers for waves having no rotational symmetry are described. These waves always consist of rotating fields and it is shown that the wave with the sense of rotation coinciding with the winding sense of the helix has smallest phase and attenuation constant.

"Helices as delay lines," G. Piefke. *Nachrichtentechnische Zeitschrift*, **13**, pp. 370-4, August 1960.

## TRANSISTOR CIRCUIT THEORY

An active device may be characterized by its terminal properties (circuit parameters) or by parameters directly related to the physical operation of the device (device parameters). A paper given at the 1959 Australian I.R.E. Convention discusses the small signal characterization of transistors in terms of device parameters. The form of equivalent circuit representation chosen is considered to give sufficient accuracy over the normal range of operating conditions and frequency. The performance of transistors with drift fields in the base region deviates from the simple theory of diffusion type devices, but it is shown that the drift transistor can also be characterized with very little modification of the simple equivalent circuit.

Theoretical relationships exist between the various semi-conductor properties and the transistor parameters. This allows the prediction of the variation of transistor parameters with operating point and temperature. The final section deals with the important problem of deducing device parameters from terminal measurements. Test circuits suitable for performing these measurements are described.

"The characterization of transistors," A. R. T. Turnbull. *Proceedings of the Institution of Radio Engineers, Australia*, **21**, pp. 530-9, August, 1960.

## TRANSISTOR D.C. CONVERTERS

A paper from the National Physical Laboratory of India discusses the design of transistor d.c. converters for application to two portable transreceivers. The various performance requirements and limitations due to the use of readily available batteries are stated. The performance of a transreceiver when operated through the transistor d.c. converter is compared with its normal performance and it is shown that satisfactory operation is obtained when transistor d.c. converters are used. Circuit and design details and performance figures for the transistor d.c. converters are made available. Probable power sources for operation of the d.c. converters are studied and it is shown that in the case of torch cells of normal trade pattern it would not be possible to comply with the existing requirements in respect of volume due to the low space factors of necessary fixtures that have to be used to ensure positive contact between the cells.

"The application of transistor d.c. converters to portable transreceivers." M. V. Joshi and M. A. Narayanan, *Electro-Technology (Bangalore)*, **4**, No. 1, pp. 3-13, January-February, 1960.

## STATISTICAL QUALITY CONTROL

Quality control in modern mass production is usually based on sampling but the statistical evaluation of the measurements, however, frequently requires much time. The Department of Electronic Valves of the Technical University of Budapest has therefore developed a computer which, by means of electric analogies, instantaneously determines the average value, variance, range or any other statistical property of the characteristic to be controlled, from a sample consisting of numerous items. The model that has been built is for controlling the mutual conductances of electronic valves. Transducers convert the values of the characteristics to proportionate alternating currents. The apparatus sums the currents to present the average value and by squaring differences between the average and the individual values and summing the squares presents the variance, both by direct reading.

"Statistical quality control using an analogue computer," A. Ambrozy. *Periodica Polytechnica (Budapest)*, *(Electrical Engineering)*, **4**, pp. 97-116, 1960.