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 22 JULY 1961 NUMBER 1

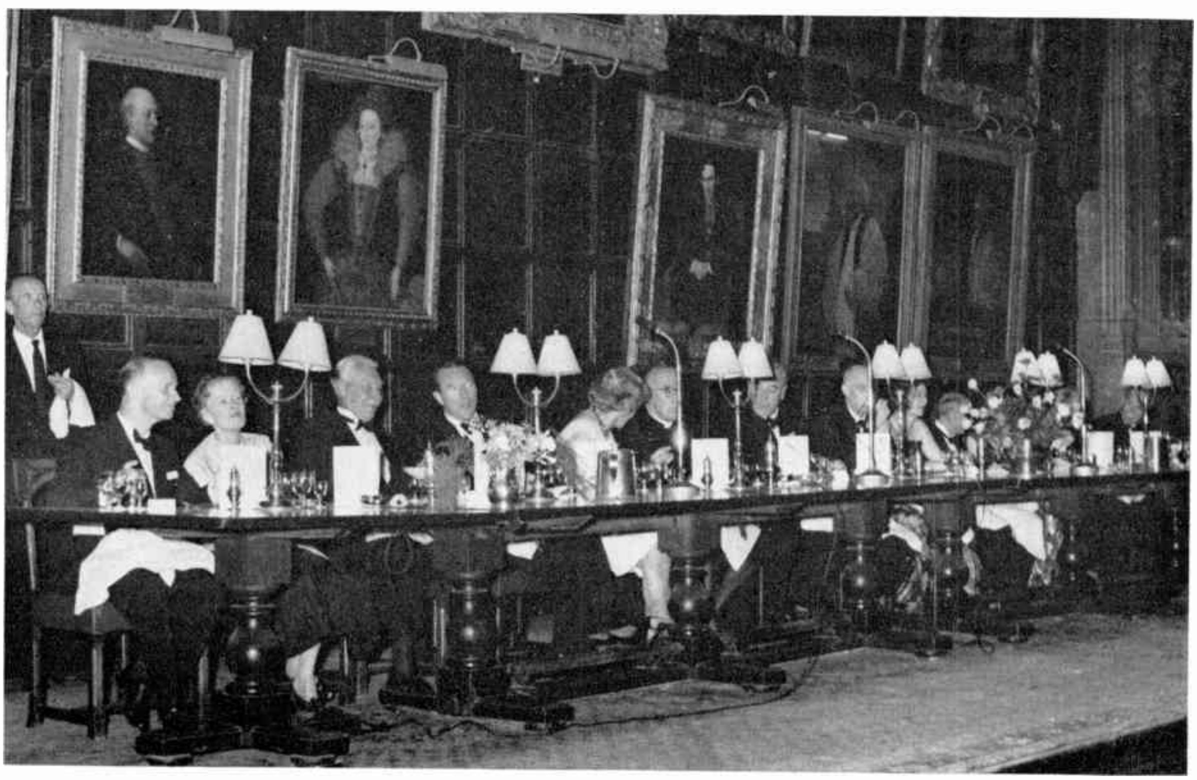
THE PRESENT AND THE FUTURE

COMPLETION of this *Journal* for printing coincides with the final day of the 1961 Convention. Whilst it may be too early to appraise the entire proceedings, the events of the first few days of July 1961 can be marked in the Institution's calendar as most eventful.

Fortuitously—since there is no claim to foresight—the Convention opened with public disclosure of European co-operation in space research. Thus, the whole proceedings opened in an atmosphere of reality which surpassed any feeling that the theme of the Convention was more of academic interest than practical feasibility. Discussions had a note of urgency so that at all times the main lecture theatre was crowded to capacity.

Traditionally the Friday night was the only social function. Even this became an evening of debate and comment on the present and future possibilities of radio and electronic engineering with particular reference to space research.

The papers presented at the Convention, together with the discussions, will be published in subsequent issues of the *Journal*.



The High Table in Christ Church Hall on the occasion of the Convention Banquet, 7th July, 1961.

INSTITUTION NOTICES

Publication of Convention Papers

In accordance with the Institution's usual practice, the papers presented at the 1961 Convention on "Radio Techniques and Space Research" will be made available to all members through the *Journal*, rather than as a separate and costly publication. The first group of papers will be published in the next issue and the September, October, and November issues will consist almost entirely of Convention papers. By early 1962 all the Convention papers will have been published in the *Journal*.

Copies of all the papers preprinted for the Convention (39 out of the total of 44 presented) are currently available and may be purchased at £4 per set or 3s. 6d. for individual papers. The final list of papers presented is as printed in the June *Journal* (pages 482–3) with the addition of two Russian papers (entitled "Methods for Determining Local Concentrations of Charged Particles in the Ionosphere and Interplanetary Space" and "Radar Contact with Venus") but excepting the French paper on "Magnetic Measurements of the Ionosphere" which had to be withdrawn, for various reasons, by the authors.

Volumes 21 and 22 of the *Journal*

This issue commences the second of the two half-yearly volumes of the *Journal* for 1961. The index to Volume 21 will be sent shortly to all members and subscribers and an announcement will then be made regarding the special arrangements for binding members' *Journals*.

New President of the R.E.C.M.F.

Mr. Arthur Bulgin, M.B.E. (Member), has been elected president of the Radio and Electronic Component Manufacturers' Federation, in succession to Mr. E. M. Lee, B.Sc. (Member). Mr. Bulgin was one of the six manufacturers who met in 1932 to form the Federation.

Recruitment to the Scientific Civil Service

A booklet entitled "Research Careers in the Ministry of Aviation" has been published with the aim of aiding recruitment of graduates with honours degrees in science and engineering, and post-graduate research workers, to the Ministry's research departments. The Ministry's Establishments, and their main activities are described. Selected recent publications by staff of the various Establishments are also quoted as a further indication of the type and level of work carried out. The booklet may be obtained from the Ministry of Aviation, Training and Education Branch, 66–72 Gower Street, London, W.C.1.

The 1960 Montefiore Prize

The quinquennial award by the Belgian engineering body, L'Association des Ingenieurs Electriciens de L'Institut Electrotechnique Montefiore, for the best original work submitted on scientific advances and progress in the technical application of electricity has just been announced. The prize of 100 000 Belgian francs is to be divided in the proportion of 3 : 2 between M. J. Robieux, a French engineer, and M. A. Calvaer, a Belgian engineer; the runner-up in the competition, who is to receive the unusual honour of having a resumé of his entry published in the *Bulletin Scientifique* of the Association, is Mr. R. A. Waldron, M.A. (Associate Member).

Mr. Waldron submitted to the Jury his work on waveguides containing ferrite materials as published in the *Brit.I.R.E. Journal*, under the title "Electromagnetic wave propagation in cylindrical waveguides containing gyromagnetic media"; the paper appeared in three parts, in the October, November and December 1958 issues. A copy of the resumé—in English—has been placed in the Institution's Library.

National Conference on Engineering Inspection and Non-Destructive Testing

A national conference is to be held in Oxford in September 1961 to discuss the function of management in relation to inspection, the economics of inspection and non-destructive testing, and the recruitment, education and training of inspection staffs. This conference has been planned at the request of the Joint Committee of Materials and their Testing and the British National Committee for Non-Destructive Testing. The Institution is represented on the British National Committee by Dr. A. Nemet (Member).

Further information may be obtained from the Oxford Conference Secretariat, The Institution of Engineering Inspection, 616 Grand Buildings, Trafalgar Square, London, W.C.2.

Scientific Manpower and Industrial Development

A report of the Conference on Scientific Manpower and Industrial Development held on 16th November last, has been published. It includes the full papers presented by Lord Hailsham, Sir Harold Roxbee Cox, Sir Owen Wansbrough-Jones, Dr. B. V. Bowden and Mr. J. E. A. Stuart, as well as an account of the discussion. A short note on the Conference was published in the *Journal* last December.† The report may be obtained from the Institute of Personnel Management, 80 Fetter Lane, London, E.C.4, price 10s. 6d.

† *J. Brit.I.R.E.*, **20**, p. 937, December 1960.

U.D.C. 621.396.677.3: 534.88-14

Multiplicative Receiving Arrays

The Angular Resolution of Targets in a Sonar System with Electronic Scanning

By

V. G. WELSBY,

Ph.D., B.Sc.(Eng.), (*Member*)†

Summary: The advantages of the multiplicative system of reception, namely the reduction of beamwidth to half that of the same array used normally and the virtual suppression of all minor lobes of the directional pattern, appear at first sight to be not fully realizable when more than one signal source is present owing to cross-product terms in the output. The theoretical examination of the problem given here shows that, in fact, these cross-product terms do not seriously interfere with the attainment of the improved angular resolution, and indeed they add a "winking" effect which may actually improve the recognition of double targets in an echo-ranging system. Preliminary trials in a reservoir, followed by sea trials of an experimental electronic sector-scanning sonar equipment using the multiplicative principle, show that in practice the angular resolution is approximately twice as good as that of the corresponding additive system, this improvement being accompanied by other advantages due to the reduction of sidelobe effects; among the latter advantages is the absence of the "smearing" of the display trace which otherwise occurs when strong echoes are received on a display unit which has been adjusted for a lower general signal level.

List of Symbols

θ bearing angle

θ_{max} ditto, corresponding to limits of scanned sector

d spacing of elements of array

d' spacing of centres of groups of elements

$p = \dfrac{\pi d}{\lambda} \sin\theta$

$n = (n_1 + n_2)$ number of elements

r distance of source from centre of array

T period of scan

ψ parameter relating to the range difference of two sources

β parameter relating to the bearing difference of two sources

ψ_0 phase difference between signals from two sources

$\left.\begin{matrix}\psi_1\\ \psi_2\end{matrix}\right\}$ symbols used only in Appendix 1 and defined there

$D(p)$ normalized directional function for one group of elements (appropriate suffixes added if $n_1 \neq n_2$)

$D_0(p)$ normalized directional function for complete system

Note: Where appropriate, suffixes A and B are used to denote quantities relating to two separate sources whilst suffixes 1 and 2 refer to the two groups of elements forming the multiplicative array. The suffix m is used where the quantity concerned is the mean of values relating to A and B.

1. Introduction

It has been shown theoretically in a previous paper[1] that a multiplicative receiving system, in which the outputs from the elements of a linear transducer array are first added in two groups and the two resultants then multiplied together, should possess certain distinct advantages over any type of purely additive system using the same array. In particular, the width of the main lobe of the directional pattern will be only half that of the uniform additive array, and, at the same time, the relative magnitudes of the unwanted sidelobes will be greatly reduced, the largest sidelobes being of negative polarity and thus easily removed by means of a rectifier. Figure 7, the exact significance of which will be explained later, gives some idea of the comparison between the multiplicative and additive patterns in a typical case. An improved directional pattern of this type appears highly desirable and there is no doubt that the reduced beamwidth and absence of sidelobes obtained with the multiplicative system should enable the bearing of a single signal source to be determined with greater accuracy than if simple addition were used. On the other hand, since the multiplier is effectively a non-

† Electrical Engineering Department, University of Birmingham.

linear device, the relative response to signals radiated simultaneously from a number of sources on difference bearings is not given directly by the directional pattern.

In an electronically-scanned echo-ranging system, for example, in which the multiplicative principle is adopted, the problem of resolution of targets appearing on different bearings at the same range is a complex one and it is by no means obvious at first sight whether or not the use of multiplication in such a system has in fact any advantages in this respect. It will be shown, however, that the advantages are actually very considerable.

2. Theoretical Analysis

It is shown in Appendix 1 that, for a multiplicative system with equal groups ($n_1 = n_2$) and for two sources of equal strength the output of the multiplier, expressed as a function of the parameter p, is of the form

$$D_0(p_A - p) + D_0(p_B - p) + \\ + 2[D(p_A - p) . D(p_B - p)] \cos(np + \psi) \cos\beta$$

ψ and β are parameters whose values depend on the difference between the ranges of the sources, and their mean bearing, respectively.

ψ also depends on the initial phase difference between the outputs of the sources. It is defined by

$$\psi = \frac{2\pi(r_A - r_B)}{\lambda} + \psi_0$$

where r_A and r_B are the ranges of the sources, measured from the centre of the array, and ψ_0 is the initial phase difference between the outputs of the sources.

β is defined by

$$\beta = \frac{\pi d'}{\lambda}(\sin\theta_A + \sin\theta_B)$$

where d' is the distance between the centres of the groups of elements forming the array and θ_A and θ_B are the respective bearings of the two sources. Since the values of θ_A and θ_B likely to be of interest will be small, β is given approximately by

$$\beta \simeq \frac{2\pi d'}{\lambda} . \theta_m = np_m$$

where θ_m and p_m relate to the mean bearing of the sources.

The first part of the expression for the output of the system will be recognized as representing the normal directional pattern which might be expected if the superposition rules were applicable, whilst the remainder is evidently the result of the presence of unwanted cross-product terms. In evaluating the effect of the latter it is important to note that its value can never exceed the limits defined by

$$\pm 2[D(p_A - p) . D(p_B - p)]$$

its actual value being determined by the product of this expression and the two factors cos $(np + \psi)$ and cos β. cos $(np + \psi)$ is similar to the usual "interferometer" term which occurs in the multiplicative directional pattern for a single source;

$$D_0(p) = D_1(p) D_2(p) \cos np$$
$$= [D(p)]^2 \cos np \qquad \text{when } n_1 = n_2$$

except that the relative positions of its zeros along the p axis will be determined by the phase angle ψ.

In any practical situation, although ψ is varying with time, it can usually be assumed to be constant during each scan, that is during each pulse duration T for a within-pulse scanning system.[6] The rate of change of ψ with time, due to changes in range difference, is

$$\frac{d\psi}{dt} = \frac{2\pi}{\lambda} . \frac{dr}{dt}$$

Thus, for example, if the wavelength λ is 0·1 feet and the rate of change of range difference dr/dt is, say, 10 ft/s, then $d\psi/dt$ will be 200π radians per second. This would cause ψ to change by only $^{1}\pi$ radian during each scan for a scanning speed of 1000 scans per second.

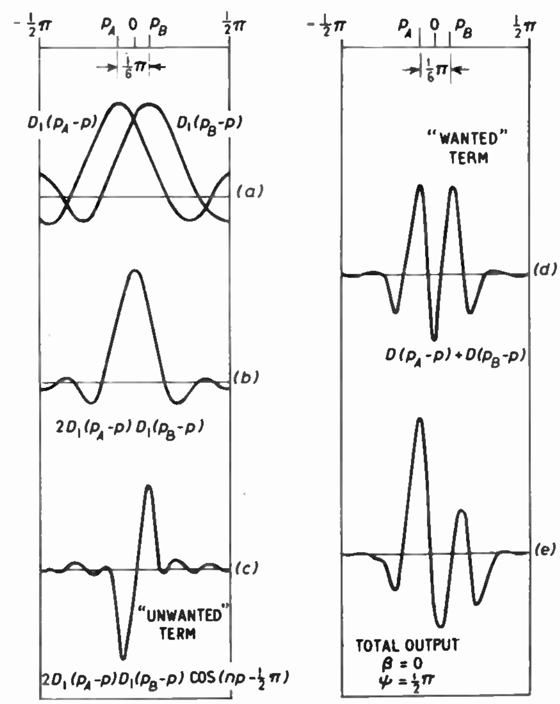


Fig. 1. Multiplicative system with two sources. Components of directional pattern for $n_1 = n_2 = 4$ and sources separated by $\frac{1}{6}$th of useful sector angle. Curves plotted for the particular case where cos $\beta = 1$ and $\psi = -\frac{1}{2}\pi$.

It can be concluded that the effect of the $\cos(np+\psi)$ factor will be to multiply the unwanted components by a cosine function of np whose position is practically constant during each scan but changes slowly with successive scans.

Figure 1 shows the form of the various components of the directional pattern of an 8-element multiplicative array in a typical case, the actual values chosen for the parameters being $\psi = -\frac{1}{2}\pi$ and $\beta = 0$ so that $\cos\beta = 1$. In this example it will be noted that the addition of the cross-product term has increased the magnitude of one of the wanted peaks but has reduced that of the other. If ψ had been shifted by π so that it became $+\frac{1}{2}\pi$, the positions of the two peaks in the output pattern would have been interchanged. It is easy to see too that if ψ is either 0 or π the whole pattern is bound to be symmetrical about $p = 0$ so that the two peaks are equal in magnitude. From this it follows that, as ψ changes with time, there will be a tendency for the peaks of the output pattern to alternate in magnitude. The curves have been drawn for the maximum value of $|\cos\beta|$; for smaller values the variation of the pattern with ψ would naturally be less marked. In general, both ψ and β will change together in more or less random manner and the patterns will pass through various forms intermediate between the extreme represented by $|\cos\beta| = 1$ on one hand and $|\cos\beta| = 0$ on the other (Fig. 1 (d)).

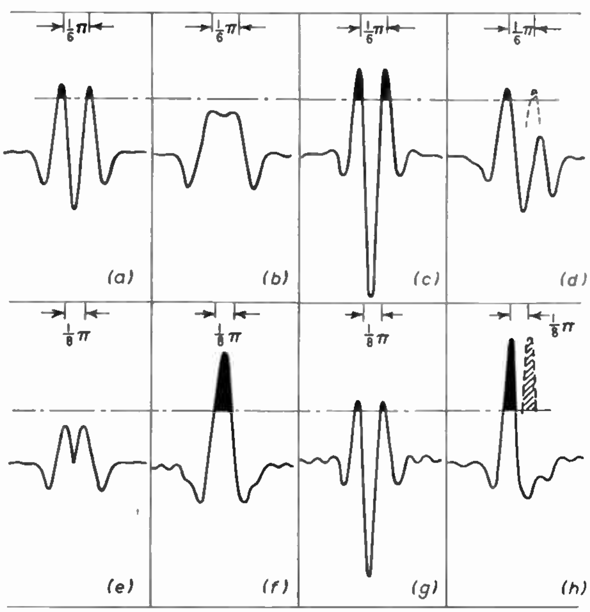


Fig. 2. Multiplicative system with two sources. Typical directional patterns for $n_1 = n_2 = 4$. Other details as follows:

(a) separation $\frac{1}{6}$th of useful sector, $\cos\beta = 0$
(b) separation $\frac{1}{6}$th of useful sector, $\cos\beta = 1$, $\psi = 0$
(c) separation $\frac{1}{6}$th of useful sector, $\cos\beta = 1$, $\psi = \pi$
(d) separation $\frac{1}{6}$th of useful sector, $\cos\beta = 1$, $\psi = \pm\frac{1}{2}\pi$
(e) separation $\frac{1}{8}$th of useful sector, $\cos\beta = 0$
(f) separation $\frac{1}{8}$th of useful sector, $\cos\beta = 1$, $\psi = 0$
(g) separation $\frac{1}{8}$th of useful sector, $\cos\beta = 1$, $\psi = \pi$
(h) separation $\frac{1}{8}$th of useful sector, $\cos\beta = 1$, $\psi = \pm\frac{1}{2}\pi$

In Fig. 2, which also relates to an 8-element multiplicative system with 4-element groups, an attempt has been made to give some idea of the effect of the unwanted components on the directional patterns for two sources with two different bearing separations. In each case $|\cos\beta|$ has been assumed to be either zero (Figs. 2 (a), (e)) or to have its maximum possible value of unity (Figs. 2 (b), (c), (d), (f), (g), (h)). The dotted curves in Figs. 2 (d) and 2 (h) indicate the alternative positions of the larger of the two peaks, depending on whether $\psi = +\frac{1}{2}\pi$ or $-\frac{1}{2}\pi$. The horizontal chain lines in Fig. 2 are intended to indicate a possible setting of the bias level of the receiving system; for this setting, only the shaded portions of the curves would actually appear on the display. One of the conclusions to be drawn from Fig. 2 is that, provided the source separation is not less than $\frac{1}{5}\pi$ on the p scale, the peaks may disappear completely from the display under certain conditions but whenever they do appear they do so at, or very near, the correct positions. In other words there appears to be a high probability of correct detection and resolution of the two signal sources at this separation.

At first sight the curves for a separation of $\frac{1}{8}\pi$ seem to be much less satisfactory since, when $\cos\beta = 1$ and $\psi = 0$ (or when $\cos\beta = -1$ and $\beta = \pi$), the curve of Fig. 2 (f) is obtained which obviously has only a single peak instead of two. It must be remembered however that this highly undesirable condition can only occur when *both* β and ψ have values lying within relatively small ranges and, since both are assumed to be varying randomly with time, the probability of this occurring will be very small. The situation can be summed up by stating that, when the separation is $\frac{1}{8}\pi$ on the p scale, there is admittedly a finite probability not only that the signals will fail to appear on the display at all but that they will appear incorrectly as a single signal on the mean bearing of the two. On the other hand there is a considerably greater probability that either one or both peaks will appear in approximately the correct positions. Furthermore the probability of detection and resolution is increased by the fact that the peaks tend to appear and disappear alternately so that, even though there may be a faint spurious trace between the two spots on the display screen, the "twinkling" effect caused by their alternate appearance and disappearance as ψ changes immediately draws attention to the existence of two separate signals on the same scan and with only a small difference of bearing between them.

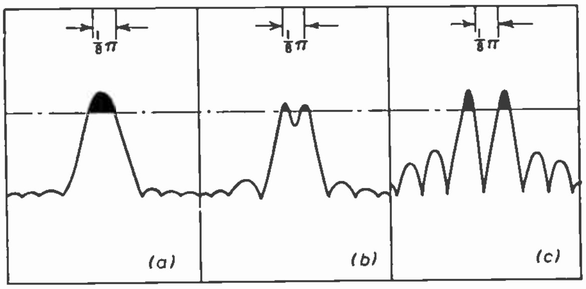


Fig. 3. Additive system with two sources. Typical directional patterns for $n = 8$ and sources separated by $\frac{1}{8}$th of the useful sector.

(a) Phase difference between sources zero

(b) Phase difference between sources $\frac{1}{2}\pi$ radians

(c) Phase difference between sources π radians.

Figure 3 shows, for comparison, typical additive patterns for an 8-element array with two sources which are emitting signals at the same frequency but with varying phase differences between them. The separation of the sources is again $\frac{1}{8}\pi$ on the p scale. Here also the signals appear either as two separate peaks or, more rarely, as a single one and it might be wrongly concluded that resolution would again be possible. In fact this is not so for several reasons. To start with, as the phase difference between two signals changes, the two peaks of the pattern move smoothly in opposite directions, passing from coincidence as in Fig. 3 (a) to a separation considerably greater than the correct value, as in Fig. 3 (c). Since the probability of occurrence of all the intermediate curves is roughly the same, the corresponding trace on the display screen will be smeared to form a continuous line. Also, since the additive patterns are always symmetrical about $p = 0$, there can be no alternation of the magnitude of the peaks and so nothing additional to show that there are in fact two separate sources.

Although only a limited number of curves have been plotted for a specific number of elements in the arrays and a specific method of grouping to form the multiplicative array (that is two equal groups), it seems reasonable to draw the following general conclusions.

(1) Provided the bearing separation of the two sources is not too small (say, not less than $1\frac{1}{2}$ times the 3 dB beamwidth for the additive array), the presence of the cross-product terms in the multiplicative pattern never causes the wanted peaks to appear in positions differing appreciably from their nominal positions; if signals appear on the display at all they appear in approximately the correct positions.

(2) The multiplicative system is still capable of resolving two sources when their bearings differ by an angle corresponding to only one beamwidth of the additive pattern. This degree of resolution is quite out of the question when the additive system is used with the same array.

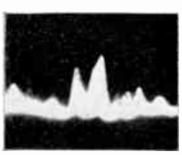
(3) Any relative motion of the sources and the array will cause the two peaks of the multiplicative pattern to rise and fall alternately, particularly when the difference in bearing of the two sources is small. This gives rise to a characteristic "flickering" or "winking" effect on the display which helps to confirm the presence of two sources with only a small angular separation between them.

So far, therefore, on purely theoretical grounds, it appears that the improved resolving power, implied by the reduced beamwidth of the multiplicative system compared with that of the additive system using the same array, can in fact be achieved with only a very slight reduction in the probability of target detection. It will now be shown that this conclusion has been amply supported by experimental evidence.

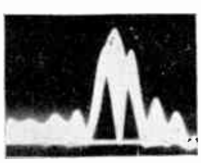
3. Results of Initial Experiments

The first experimental investigations[3] were carried out at the University of Birmingham's underwater acoustics laboratory at a British Waterways reservoir in Staffordshire. For this purpose two transmitting transducers were used, one supported by a rigid structure resting on the bed of the reservoir and the other suspended from a floating platform so that its position could be adjusted until the two sources were at the same range and at any desired angular separation. The changing phase angle ψ was provided, apart from any incidental changes due to slight movements of the floating transmitter, by feeding both the transmitters from separate oscillators which, although both operating at a nominal frequency of 50 kc/s, were in fact set so that their frequencies differed by a few cycles per second.

The original scanning system[2] was used for reception but, since it was unnecessary for the present purpose, the two-dimensional display was not used, the "video" output being displayed on an oscilloscope using the bearing scan as a time-base. Figure 4 shows



(a) Multiplicative system ($n_1 = n_2 = 4$)



(b) Additive system ($n = 8$)

Fig. 4. Experimental directional patterns obtained with scanning system operating at a rate of 1000 scans per second. Carrier frequency 50 kc/s c.w. The separation of the sources was approximately $\frac{1}{8}$th of the useful sector angle.

some of the results obtained in this way, using the same 8-element array either with a normal additive system or as a multiplicative system with two 4-element groups. The two sources were separated by an angle corresponding to the 3 dB beamwidth of the additive system. Although showing considerable distortion, largely due to technical shortcomings of the experimental apparatus used, the appearance of two distinct peaks in Fig. 4 (a) seemed to suggest that the multiplicative system might be capable of resolution of two sources even at small separations for which resolution with the additive system would be quite impossible.

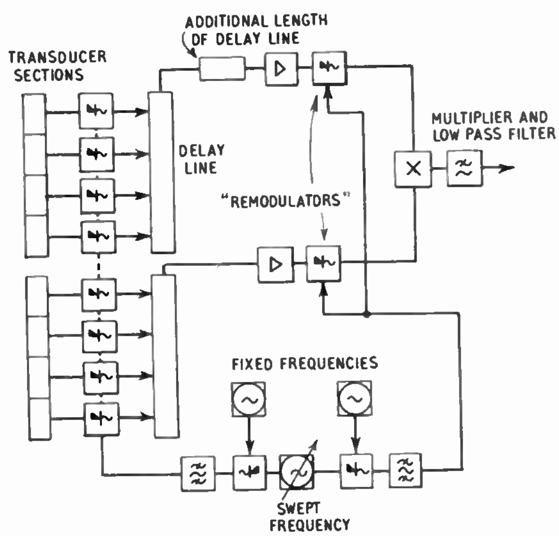


Fig. 5. Block diagram of "remodulation" version of the electronic scanning system. (Shown arranged for multiplicative working.)

The significance of the "cos β" factor, that is of the possibility of partial or even complete mutual cancellation of the cross-product terms, was not fully realized at the time and, although the angle separating the two sources was accurately measured, the exact value of the mean bearing of the two sources relative to the array was not measured to the same degree of accuracy. The value of β during these tests was, therefore, somewhat uncertain. The main usefulness of the tests lies in the fact that they drew attention, for the first time, to the possibility that the practical significance of the cross-product effect might not be as great as had been feared and that at least some of the advantages implied by the improved directional pattern of the multiplicative system might be obtained even with multiple targets. This led to a more detailed theoretical study of the problem (as set out above) and to operational trials of a complete sonar system which are described in the next Section.

4. Results of Sea Trials

In October 1960 it became possible, with the kind co-operation of the National Institute of Oceanography, who provided the ship and the transducer, to carry out sea trials on board the Royal Research Ship *Discovery II* with a complete sector-scanning sonar system which was arranged for alternative operation using either the additive or multiplicative principle. Although the fact is not of primary importance as far as the present work is concerned, the scanning system used on this occasion, for both additive and multiplicative operation, was of a recently developed "remodulation" type which is fully described elsewhere.[4] Figure 5 shows the new system (in its multiplicative form) in which the frequency modulation process which provides the time-varying phase-shifts required for scanning has been rearranged in order to simplify the filter design requirements, thus enabling both the dynamic range and the stability of the system to be improved.

The geometry of the tests, which were carried out in Falmouth harbour, roughly followed that used in the initial experiments, except that the transmitting transducers were now replaced by passive targets consisting of 18 in. diameter hollow steel spheres, one of which was fixed and the other arranged so that it could be towed slowly past the first on a constant bearing relative to the array. Both were in mid-water.

Figure 6 shows some of the results obtained. One of the most striking features is the increase in general sharpness of the picture presented by the display on changing over from additive to multiplicative working. The explanation of this is given in Fig. 7 which shows how the multiplicative process not only reduces the size of the spot representing a small target because the beamwidth has been halved but also, since there are no appreciable sidelobes in the directional pattern, causes no "smearing" of the trace of the kind which occurs when the additive system receives a single strong echo at a time when the overall gain of the receiver has been set for a lower general signal level. The chain lines A and B in Fig. 7 indicate a typical bias setting of the display, relative to the scanning pattern, for weak and strong signals respectively and it is clear how the multiplicative system gives a large improvement. Even though in Fig. 6 (d) the very strong echo from the sphere shows small sidelobe responses due to imperfect setting-up of the equipment, yet the effect of the large negative-polarity sidelobes in the directional pattern ensure that there will always be a gap between the main lobe and any sidelobes so that it always remains clear that the target is small in angular extent; this is not of course the case with the additive system (Fig. 6 (c)). It

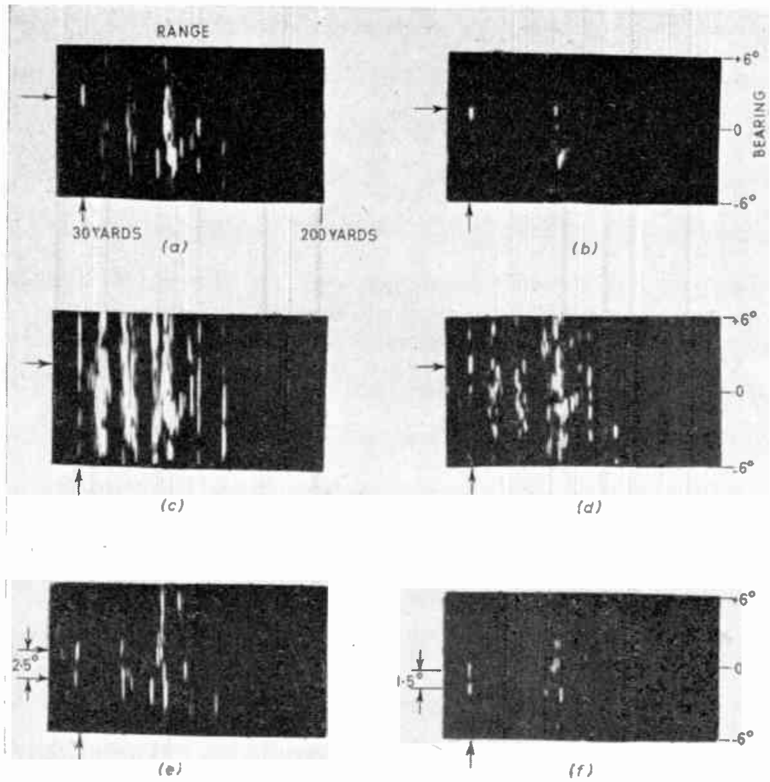


Fig. 6. Photographs of display taken during tests with 18 in. diameter target spheres in Falmouth Harbour. The ranges and bearings of the targets are indicated by the arrows in each case.

(a) Additive ($n = 8$), single target.

(b) Multiplicative ($n_1 = n_2 = 4$), single target.

(c) Additive ($n = 8$), as (a) but brightness control of display set to higher level in attempt to resolve bottom echoes. Note target trace spreading across the scan.

(d) Multiplicative ($n_1 = n_2 = 4$), as (c) but showing good resolution not only of the bottom echoes but also of the relatively intense echo from the target sphere.

(e) Additive ($n = 8$).

(f) Multiplicative ($n_1 = n_2 = 4$). Both (e) and (f) were taken with two targets at roughly equal range so that both echoes occur within the same scan in each case. Note that the multiplicative system is able to resolve the two targets quite clearly when their angular separation is only $1/n$th of the useful sector angle.

Note. In (b) and (f) the brightness control on the display unit was set slightly too low. It was later confirmed however that very little change occurred in the form of the target echo when the brightness control setting was increased a little to correspond to that in (a).

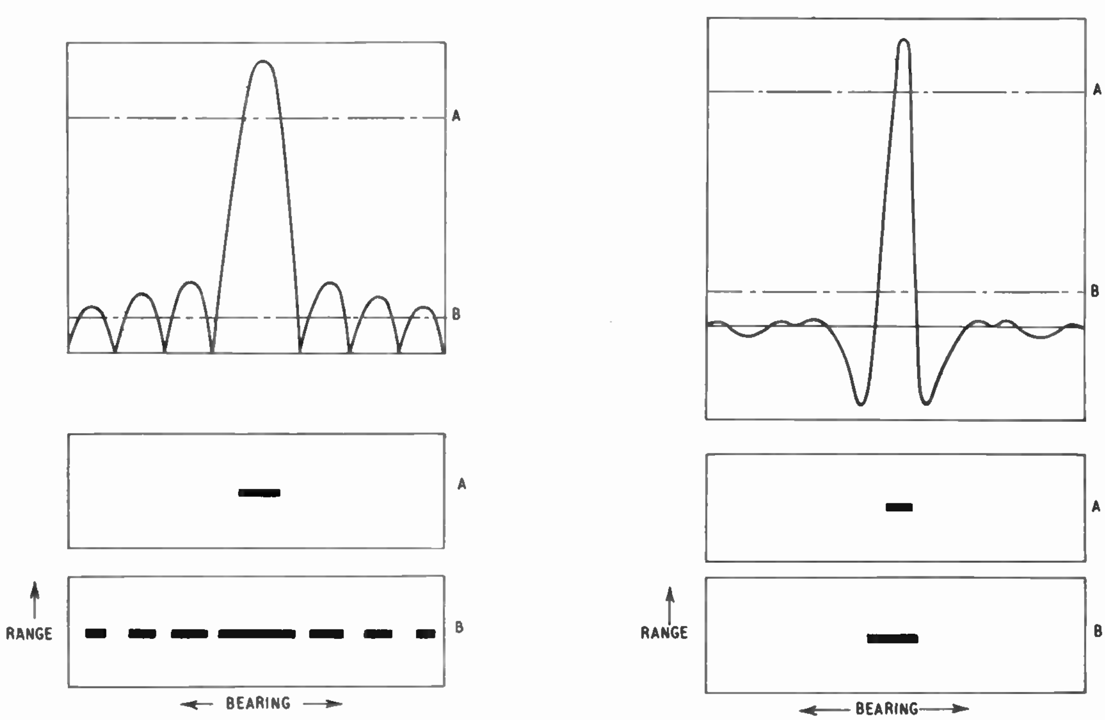


Fig. 7. Diagrams showing how the virtual absence of sidelobes in the multiplicative pattern prevents "smearing" of the trace when a strong echo is received from a single small target. The chain lines A and B represent typical relative position of the bias level of the display for weak and strong signals respectively.

should be added that the numerous targets in the middle part of the range are piles and other timber works forming a quay.

The improvement in angular resolution afforded by the multiplicative system is strikingly shown in Figs. 6 (e) and (f). It is clear from Fig. 6 that the unwanted-product effect described in Section 2 is not sufficiently marked to offset, to any appreciable extent, the advantages gained by the use of multiplication.

The multiplicative system was also seen to provide the previously mentioned aid to the identification and resolution of closely-spaced targets within the same scan; this is the tendency for the echo traces from the two targets to appear alternately on the display as a result of interference from the cross-product terms (see Sect. 2) thus causing a characteristic flickering or twinkling of the composite trace which immediately identifies it as being due to a double target.

5. Conclusions

The results of practical trials with experimental equipment have confirmed that a multiplicative sector-scanning sonar system is capable of providing approximately twice as good resolution of multiple targets as is given by an additive system using the same array. The advantages thus gained far outweigh the small theoretical reduction in probability of target detection due to the presence of unwanted cross-multiplication effects.

6. Acknowledgments

The author would like to acknowledge the valuable contributions made to this work by his colleagues in the Electrical Engineering Department of the University of Birmingham, particularly by Mr. J. Zaidman and Mr. B. S. McCartney, and also to thank the National Institute of Oceanography and the personnel of R.R.S. *Discovery II* for their help in the sea trials.

7. References

1. V. G. Welsby and D. G. Tucker, "Multiplicative receiving arrays", *J.Brit.I.R.E.*, **19**, pp. 369–82, June 1959.
2. D. G. Tucker, V. G. Welsby, L. Kay, M. J. Tucker, A. R. Stubbs and J. G. Henderson, "Underwater echo-ranging with electronic sector scanning: Sea trials on R.R.S. *Discovery II*", *J.Brit.I.R.E.*, **19**, pp. 681–96, November 1959.
3. J. Zaidman, "Properties of Multiplicative Arrays", University of Birmingham, Electrical Engineering Department Memorandum (unpublished).
4. B. S. McCartney, "An Improved Sector-scanning Sonar Receiver", University of Birmingham, Electrical Engineering Department Memorandum, No. 67.
5. D. G. Tucker and V. G. Welsby, "Electronic sector-scanning sonar: a new navigational and surveying instrument and its prospective developments", Paper read at the International Conference on Navigation and Safety at Sea, held at Kiel, September 1960.
6. D. G. Tucker, V. G. Welsby and R. Kendell, "Electronic sector scanning", *J.Brit.I.R.E.*, **18**, pp. 465–84, August 1958.

8. Appendix 1

Derivation of an expression for the output of a multiplicative system with simultaneous reception from two sources on different bearings.

Let p_A and p_B denote the respective values of the bearing parameter p corresponding to the bearings of the two signal sources A and B. $D_1(p)$ and $D_2(p)$ are the directional functions for the two groups of transducer elements, composed of n_1 and n_2 elements respectively. Taking the strength of source A as unity, let S represent the strength of source B. Then the output of group 1 will be proportional to $n_1[D_1(p_A-p)+SD_1(p_B-p)]$ and that of group 2 to $n_2[D_2(p_A-p)+SD_2(p_B-p)]$. The components represented by $D_1(p_A-p)$ and $D_2(p_A-p)$ are coherent and differ in phase by an angle $n(p_A-p)$ radians, where $n=n_1+n_2$. On multiplication and filtration, therefore, and omitting the common factor n_1n_2 the product of these two terms will be proportional to

$$D_1(p_A-p).D_2(p_A-p)\cos n(p_A-p)$$

that is to $D_0(p_A-p)$ where $D_0(p)$ is the directional function of the complete system for a single source, namely,

$$D_0(p) = D_1(p).D_2(p)\cos np$$

Similarly, the product of the other pair of components will contribute an output term proportional to $S^2D_0(p_B-p)$. So far the result is simply what would be expected if the linear superposition rule could be applied. In addition however there will be two cross-product terms, one of which for example involves $D_1(p_A-p)$ and $D_2(p_B-p)$. This time, the relative phases are not fixed and the product will contribute a term of the form

$$SD_1(p_A-p)D_2(p_B-p)\cos(np+\psi_1)$$

where the value of ψ_1 depends on the phase relationship between the signals from A and B. Finally there will be the second cross-product term of the form

$$S_1D_1(p_B-p).D_2(p_A-p)\cos(np+\psi_2)$$

The complete expression for the output of the whole system is thus

$$D_0(p_A-p)+S^2D_0(p_B-p) \quad \text{(wanted term)}$$
$$\left.\begin{aligned}&+S[D_1(p_A-p).D_2(p_B-p)]\cos(np+\psi_1)\\&+S[D_1(p_B-p).D_2(p_A-p)]\cos(np+\psi_2)\end{aligned}\right\}\text{(unwanted term)}$$

For the particular case where

$$n_1=n_2, \qquad D_1(p)=D_2(p)=D(p)$$

and the unwanted term reduces to

$$S[D(p_A-p)D(p_B-p)].[\cos(np+\psi_1)+\cos(np+\psi_2)]$$

Although both ψ_1 and ψ_2 may be varying with time, there is a relationship between them which depends on the geometry of the system. It is shown in Appendix 2 that

$$\psi_1 = \psi + \beta \qquad \psi_2 = \psi - \beta$$

where ψ includes any initial phase difference between the signals from the two sources, plus an amount corresponding to the difference OA − OB (see Fig. 8) between their ranges, and β is the phase difference corresponding to the distance $\frac{1}{2}d'(\sin\theta_A + \sin\theta_B)$ in the medium. For given sources ψ is a function of range only whilst β is a function of the bearings of the two sources. It will be noted that, if $n_1 = n_2$, the unwanted term is proportional to

$$\cos(np+\psi_1)+\cos(np+\psi_2) = 2\cos(np+\psi)\cos\beta$$

Thus, for example, if the two sources are symmetrically placed relative to the array so that $\sin\theta_A = -\sin\theta_B$, the angle β will be zero and the unwanted term will be multiplied by a factor varying between the limits ± 2.

If now the array is rotated relative to the pair of sources, β will increase, at a rate which depends on the bearing separation of the sources, with a corresponding fall in the value of $\cos\beta$. When β reaches $\frac{1}{2}\pi$ radians, $\cos\beta = 0$ and the unwanted term will disappear completely. This condition will occur when $\beta = \frac{1}{2}\pi$, i.e. when

$$\beta = \frac{\pi d'}{\lambda}(\sin\theta_A + \sin\theta_B) = \frac{\pi}{2}$$

or

$$\sin\theta_A + \sin\theta_B = \frac{\lambda}{2d'}$$

where d' is the distance between the centres of the groups forming the array. Assuming that θ_A and θ_B will be small over the sector which is of interest, this means that, approximately,

$$\theta_A + \theta_B = \frac{\lambda}{2d'} \quad \text{or} \quad \theta_m = \frac{\lambda}{4d'} = \frac{\lambda}{2nd}$$

where θ_m is the mean bearing of the two sources. The limits of the useful sector in the scanning system[6] are set by

$$\frac{d}{\lambda}\sin\theta_{max} = \pm 1$$

or, approximately, $\lambda/d = \pm\,\theta_{max}$

Thus the condition for $\beta = \pm\frac{1}{2}\pi$ is

$$\theta_m = \frac{\lambda}{2nd} = \pm\frac{1}{2n}\theta_{max}$$

As θ_m is increased further, $\cos\beta$ will oscillate between +1 and −1, passing through successive zeros at intervals of $\frac{1}{n}.\theta_{max}$ that is at intervals equal to half the beamwidth of an n-element additive array (between zeros).

To sum up, the unwanted term (for $n_1 = n_2$) is proportional to

$$2[D(p_A - p).D(p_B - p)]\cos(np+\psi)\cos\beta$$

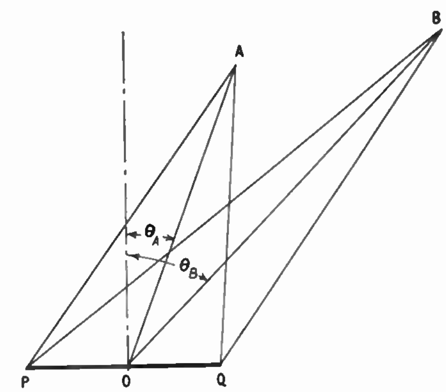


Fig. 8. Diagram showing geometry of multiplicative array and two sources. P and Q are the mid-points of the two groups of elements forming the array. A and B are two sources at bearings θ_A and θ_B respectively relative to the centre of the array.

where ψ is a function of the difference between the ranges of the two sources and β is a function of the mean bearing of the sources, given approximately by $\beta \simeq np_m$ where p_m is the value of p corresponding to the mean bearing.

9. Appendix 2

Geometry of array with two targets

Figure 8 represents the array with two signal sources A and B. P and Q are the centre points of the two groups of elements forming the array.

Let $\quad \text{AP} = x \qquad \text{BQ} = y$

$$\frac{\text{PQ}}{\text{OA}} = 2a \qquad \frac{\text{PQ}}{\text{OB}} = 2b$$

Then

$$\text{AP} = \text{OA}\sqrt{1+2a\sin\theta_A + a^2}$$

$$\text{AQ} = \text{OA}\sqrt{1-2a\sin\theta_A + a^2}$$

$$\text{BP} = \text{OB}\sqrt{1+2b\sin\theta_B + b^2}$$

$$\text{BQ} = \text{OB}\sqrt{1-2b\sin\theta_B + b^2}$$

$$\text{AP}-\text{BQ} = x - y = \text{OA}[1+(a^2+2a\sin\theta_A)]^{\frac{1}{2}} - \text{OB}[1+(b^2-2b\sin\theta_B)]^{\frac{1}{2}}$$

$$\simeq (\text{OA}-\text{OB}) + \tfrac{1}{2}\text{PQ}(\sin\theta_A + \sin\theta_B)$$

when a and $b \ll 1$

Similarly it follows that

$$\text{AQ}-\text{BP} \simeq (\text{OA}-\text{OB}) - \tfrac{1}{2}\text{PQ}(\sin\theta_A + \sin\theta_B)$$

This result applies for all values of θ_A and θ_B provided a and b are both small, i.e. provided the ranges of A and B are both large compared with the distance between the centres of the two groups of elements.

Manuscript received by the Institution on 28th December 1960. (Paper No. 647.)

The Symposium on "New Components"

26th and 27th October, 1960

Over 400 radio and electronic engineers attended a two-day symposium held in London at the School of Pharmacy, Brunswick Square, W.C.1, by permission of the Dean. The detailed arrangements of the programme was in the hands of a small sub-committee under the Chairmanship of Mr. G. W. A. Dummer, M.B.E. (Member) who presided over the sessions.

Two introductory papers reviewed recent developments in Government establishments and in industry, and a further seventeen papers were presented dealing with progressively more complex components, leading up to a group of papers which discussed the reliability obtained with modern components in domestic, industrial and military equipment.

The Chairman's concluding address, after summing up the main points of the papers, looked ahead to future trends of component progress. The papers were supported by an exhibition of components and associated devices.

Publication of the papers presented at the Symposium commenced in the February 1961 issue of the *Journal* and is completed with this issue.

A complete list of the papers presented is given below, together with publication details.

"Component Developments for the Services"—D. E. H. Jones, M.Sc. (*July*)

"The Application of Modern Materials to Electronic Components"—J. M. Herbert, B.Sc. and R. G. Martin. (*February*)

"Tin Oxide Resistors"—R. H. W. Burkett, B.Sc. (*April*)

"Resistive Pick-off Devices utilizing Oxide Film Tracks"—L. S. Phillips, B.Sc., M.A., D. F. A. McLachlan, B.Sc., A.R.C.S., G. V. Planer, Ph.D., M.Sc. and K. R. Honick. (*March*)

"Thin Polymeric Films for use as Dielectrics"—L. W. Turner. (*March*)

"High Stability Ferrite Pot Cores"—W. A. Everden. (*May*)

"Recent Developments in Coaxial Cables for Television Distribution"—J. D. S. Hinchliffe, B.Sc. (*May*)

"Miniature Connectors for Severe Operating Conditions"—G. L. Stephens. (*Informal paper—not published*)

"Miniature Medium-duty Sealed High-quality Relays"—N. E. Hyde. (*June*)

"Sealed Contact Relays"—J. G. Bannochie, M.Sc. and R. A. E. Fursey, B.Sc. (*February*)

"Contact Resistance Effects in Mechanical Choppers"—I. C. Hutcheon, M.A. (*February*)

"Parametric Diodes—Design and Manufacture"—D. B. Day. (*March*)

"Piezoelectric Ceramic Transformers and Filters"—A. E. Crawford (Member). (*April*)

"The Reliability of 'Potted' Transformers"—A. G. Gilmore, B.Sc.(Eng.). (*Informal paper—not published*)

"The Status of Semi-conductor Networks"—J. S. Walker, M.Sc. (*Informal paper—not published*)

"Silicon Surface Alloy Transistors for High-frequency Switching and Chopper-amplifier Applications"—P. A. Charman. (*February*)

"Life Characteristics of Some Typical Semi-conductor Devices"—R. Brewer and D. J. E. Richards, B.Sc. (*June*)

"Component and Valve Reliability in Domestic Radio and Television Receivers"—D. W. Heightman (Member). (*May*)

"The Reliability of an Experimental Transistorized Data Handling System"—V. J. McMullan, B.Sc. and P. Cox. (*July*)

"Maximizing Electronic Reliability"—M. Halio, B.Sc. (*February*)

SUMMARY OF THE DISCUSSIONS ON THE PAPERS

The discussion on the two review papers by Mr. D. E. H. Jones and Messrs. R. G. Martin and J. M. Herbert centred on reliability and microminiaturization. The arguments for and against micromodules were cogent and showed the need for accurate evaluation of the three systems described in both papers. Mr. K. M. McKee and Mr. Ward made a case for the use of micromodules as an interim system but Mr. Martin pointed out that the order of reliability required would be difficult to obtain with a range of newly developed components; in addition there would be problems arising from the multiple connection system employed and he also said that the range of new components to be developed would be very great because of orientation difficulties. He preferred the circuit approach. Several speakers raised the question of who should make microcircuits—the component manufacturer or the equipment manufacturer, and Mr. Martin suggested that, just as printed wiring circuits were produced for use by manufacturers, a similar situation would prevail. The cost of microminiature assemblies was also discussed.

On Mr. Burkett's paper on tin oxide resistors, Mr. Pearce referred to the protection of the film—was it necessary to have heavy coatings of epoxy or similar resins for full humidity protection? Mr. Burkett replied that the unprotected coatings stood up very well provided no d.c. was applied, and even under these conditions the tin oxide film was superior to most other films.

During the discussion on Mr. Hyde's paper on microminiature relays, Mr. Bedford raised the question of reliability of relays wound with 50 gauge wire, and Mr. Hyde agreed that this was a possible weakness, but after initial difficulties good results were now being obtained.

After Messrs. Bannochie and Fursey's paper on sealed contact reed relays, many speakers asked about contact ratings and whether the figures quoted referred to the 2½ in. or the new miniature reed. Mr. Bannochie's reply was that all data quoted were on the 2½ in. relay. Mr. Hutcheon, in reply to a question about life of mechanical choppers, said that 1500 million or more operations was possible, but this was mechanical operation only.

Mr. Gilmore's paper on the reliability of potted transformers raised many questions. Mr. Burkett asked about low temperature and humidity cycling, and said that 50 humidity cycles was not too long in the life of a transformer used in the tropics. Mr. Gilmore gave full details of the fall in insulation resistance with days of humidity cycling and pointed out that the testing was overstressed.

Mr. Walker's paper on semi-conductor networks aroused considerable interest and Mr. Clarke inquired about the cost and Mr. McKee asked about the spread of characteristics. Mr. Walker felt that cost would come down as more experience was obtained, and pointed out that lots of 50 could be conveniently made by the process. The characteristics could be accurately controlled.

There was a useful discussion on Messrs. Brewer and Richards' paper on life characteristics of semi-conductor devices in which points of statistical accuracy were raised. The authors' replies emphasized the care with which the studies were being carried out.

Following Mr. Heightman's paper on component and valve reliability in domestic radio and television receivers, Mr. Bushby made a detailed statement from the point of view of the valve engineer, in which he pointed out many factors affecting valve reliability.

Mr. Halio's paper on electronic reliability was felt to be an excellent review of the reliability position in the U.S.A., and compared well with experience in this country. The inclusion of an overseas paper in the Symposium was especially welcomed.

G.W.A.D.

Concluding Remarks by the Chairman, G. W. A. DUMMER, M.B.E. (Member)†

It is a difficult task to sum up the Symposium because such a wide variety of papers have been read, mostly on specialized fields. I am sure, however, that in spite of this wide variety of subjects presented, each of us must have learnt a great deal about the position on component development as it stands to-day.

Some of the papers have stressed the importance of work on materials; particularly one might mention piezo-electric materials leading to a new class of components, polymeric dielectric films, ferrite cores and resistive materials and in addition the two opening papers covered a great deal of new materials research. I think it is obvious to all of us that work on materials is of vital importance in the development of new components. No study of deterioration effects or change of state in materials is ever lost because of the increasingly severe environmental conditions to which components using these materials are put. I refer to vibration stresses, temperature stresses, the effect of humidity, etc. At one time there was the feeling in this country that our work on materials lagged behind that of other countries, notably America and Germany, but the importance of work on materials has now been realized.

The opening session gave us two excellent review papers, one on military applications of components and one on commercial applications. Although the subjects of the two papers are intermingled, and are becoming more so, it is true to say that the co-operation between the two is most gratifying. Military services are dependent upon industry for manufacturing capacity of components and industry is dependent on the military for pioneering and sponsoring some of the early work which would otherwise be difficult, or let us say unprofitable, for commercial organizations. In addition, military establishments will provide an independent assessment of components which can be very useful to industry.

There have been arguments throughout the Symposium on the relative merits of micro-modules, micro-circuits and solid circuits. The pros and cons of the micro-module system which were argued yesterday and to-day were most interesting and bring out the importance of timing in the introduction of a new development. This is one of the facts which can never be forecast. At any particular moment a development may be brought out which is a great step forward in techniques, but one can never be sure that the next week someone else will not bring out a new development which will either put it out of date or invalidate it. Nevertheless, one thing is quite clear—that micro-miniaturization is here to stay, and I am sure that work in this country must be carried on with all emphasis—in fact, we cannot afford *not* to do this. It seems from our own work at R.R.E. that the best hope for maximum reliability will be in the solid circuit, but I would be the last to make any extravagant claims on this; it is a possibility on which time alone will tell.

One of the major problems which has been posed and one which will obviously continue to be a problem, is the question of yield of microminiature units. These units will have to be sold commercially, and I do not think any firm can afford to make an equipment

† Royal Radar Establishment.

which does not have an appreciable yield in production. Obviously all new developments go through the inevitable phase of teething troubles, and high yields are just not possible early in development—indeed who would have thought in 1948 that the transistor itself would have been made at the high yields which are now achieved.

Discussion on microminiaturization also raised the question: who makes the units—the component manufacturer or the equipment manufacturer? This is obviously going to be difficult, I have the impression that the large component manufacturers may set up micro-circuit plants to supply circuits to equipment manufacturers' requirements, and also that some of the larger manufacturers who, after all, have the direct requirement, may set up facilities of their own so that they can have complete control over the processes and therefore, to some extent, the reliability. I have stressed again and again that microminiaturization must show a gain in reliability over conventional components; unless this is achieved, the only advantage will be that of size reduction.

At the beginning of the Symposium I posed the question: have we reached the limit of reliability with conventional components? In the paper by McMullan and Cox on "The Reliability of an Experimental Transistorized Data Handling System", failure figures were given on a very large number of transistors and components—some 370 000 components in service, giving a failure rate of 0·0087% per 1000 hours. Environmental conditions were, of course, excellent—almost ideal—and I would imagine this represents about the best which can be done to-day using components which are available now. This is a good figure of reliability, but in military requirements this is the figure we need under very strenuous conditions of service—vibration, shock, humidity, temperature extremes, etc. Using similar components, we cannot possibly get better figures than the one quoted here, and we are bound to get many worse. The big problem is how far we can go in this respect. There are two possibilities; either existing miniature components on the lines of the "special quality" valves and "special quality" transistors can be further developed, or a long-term view can be taken and micro-circuits and solid circuits can be developed in an attempt to realize the possibilities of high reliability which are offered by the solid circuit system. Both these systems are, of course, being sponsored by the Royal Radar Establishment.

I think the Post Office under-sea cable repeater amplifiers, which have not so far been mentioned in this Symposium, show clearly what is possible in the design of reliable components, and some excellent work has been done by the Post Office and Standard Telephones & Cables Limited, in designing components for these repeater amplifiers. They are supposed to have a lifetime of 20 years, and there seems a definite possibility that this hope may be realized, although I am not sure how much redundancy has in fact been built into the system. This Symposium has several times stressed the question of cost in reliability, and the Post Office work has, I think, shown that reliability with conventional components is possible, although the cost will naturally be higher. This raises the inevitable compromise which has been discussed several times during the Symposium—how much reliability is really needed for a specific application and how much will it cost?

This might be an appropriate time to review the size of this components industry of ours. Through the kindness of the Radio and Electronic Components Manufacturers' Federation I have been provided with a few figures which I am sure will be of interest.

The present production in the United Kingdom of component parts is around 2 400 000 000 parts per year. Taking a 50-hour week (approximately 6-day week with an 8-hour day), this works out at 1 000 000 component parts per hour. This is a remarkable figure and I am sure reflects great credit on all those engaged in the component industry. I have tried to do a similar sum on the world production of the most common component, the fixed resistor. On my calculation it works out at about 7 500 000 000 per year, or 150 000 000 per week, or 3 000 000 a day, or 375 000 per hour. This is the most common component, but we should not lose sight of the fact that this vast production is going on at this very moment and will continue to go on for many years to come.

It has become obvious from the papers and the discussions that the advent of the transistor has made a major change in the development of components. It is probably the biggest change since the early days of 1922–23 and, in my opinion, the research work on semi-conductors which is now being done will affect the design of components even more in the future.

Before the Symposium closed, Mr. L. H. Bedford, C.B.E. (Past President), thanked the Chairman on behalf of all present for his very considerable contribution to the planning and execution of the two-day meeting. Mr. Dummer was the leading authority on component reliability in this country and Mr. Bedford said that through his writings he had done much to make radio engineers aware of the magnitude of the problem and of ways in which it might be met.

REPORT OF EXTRAORDINARY GENERAL MEETING

Notice of an Extraordinary General Meeting, as given on page 378 of the May 1961 Journal, *was sent to all corporate members of the Institution on 15th May 1961. The meeting was held at the London School of Hygiene and Tropical Medicine on Wednesday, 7th June 1961. The President, Professor E. E. Zepler, took the Chair and was supported by other officers and members of the Council. Mr. C. Gray Hill, Solicitor to the Institution, was in attendance.*

When the meeting opened at 6.5 p.m. 55 corporate members had signed the attendance book and 606 proxies had been received.

After the President had called on the Secretary to read the notice convening the meeting, he referred to Item 1 of the Agenda. Professor Zepler stated that the Institution's Past President, Admiral of the Fleet the Earl Mountbatten of Burma, K.G., had advised the Council that he would be prepared to accept once more the office of President. In pursuance of Article 35 therefore, the Council resolved that Admiral of the Fleet the Earl Mountbatten of Burma, K.G., be appointed President. This appointment was greeted with acclamation by all members present.

Professor Zepler also stated that again in pursuance of Article 35, the Council had also appointed the following Members as Vice-Presidents of the Institution:

L. H. Bedford, C.B.E., M.A., B.SC., F.C.G.I.
W. E. Miller, M.A.
Professor E. E. Zepler, PH.D.
J. L. Thompson
Colonel G. W. Raby, C.B.E.
Professor E. Williams, PH.D., B.ENG.
Air Vice-Marshal C. P. Brown, C.B., C.B.E., D.F.C.

The President commented on the invaluable service which all these officers had given to the Institution. Their election as Vice-Presidents of the Institution was received with enthusiasm.

Special Resolution

Professor Zepler said that Item 2 of the Agenda had to be dealt with as a Special Resolution. In recommending the substitution of a new Article 16 the Council was influenced by the necessity to implement the agreement which members gave at the Annual General Meetings held in 1959 and again on 11th January 1961. A report was also given on page 300 of the April 1961 *Journal*.

The number of proxies received *in favour* of the Special Resolution gave very ample support to the Council's proposition. There were, however, three proxies which were uncertain and in the hands of members attending the meeting. (At this point in the proceedings the majority of members attending the meeting indicated their willingness to support the Resolution. The President pointed out, however, that he would prefer to have discussion before finally putting the Resolution to the meeting.)

In reply to questions the Secretary pointed out that the *maximum* subscriptions specified in the Special Resolution did not mean that the Council would raise subscriptions to that level without the consent of corporate members. The Special Resolution would, however, enable such business to be considered at a General Meeting of which requisite notice would be given to all corporate members of the Institution. This point had also been explained in the letter which the President had addressed to all corporate members of the Institution on 15th May.

In his letter the President had in fact, pointed out that if approval was given to the Resolution, the Council proposed to adopt a new scale of subscriptions immediately. The meeting provided an opportunity for comment by corporate members.

The new subscriptions proposed by Council come well within the maximum specified in the Special Resolution and are as follows:

Members	£9 0s. 0d.	per annum
Associate Members	£7 10s. 0d.	,, ,,
Companions	£9 0s. 0d.	,, ,,
Associates	£7 10s. 0d.	,, ,,
Graduates over 35 years	£7 10s. 0d.	,, ,,
,, 25–35 years	£6 0s. 0d.	,, ,,
,, under 25 years	£5 0s. 0d.	,, ,,
Students over 25 years	£5 0s. 0d.	,, ,,
,, under 25 years	£3 10s. 0d.	,, ,,
,, under 21 years	£2 10s. 0d.	,, ,,

with a reduction of 15s. for all grades of members resident overseas.

Subsequent discussion emphasized the need for every economy where reasonable—a point that had been dealt with by the Finance Committee in recent Annual Reports.

Including the exercise of three proxy votes, only five members voted against the Special Resolution which was therefore approved by a very large majority.

U.D.C. 621.3.004.6

The Reliability of an Experimental Transistorized Data Handling System

By

V. J. McMULLAN, B.Sc.,†

AND

P. COX†

Presented at the Symposium on New Components held in London on 26th–27th October, 1960

Summary: Factors which influence reliability of large systems are considered. The construction of the equipment itself is briefly described. The commissioning and maintenance of the equipment and details of the docket-return system used to provide information about the reliability of the components used are discussed. A system of written logic, supplanting conventional drawings, facilitates maintenance. Component failure rates calculated from the fault recording system are given and observations made regarding the reliability achieved and considered possible.

1. Introduction

The paper is concerned with the reliability of a large experimental data handling system. The equipment is, in the main, transistorized and employs printed-card techniques, the card assemblies being stacked in units which are in turn housed in cabinets. Ferrite cores are used as the storage medium.

The paper divides broadly into four sections:

The first section considers factors which influence the reliability of a system.

The second section consists of a brief description of the equipment itself.

The third section deals with the commissioning and maintenance of the equipment and includes a description of a system of written logic which has supplanted conventional drawings and which has proved greatly to facilitate the maintenance function. Details are also included in this section of the fault recording arrangements which provide information about the reliability of the components used.

The final section is devoted to the topic of component reliability and includes an interim consideration of the component fault data up to a maximum service period of about 6000 hours.

2. Reliability Factors

The user of a data processing system is mainly concerned with the serviceability of his equipment. Serviceability is defined as the time during which the equipment was serviceable expressed as a percentage of total time. In order to achieve maximum serviceability the engineer requires reliability and minimum fault clearance time. The reliability of a system depends on the design, both electrical and mechanical, of the component parts of the system and on these parts being used correctly in the system.

Since reliability is related to quality in design, basic components and materials, it is also related to cost. In order to keep purchase price to a minimum therefore the manufacturer is guided in his pursuit of reliability by user requirements.

2.1. *Element Design*

Element design and component selection are closely related, each depending to some extent upon the other. Component tolerances are normally made as wide as the circuit can reasonably be designed to accept, bearing in mind not only the initial component tolerances, but also changes in parameters over life.

In order to ensure high circuit reliability, the temperature and relative humidity of the air in which the element must function has to be taken into account when the components are selected. Also, the element designer should de-rate components in cases where such measures can be expected to improve the reliability of the component, either by virtue of a lower incidence of catastrophic failure, or by a reduction of parameter drift with time.

2.2. *Mechanical Design*

The mechanical design must be such as to ensure satisfactory housing of the circuit elements, due attention being paid to thermal cooling arrangements and the accessibility of the circuits for servicing purposes.

2.3. *System Design*

In order to obtain low fault clearance time careful attention is required on the part of the systems designer. It can be argued that measures which decrease fault clearance time often increase the

† Automatic Telephone and Electric Co. Ltd., Liverpool.

incidence of circuit failure. A proper balance must be held between these two factors if serviceability is to be high.

In a large system manual methods of fault finding are too slow and some automatic method must be used. It is desirable that individual equipments within the system are self checking, otherwise commissioning of a large system is impossible. Fault finding is made difficult if more than one fault exists on an equipment. The maintenance engineer attempts to relate the symptoms of two or more faults to one cause and the time taken to cure such a fault is always long. Every effort should be made to ensure therefore that a fault on one element of the system does not damage or effect other elements.

Fault finding on a closed loop circuit such as a ring-type counter, which must finish before it can restart, is again difficult and such circuitry should be avoided whenever possible.

The designer of the system must take into account the limitations of the signal interconnecting arrangements and make provision for the detection and localization of faults. Circuitry must be provided which will ensure the desired degree of reliability, bearing in mind the expected rate of fault incidence due to component failure and the failure of peripheral equipment, together with the expected fault detection and repair time.

2.4. *Physical Environment*

A controlled and moderate physical environment represents the ideal for data processing equipments. While the physical environment of the system discussed here is not controlled, in the strict sense of the word, the conditions are moderate. Some details are given below:

Table 1

Type of installation	Ground
Average atmospheric pressure	1040 millibars
Average relative humidity of outside air	65%
H_2S content of atmosphere	Below detection level
SO_2 content of atmosphere	Slight trace
Mechanical stress	Nil

The temperature of the outside air drawn in for cooling purposes lies in the usual range for the British Isles.

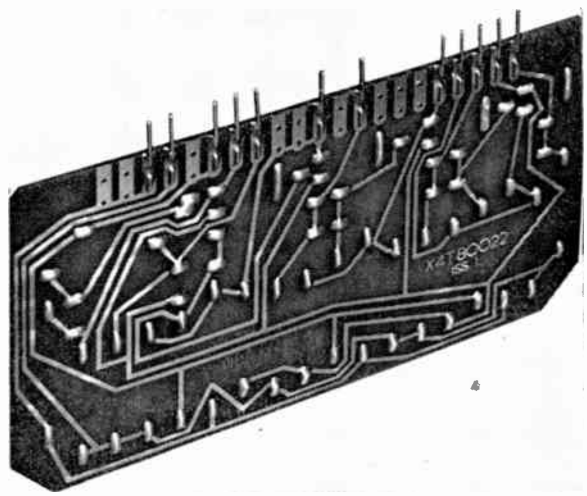
The relative humidity of the cooling air can be expected to be lower than that of the outside air as a result of dust filtering processes.

3. Description of Equipment

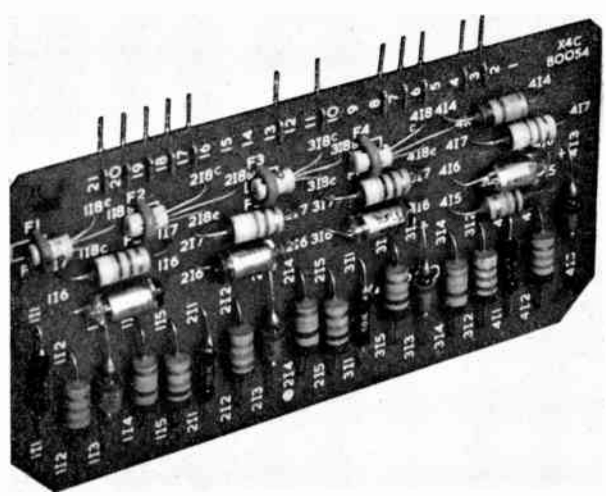
3.1. *Computers*

The equipment is fully transistorized and ferrite core storage is employed. Elements are of the printed card type, the number of elements per card being a function of the element complexity, e.g. 1 flip flop (toggle), 2 followers, 4 inverters, etc. Various configurations of gating cards are used and store access and reading amplifiers are card mounted. The basic clock frequency is 100 kc/s. Signals are defined by a potential of $-6{\cdot}6$ V with reference to earth.

The various types of element cards are mounted in standard plug-in units, 20 cards per unit being the maximum used. Four test points per card are provided on the front of the unit in order to facilitate mainten-

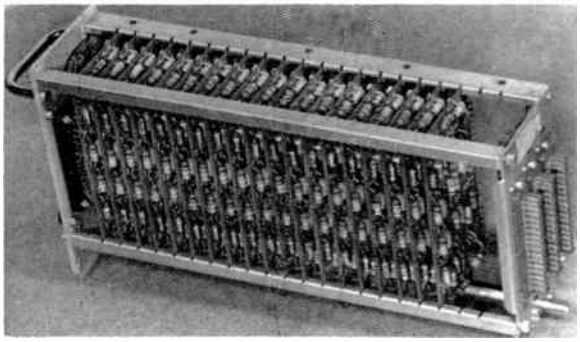


(*a*) Circuit side.

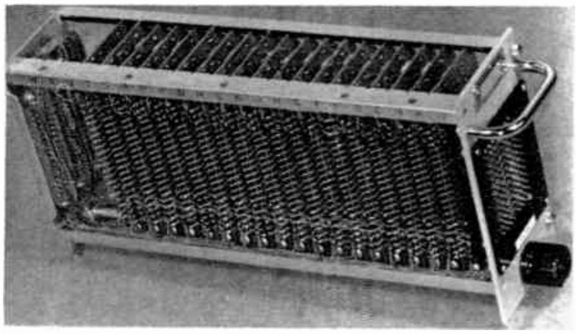


(*b*) Component side.

Fig. 1. Typical printed circuit card.



(*a*) Component side.



(*b*) Wiring side.

Fig. 2. Typical plug-in unit.

ance. The number of different types of unit employed in the system has been kept to a low figure and units generally contain a simple configuration of elements, thereby making the unit easy to test as an entity. Units are grouped in racks or groups of racks according to circuit requirements. Forty-five units may be mounted in a rack in five horizontal by nine vertical positions. A panel is provided for fuses, test points etc.

The racks are air-cooled from a common air-duct, the air entering through an inlet in the bottom of the rack, and exhausting through a vent in the top of the rack. The quantity of air flowing can be controlled on both a rack and a suite basis. No suction is employed at the exit vents, and no special arrangements have been provided to ensure a constant input air temperature.

The racks dissipate less than 300 watts of electrical energy.

Printed card element, unit and racks are illustrated by Figs. 1, 2 and 3 respectively.

3.2. *Power Supplies*

Power supplies have received detailed study, both power source and supply connections being investigated. Both locally situated transistorized power units and a centrally located power source were considered, and, for reasons of economy and practicability, centrally located, high performance secondary storage batteries were finally selected as the power source. Since continuous operation is demanded of this equipment, the issue of providing standby power was an important one and influenced the final selection. The batteries are continuously floated across mains-supplied charging sets.

Various power distribution arrangements are used, including a complete ring main for certain supplies. Wide use is made of multiple circuits in order to reduce the inductance of the supply system and capacitors of the metallized paper type are used as local power reservoirs for the elements. The whole supply system is designed to reduce unwanted

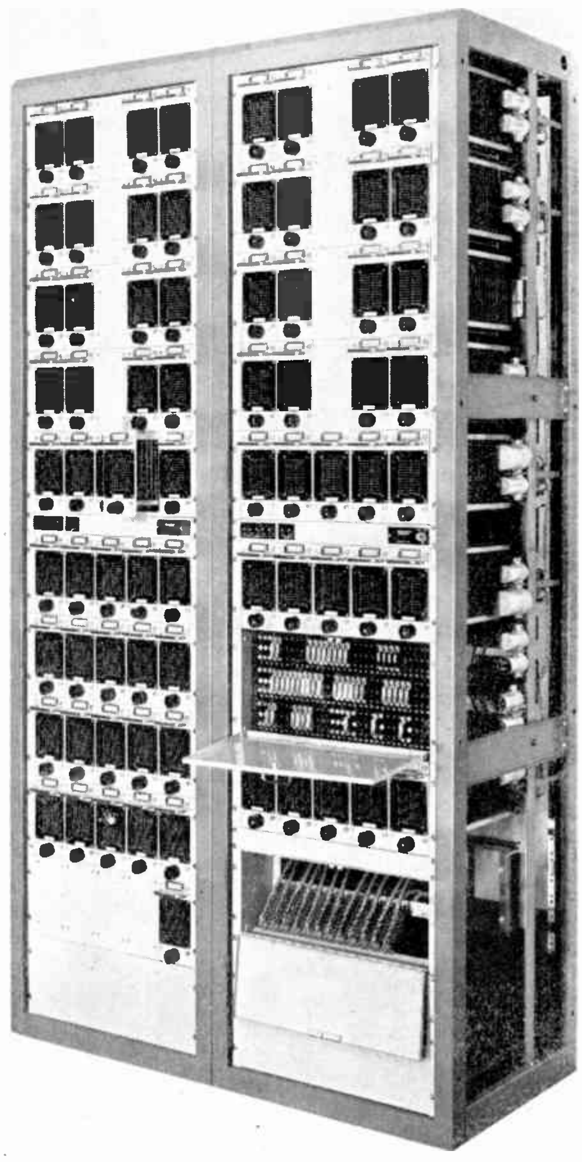


Fig. 3. Typical equipment.

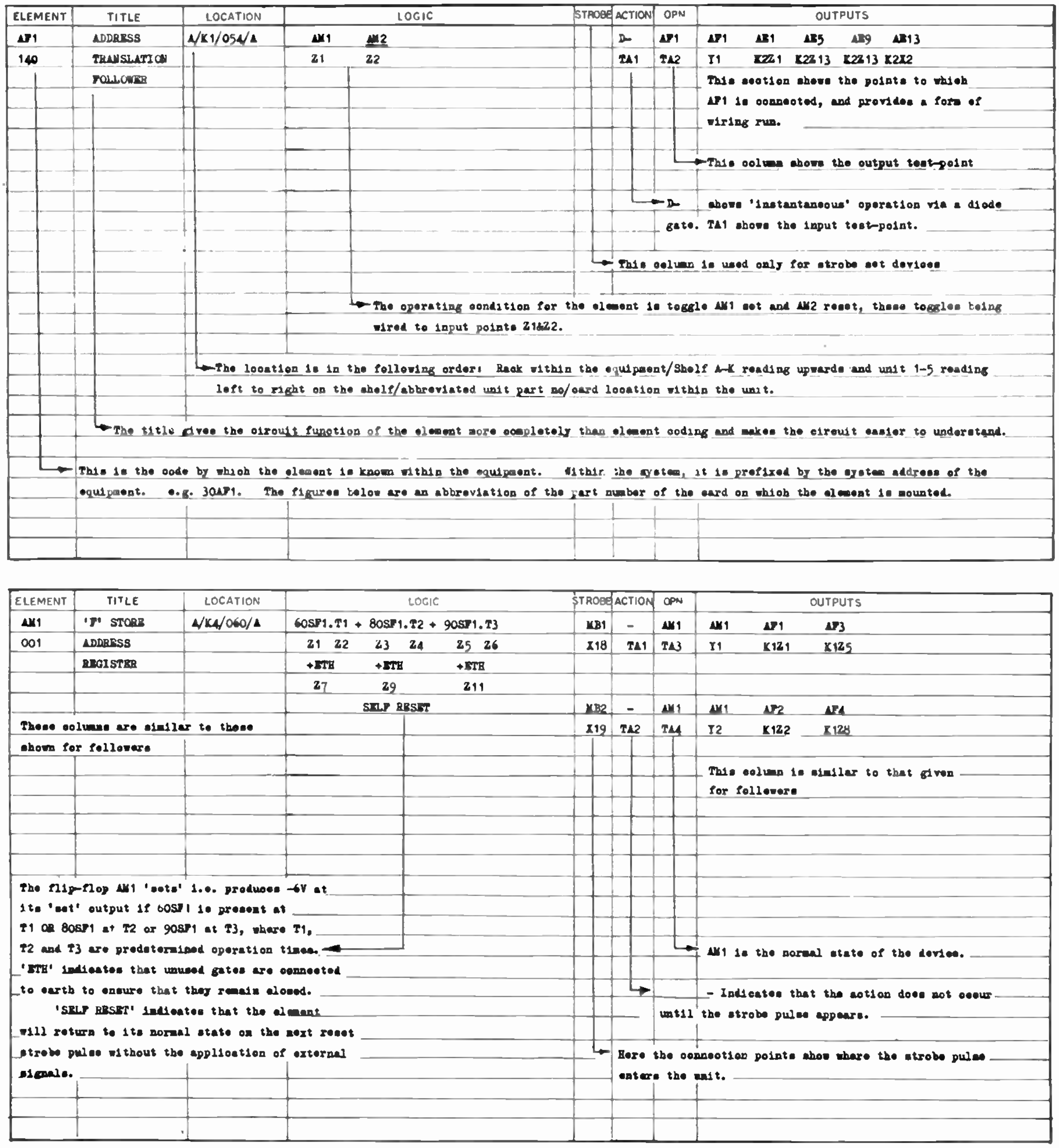


Fig. 4. Typical logic directory sheets.

transients to a minimum and provide potentials to close tolerances at the elements.

3.3. *Signal Connections*

The signal distribution system has also received much consideration and relatively long interconnections between computers are possible.

3.4. *Peripheral Equipment*

The system includes tote displays and detailed information displays, to data injection positions.

4. Maintenance Considerations

The need for speedy fault finding was appreciated in the early design stages. A high level of component reliability is not enough in itself for, in a large equipment, the frequency of fault incidence may still be quite high and if the time taken to effect repair is lengthy, another fault may develop before the first is cleared. Reliability in the system sense is therefore a function of both the frequency of fault incidence and the time taken to effect repair and can be defined as serviceability.

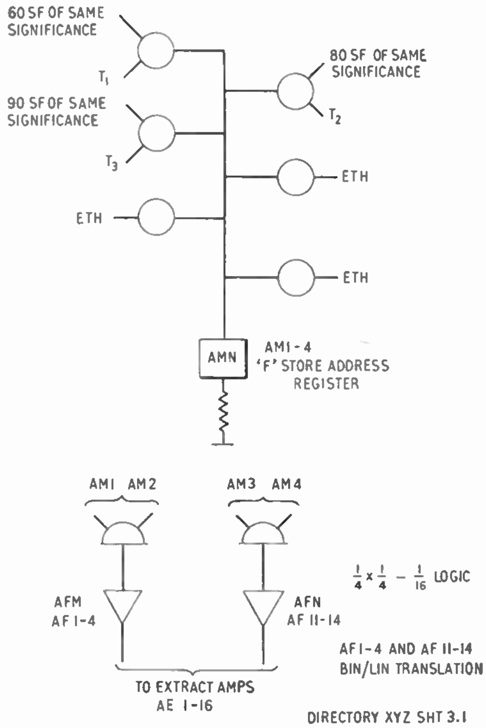


Fig. 5. Flow diagram for use with written logic.

Unless the equipment incorporates suitable protection arrangements further faults may be caused by the maintenance staff while carrying out fault location and repair.

The diagnosis of two or more faults present simultaneously is extremely difficult, mainly because an attempt is made to ascribe the symptoms to one fault.

The higher the intrinsic reliability of the equipment comprising a data handling system the less exercise maintenance staff obtain in fault location. Automatic fault finding aids are therefore very necessary if the degree of maintainability necessary to give high serviceability is to be attained.

4.1. *Fault Finding Aids*

The following important aids have been incorporated:

(1) The standard plug-in unit is well equipped with test points and the operation of a circuit may be studied in detail. An extendor may be used so that the unit is mounted clear of the rack while still operative, and all input and output connections to the unit may be broken if necessary. The units may also be tested on a universal test set. The set is simple and a relatively unskilled operator can use it.

(2) Rack inputs go through links which can be removed, thereby permitting the introduction of inputs controlled by keys, or inputs from a fault finder.

(3) Drawings in the accepted sense have been replaced by a logic system. As most designers use written logic during design it was felt that this was possibly a more useful manner of presenting circuit information to the maintenance engineer. Typical logic sheets are shown in Fig. 4 and the associated flow diagram is shown in Fig. 5. Elements are numbered alpha-numerically, no circuit coding, as such, being used and the position of elements in the rack is given by a system of shelf and column co-ordinates. The method ensures standardization between circuits and facilitates the tracing of logic paths throughout the equipment. A block diagram is provided for use in conjunction with the logic sheets and flow diagrams. Timing charts are also provided where necessary.

(4) All tag locks, fuse-panels, units and racks are clearly labelled giving circuit references to the element signals concerned. Signal tracing is thus performed without recourse to drawings, as all equipments have an address code allocated.

(5) The clock signals to each equipment may be interrupted and single clock pulses applied to the equipment. This facility is extremely valuable for the detection of logical design errors in equipments being commissioned.

4.2. *Fault Detection*

With a working equipment faults may be detected in a number of ways:

(1) By observation—

(a) Observation of the system operation.

(b) Alarm observation, i.e. fuse warnings etc.

(2) By routining.

In a large system human observation of faults is a most unsatisfactory method except where the faulty piece of apparatus is very obvious. For speedy detection and rectification of other faults automatic routining must be employed. The system under review is especially adaptable to routining methods as it works on a time-division basis. Test programmes and patterns can be injected in unused slots in the time cycle. Faulty equipments can therefore be detected rapidly and stand-by equipment put into service. Equipment faults at the moment are found by breaking the input connections from the remainder of the system, with the exception of certain timing signals required to activate the equipment, and replacing them by instructions and data fed from central key controls. An equipment may then be cycled using the programme

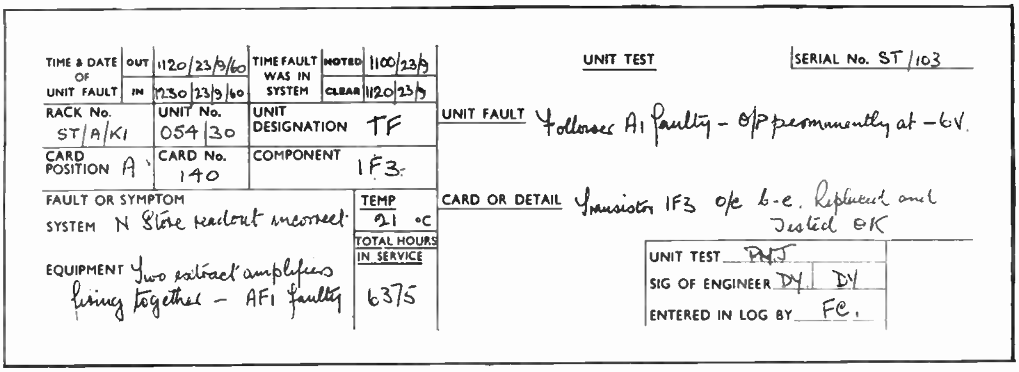

TIME & DATE OF UNIT FAULT OUT 1120/23/9/60 IN 1230/23/9/60
TIME FAULT WAS IN SYSTEM NOTED 1100/23/9 CLEAR 1120/23/9
RACK No. ST/A/K1
UNIT No. 054|30
UNIT DESIGNATION TF
CARD POSITION A
CARD No. 140
COMPONENT 1F3
FAULT OR SYMPTOM
SYSTEM N Store readout incorrect
TEMP 21 °C
EQUIPMENT Two extract amplifiers firing together – AF1 faulty
TOTAL HOURS IN SERVICE 6375
UNIT TEST
SERIAL No. ST/103
UNIT FAULT Follower A1 faulty – O/P permanently at –6V.
CARD OR DETAIL Transistor 1F3 o/c b-e. Replaced and Tested OK
UNIT TEST PHJ
SIG OF ENGINEER DY. DY
ENTERED IN LOG BY FC.

Fig. 6. Typical unit fault log sheet.

on which the routiner detected failure. Charts of time versus element state for all routiner programmes are prepared and the faulty unit easily found. Due to careful attention and inspection, faults involving equipment wiring etc., are rare, but are obviously more difficult to detect.

A more elaborate fault locater is at present being designed using a drum store and a large number of programmes. On a faulty rack the incorrect results will be assessed automatically, and the fault localized to a unit or group of units.

4.3. *Fault Records*

Very careful attention has been paid to the fault recording system. Emphasis is laid on the fact that every fault must be recorded if the information is to be of value. The fault books are kept in the racks so that notes may be made on the spot. All units are labelled geographically in the system and units stay in the same location for the whole of their operational life. A history sheet is kept on each unit and on this all faults, modifications etc are noted and dated. A typical completed report card is shown in Fig. 6.

Complete cards are only replaced if they have been damaged beyond repair. Usually, components only are faulty and in such cases replacement is effected and the card returned to the unit. The elements therefore remain in one location throughout life. This arrangement was felt to be very desirable from the point of view of failure analysis, since it may be possible to correlate any unusually high incidence of failure in any one unit or equipment with environmental conditions.

All faulty components are returned from site to central laboratories where further examination is carried out.

5. Component Fault Data

The mounting importance which is being attached to the reliability of electronic equipment, largely as a result of the increasing use of data handling equipment, is leading to the collection and publication of much data regarding component reliability. Often, these data relate to components tested or used under conditions which differ from the environment in which most large data handling equipments operate. A user, in attempting to gain something from such evidence may be tempted to apply some sort of environmental correction factor. The validity of this approach is more than doubtful, the only really satisfactory data in the present state of our knowledge being those obtained from equipments comparable with that in issue.

The equipment discussed in this paper was designed without recourse to really relevant reliability data since such information was not available to the manufacturer. In consequence, this equipment is the subject of the component fault recording system already detailed, the prime object of the fault records being the provision of such information.

As indicated in the introduction, this section of the paper is in the nature of an interim report because the installation and commissioning of the equipment has only recently been completed. The most significant results will clearly not be available until the entire equipment has been operating for some time as a system, for system reliability records will be possible and they should give important perspective to the basic component failure characteristics.

The operation of a large equipment for an appreciable period without component failures, although very encouraging and indicative of a high component reliability, does not enable quantitative predictions to be made regarding the component reliability parameters of the system.

Component failures are an essential ingredient of reliability assessments and the more failure data there is available, the better the parameter estimates are likely to be.

This is the reason why fault records covering large numbers of components are necessary to establish reliability limits for components which are inherently highly reliable in their working environment.

The relatively few failures which have occurred to date prohibit exhaustive analysis of the component reliability at this time and such a treatment must await the occurrence of more component failures. Accordingly, the results presented here comprise the bare outlines of the data so far collected.

6. Difficulties of Data Analysis

The fact that reliability data are dependent upon failures for their derivation has been commented upon. The interpretation of these data is also in terms of failures because a failure distribution of some sort is looked for. A few comments about the nature of the distributions which one might expect are appropriate here.

The occurrence of failures in an entirely random manner, not associated in any way with a "wear-out" phenomenon can be expected to show a Poisson type of distribution, assuming that the number of failures occurring is small compared with the total number of components.

Failures resulting from a definite "wear-out" activity will very likely follow a Gaussian distribution.

Failures propagated by other failures due to circuit interaction, and failures caused by inadvertent and undetected mishandling may, if a sizeable proportion of the total failures, deform the appropriate distribution to such an extent as to conceal its nature completely. Long-term results might permit some estimation of failures of this type.

Difficulty arises also in the definition of a failure. A component which has ceased to operate according to the principles which define its function can be termed catastrophic, and its failure cannot be disputed. However, where a component still behaves essentially in accordance with its defined working principles, but causes inoperation of the circuit by virtue of some change from its original performance level, the issue is less clear. In such instances the failure is related to the safety factors designed into the circuit initially, and these will vary from manufacturer to manufacturer. Indeed, if practice is not standardized, individual design engineers working on the same project may make different allowances for the drift of component characteristics. In this paper, therefore, the definition "degraded failure" is applied to components which have been classed as failures as a result of circuit inoperation, even though they are still functional as a component. For example, a resistor would be failed if its value changed beyond the limit which the circuit tolerates.

A strict comparison of "degraded failure" data from two dissimilar equipments, especially if of different manufacture, is, in consequence not readily made. Elements becoming inoperative because of "degraded" component characteristics may do so as a result of a drift in the characteristics of a single vital component, or as a result of the combined effect of a number of component characteristic changes. Clearly therefore, the term "degraded failure" is associated with particular circuitry and failures of this type are related to the practice current with the manufacturer at the time of design.

7. Component Fault Rate Analysis

Some components, as a consequence of the phased installation and commissioning programme, have been in operation longer than others. A convenient method of utilizing the service of every component for analysis purposes is to use the total component hours as a basis for failure rate calculation. Failure rates derived in this way are given in Table 2 but, in order to give perspective to the component-hour totals, the failure rates appropriate to the number of components which have completed 5500 hours service are also given. The 5500-hour point was chosen because it was felt to be a good compromise between the dual requirements of large component numbers and long working time.

In general, the non-semi-conductor type components have suffered too few failures to make anything more than a statement of a simple failure-rate figure worthwhile. Results for such components are included in Table 2.

The figure for plugs and sockets requires some comment. The failure rate quoted is based on contacts requiring replacement. The inclusion of faults cleared by cleaning, knowingly and unknowingly, would result in a higher figure. Recently, arrangements have been made to record faults known to be cleared by cleaning. Even so, the resulting failure rate may be optimistic, for insertion in the unit test set may clean a dirty contact and no fault will be registered.

Results for the semi-conductor components are also shown in Table 2, but, in addition, Figs. 7 to 11 show some distributions of failures per running period of 500 hours and curves of failure rate against time. These latter are simply plots of a function of the failures/total components ratio with time. These distributions show results up to 5500 hours, the component totals existing at this time only being considered.

No particular distribution is evident in the results, with the possible exception of the results for group A transistors (Fig. 7 (a)). Here a Poisson distribution may be appropriate for the catastrophic failures, although the total of only ten failures virtually precludes significance tests and suggests the wisdom of awaiting further data. (See Appendix 1.)

Table 2

Component Fault Rate Analysis

Type of component	Assessment at 5500 hours running time				Assessment for total component hours of operation		
	Number of components	Failures: Catastrophic	Failures: Degraded	Total failure rate % per 1000 hours	Maximum number of components in service	Total component hours	Failure rate % per 1000 hours
RESISTORS:							
Carbon film	29 473	0	2	0·001	55 121	649 × 10^6 (carbon film and carbon composition)	0·0006
Carbon composition	64 228	2	0	0·0006	118 986		
CAPACITORS:							
Polystyrene film	14 976	0	0	—	28 359	164·6 × 10^6 (all capacitors)	0·0018
Metallized paper		0	0	—	12 860		
Electrolytic	188	1	0	0·106	342		
Tantalum		0	0	—	598		
SEMI-CONDUCTOR DEVICES:							
Germanium point contact diodes (CV448)	49 156	5	4	0·003	100 970	346·3 × 10^6	0·0043
Germanium junction diodes	8 623	20	2	0·046	15 016	59·8 × 10^6	0·045
H.f. germanium alloy junction transistors:							
Group A	13 122	10	6	0·022	23 274	91·2 × 10^6	0·027
Group B Input	2 268	3	5	0·064	4 044	16·3 × 10^6	0·061
Group B Output	2 268	53	3	0·449	4 044	16·3 × 10^6	0·429
PULSE TRANSFORMERS (ferrite pot core)	4 449	3	0	0·001	7 250	29·1 × 10^6	0·01
CONNECTIONS:							
Plug and socket contacts	43 700	2 bad contacts	1 short circuit	0·001	86 200	Total contact hours: 308·4 × 10^6	0·001
Soldered joints	47 700	1 broken joint	17 dry joints	0·007	916 000	Total joint hours: 3 311 × 10^6	0·007

Assuming a Poisson failure characteristic to be the case for Fig. 7 (a) however, the average failure rate would be 0·014% per 1000 hours. There would be a 40% chance of no incidence of catastrophic failure over a 500 hour working period, the corresponding period for 99% chance of no failure incidence being about five or six hours. This latter type of statistic is useful in the preparation of fault routining programmes. The mean time between failures is 550 hours. This is sometimes called the "reliability index".

The transistors designated group B are all used in a particular type of amplifier element. Each circuit contains two transistors, one of which may be designated "input" and the other "output" by virtue of their circuit position.

An important feature of these transistors is that they can be regarded as two samples, comprised respectively of input and output transistors, identical in type, numbers, running time and physical environment, but differing in electrical environment. Figures 8 and 9 show results for the input and output transistors respectively and it is at once apparent that the incidence of catastrophic failure in the output stage is much higher than in the input stage. The electrical environment is presumably responsible for this great difference. The output stage works under conditions of higher power dissipation and characteristic changes might cause the dissipation to be excessively high in a few instances. Such failures would probably occur in the first few thousand hours working and the results tend to support this hypothesis.

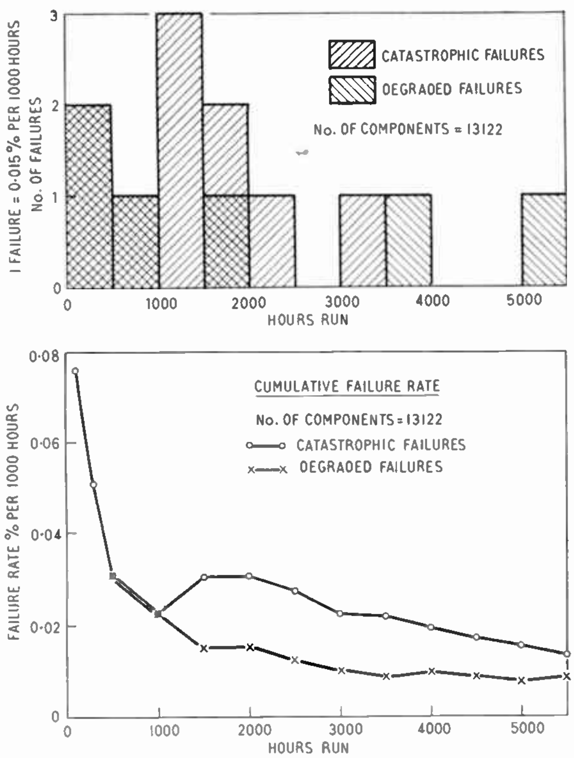


Fig. 7. Germanium alloy junction transistors (Group A).
(*a*) Failure rate for 500 hour running periods.
(*b*) Cumulative failure rate.

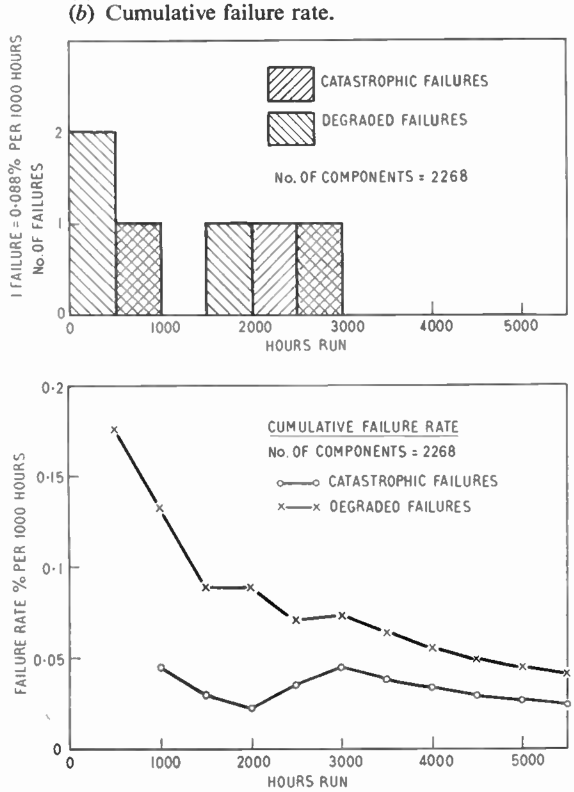


Fig. 8. Germanium alloy junction transistors (Group B—input).
(*a*) Failure rate for 500 hour running periods.
(*b*) Cumulative failure rate.

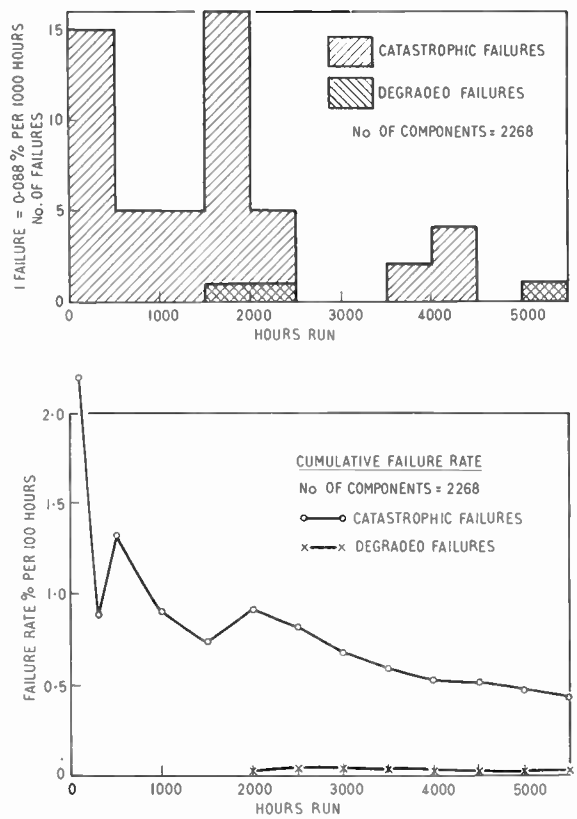


Fig. 9. Germanium alloy junction transistors (Group B—output).
(*a*) Failure rate for 500 hour running periods.
(*b*) Cumulative failure rate.

Also, the output transistors, more than any others in the equipment, are liable to mishandling and undetected cases may have occurred during commissioning. Here again, if such mishandling took place it would occur during the first few thousand hours of operation.

Some resolution of these possibilities is expected when the equipment has been in service for a longer period of time. In fact, a clearer picture is hoped for in the case of all components as the working time extends.

Faults known to be due without doubt to accidental, and in principle, avoidable damage, have been excluded from this consideration. Nevertheless, the possibility of a significantly large proportion of unknown accidental mishandling failures being included is present in the case of the output transistors of group B. Other components are not likely to suffer a significant proportion of failures of this type.

As a general principle however, when evaluating equipment failure data, the "genuine" failures remaining when all known accidents have been allowed for, must be regarded as "failures not known

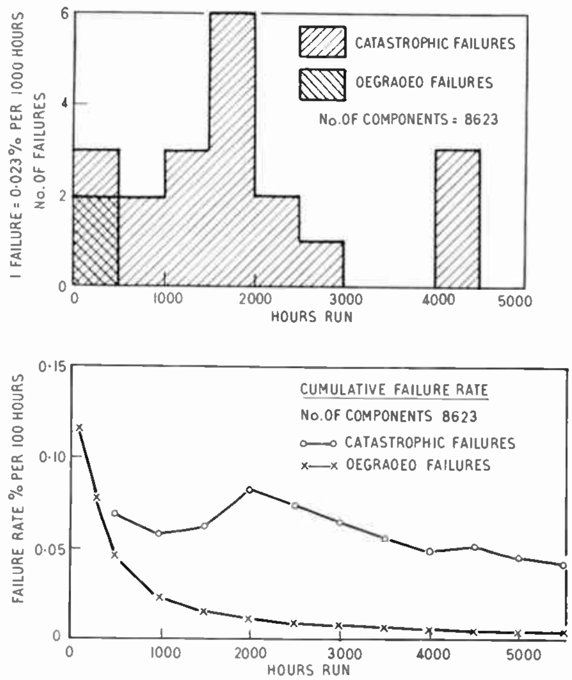


Fig. 10. Germanium junction diodes.
(*a*) Failure rate for 500 hour running periods.
(*b*) Cumulative failure rate.

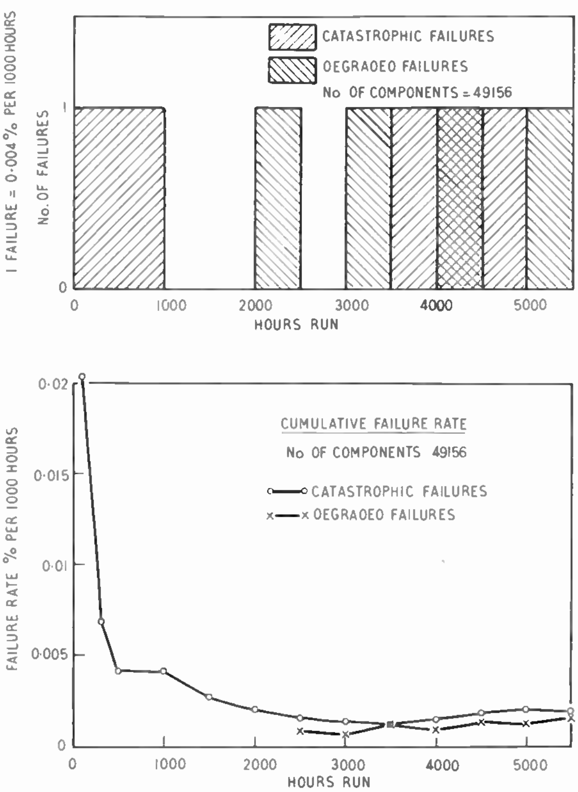


Fig. 11. CV448 Diodes.
(*a*) Failure rate for 500 hour running periods.
(*b*) Cumulative failure rate.

to be due to accidental mishandling". This point is mentioned only as a reminder that attempts to establish absolute life data from field evidence should be treated with reserve.

Some comment on the use of components is worthwhile. Capacitors, with the exception of the electrolytic types, are operated well within their maximum voltage rating, this being a natural consequence of the use of low voltage semi-conductor components. Resistors are, in general, used at a maximum of half their power rating in order to obtain improved stability. This practice is not advisable where very high relative humidities are encountered for long periods[1] but is considered permissible for the equipment discussed here.

Semi-conductor diodes are also operated well within their maximum voltage and current ratings. Transistors, however, while generally dissipating much less power than the permitted maximum, are frequently used near to the maximum permissible voltage. This state of affairs is difficult to avoid and may have some bearing on the higher failure rate prevailing for these devices. Circuit design normally provides for a 30% decrease in the minimum current gain value for a transistor type.

8. Conclusions

A brief description has been given of an experimental data handling system which has just completed commissioning, and reference has been made to certain design principles followed in an attempt to achieve high reliability.

Data have been given regarding the incidence of component failure in the system, but this is of an interim nature. A fuller treatment is projected when the amount of fault data makes this justifiable.

The completion of commissioning makes a consideration of system reliability possible and this work also is projected.

The combination of component and system reliability information is expected to give the measure of success achieved in the design of the equipment and permit the detection of any localized weaknesses, if such exist.

At the time of this assessment, a total of 370 864 components was in service, excluding plugs, sockets and soldered joints. These have completed an overall total of $1\,372{\cdot}7 \times 10^6$ component hours operation with a simple failure rate of 0·011% per 1000 hours. The failure rate when plugs, sockets and soldered joints are included is 0·0037% per 1000 hours.

9. Acknowledgments

The authors wish to acknowledge the co-operation of the commissioning group and the help of Miss D. J. Taylor and Mr. R. A. Boulton. They also wish to thank the Ministry of Aviation and the management of the Automatic Telephone and Electric Company Ltd., for permission to publish the paper.

10. References

1. "Inter-Service Standards for Radio Components." Note 5 of RCL 122. (Carbon Film Rèsistors.)
2. M. G. Kendall, "Advanced Theory of Statistics". (Griffin, London, 1958.)
3. "Reliability Factors for Ground Electronic Equipment." (McGraw-Hill, New York, 1956.)
4. *Proceedings of the Sixth National Symposium on Reliability and Quality Control 1960*, Institute of Radio Engineers.
5. B. M. Chakravarti and P. S. K. Prasad, "Environmental engineering for operational reliability of ground electronic equipment systems", *J. Soc. Electronic Engrs, (Bangalore)*, **3**, No. 5, pp. 213–32 (1959).
6. G. C. F. Whitaker, "The problems of reliability and maintenance in very large electronic systems for shipboard use", *J.Brit.I.R.E.*, **19**, pp.625–46, October 1959.
7. A. Davison and R. Threadgold, "Design for Reliability in Data Handling Systems". A.T.E. Technical Memorandum XTM 40024.
8. C. G. Paradine and B. H. P. Rivett, "Statistics for Technologists". (English Universities Press, London, 1953.)

11. Appendix 1: Poisson Distribution

The Poisson distribution applies in cases where the average failure rate is constant and where only a small proportion of the total components in service fail.

Consider N components in service. If the total service completed up to the time of analysis is divided into n equal intervals, each of duration t, the total number of faults which have occurred in n periods of duration t is F and $F \ll N$, then the Poisson probability function is defined as

$$P_{(x)} = \frac{\alpha^x}{x!}\exp(-\alpha) \qquad \ldots\ldots(1)$$

where $\alpha = \dfrac{F}{n}$

and $P_{(x)}$ is the probable proportion of intervals of duration t which will contain x failures.

Sometimes the Poisson probability function, as used in reliability studies, is defined as

$$P_{(x)} = \frac{\alpha^x}{x!}\exp\left(-\frac{t}{m}\right) \qquad \ldots\ldots(2)$$

where $m = \dfrac{nt}{F}$

m is seen to be the "mean time between failures" and is often called the "reliability index".

The probabilities of having intervals containing 0, 1, 2, etc. failures can be calculated, the following sequence proving the most convenient.

$$P_{(0)} = \exp(-\alpha)$$

$$P_{(1)} = \alpha P_{(0)}$$

$$P_{(2)} = \frac{\alpha}{2} P_{(1)}$$

$$P_{(3)} = \frac{\alpha}{3} P_{(2)}$$

and generally, $$P_{(n)} = \frac{\alpha}{n} P_{(n-1)}$$

Alternatively, the probabilities can be determined from a Poisson Summation Chart. These charts are often included in statistical texts.

The proportion of the total number (n) of intervals (t) corresponding to each failure incidence x is given by $nP_{(x)}$ and these values $nP_{(0)}$, $nP_{(1)}$ etc., are called the "expected" frequencies (f_e). The observed frequencies (f_o) are derived from the fault data.

The problem of whether or not the postulated Poisson distribution is a sufficiently good (not perfect) fit for the observed data must next be examined. The first step is to form the null hypothesis that the observed and calculated distributions are not different. The second step is to tabulate the observed and expected failure frequencies as shown in Table 3. The table must extend to a value of x where the total observed failure frequencies (Σf_o), and the total expected failure frequencies (Σf_e), each equal the total number (n) of time intervals (t).

For the third step use is made of the χ^2 (chi-squared) test, full details of which can be found in statistical texts.

Table 3

Poisson Distribution

Number of failures x	Number of intervals (f) of duration t hours ($\Sigma f = n$) Observed (f_o)	Expected (f_e)	$\frac{(f_e - f_o)^2}{f_e}$
0	f_{o0}	f_{e0}	
1	f_{o1}	f_{e1}	
2	f_{o2}	f_{e2}	
3	f_{o3}	f_{e3}	
.	.	.	
.	.	.	
.	.	.	
$(c-1)$	$f_{o(c-1)}$	$f_{e(c-1)}$	
	$\Sigma f_o = n$	$\Sigma f_e = n$	$\chi^2 = \Sigma \frac{(f_e - f_o)^2}{f_e}$
	$u = c - 2$		

In essentials, the test consists of evaluating the expression,

$$\sum \frac{(f_e - f_o)^2}{f_e} \quad \ldots\ldots(3)$$

If the values of f_e and f_o appropriate to each x value are less than a value f_m, grouping of failure frequencies for adjacent x values is permissible. One authority[2] suggests fifteen as a suitable value for f_m. A value of ten is commonly taken for f_m however.

The significance to be attached to a particular value of χ^2 can be obtained from statistical tables. First however, the "degrees of freedom" (u) must be determined. The "degrees of freedom" can be regarded as the number of independent classes (c) subjected to the χ^2 test, less any restrictions. For a Poisson distribution two statistics, the total n and the mean α, are determined from the observed data and these comprise restrictions. Therefore in this case $u = c - 2$.

Lastly, the level of significance corresponding to the calculated χ^2 value for the appropriate value of u is found from statistical tables. A significance level in excess of 5% does not refute the null hypothesis, and a level of 50% is the most favourable. The hypothesis is best rejected for a level of 5% or less.

Once a set of fault data has been adequately fitted by a Poisson distribution, the following parameters can be evaluated:

(a) Failure rate $= \frac{F}{n}$ components per interval of t hours

$= \frac{F}{nt}$ components per hour

$= \frac{F}{ntN} \times 10^5$% per 1000 hours

(b) Mean time between failures $(m) = \frac{nt}{F}$

(c) Probability of zero failures occurring in any interval of t hours is $P_{(0)}$.

(d) Since $P_{(0)} = \exp(-t/m)$, (from eqn. (2))

$$t = -2{\cdot}303\, m \log_{10} P_{(0)} \quad \ldots\ldots(4)$$

Hence the interval of time t hours during which zero failures can be expected can be found for any desired probability.

12. Appendix 2: Normal (or Gaussian) Distribution

The normal probability function applies in cases where some force causes failure of components in a time which is dependent on the ability of the component to resist the "wearing out" force, and where this ability varies normally, in the statistical sense.

The normal probability function is given by

$$y = \frac{1}{s\sqrt{2\pi}} \exp\left[-\tfrac{1}{2}\left(\frac{t-\bar{t}}{s}\right)^2\right] \quad \ldots\ldots(5)$$

where y = probability density

t = duration of service (total T hours)

$\bar{t}$ = the mean of the failure distribution (or mean life)

s = the standard deviation of the failure distribution

Figure 12 (a) shows the normal curve.

To facilitate calculations with the normal distributions, the probabilities $\phi(x)$ of a "standard normal curve" have been tabulated in statistical tables. For this curve

$$\bar{t} = 0; \quad s = 1; \quad x = \frac{t-\bar{t}}{s}$$

Equation (5) therefore reduces to

$$y = \frac{1}{\sqrt{2\pi}} \exp(-\tfrac{1}{2}t^2).$$

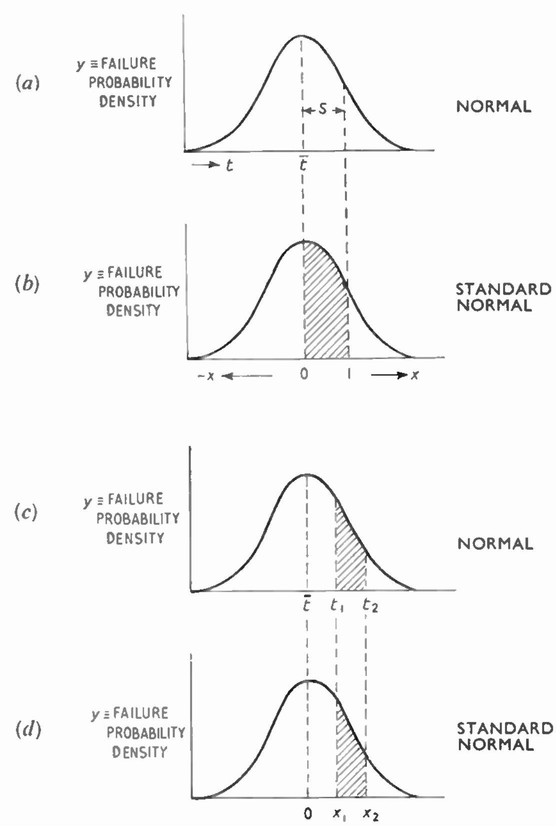


Fig. 12. Normal curves.

The area under this curve represents probability and the total area and probability is equal to unity. The standard normal curve is shown in Fig. 12 (b) and the area between 0 and $x = 1$ represents the probability of a frequency occurring between the mean life and the mean life plus one standard deviation.

In order to test for a normal distribution, the total service time T must be divided into suitable intervals of time, as in the case of the Poisson distribution (Appendix 1). The number of observed failures f_o appropriate to each interval are then counted and hence the mean life $\bar{t}$ calculated from,

$$\bar{t} = \frac{\sum ft}{N} \qquad \text{......(6)}$$

where $N = \sum {}_o$.

The standard deviation s is calculated from

$$s^2 = \frac{\sum (t-\bar{t})^2}{N} \qquad \text{......(7)}$$

The areas, as a proportion of unity, and hence probabilities corresponding to the observed frequencies, are evaluated by a difference method.

Consider an interval t_1 to t_2 on the normal curve of Fig. 12 (c). Let these correspond to the points x_1 and x_2 respectively of the standard normal curve of Fig. 12 (d).

Then, $$x_1 = \frac{t_1 - \bar{t}}{s}$$

and $$x_2 = \frac{t_2 - t}{s}$$

From the tabulated areas $\phi(x)$ of the standard normal function, $\phi(x_1)$ and $\phi(x_2)$ can be determined. Hence the required probability is

$$\phi(x_2) - \phi(x_1) \qquad \text{......(8)}$$

and the probable (or expected) frequency of failure is therefore

$$N[\phi(x_2) - \phi(x_1)] \qquad \text{......(9)}$$

All the expected frequencies (f_e) corresponding to the observed frequencies (f_o) can be calculated in this way. Negative values of x can be treated as positive ones since the standard normal curve is symmetrical about the mean.

Table 4

Normal Distribution

Interval t (hours)	Frequency of failure Observed (f_o)	Expected (f_e)	$\frac{(f_e - f_o)^2}{f_e}$
$0 - t_1$	f_{o1}	f_{e1}	
$t_1 - t_2$	f_{o2}	f_{e2}	
$t_2 - t_3$	f_{o3}	f_{e3}	
.	.	.	
.	.	.	
.	.	.	
$t_{(c-1)} - t_c$	f_{oc}	f_{ec}	
	$\Sigma f_o = N$	$\Sigma f_E = N$	$\chi^2 = \Sigma \frac{(f_e - f_o)^2}{f_e}$
	$u = c - 3$		

The observed frequencies (f_o) can be obtained from the fault data.

The results can be set out as shown in Table 4.

The χ^2 test can be used to determine the "goodness of fit" of the observed to the theoretical frequencies, exactly as in the case of the Poisson distribution, but there are three restrictions on the "degrees of freedom". This is because the theoretical distribution is based on the total ($\Sigma f_o = N$), the mean ($\bar{t}$) and the standard deviation (s) calculated from the fault data. Hence $u = c - 3$.

Assuming that a particular practical case gives significant agreement with a theoretical distribution, the derived parameters may not be precisely correct if applied to another equipment. Particular equipments are somewhat akin to samples drawn from a population. The larger the number of failures used as a basis for estimation, the closer the "confidence limits" should be.

Manuscript first received by the Institution on 21st October 1960 and in final form on 5th April 1961 (Paper No. 648).

NEW BRITISH STANDARDS

The following is a selection of the new and revised British Standards on subjects of interest to members which have been issued in recent months. The Brit.I.R.E. has been directly represented on the Technical Committees concerned with those Standards marked with an asterisk (*). Copies of the Standards may be obtained from the British Standards Institution, Sales Branch, 2 Park Street, London, W.1. (Postage will be charged extra to non-subscribers to B.S.I.)

Glossary of Terms used in Telecommunication (including radio) and electronics* (B.S. 204 : 1960. *Price 35s.*)

The 2700 definitions in this new 350-page volume represent a decade's work on the part of one of the B.S.I. Technical Committees TLE/1, on which the Institution is represented. The standard brings together all the terms previously dealt with in the 1943 edition and the various supplements published between 1948 and 1951. Throughout its preparation, account was taken of parallel international work having a bearing on important sections of the glossary.

The glossary contains many new terms and definitions and, where necessary to reflect technical developments and changes in usage, many of the definitions have been extensively revised. Deprecated terms are indicated in a distinctive typeface, as are obsolete terms.

The main section headings are:

General	Radio terminal equipment
Telecommunication components	Propagation and media
Telecommunication circuits	Services
Classification of radio waves and transmissions	Inductive coordination

The section on "Services", for example, includes sub-sections giving terms and definitions for telegraphy, telephony, facsimile, television, radio broadcasting, mobile radio, radiolocation, radio navigation, and fire service communications.

Noteworthy additions to the publication are a treatment of the terminology of semi-conductor devices, and data on information theory and inductive coordination.

Electronic-valve bases, caps and holders, Sections B8D/3 and 7/3.* (B.S. 448. *Each section costs 3s.*).

These two further sections of B.S. 448 lay down dimensions for valveholders and for the gauges needed to ensure compatibility with the appropriate valves. Section B8D/3 applies to holders, and associated gauges, for valves having B8D type bases. Section 7/3 applies to holders (and associated gauges) for valves having 5 or 7 lead in-line bases.

Preparation of mathematical copy and correction of proofs (B.S. 1219M : 1961. *Price 2s. 6d.*)

In response to numerous requests, the British Standards Institution has produced a four-page card setting out the recommendations and marks for the clarification of mathematical copy and the correction of mathematical proofs contained in B.S. 1219 : 1958. This card (B.S. 1219M) is similar in style to B.S. 1219C, "Table of symbols for printers' and authors' proof corrections" which was published some three years ago.

Telecommunication Components* (B.S. 2133B : Part 1 : 1961 and B.S. 2136 : Part 1 : 1961. *Price 12s. 6d. each part.*)

Two more British Standards in the series for components intended primarily for use in telecommunication and allied electronic equipment have been published. *B.S. 2133B* applies to capacitors with a rated voltage of not more than 1500 volts. It defines a ceramic dielectric capacitor, Grade II, as being a capacitor suitable for bypass and coupling applications or for circuits where low losses and high stability of capacitance are not of major importance. *B.S. 2136* covers fixed metallic-paper dielectric capacitors suitable for d.c. operation with or without a small superimposed a.c. component. These capacitors have a dielectric of impregnated paper with thin metal electrodes deposited on it and exhibit self-healing properties. The specification divides the capacitors into two grades: Grade I, in which the self-healing failure rate during service is negligible, and Grade II, in which the self-healing failure rate is of significant proportions. The criteria for this classification are laid down.

These two standards provide manufacturers and users with a means of judging the capacitors' suitability for use over stated ranges of temperature and humidity, their ability to withstand mechanical shock of the kind to be expected in transit or in operation, and their ability to remain unharmed by normal assembly processes, such as soldering. Exacting climatic and durability requirements are laid down, with tests. Most of the tests are described in detail in B.S. 2011, "Basic climatic and durability tests for components for telecommunication and allied electronic equipment" and reference to that standard is therefore necessary.

Each standard specifies different requirements for various grades of capacitors according to the climatic environment in which they are intended for use. By stipulating the appropriate climatic classification, users can select capacitors suitable for use in high-grade equipment, which is required to operate in widely different climatic conditions, or capacitors which are suitable for use in domestic radio equipment intended, in general, only for indoor use in temperate climates.

Graphical symbols for components of servo-mechanisms. Part 1: Transductors and magnetic amplifiers (B.S. 3238 : 1960. *Price 4s. 6d.*)

The first part of a standard which will serve as a companion volume to B.S. 1523 : Section 5 : 1954, this 15-page publication tabulates graphical symbols for diagrams containing transductors and magnetic amplifiers. A number of typical diagrams are included to exemplify the use of the symbols.

Following twenty-two diagrams is an appendix which provides a series of useful notes on polarity marking. Dealt with in the notes are: conventions used and their application; polarity convention indicated in B.S. 822; "dot" conventions used on transductor and transformer windings; "dot" conventions used on magnetic amplifier circuit diagram symbols.

Letter symbols for light-current semi-conductor devices* (B.S. 3363 : 1961. *Price 5s.*)

International work on the standardization of letter symbols for semi-conductors, sponsored by the International Electrotechnical Commission, is well advanced but has not reached the publication stage; the international agreements to date have been taken into account and largely incorporated in this new British Standard.

The Standard is primarily intended as an aid to manufacturers and users of semi-conductor devices: it should simplify, speed up and cut down the costs of cataloguing and ordering. It should also, however, be found useful for most technical literature concerned with the characteristics or behaviour of light-current semi-conductor devices.

U.D.C. 621.374.32 : 681.142

A Fast Binary Counter

By

E. TARANTO, M.S.†

Summary: A transistor binary counter employing seven flip-flops is described. Its operation is dependent only on the switching time of one flip-flop which may be ~ 100 ns.

The general trend to higher clock frequencies and faster ring counters with general-purpose computers puts a heavy burden on the development of computer hardware and circuit design.

Although emphasis has been laid on faster switching elements and new circuitry, ring counters have additional operational limitations due to the switching time of individual flip-flops and "carry" ripple propagation. The time required for results to be available from a ring counter is normally the sum of the switching time of the many individual flip-flops employed. When a number of flip-flops are used in decade, the time required for the result to be available could be most troublesome.

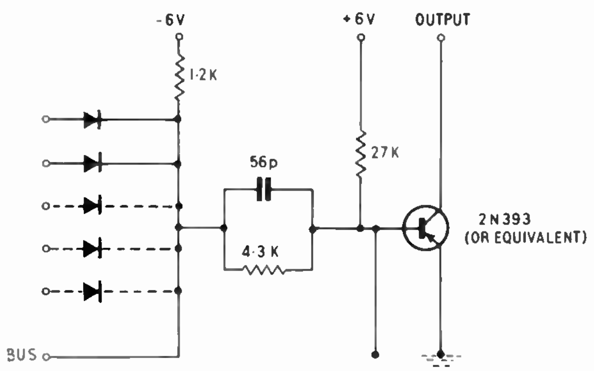


Fig. 1. Circuit of the basic flip-flops.

This note presents a transistor binary counter which was designed for a general digital computer application. The counter is of the gated amplifier type, employs seven flip-flops and has a stepping sequence of up to 30 steps. The main five binary flip-flops Q0, Q1, Q2, Q3, and Q4, are set and reset individually at each step, thus making the counter dependent only on the equivalent switching time of one flip-flop and quite independent of carry ripple propagation.

An important factor in the switching rate limitation is, of course, the circuit, i.e. the logic used as well as the individual switching elements and associated components.

With diffused base transistors employed in a current mode, the switching time of each flip-flop could be reduced to some 10–20 millimicroseconds. The counter originally built and described in this note used high-speed transistors in a common emitter configuration with diode NAND-NOR logic as shown in Fig. 1.

Table 1

Truth Table

STEP NO	DS1	DS0	T4	T3	T2	T1	QB	QA	P4	P3	P2	P1	Q4	Q3	Q2	Q1	Q0
0		×															
1	×					×											×
2		×										×				×	
3	×				×			×								×	×
4		×						×			×				×		
5	×					×									×		×
6		×										×			×	×	
7	×			×			×								×	×	×
8		×					×			×				×			
9	×					×								×			×
10		×										×		×		×	
11	×				×			×						×		×	×
12		×						×			×			×	×		
13	×					×								×	×		×
14		×										×		×	×	×	
15	×		×				×	×						×	×	×	×
16		×					×	×	×				×				
17	×					×							×				×
18		×										×	×			×	
19	×				×			×					×			×	×
20		×						×			×		×		×		
21	×					×							×		×		×
22		×										×	×		×	×	
23	×			×			×						×		×	×	×
24		×					×			×			×	×			
25	×					×							×	×			×
26		×										×	×	×		×	
27	×				×			×					×	×		×	×
28		×						×			×		×	×	×		
29	×					×							×	×	×		×
30		×										×	×	×	×	×	

† IBM Deutschland GmbH, Development Laboratory, Boeblingen, Western Germany.

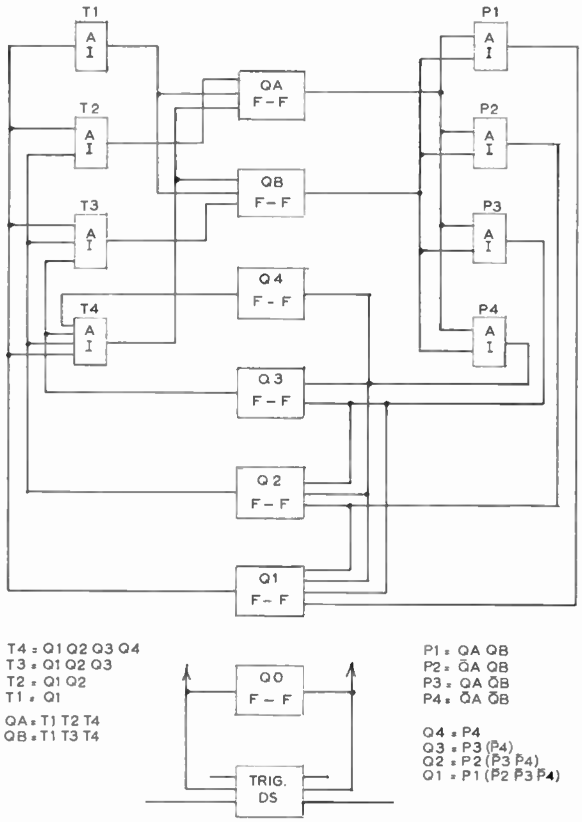


Fig. 2. Block diagram of the counter.

With this logical configuration a switching speed of 80–100 millimicroseconds per block was achieved, which made a 10 Mc/s clock operation rate feasible. Furthermore, eliminating the carry ripple and setting and resetting all flip-flops simultaneously at each step made the count available in less than 0·1 microsecond, this being the approximate setting time of the flip-flops.

Some 17 distinctive signals are involved with the sequence counter as can be seen from the truth table (Table 1).

In addition to the binary flip-flops Q0–Q4 already mentioned, two more, QA and QB, are used which, together with a trigger, provide part of the driving mechanism. Each step of the counter is sensed (one step early), decoded and amplified with the aid of four NAND, inverter amplifier, circuits. The outputs of this drive the two flip-flops, QA and QB respectively. Another four NAND circuits, similar to the above-mentioned, sense QA and QB, and their decoded outputs in return drive the counter's next step. A general block diagram is shown in Fig. 2.

The drive signal is a clock signal via a binary trigger. The Q0 flip-flop is directly driven from this binary generator. The output signals from the binary trigger are DS0 and DS1, where DS0 drives the even and DS1 the odd positions of the counter as can be seen from the truth table.

For resetting the counter a reset signal CS is used which resets the counter to zero when applied.

The flip-flops QA and QB provide the basis of the counter control and drive. The relationship between the true resolution time of these flip-flops and the decoded pulse width, which is the decoded previous position, allows QA and QB to be sensed and changed in state with the same pulse. However after decoding QA and QB the signals which drive the counter are those for the next step.

While the exact circuit and logic detailing is too lengthy to be covered here, the average logical designer should be capable of designing a counter as described above with the aid of the information presented.

Manuscript first received by the Institution on 1st September 1960 and in revised form on 27th March 1961 (Contribution No. 33).

U.D.C. 534.88: 629.2.081.7

The Quantitative Evaluation of Echo-Sounder Signals from Fish

By

R. W. G. HASLETT, Ph.D.†

Summary: The possibility of calibration is discussed, depending upon the effects of transducer, propagation, medium and electronic circuits. Calculations are made of the signal strengths expected from fish of given acoustic back-scattering cross-sections and these are compared with experimental results at sea under good weather conditions. This paper is an introduction to a programme of research. Twenty-four references.

1. Introduction

The reception of echo-pulses from reflecting targets is a technique well known in radar and in underwater acoustic echo-ranging. In particular, the echo-sounder, using a vertical sound beam, has been employed increasingly in recent years as a means of locating and, sometimes, identifying fish shoals. Its economic importance in this role, therefore, is great.

An important problem facing research workers in acoustic echo-ranging applied to fishing, is the analysis and quantitative evaluation of the results obtained *from types of equipment currently in use*, in order to extract from the received echoes, more information about the fish.

The present paper discusses the possibility of calibration of an echo-sounder and compares experimental evidence with theory in this field, which combines physics, zoology and electronic engineering.

The signal strengths and characters of acoustic echoes from geometrically-simple underwater targets may be calculated on the basis of the propagation of sound through a fluid medium and reflection, scattering and absorption by objects which represent discontinuities. In contrast, the examination of the echoes to determine the shape, size, number and positions of the targets, as required in the detection of fish at sea, is fraught with difficulties. Thus, the correlation between the number of fish caught and the observed echo-sounder signals, has been found to be poor.

The difficulties are largely due to lack of knowledge concerning:

(a) the acoustic properties of a fish and of its various parts,

(b) the echoes to be expected from known arrays of targets, and

(c) the distinctions between echoes from fish and from sea-bed when they occur at the same range; also between echoes from fish on the axis and those at the periphery of the beam.

An isolated fish is a very complicated reflector of acoustic waves and its echo changes rapidly with aspect-angle in three dimensions.[1] When the acoustic beam is inclined towards the horizontal (as in the "Asdic" type of gear), fish echoes may become confused with the sea-bed echo. This also occurs with vertical sounders and is of particular interest when trawling on the sea-bed.

In this paper, it is proposed to consider targets *free of interference by the sea-bed echo, detected by vertical beams*, as, under this condition, propagation is much more predictable than for a horizontal beam.

Clearly, a thorough appreciation of the essential properties of the underwater signalling system is required. Hence the following Section gives details of each part.

2. Details of a Typical Echo-Sounder

Many types of recording echo-sounder embody the features shown diagrammatically in Fig. 1.[2,3,4] The pulse interval is determined by the time of rotation of a contact drum, synchronized with the motion of a recording pen across chemical paper, which is darkened by an electric current. The path of the pen is either a wide arc of a circle or a straight line.

When the "transmission" contact closes, a pulse of high-frequency alternating current (generally of duration 0·25 to 10 ms and frequency between 10 and 50 kc/s) is applied to the transmitting transducer, mounted underwater.

The echoes resulting from discontinuities in the acoustic impedance of the water, impinge on the receiving transducer and are amplified. These signals cause an electric current to flow from the pen through the paper and give an intensity-modulated record.

To the echo-sounder, a cathode-ray display [3,5,a] may be added to facilitate observation of the precise shape and character of the echoes from fish-shoals. A portion

† Kelvin and Hughes Ltd., Research Dept., Ilford, Essex and West Ham College of Technology.

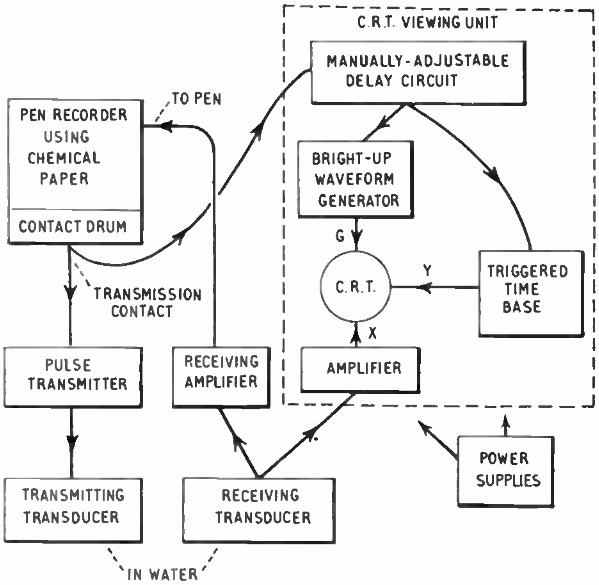


Fig. 1. Block diagram of a typical echo-sounder (with the addition of a cathode-ray viewing unit).

of the reflected sound, selected on a time basis, corresponding to an annulus of range, is viewed on an expanded time-base (e.g. equivalent to 5, 10 or 15 fathoms). The triggering of this time-base is delayed by an amount suitable for the range of interest. Deflection is strictly proportional to echo-amplitude.

Of the apparatus available, the use of this scale-expansion technique on a cathode-ray tube, combined with a chemical-paper recorder, represents probably the most promising arrangement for the detection of fish at sea.[6]

3. Consideration of the Factors concerning Quantitative Interpretation

3.1. *Transducers*

These may be magneto-strictive, piezo-electric or electro-strictive. In older equipments, large numbers of which are still in use, the "pack" of magneto-strictive laminations was mounted at the centre of a conical air-backed metal reflector, having a semi-apex angle of 45 degrees[2,3,4] and two such transducers may be mounted some distance apart as in Fig. 2,[5b] one acting as transmitter and the other as

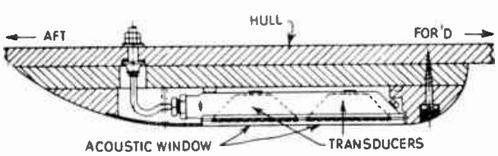


Fig. 2. "Limpet" type of transducer, mounted outside the hull (side view).

receiver. The radiation pattern of this form does not depart very much from that of a plane circular piston excited with uniform strength and phase,[7] equal in size to the aperture of the reflector (mounted in an infinite rigid baffle). Some distortion of the beam occurs as this assembly is fixed in a water-filled case, having a thin metal acoustic "window".[8]

More modern transducers are open to the sea and are of the "bar" type,[4] in which the acoustic energy is radiated from a rectangular face and the back is covered with a pressure-release material. The method of mounting this type of transducer is seen in Fig. 3[5c] and requires a hole to be cut in the ship. Figure 4 gives typical radiation patterns of pressure for the Fraunhofer region[5d] (based on the distribution of pressure with angle at constant range, with no allowance for the absorption of sea-water). As the "window" is now eliminated, these patterns compare favourably with the idealized case of the plane rectangular piston source, excited with uniform strength and phase[7] (mounted in an infinite baffle).

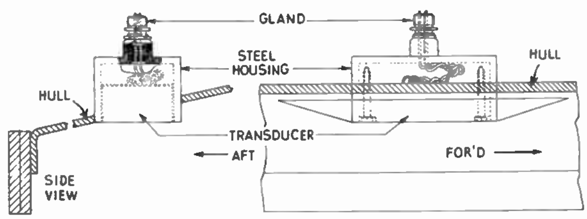


Fig. 3. Rectangular transducer, inserted in the steel hull.

Transducers made from pieces of piezo-electric crystal or electro-strictive ceramic are sometimes used, especially in the higher frequency range, for example, quartz crystal and barium titanate,[9,10] the latter being more convenient for the manufacture of transducers having more complex shapes, e.g. concave or convex radiating areas.

The radiation patterns for the simpler plane configurations are readily amenable to calculation, but a computer facilitates rapid evaluation of beam patterns for more complicated transducer shapes.[5e,11] While the shape and size of the front surface, in acoustic contact with the water, mainly determines the form of the radiation pattern beneath the ship, the absolute magnitude may be modified to some extent by the position of the transducer relative to the hull, as this differs from the ideal infinite rigid baffle.

Obviously it would be best to plot the radiation patterns *in situ*, but this is very difficult as the ship would, for example, need to be very precisely navigated over a fixed calibrated transducer. However, a measurement using a target of known acoustic cross-section may readily be made. General experience

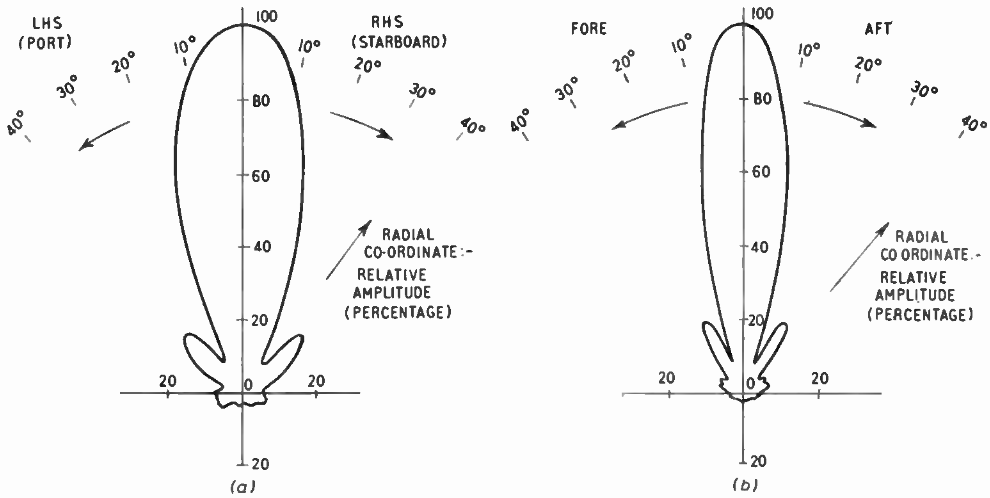


Fig. 4. Typical radiation patterns for a rectangular transducer:
(a) Athwartships (width of transducer in this plane = 2λ). (b) In fore/aft direction (width of transducer in this plane = 3λ).

indicates close agreement between measured and theoretical radiation patterns for transducers open to the sea, but an increase in sidelobes when using acoustic windows.

If the transmitting and receiving transducers are separate, corrections based on the geometry, must be applied at close range. (In any case, there is fine structure of the radiation patterns in the Fresnel region.) When a single transducer is used for both transmission and reception, with a fast-acting switch for change of function, the calculation of the combined directivity pattern is simplified.

3.2. *Propagation*

Neglecting the acoustic absorption, for monochromatic continuous waves under ideal conditions, namely:

(a) with an infinite homogeneous medium,

(b) with good acoustic contact between the transducers and water, and

(c) for distances from the transmitting transducer, large compared with the length of its Fresnel zone,

the intensity falls off according to an inverse-square law. On reaching the target, the incident energy is scattered in three dimensions, depending on the size, shape and constitution of the target and it has its own Fresnel zone. On the return journey, at ranges large compared with the size of the target, the intensity of the scattered energy will also fall off inversely as the square of the distance from the target, plus the absorption of the water with distance, or:

$$\frac{I_1}{I_2} = \frac{r_2^4}{r_1^4} 10^{-0.2\alpha'(r_2-r_1)} \quad ......(1)$$

where I_1 is the received intensity with target at range r_1, e.g. in kilo-yards (kyd),

I_2 is the received intensity with the same target at range r_2 (in kyd),

and α' is the coefficient of absorption of the water (in dB/kyd).

(It is assumed that the axes of the two transducers are coincident, the target is moved along this axis and that target aspect remains constant). The absorption of sea-water (in dB/unit length) is approximately proportional to the square of the frequency, at least up to 30 Mc/s.[12, 5f, 13] and has a value of about 7 dB/kyd at 30 kc/s.[14]

Equation (1) also applies to an echo-ranging system using pulses, providing the pulse is many wavelengths long. The centre of the pulse, for all practical purposes, may then be considered to be continuous.

At sea, there are factors beyond the control of the observer which tend to distort the accepted radiation patterns,[4,8] e.g. variations in temperature, salinity, absorption, density and scattering by organisms, sea-weed, air-bubbles, turbulence, etc. The commonest type of thermocline has a vertical sound velocity gradient only, the velocity (and temperature) decreasing with depth.[12] (The velocity varies by about 1% for a temperature change of 7 deg F.)

In a region of constant vertical velocity-gradient, a sound ray takes the form of an arc of a circle of radius

$$\frac{c}{g \sin \theta}$$

(where c is the velocity of sound at transmitting transducer, g is the value of the gradient (feet/second per foot vertical height), and θ is the angle between the initial direction of projection and the vertical).

A temperature change of 25 deg F in 250 feet depth is regarded as high.[12] Thus, for a ray at 15 deg to the vertical for the above thermocline (temperature decreasing with depth), the radius of the path would be 27 000 ft and the acoustic beam slightly more concentrated.

On the other hand, even in isothermal water, the increase in pressure in a depth of 1200 feet, raises the velocity by about 0·44% and the beam is slightly more divergent. An increase of salinity of 13 parts per 1000 also results in a 1% rise in sound velocity.

The effect of motion of the water is small as the acoustic velocity is high in comparison.

In general, the velocity gradients are usually vertical and, thus, in echo sounding little deviation of the sound occurs, as it is propagated normally or almost normally to the surfaces containing points having the same acoustic velocity. *These effects, then, are relatively small*, especially in the lesser depths and at the lower frequencies (when there is little effect due to the variations in absorption) and eqn. (1) may be used with sufficient accuracy. (This would not be true in horizontal ranging when the errors become more pronounced.[4])

3.3. *Formula for Absolute Calculations*

Assuming ideal conditions as in the last Section, the treatment may be extended to take account of transducer parameters (see Appendix 1). In the centre of an echo-pulse from a target at angle θ off the axis of the beam, the resultant power (W'_θ) dissipated instantaneously in the receiving transducer load, can be related to the electrical power (W) accepted by the transmitting transducer, thus:

$$W'_\theta = \frac{W.10^{-0\cdot 2\alpha r}\sigma\eta_{MA}\eta_{EM}\eta'_{MA}\eta'_{EM}\lambda^2 D_\theta^2 D_\theta'^2}{64\pi^3 r^4(\eta_D)_f(\eta'_D)_f} \quad \ldots.(2)$$

where α is the acoustic absorption (dB/cm),

σ is the acoustic back-scattering cross-section of target (cm²),

λ is the wavelength in water (cm),

r is the range (cm),

η_{MA} is the mechano-acoustic efficiency, ⎫ of the transmitting transducer,

η_{EM} is the electro-mechanical efficiency, ⎬ of the transmitting transducer,

$(\eta_D)_f$ is the directivity factor[13] ⎭ of the transmitting transducer,

D_θ is the relative pressure directivity factor of the transmitting transducer at angle θ off its axis (compared with the axial ray)

and other similar terms (dashed) refer to the receiving transducer.

The mechano-acoustic and electro-mechanical efficiencies of the transducers[15] can be determined by bridge measurements. Hence, knowing all other parameters in eqn. (2), the acoustic cross-section can be calculated.

3.4. *Receiving Amplifier*

The display depends greatly on such aspects of the amplifier as the degree of linearity of the graph of output- against input-voltage, the point of overload, the ringing of the tuned circuits when transients are applied, and the background noise. With care, these defects can be minimized in a practical design. Changes of gain due to "initial suppression" or time-varied gain[2,3,4] must either be eliminated or made to conform to a stable and accurately-known law.

4. Comparisons between Theory and Experimental Results

4.1. *The Zone of Detection*

Knowing the following factors:

(a) the directivity patterns of the transducers,

(b) the acoustic absorption of the water,

(c) the angle (θ) between the line joining the target to the transducer and the axis of the transducer, and

(d) the law of time-varied gain,

it is possible to draw diagrams representing a series of "concentric" calibrated fields of detection of a single target beneath the ship, consisting of pear-shaped surfaces, as indicated by Craig.[16] Each surface gives a uniform echo-level received from a target of a given acoustic cross-section, placed on the surface (at a known gain setting).

During the period of "initial suppression", the gain increases approximately in proportion to range.[2] Thus, when the effect of absorption is small, if the target is moved off the axis by an angle θ so that the amplitude directivity factors (D_θ, D_θ') of the transducers each fall to 0·71, the range of detection is reduced to half.

Confirmation of this zone of detection may be seen in the work of Sünd,[17] for example, who lowered a target consisting of twenty air-filled glass floats to map the actual acoustic beam. With his echo sounder adjusted so that an echo from this target at a depth of 50 m was only just recorded, he found that at a depth of 25 m, the echo disappeared with a transverse movement of target 4 m off the axis, as illustrated in Fig. 5. At these ranges, "initial suppression" was in operation, so that, as absorption is small, the 3 dB points for one transducer correspond to half range.

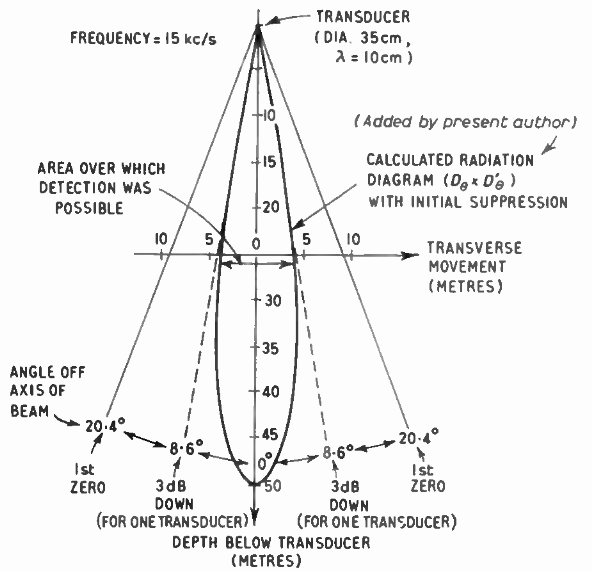


Fig. 5. The zone of detection beneath the ship, observed by Sünd (correlated with calculation).

The present author has superimposed a directivity pattern passing through a point 50 m below the transducer on the axis, calculated from the known details of the transducer employed by Sünd (diameter 35 cm ; $\lambda = 10$ cm in water). The 3 dB points occur at 8·6 deg off the axis and there is close agreement with Sünd's result.

Also, from a knowledge of the sounding rate, the speed of the ship and the depth of the target, Sünd predicted the number of echoes received from a small target.

Again, Von Brand and Schärfe[18] confirmed the zone of detection at greater ranges where the gain is constant and showed how it expanded as the gain of the receiving amplifier was increased (gain settings 1–4 in Fig. 6). In this case, the transducer was rectangular and was 17·2 cm wide in the fore/aft direction ($\lambda = 5$ cm in water). An approximate zone of detection has been added by the present author, based on a maximum range of 300 m for the target used. Half range now corresponds to the 6 dB points for one transducer, approximately, and again there is close agreement between the calculations and the experimental measurements.

4.2. *Cross-checks on Absolute Calculation*

A typical stringent cross-check on eqn. (2) may be made by means of a calculation based on measurements taken at sea whilst on board the R.V. *Ernest Holt*, by Harden-Jones,[19] who lowered a 6-in. diameter spherical air-filled metal float on a line directly under an echo sounder operating at 30 kc/s and compared the echo received across the transducer load with a voltage injected from a signal generator at the same frequency. (See Fig. 7.)

A Cod fish (85 cm long) was also lowered to 90 fathoms and it is seen that the results for the sphere and the fish in dorsal aspect, are closely similar. The present author has inserted a line in Fig. 7 giving the best mean graph for the Cod fish, taking due account of the calculated effects of spreading of the beam and acoustic absorption, using eqn. (1).

For a perfectly-reflecting sphere, the acoustic cross-section can be calculated from the radius (a):

$$\sigma = \pi a^2 = 182 \text{ cm}^2$$

in the present example.

On substituting all the parameters in eqn. (2), (see Appendix 2), the calculated values agree closely with the observed signals at ranges between 25 and 60 fathoms.

Thus, it must be concluded that eqn. (2) may be used with reasonable accuracy in good weather, particularly at the shorter ranges below 100 fathoms and at the lower frequencies (where variations in the

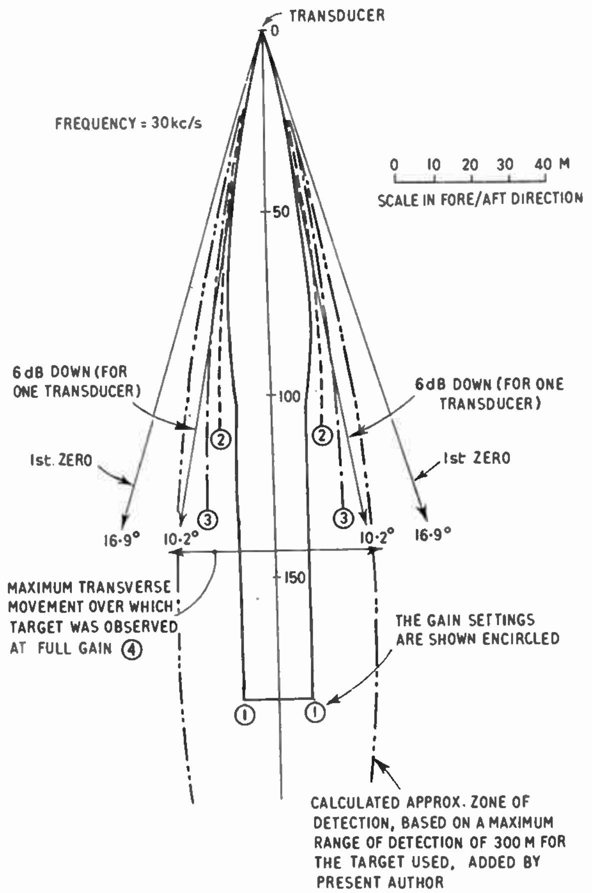


Fig. 6. Zone of detection and effect of amplifier gain setting (after v. Brand and Schärfe).

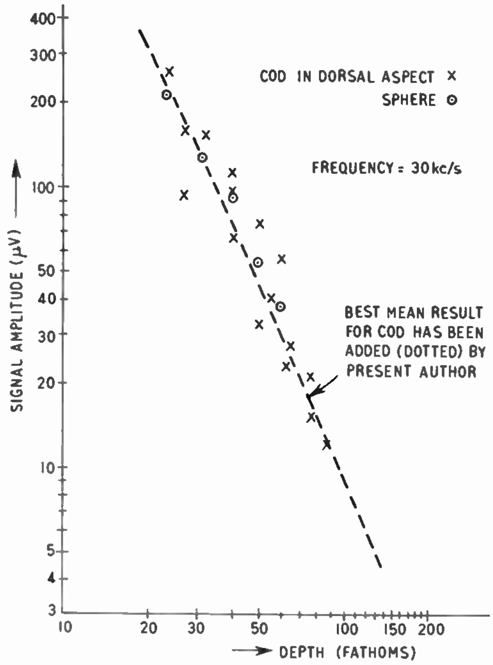


Fig. 7. Harden-Jones's results for Cod (of mean length 85 cm) and a 6-in. diameter air-filled spherical metal float suspended on a wire.

acoustic absorption of the sea-water will not significantly affect the result).

4.3. *Variation in the Signal Received from a Target*

An indication of the variation in the signal received from a target can be obtained from some observations[5j,5k] obtained recently from an echo sounder operating at 30 kc/s on the F.V. *Chichester Lass*, whilst on a steady course in Lyme Bay in good weather. The sea-bed was very flat and consisted, mainly, of sand. Recordings were made of the sea-bed echoes on a special tape recorder, operating well within the dynamic range, and the individual echoes were later analysed in the laboratory. To facilitate observation, the tapes were replayed at one quarter the normal speed and a simplified scale of amplitude was adopted (from 0–14 arbitrary units, in increments of 0·5 unit). The echoes were displayed on a wide-band oscilloscope, readings of *peak amplitude* being taken.

It is interesting to note the degree of constancy of the sea-bed echoes. One recording, lasting 14½ minutes, consisted of 1924 consecutive transmissions. A typical sample of the variation is plotted in Fig. 8. For the entire run, the average value of the amplitude of the sea-bed echo was 8·64 units and it is particularly significant that *the mean deviation was only* 11·7% of this. The corresponding histogram appears in Fig. 9. 99·84% of the readings have amplitudes between "5·0" and "13·0". (This represents a reduction to 38% of the maximum value.) Of the remaining readings, one, only, lies above "13·0", whilst the two below "5·0" might be attributable to poor coupling (out of 1924 consecutive echoes).

As the water was shallow, the effects of anomalous propagation were negligible (see Sect. 3.2); also, the ship did not have time to roll appreciably whilst the sound travelled to the sea-bed and back (in 40 ms). The observed variations of amplitude may, thus, be attributed, mainly, to:

(a) the geometrical effect of the beam patterns, due to rolling and pitching,

(b) the variation in coupling between the transducers and the water, and

(c) variations in the reflectivity of the sea-bed.

An approximate calculation can be made (see Appendix 3), taking into account the acoustic beam angles and the angles of roll and pitch of the vessel observed at the time. This indicates that the variations in amplitude of the sea-bed echo agree with those calculated to result from the motion of the vessel, alone. The pattern of these variations depends upon the waves on the surface of the sea (known to be very complicated), the periods of roll and pitch of the ship and the transmission interval. Thus, it can be expected to be very complex. There was some evidence that parts of the pattern did, in fact, repeat.

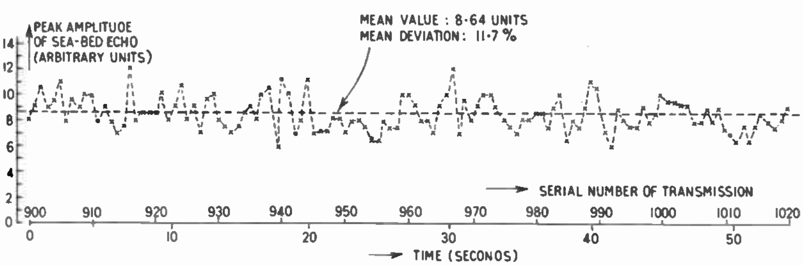


Fig. 8. Variation in peak amplitude of sea-bed echo.
A typical sample of 120 consecutive sea-bed echoes, taken from a 14½-minute tape recording. (The above details refer to the entire recording (1924 echoes).)

F.V. *Chichester Lass* in Lyme Bay (between Brixham and Sidmouth).
Sea-bed: Sand with a few scattered pieces of rock.
Speed of vessel: 6 knots.
Transmission interval: 0·45 s (133 rev/min).
Depth: 16 fathoms (+ 2·6%, − 3·7%; mean deviation: 1·0%).
Frequency: 30 kc/s.
Pulse length: 0·5 ms (approx.) (50% amplitude).
Maximum angle of roll: ± (10°±2°).
Maximum angle of pitch: ± (5°±1°).

The conclusion is drawn that these variations of target echo-amplitude are largely due to the geometrical effect. In addition, the acoustic coupling to the water cannot have varied much as this would have given many readings at lower values of amplitude than found in Fig. 9. Even if the effects of rolling and pitching were ignored, the mean error in measurement of echo-amplitude would only be of the order 10% of the mean value.

More work is required along these lines, but with small targets.

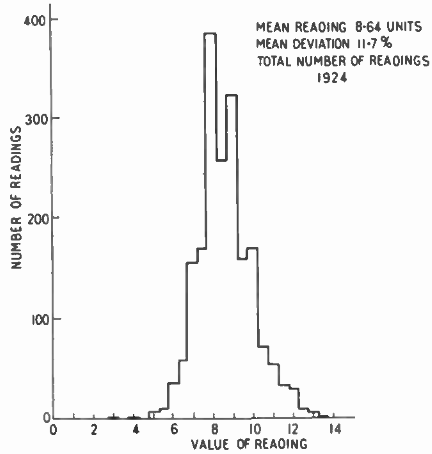


Fig. 9. Histogram of 1924 consecutive readings of amplitude of the sea-bed echo.

(The half values are more difficult to read and this accounts for the re-entrant nature of those readings in the above figure).

5. Best Display for Accurate Measurements

Turning to the question of how best to measure the signals received from fish, it would be possible to observe:

(a) the maximum amplitude and/or

(b) the characteristic shape of the echo-pulse.

The determination of the acoustic cross-section of an isolated fish† is possible from observation of the maximum amplitude. Moreover, this is unaffected by pulse length, as, with present installations, the pulse embraces the fish. This holds out the hope of a fairly straightforward measurement of fish size, once the relations between fish size, wavelength and acoustic cross-section have been investigated.[20]

On the other hand, Hodgson[21] and Fridriksson[6] have suggested that there are so many variations in the

† This is relevant, since, in sea-bed trawling, an average rate of catch equal to one fish every ten yards of tow, is regarded as a commercial proposition.

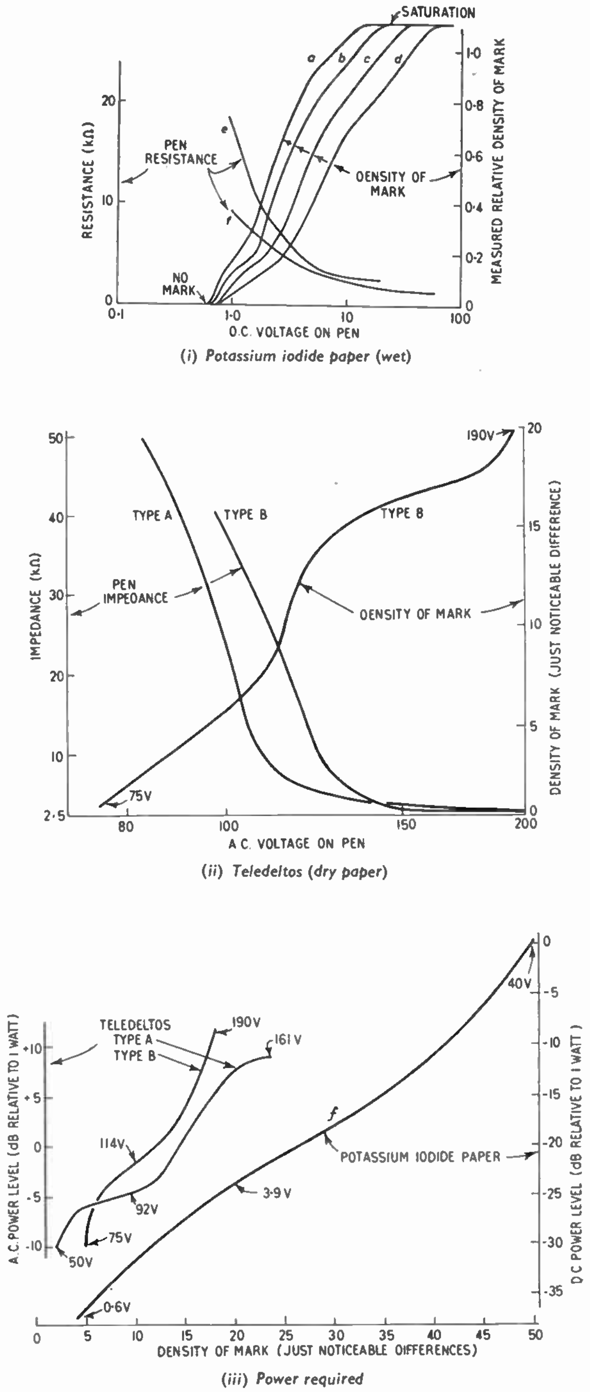


Fig. 10. Characteristics of wet and dry recording paper.[5g, 5h] Conditions operating during measurements:

Wet paper	Dry paper
Pen pressure: 35 grammes	Pen pressure: 20 grammes
Pen speeds: a: 2·6 in/s	Pen speed: 40·8 in/s
b: 5·2 in/s	Frequency of alternating voltage: 22 kc/s
c: 10·4 in/s	
d: 20·8 in/s	
e: 28·5 in/s	
f: 40·8 in/s	

appearance of shoal echoes on a recording sounder that identification of type of fish might be possible from the character of the trace, taking into account such factors as the depth of the fish and the width of the sound beam. This is rather subjective and depends greatly on the experience and skill of the observer. The design of electronic apparatus to facilitate these complex observations is much more difficult than that required to estimate the size of a single fish.

The possibility of calibration of a pen recorder is worthy of consideration, as there are more recorders than cathode-ray displays in use.

Concerning chemical paper for pen recorders, two main types are available, wet and dry. In the former, the action is electrolytic.[22] The intensity of the mark depends on dampness of paper, care in storage and the ambient humidity. With dry paper [22,23] the action is mainly "blasting" or allotropic and partly electrolytic. In both cases the results depend also on the d.c. or a.c. voltage applied to the pen, the degree of overlap between successive scans, and the velocity, pressure and area of contact of the pen. The impedance of the paper changes with applied voltage. Thus, the intrinsic non-linear characteristics of recording papers in general (illustrated by Fig. 10) and their changeable nature, make them unsuitable for quantitative observations.

Despite these difficulties, Hashimoto[24] has been able to measure the power required to make a marginal mark on recorder paper within 1 dB, but only by taking the mean of many readings.

In contrast with the impracticability of calibration of recording papers, the deflection on a cathode-ray display can, with careful design, be made strictly proportional to signal voltage and the latter affords an accurate method of measurement. It does, however, lack the convenience of a permanent record.

6. Conclusions

A formula is derived relating the received echo to the acoustic back-scattering cross-section and all the other parameters of the system.

When using a vertical sound beam at sea in good weather, the evidence indicates that

(a) the polar diagrams are only slightly distorted by anomalous propagation due to thermoclines, salinity gradients and changes of pressure,

(b) the observed variations in target echo are largely due to the geometrical effect of rolling and pitching of the vessel, whilst the acoustic coupling between the transducer and water does not vary greatly, and

(c) most important of all, the echo received from a target of known acoustic cross-section, agrees closely with the value calculated from the formula.

On this basis, it is clear that the method of calibration of echo sounders described in this paper can be used to determine the acoustic cross-sections of fish, previously unknown.

Alternatively, if the cross-sections of fish over wide ranges of fish length and wavelength were measured in a separate series of experiments,[20] the method can be used to determine fish size.

Points (a) and (c), above, are especially true at the shorter ranges and the lower frequencies.

The maximum overall echo-amplitude is the observation which may be made most readily and this is best seen on a cathode-ray tube.

7. Acknowledgments

This paper is based on part of a thesis[1] submitted for a higher degree and the advice of my Supervisor, Dr. A. E. Bate, Department of Physics, West Ham College of Technology, is gratefully acknowledged.

The author is indebted to the Directors of Kelvin and Hughes Ltd. for permission to publish this paper. Thanks are due to several colleagues (listed in the references[5]) for experimental data and helpful discussions, also to Professor D. G. Tucker, Dept. of Electrical Engineering, University of Birmingham and Dr. F. R. Harden-Jones of the Fisheries Laboratory, Lowestoft.

A grant from the Central Research Fund towards the cost of apparatus, used later in the work, is also acknowledged.

8. References

1. R. W. G. Haslett, "The Application of a Scale Model Technique to the Analysis of the Principles Underlying the Formation of Ultrasonic Echoes, with Special Reference to Fish in Water", Ph.D. Thesis, London University, February 1960.
2. S. C. Sparling, "Echo Sounder Engineering", 1945 (Marine Instruments Ltd., London).
3. "An Introduction to Echo Sounding", (Elac-Electroacustic GmbH, Kiel, Germany, 1955).
4. D. G. Tucker, "Underwater echo-ranging", *J.Brit.I.R.E.*, **16**, p. 245, May 1956.
5. Kelvin and Hughes Ltd., Ilford, Essex:
(a) Publication M.227; (b) Publication M.244; (c) Publication M.306, Fig. 14, p. 14; (d) F. Youell; (e) W. Halliday and G. Pearce, "Computer for Evaluation of Transducer Polar Diagrams" (unpublished work); (f) W. Halliday, R. W. G. Haslett and G. Pearce, "Sea-water Attenuation Measurements" (internal report), 23rd March, 1951; (g) P. Hopkin; (h) G. Pearce; (j) N. Benning; (k) R. W. G. Haslett, "Sea-bed Echoes, Rolling of Vessel and Acoustic Coupling between Transducer and Water" (internal report), 5th October, 1960; (l) E. L. Freeman.

6. W. C. Hodgson and A. Fridriksson, "Report on echo sounding and asdic for fishing purposes", *Rapp. Cons. Explor. Mer*, **139**, pp. 16 and 24–6, September 1955.
7. T. F. Heuter and R. H. Bolt, "Sonics", Table 3.1, p. 63 (Wiley, New York, 1955).
8. H. Galway, "Echo Sounding at Sea—British Practice", pp. 15 and 38–52 (Pitman, London, 1951).
9. E. G. Richardson, "Ultrasonic Physics", pp. 26–7 (Elsevier, London, 1952).
10. P. Popper, "An electrical engineering review—ferro-electric materials", *J. Instn Elect. Engrs*, **2** (New Ser.), p. 450, August 1956.
11. D. G. Tucker, "An analogue computer for Fourier transforms", *J.Brit.I.R.E.*, **18**, p. 233, April 1958.
12. "Physics of Sound in the Sea", Summary Tech. Report of Division 6, N.R.D.C., Washington, Vol. 8, 1946.
13. J. W. Horton, "Fundamentals of Sonar", Fig. 3A–5, p. 81 and pp. 199–201 (U.S. Naval Institute, Annapolis, Maryland, 1957).
14. V. P. Glotov, "Reverberation tank method for the study of sound absorption in the sea", *Soviet Physics—Acoustics*, **4**, p. 247, July–September 1958 (Translation by American Institute of Physics).
15. F. A. Fischer, "Fundamentals of Electroacoustics, pp. 143–147 (Interscience, London, 1955).
16. R. E. Craig, "The use of the echo-sounder in fish-location —a survey of present knowledge", *Rapp. Cons. Explor. Mer*, **139**, September 1955, App. 2.
17. O. Sünd, "The fat and small herring on the coast of Norway in 1940", *Rapp. Cons. Explor. Mer—Ann. Biol.*, **1**, p. 62, 1939–41.
18. A. v. Brandt and J. Schärfe, "Zur quantitativen Auswertung der Echolot-Beobachtungen", *Protokolle zur Fischereitechnik*, **2**, No. 4, 1950.
19. F. R. Harden-Jones, "Results of Echo-sounding Experiments on Single Fish—R.V. *Ernest Holt*—Cruise VI/1955" (Fisheries Laboratory, Lowestoft—personal communication).
20. R. W. G. Haslett, "The back-scattering of underwater acoustic waves by an obstacle". Paper read to Physical Society Acoustics Group, 26th May 1960. (Paper in preparation.)
21. W. C. Hodgson, "Echo-sounding and the pelagic fisheries", *Min. of Ag. and Fish., Fishery Investigtns* (Series 2), **17**, 4, 1950.
22. J. W. R. Griffiths and I. G. Morgan, "The chemical recorder and its uses in detecting pulse signals in noise", *Trans. Soc. Instrum. Technol.*, **8**, p. 62, June 1956.
23. G. Hotchkiss, "Electro-sensitive recording paper for facsimile telegraph apparatus and graphic chart instruments", *Western Union Tech. Rev.*, **3**, p. 6, January 1949.
24. T. Hashimoto, "Report of Fishing Boat Lab.", Fishing Boat Lab., Fishing Agency, Min. of Ag. and Forestry, Tokyo, Japan, Dec. 1953, p. 1.

9. Appendix 1: Derivation of a Formula for Calculation of the Echo Received from a Small Target

Equation (1) of Section 3.2 may be extended to take into account the transducer parameters and the acoustic cross-section of the target.

Thus, when the target is on the axis of the transducer, the incident intensity:

$$I_0 = \frac{W\eta_{MA}\eta_{EM}\, 10^{-0\cdot 1\alpha r}}{4\pi r^2(\eta_D)_f} \qquad \ldots\ldots(3)$$

The directivity factor of a projector $(\eta_D)_f$ has been defined by Horton.[13]

Again, the intensity returned to the receiving transducer is

$$I' = I_0 \frac{\sigma 10^{-0\cdot 1\alpha r}}{4\pi r^2} \qquad \ldots\ldots(4)$$

σ is the acoustic back-scattering cross-section of the target. This is defined as the plane area intercepting an amount of energy, which, if it were scattered omnidirectionally from the target, would produce an echo equal to that observed. (This area is placed at the same position as the target and is perpendicular to the direction of the incident waves.)

It follows that the power dissipated in the load connected across the receiving transducer is

$$W' = I'\eta'_{MA}\eta'_{EM}\left[\frac{\lambda^2}{4\pi(\eta'_D)_f}\right] \qquad \ldots\ldots(5)$$

The expression within the brackets, above, is known as the capture area (A_c) of the receiving transducer.[13] Combining eqns. (3), (4) and (5):

$$W' = \frac{W10^{-0\cdot 2\alpha r}\sigma\eta_{MA}\eta_{EM}\eta'_{MA}\eta'_{EM}\lambda^2}{64\pi^3 r^4(\eta_D)_f(\eta'_D)_f} \qquad \ldots\ldots(6)$$

When the target lies at angle θ off the axis of the transducer system, the received power is

$$W'_\theta = W'(D_\theta)^2(D'_\theta)^2$$
$$= \frac{W.10^{-0\cdot 2\alpha r}\sigma\eta_{MA}\eta_{EM}\eta'_{MA}\eta'_{EM}\lambda^2(D_\theta)^2(D'_\theta)^2}{64\pi^3 r^4(\eta_D)_f(\eta'_D)_f}$$

10. Appendix 2: Absolute Calculations based on Harden-Jones's Results at Sea

The echo sounder used by Harden-Jones[19] (Fig. 7) had the following characteristics[1] (using the nomenclature of Sect. 3.3):

W	= 700 watts,
α	= 7×10^{-5} dB/cm (at 30 kc/s),
r	= 25 fathoms = $4\cdot 58 \times 10^3$ cm,
σ	= 182 cm^2,
$\eta_{MA}\eta_{EM}$	= 0·45,
η'_{MA}	= 0·12 (an inboard transducer in a tank),
η'_{EM}	= 0·46,
Frequency	= 30 kc/s and
λ	= 5 cm.

Dimensions of the transmitting transducer:
$2\lambda \times 3\lambda$

$$\text{Thus, } (\eta_D)_f = \frac{1}{71} \text{ (ref. 13)}$$

Dimensions of the circular receiving transducer:

Diameter = 18 cm = $3{\cdot}6\lambda$,

$$\text{so that } (\eta_D)_f = \frac{1}{126} \text{ (ref. 13)}$$

Target on axis of transducer system.

Substituting in eqn. (2), we have:

$$W' = \frac{(700)(0{\cdot}86)(182)(0{\cdot}45)(0{\cdot}12)(0{\cdot}46)(25)(71)(126)}{(64)(\pi^3)(4{\cdot}58 \times 10^3)^4}$$

$$= 7{\cdot}1 \times 10^{-10} \text{ watts.}$$

The echo-voltage, received across a resistor of 26Ω, was compared with a calibrating signal injected through a circuit giving an attenuation of 0·86 (amplitude). Thus the voltage read on his signal generator (as plotted in Fig. 7) would be

$$\frac{(7{\cdot}1 \times 10^{-10} \times 26)^{\frac{1}{2}}}{0{\cdot}86} = 158\ \mu\text{V } (\pm 20\% \text{ probable error}).$$

In the above calculation, the tolerance was added after careful consideration of the probable errors.

In Fig. 7, the mean figure for the 6-in. diameter sphere at 25 fathoms range, is 180 μV.

11. Appendix 3: Calculation of the Geometrical Effect of Rolling and Pitching of Ship

Further details of the trial are as follow:

Vessel: F.V. *Chichester Lass* (used for mid-water trawling). Length: 40 ft; beam: 4 ft 6 in; draught: 6 ft (aft), 4 ft (f'ward).

Depth: 16 fathoms.

Echo-sounder:

Frequency: 30 kc/s, (λ = 5 cm).

Transmitter: Capacitor discharge.

Transducers: Separate T and R. Ring packs, mounted amidships in circular reflectors of diameter d = 6 in. (as in Fig. 2).

Beam angles: 19·3 deg (between 3 dB points).

Course: East. Wind: Fresh (force 3–4), S.E.

From the recording (running at full speed), it was observed that most of the sea-bed echoes rose to their peak amplitude within 0·35 ms,† a number rose in under 0·8 ms and a few as late as 1·6 ms. Thus, the main contributions to the echoes must have come from directions confined within angles of 0·5 deg, 1·1 deg or 2·3 deg (respectively) to the vertical and the assumption may be made that the effective area on the sea-bed was small.

For a circular transducer,[7] the relative pressure directivity factor:

$$D_\theta = \frac{2J_1(x)}{x} \text{ where } x = \frac{\pi d}{\lambda} \sin\theta$$

and θ is the angle between the direction under consideration (i.e. the vertical) and the axis of the transducer.

At 10 deg roll and 5 deg pitch, θ = 11·2 deg. Substituting, also, d = 15·2 cm and λ = 5 cm, then x = 1·86 and D_θ = 62%.

As the transducers were mounted close together (compared with 16 fathoms), the transmitting and receiving beams are assumed to be identical, so that the minimum amplitude of the echo would be $(0{\cdot}62)^2 \times 100\% = 38\%$ of the maximum. (The fact that this is identical with the observed result is fortuitous, as the errors in measurement of the angles of roll and pitch lead to a wide tolerance.)

†Including the effect of the restricted bandwidth of the tape recorder.

Manuscript first received by the Institution on 17th March 1958 and in final form on 23rd February 1961. (Paper No. 649.)

U.D.C. 621.314/9 : 623

Component Developments for the Services

By

D. E. H. JONES, M.Sc.†

Presented at the Symposium on New Components held in London on 26th–27th October 1960.

Summary: Development of new types of components and improved versions of existing types to meet more stringent environmental conditions and research into materials for electronic components are sponsored by the Radio Components Research and Development Committee. Some of the more important examples of new components are discussed under the headings of: capacitors, resistors, plugs and sockets, transformers and transductors, electromechanical devices, microwave components, and microminiaturization.

Table of Contents

1. Introduction

The development of components for the Services is mainly carried out through a Joint Service Committee known as the Radio Components Research and Development Committee. This committee and its sub-committees, one for each type of component, are formed from representatives of the main Service establishments, the National Physical Laboratory, the Post Office and the Atomic Energy Research Establishment. The committee has finance at its disposal so that it can sponsor particular component development programmes with industry.

The developments sponsored fall into two categories: completely new types of components and improvements of existing types of components to meet more stringent environmental conditions of temperature, humidity and vibration. Also, a very important part of the programme is devoted to miniature components to satisfy the demand for components for transistorized and printed circuit equipments. There is usually only a limited requirement by the Services in peace time for the components so developed. However, they are often also used in the professional electronic field and finally perhaps in domestic electronic applications—a process to be encouraged for furthering the advance of component performance and electronic techniques, and also spreading the development costs.

In addition a large programme of research into materials is sponsored by the R.C.R.D.C. as component development largely depends on improvement in materials.

The development contracts which are placed with a firm for a particular component cover the cost of initial design study and design samples and also the cost of fully developed engineered models off production type tooling. These are submitted to the Radio Components Standardization Committee for type approval testing. These developments, therefore, are closely linked with production methods.

In many cases the developments are carried out in parallel with similar developments by industry for their own applications and the two cannot be separated. The successful completion of development for Service applications usually means the component satisfies the relevant R.C.S.C. specification and a type approval certificate is issued.

A convenient way to survey this work is to consider the programmes for some of the main components and detail the more interesting developments.

† Royal Radar Establishment, Malvern, Worcs.

2. Capacitors

A great deal of development effort is devoted to capacitors and dielectrics and as a result capacitors of much improved performance are becoming available.

2.1. *Stacked High K*

The development of the stacked high-*K* ceramic capacitor for Service applications has now been completed and these capacitors are available and approved to the R.C.S.C. humidity class H1 and temperature category 40/125° C in values up to 0·5 μF and 350 V working. The capacitors are produced by casting a thin ceramic sheet from a dispersion, applying palladium electrodes, stacking and firing. They are then enclosed and sealed in a metal case. Further development is being carried out by one firm to produce thinner ceramic sheet of suitable quality free from pin holes.

2.2. *Miniature Sintered Tantalum Anode*

The 70 V 50 μF castanet type is now well established and is approved by R.C.S.C. as an H1, 40/125 component. Development of miniature and sub-miniature versions is proceeding but sealing difficulties have been encountered with the very small cases used. These will no doubt be resolved and the capacitors will then receive R.C.S.C. approval. A typical construction for this capacitor is shown in Fig. 1.

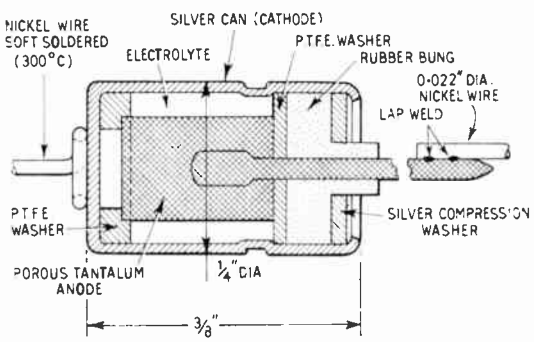


Fig. 1. Miniature sintered anode tantalum capacitor—typical construction.

2.3. *Thin Film*

Perhaps the most promising of the thin film developments is the polycarbonate film. This has been produced with a thickness of 1·7 microns and worked into experimental capacitors by a capacitor firm. A capacitance of about 2 μF/in^3 compared with 0·9 μF/in^3 for paper should result. The voltage rating would be of the order of 20 V compared with the 150 V minimum obtainable with paper. The power factor is about 0·003 and the upper temperature limit 140° C. Figure 2 shows the relative sizes of the polycarbonate and paper capacitors.

2.4. *High Temperature Ceramic*

The development of a high temperature high *K* ceramic has been sponsored with a French firm and its British associates. The *K* of the material is of the order of 1000 and the target temperature range is −55° C to 200° C. Sample capacitors to meet this requirement are expected to be available shortly.

2.5. *Barrier Layer*

Very high capacitance values can be obtained in the barrier layer capacitor. In this type a wafer of barium titanate is first reduced to the conducting state and then re-oxidized on the surface to give a very thin dielectric film. Capacitance values of 0·1 μF/cm^2 can be obtained and the working temperature range is −55 to 125° C. An inherent drawback is its low voltage rating, about 3 V, and it is only suitable for power frequencies. However it should be satisfactory where a cheap and robust capacitance of high value is required within these limits.

3. Fixed Resistors

3.1. *Oxide Film*

Oxide film resistors are now available in this country as possible replacements for the cracked carbon version in the lower values and are approved to R.C.S.C. H1, 40/125. Two versions are available, one being tin-antimony oxide on glass rods and of American origin, and the other tin-boron on ceramic rods. These resistors are produced by deposition in a furnace from the soluble chlorides on to the hot rods. They have excellent stability, about 0·25% under R.C.S.C. tests, though the temperature coefficients at present are rather high, some 250 parts in 10^6 per deg C. Long term storage stability is excellent.

A further development, using tin-antimony oxide film, being sponsored by the R.C.R.D. is to coat glass fibre, 0·001 in. diameter, with the oxide and wind resistors with the coated fibre. An automatic coating machine has been developed which produces coated fibre of excellent quality. The coated fibre has a resistance value up to 150 kilohms per inch and a temperature coefficient better than 150 parts in 10^6 per deg C or better than 50 parts in 10^6 per deg C by special control. Sample resistors will soon be available for test. A satisfactory method of making end connections has been devised.

3.2. *Evaporated Nichrome*

One firm is now producing these resistors on ceramic rods in this country under licence. A development contract to produce high temperature high stability resistors of this type on glass rods has been in existence for some time and samples will be available shortly. These resistors will operate up to 150° C and

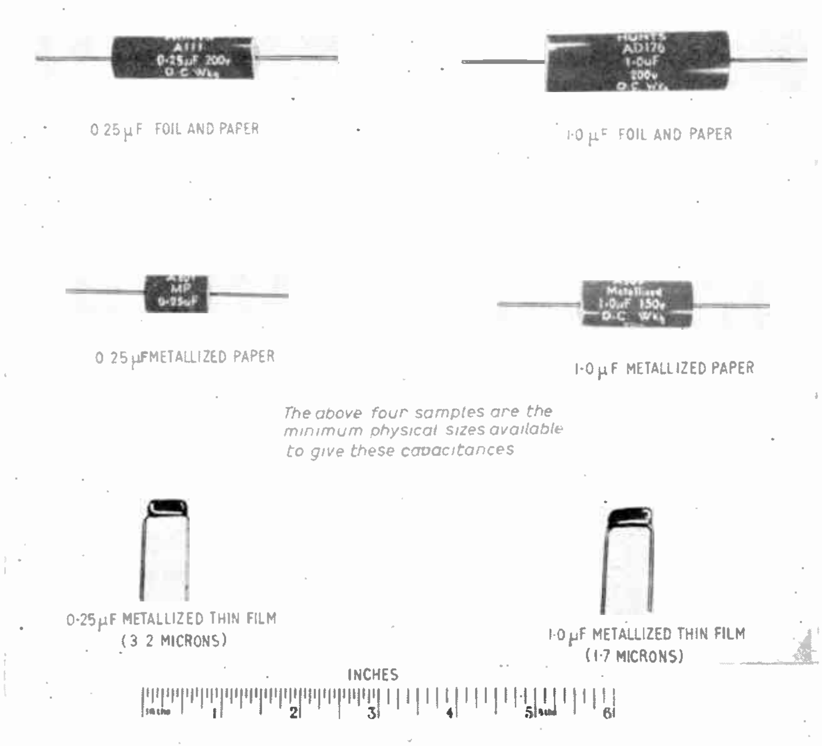


Fig. 2. Relative sizes of paper and thin plastic film capacitors.

should have a temperature coefficient better than 20 parts in 10^6 per deg C and stability of 0·1 %.

3.3. *Glass Coated Resistance Wire*

An interesting development which has been started recently is to produce glass coated resistance wires less than 0·001 in. diameter. The proposed method is to draw the coated wire in one operation from a molten billet of resistive material surrounded by glass. By this means experimental lengths of glass coated manganin wire, 10 microns dia., have been drawn and in Fig. 3 is shown a photomicrograph of the wire which illustrates the excellent concentricity obtained.

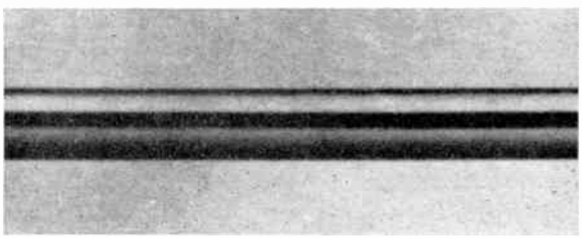


Fig. 3. Photomicrograph of glass-coated magnanin wire of 10 microns diameter.

4. Variable Resistors

4.1. *Oxide Film*

A method of producing meandered tin-antimony oxide film variable resistor tracks on flat glass plates has been developed and is available for further development into an engineered resistor. The wiper runs on a reinforced part of the track consisting of a rhodium deposit on silver. The geometry is such that no change results in resistance value due to wear and a life better than 10^6 cycles can easily be achieved. Resistance values up to 5 MΩ can be obtained with a 2 in. diameter circular track. A track with an experimental wiper for test purposes, is shown in Fig. 4.

The development of a miniature pre-set potentiometer using the oxide film track has recently been started for Service applications. Resistance values are from 10 kΩ to 2 MΩ.

4.2. *Wire Wound*

The development of a precision sealed high temperature wire wound potentiometer has been recently completed and samples are undergoing R.C.S.C. approval tests. These are for operation up to 150° C and have a linearity better than 0·1 %. Silicone rubber "O" ring seals are used for the panel, case and spindle sealing. Another development nearing completion is for a miniature low torque precision wirewound potentiometer with a torque not greater than 0·1 g.cm.

5. Plugs and Sockets

Plugs and sockets are an essential part of Service equipments and have to meet very severe environ-

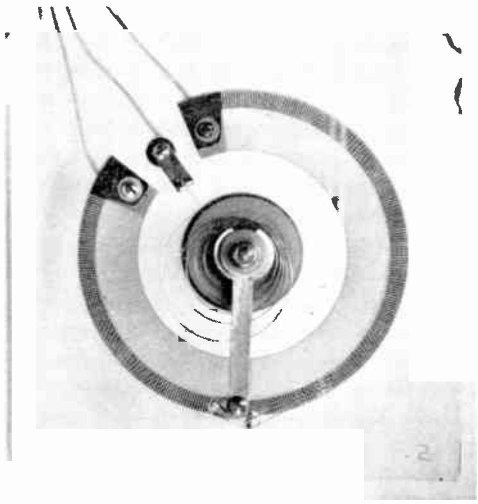


Fig. 4. Experimental tin-antimony oxide film potentiometer track.

mental conditions. The fully sealed version is necessary for satisfactory operation under conditions of high humidity and this is often required in addition to high temperature performance. Considerable development effort has been devoted to this end and has resulted in multi-way types using "one piece" silicone rubber bung inserts. These have excellent electrical performance and cover a wide temperature range. The M4 range of plugs and sockets, known as R.C.S.C. Pattern 104, is now available as R.C.S.C. H1, 40/150 components. The development of the BMS range, which are American AN sizes, for temperatures up to 190° C is nearing completion. Other types now coming into use and using silicone inserts are the miniature ranges. The chief drawback to the silicone materials at present available is their poor resistance to various organic fluids such as kerosene and hydraulic oils, and development of oil resistant versions has high priority.

An example of the complex multi-way plugs and sockets now being used in Service ground equipment is the 70+1 coaxial type. This has a neoprene rubber insert as high temperature is not a requirement.

Development in r.f. matched plugs and sockets has been towards sealed versions of the BNC types in polythene for temperatures up to 70° C and in p.t.f.e. for temperatures up to 150° C. The polythene types are now approved to R.C.S.C. H2 40/70 and design samples of the p.t.f.e. version have shown satisfactory sealing at 150° C. Other recent developments are sealed Pattern C types in p.t.f.e. for helical membrane cables and a sealed polythene plug and socket, for DR 68 cable, of comparable size to the R.C.S.C. Pattern 2 range. The high temperature version of the Pattern 4 using glass seals has been approved for the temperature range −40° C to 150° C. A few of these plugs and sockets are shown in Fig. 5.

One of the more difficult plug and socket developments has been the demountable double screen type for UR 92 cable and rated at 9 kV working. It is a sealed design using a system of silicone rubber "O" ring seals and the two screens are carried though independently.

Development has recently been started on a range of printed circuit connectors to meet Service requirements. These will be of the two types, edge connectors using the board as a plug and the separate plug and socket connector. They will be based on 0·1 in. spacing which has been adopted as the Service standard.

6. Transformers and Transductors

6.1. *Resin Cast Transformers*

Resin cast transformers now have R.C.S.C. approval, and are at present made in the standard sizes for oil-filled transformers to maintain interchangeability. They have greater mechanical strength but are rather heavier because of their unnecessarily large size for their rating. Great care must be taken to prevent the formation of voids during casting and work has been sponsored to investigate resin casting systems and devise test specifications. For successful casting a vacuum process is considered essential for impregnation of the winding and high internal temperature must be avoided. Hence the exothermic temperature rise and, therefore, the amount of catalyst must be kept at a minimum.

6.2. *Miniature Transformers*

Three sizes of miniature transformers for transistor circuits and other low-power applications have been developed. The limiting factor in the design of these transformers is the difficulty in obtaining very fine insulating wire of good space factor, close tolerance and uniform covering.

Fig. 5. Recent plug and socket developments
(*a*) 70-way + 1 coaxial,
(*b*) range for DR.68 cable,
(*c*) pattern 104 high temperature multiway range.

6.3. *Transductors*

Standard ranges of transductors for 400 c/s and 1600 c/s have been developed to a draft DEF 5217 specification and the development of a 2400 c/s range is proceeding and will be included in the specification when completed. The development of high temperature versions of the 400 c/s and 1600 c/s ranges has recently started and the work is to include a study of materials and assembly techniques. These transductors are designed for working at temperatures up to 250° C.

6.4. *Miscellaneous*

Work on magnetic materials includes development of iron-aluminium high permeability alloys, improvement of temperature stability of ferrite cores, investigation of the anomalous behaviour of thin magnetic strip and a study of Barkhausen noise. The method of detecting gaseous voids in transformer insulation by measuring ionization inception voltage is being further investigated, and work is continuing on casting resins and processes.

7. Electromechanical Devices

7.1. *Relays*

The main relay development is for miniature and high reliability relays for use with printed circuits and for high *g* relays. The relays for printed circuits and transistor applications have up to four change contact action and are designed to withstand centrifugal acceleration up to 30 *g*. One design, using a separate contact compartment, is built up on the unit principle, each unit being a complete one change action relay. Another design, also with contacts sealed in a separate chamber, is polarized and uses a permanent magnet.

7.2. *Switches*

The development of a sub-miniature toggle switch for transistor circuits, rated at 50 volts d.c. 1 A, is well advanced and tests on design samples have given good results. A miniature multi-way rotary wafer switch for use in r.f. circuits has reached the approval test stage.

7.3. *Spindle Seal*

A high temperature spindle seal using conical p.t.f.e. bush seals compressed by a coil spring has been developed and is the only satisfactory seal available for temperatures up to 200° C. The leakage rate, using brass housings is not greater than 0·02 cm^3/hr. This spindle seal is illustrated in Fig. 6. An investigation into a method of fully hermetic spindle sealing has not led to a satisfactory design.

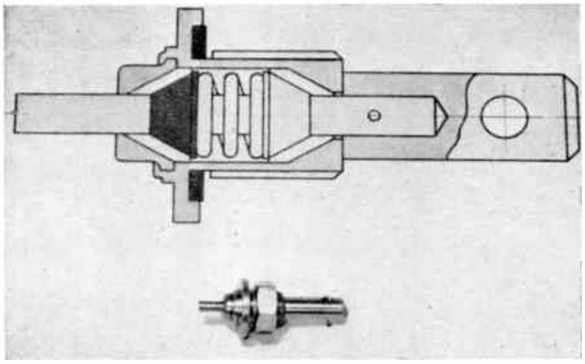


Fig. 6. P.t.f.e. bush high temperature spindle seal.

8. Microwave Components

Metallized glass waveguide attenuating elements of good reproducibility and high panclimatic stability have been available commercially for some time. Further development however is being carried out with the following aims:

(*a*) Coverage of the full frequency band of standard waveguide sizes, i.e. constant attenuation at a given setting.

(*b*) Substantially linear characteristics over the operating range, i.e. attenuation directly proportional to vane movement.

(*c*) Low frequency sensitivity of attenuation.

A theoretical analysis has been made and it is hoped this will lead to a method of design giving these characteristics.

The electro-deposited copper method of producing waveguide components is now well established. In applications where weight is important similar components are required in light alloy and the present Mercast process has met production difficulties. An alternative method being investigated is to deposit thin copper surfaces and reinforce these with plastic materials.

An investigation has been sponsored to establish the relation between dimensional tolerance and the relevant parameters of waveguide components. Experimental verification of the theoretical formulae is being made. This will provide information on the maximum permissible dimensional tolerances for a given spread in the electrical parameters.

9. Microminiaturization

The trend of development in the electronic field is towards smaller components and the use of transistors to replace conventional valves demanded a range of conventional components of comparable size. This range of components, as used in printed circuit construction, is now largely available and most components can be obtained in miniature or sub-miniature sizes. The sizes of the individual components cannot be further reduced while still maintaining reasonable reliability and the practical limit has probably been reached in these sub-miniature sizes.

Further size reduction can only be achieved by a radical change in construction, and this has led to microminiaturization. Three approaches to microminiaturization have evolved, namely, micromodules, microcircuits and solid circuits.†

The micromodule system is an extension of the "Tinkertoy" concept with transistors replacing thermionic valves, and is being developed mainly by R.C.A. in the U.S.A. In essentials, a micromodule consists of a stack of ceramic wafers, of dimensions 0·31 in. × 0·31 in. × 0·020 in. thick, held in a cage of 12 riser wires. Each wafer carries one, or sometimes more, active or passive component. Other micromodule constructions are possible and have been developed on a small scale.

Microcircuits differ from micromodules in that the whole circuit function, instead of a single component, is laid on one wafer. The wafer or plate is larger than the micromodule wafer and may be up to 1 in. square. Transistors and diodes are set in recesses in the wafer and resistors and capacitors can be deposited on one or both surfaces of the wafer by a variety of methods.

A solid circuit is a functional unit fashioned from a semi-conductor block by what are essentially transistor making techniques. This concept is the most advanced form of microminiaturization, for very high packing densities can be achieved.

It is essential that circuit assemblies produced by these new techniques must be at least as reliable as equivalent circuits made with conventional components. At present, there are no figures available on the reliability of any of the microminiaturization systems, but there is reason to believe that they will be very reliable.

A substantial development programme has been sponsored by the Government with industry for microcircuit development for a Services application. The techniques used involve the deposition of resistors and capacitors by vacuum evaporation or sputtering and contracts have been placed with industry and Universities for fundamental investigations of these processes.

Microcircuitry techniques are also being investigated at the Royal Radar Establishment. Resistance elements are formed by evaporating nickel-chromium alloy on to glass plates. The use of glass has been dictated by the requirement for a surface which is smooth compared with the thickness of the nichrome film. Values up to 0·5 MΩ in an area of less than 1 cm^2 have been obtained. Basic studies are being made of the binding properties of thin films as good adhesion between film and substrate is of prime importance. The deposition of dielectric films for capacitors presents greater difficulties. Satisfactory films of silicon monoxide have been deposited giving capacitors of 4000 pF/cm^2. The main problem existing is the way to protect satisfactorily the completed thin films capacitors against the effect of adverse environments. The use of miniature wrapped joints for inter-substrate connections is being investigated.

Work on solid circuits has also been Government-sponsored with industry. Initially basic techniques are being investigated but, eventually direct applications to the Services equipments will be produced. Solid circuit techniques are also being studied at R.R.E.

† The last two terms, hitherto in general usage, have now been registered as trade-marks in the U.S., "Solid Circuits" by Texas Instruments Inc., and "Microcircuits" by International Resistance Co.

10. Acknowledgment

This paper is published by permission of the Controller, H.M. Stationery Office.

11. Bibliography

1. G. W. A. Dummer, "Modern Electronic Components" (Pitman, London, 1959).
2. A. G. Milnes, "Transductors and Magnetic Amplifiers" (Macmillan, London, 1957).
3. I.E.E. Symposium on Electronic Equipment Reliability, May 1960.
4. G. W. A. Dummer, "Future electronic components" *Wireless World*, **64**, pp. 591–3, December 1958.
5. G. W. A. Dummer, "Components for use with transistor techniques", *Brit. Commun. Electronics*, **6**, pp. 422–8, June 1959.
6. "Dielectric research at National Bureau of Standards", *Radio Electronic Components*, November 1959.
7. K. H. McPhee, "Introduction to inorganic dielectrics", *Trans. Inst. Radio Engrs, (Component Parts)*, **CP-6**, No. 1, pp. 3–33, March 1959.
8. H. F. Church, "The long term stability of fixed resistors", *Proc. Instn Elect. Engrs*, **107 B**, No. 34, pp. 377–85, July 1960.
9. N. E. Hyde, "Special quality miniature relays", *Brit. Commun. Electronics*, **7**, pp. 338–45, May 1960. Also "Miniature medium duty sealed high-quality relays", *J.Brit.I.R.E.*, **21**, pp. 557–9, June 1960.
10. "Project Tinkertoy", *N.B.S. Bulletin*, **37**, Pt. II, November 1953.
11. "Recent advances in electronic process technology", *N.B.S. Bulletin*, **39**, Pt. 1, January 1955.
12. R. Langford, "Three approaches to microminiaturization", *Electronics*, **32**, No. 50, pp. 49–52, 11th December 1959.
13. G. W. A. Dummer, "Recent advances in microminiaturization, reliable components and cooling techniques", *Radio Electronic Components*, October and November 1960.

Manuscript received by the Institution on 15th April 1961 (Paper No. 650).

U.D.C. 681.2.085

An Optical Projection System for Information Data Display

By

GILBERT EISNER †

Presented at a Computer Group Symposium on Alpha-Numeric Display Devices, held in London on 19th January 1961. (The paper was read on behalf of the author by Mr. P. E. H. Werner.)

Summary: The paper discusses generally the desired characteristics of visual display devices and specifically describes a highly versatile, uniplanar, electro-optical rear projection-type information data display unit. The design of this unit features a plurality of optical systems, each with an independently activated light source, focused upon a common viewing screen. Each optical system may thus be used to display either alphanumeric, symbolic or word messages (complete or progressive), and/or colour information. The theory of operation, construction, operational characteristics and performance of the device are discussed.

1. Requirements of Display Devices

The purpose of this paper is to discuss an electro-optical projection system. Before proceeding, it would be well to enumerate some of the desired characteristics of display devices. The relative degree of importance of these characteristics is contingent upon the particular purpose of the display and will vary from situation to situation. The following are the main points which should be considered prior to the selection of any display.

(a) Analysis of the type of information data to be communicated and sufficient adaptability of the display to fulfil this requirement.

(b) No additional or special circuit requirement.

(c) Sufficient viewing angle, with minimum display degradation when viewed from extremes.

(d) Clear, uncluttered, one plane presentations.

(e) Minimum transient time.

(f) No possibility of misinterpretation of presentation due to failure (fail-safe).

(g) Low viewer fatigue, human engineered.

(h) Long life.

(i) Low initial cost.

(j) Low maintenance cost and maintenance simplicity.

(k) Packaging, etc.

For sake of clarity, "information data" is defined as any symbolic means of representing data whether it be an alpha-numeric character, a single word, a message comprised of several words, a picture and/or a colour.

Most presently known visual display devices suffer from one or more undesirable characteristics which are inherent in their design. Mechanical stepping devices operate slowly as compared to electric devices; they must be stepped to normal after each operation, and require auxiliary stepping equipment. Selective element cathode illumination devices are restricted in the shape and colour of the information data displayed, have low luminous intensity, exhibit poor resolution due to the characteristic cathode glow, and require high voltage power supplies and auxiliary switching apparatus. Edge-illuminated stacked and etched translucent sheet devices are restricted to small limited viewing angles due to the depth of the stack and suffer character degradation due to interference by the overlaid characters. Neon segmented lamps, selectively operated, require extensive auxiliary switching circuitry and are inflexible to general information data display. Segmented electro-luminescent lamps require auxiliary power supplies and have poor resolution due to low light output.

2. Description of the Projection Display

The device‡ to be discussed in this paper overcomes most of these undesirable characteristics and has a number of meritorious characteristics. It is a rear projection type electro-optical system which contains twelve individual projectors in a common housing, focused upon a common viewing screen (Fig. 1). Each of these twelve projectors has its own unique bit of information data and light source, which when activated, projects the information on the viewing screen.

† Industrial Electronic Engineers, Inc., North Hollywood, California, U.S.A.

‡ Manufactured by Counting Instruments Ltd., Borehamwood, Hertfordshire, under licence from Industrial Electronic Engineers, Inc., North Hollywood, California, U.S.A.

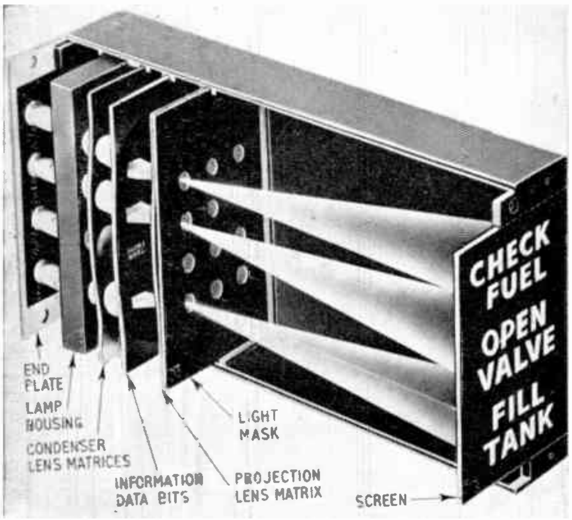


Fig. 1. Cutaway view of an in-line digital display.

Figure 2 illustrates a typical projector utilizing a miniature lamp as the light source.† The condensing lenses converge light from the source through a film reduction of the information data to be displayed on to the projection lens. The projection lens in turn magnifies and images the information upon the viewing screen (ground glass or diffused plastic surface). By suitable selection of the screen surface, various radiation patterns may be obtained. Two of these patterns are illustrated in Fig. 3. Due to the single plane nature of the display and selective screen properties permit all presentations to be viewed from an included angle of 150 deg.

Each of the twelve projectors has its own optical axis which is directed to the centre of the viewing screen, where they intersect (Fig. 4). This axial convergence necessitates placement of each type of projector element on a spherical surface with a radius of curvature equal to the distance of that particular element to the viewing screen. For ease of fabrication each type of lens is moulded into a plastic spherical section with the proper radius. The light source is adjusted by mounting variations of the base socket on the end plate of the unit.

Figure 1 relates to the general construction of a typical unit. At the left is the end plate with lamp sockets and terminals mounted. The lamps when mounted insert into a housing which acts as a light shield and heat sink. The two condensing lens matrices are just forward of the lamp housing. The object film, with its twelve bits of information data is affixed to the concave surface of the second condenser. The next and final matrix is that of the projection lenses, with a light mask mounted between it and the viewing screen. By proper activation any one of the twelve information bits may be selected for display. It is possible by step activation to present a message in increments or to change part of an existing message. Insertion of a colour filter overlay on an information bit, or in an information bit position, will permit coloured presentations or flooding which may be used to indicate special conditions. The information displayed by this unit is entirely adaptable to meet the needs of the design engineer, without compromise.

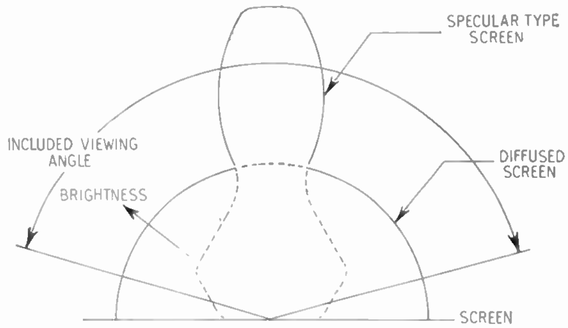


Fig. 3. Polar intensity plot.

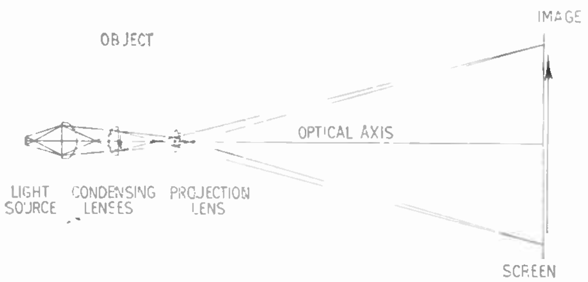


Fig. 2. Single projection system.

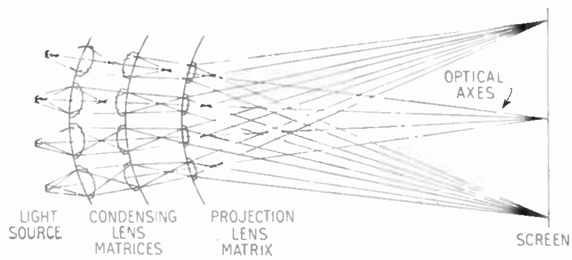


Fig. 4. Multiple projection systems focused upon a common viewing screen.

† Any miniature lamp possessing a T3-1/4 bayonet base may be used, providing the filament location is compatible with the optical design of the unit and does not exceed 8 watts power dissipation at an ambient temperature of 120°F, see Fig. 6.

3. Performance

Lamp selection would be predicted upon available circuit voltages and lamp switching can be achieved in less than 100 milliseconds (time required for the filament of a lamp to decay and another to activate). The lamps are easily serviced by removing four screws which hold the end plate to the case, thus providing accessibility to all twelve lamps. It is not necessary to replace the entire unit when one lamp fails. The rated voltage life of any single lamp can be as high as 3000 hours (Table 1), with random lamp activation the "mean time to maintenance" can be as great as 36 000 hours. Normally a failure is not catastrophic but the results of gradual lamp degradation due to filament deterioration. If and when a "catastrophic" lamp failure should occur no misinterpretation can be obtained, the information is either presented or not presented. Input to the display unit is straight decimal; that is, for each information data bit there is one terminal available for wiring purposes. Since the unit operates on this single signal, no special intermediate coding is required. There are no requirements for auxiliary amplifier circuits or mechanical drives to operate the unit. Several units may be grouped together in assemblies, maintaining the same included viewing angle without loss of resolution or brightness. Various size displays may be obtained by minor optical design changes and corresponding case dimensional changes. Three different alpha-numeric character sizes are currently available, ⅝ in., 1 in. and 3¾ in.

Table 1

Lamp Selection Chart

General Electric Lamp Number	Voltage	Current (mA)	Wattage per lamp	Life at rated voltage (hours)	Relative brightness†
44	6·3	250	1·6	3000	1‡
47	6·3	150	0·9	3000	2
1815	14	200	2·8	3000	3
1813	14	100	1·4	3000	4
1819	28	40	1·1	1000	5
1820	28	100	2·8	1000	3
1829	28	70	2·0	1000	4

† The brightness of the character displayed depends upon the current of the lamp and the design of the filament. The 6·3 V lamp has a more concentrated filament than either the 14 V or 28 V lamp, and therefore provides a brighter picture.

‡ Maximum brightness is indicated by the lowest number. Brightness decreases as the numbers increase.

Manuscript received by the Institution on 25th January 1961 (Contribution No. 34).

APPLICANTS FOR ELECTION AND TRANSFER

As a result of its meeting on 29th June the Membership Committee recommended to the Council the following elections and transfers.

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

Direct Election to Member

CONNERTON, Wing Commander Charles Daniel, R.A.F. *Dublin.*
HAYWARD, William Edward John, B.Sc. *London, S.W.1.*
MOULTON, Group Captain Leslie Howard, R.A.F. *Bushey Heath, Herts.*
WOODGET, Thomas Silas. *Pinner, Middlesex.*

Direct Election to Association Member

BOFF, Albert Frank, B.Sc. *Shenfield, Essex.*
DANIELL, Royston William Grant, B.Sc.(Eng.). *Box, Wiltshire.*
FORREST, Robin Alan. *Nairobi, Kenya.*
GREEHY, Patrick John. *Farnborough, Hampshire.*
HILL, David Ernest Edward. *Ilford, Essex.*
HOLLING, Kenneth, B.Sc., M.Sc. *Chesterfield.*
HORRY, Dennis John, B.Sc. *Lagos, Nigeria.*
WALLER, Peter John. *Chelmsford, Essex.*
WOODS-HILL, William. *Welwyn Garden City, Hertfordshire.*

Transfer from Associate to Associate Member

CUDLIP, Dennis Norman John. *Lagos, Nigeria.*
HULL, Michael Dias. *London, S.E.24.*
ROSKROW, Major Brian, R. Sigs. *Bexley Heath, Kent.*

Transfer from Graduate to Associate Member

BUMFORD, Brian Arthur. *Reading, Berkshire.*
FREER, Colin George Harry. *Kettering, Northamptonshire.*
GRICE, Lieutenant Henry Richard, R.N. *Lee-on-Solent, Hampshire.*
HITCHEN, Eric. *Chelmsford, Essex.*
KEATS, Albert Brian. *Dorchester, Dorset.*
MOLE, Lindsay Gerald Richard. *Lancing, Sussex.*
OLISA, Peter Enebeli. *Ibadan, Nigeria.*
PEARCE, Richard John. *Sutton Coldfield, Warks.*
RYDER, Geoffrey. *Havant, Hants.*
SANDERS, Robert George. *Rugby, Warks.*
SWAINSON, Brian John. *Southport, Lancs.*

Transfer from Student to Associate Member

HOLLAND, Major Peter John, R. Sigs. *B.F.P.O. 40.*

Direct Election to Associate

BARROWS, Arthur Frederick. *Romford, Essex.*
HOLLINGSWORTH, Peter. *Hitchin, Hertfordshire.*
IQBAL, Major Muhammad. *Karachi, Pakistan.*
McCREADIE, Major Anthony Robert, *Catterick Camp, Yorkshire.*
PRINCE, Ivan Edwin. *Gosport, Hampshire.*
ROWE, Peter Lambert. *Hitchin, Hertfordshire.*
SPENCE, Stanley Arthur. *London, S.W.15.*
TOVEY, Arthur William. *Wroughton, Wiltshire.*
WHEATLEY, Norman. *Hong Kong.*
WILSON, Clifford. *Manchester.*
WOODMORE, Peter Philip. *Wolverhampton, Staffordshire.*

Transfer from Student to Associate

CARLTON, John William. *Cherry Hinton, Cambridgeshire.*
TIMBRELL, Leslie Alan. *Wellingborough, Northants.*

Direct Election to Graduate

AL-HAMAD, Abdul Khaliq Jassim. *Basrah, Iraq.*
BASU MALLICK, Sisir, M.Sc., B.Sc. *Loughborough, Leicestershire.*
CARTER, David John Robert. *Reading, Berkshire.*
DAVID, Joseph Haim Hakham, B.Sc.(Eng.). *London, S.W.4.*
HARPER, Roy Douglas. *London, N.W.2.*
HINGSTON, Reginald John. *Holmer Green, Buckinghamshire.*
MALIK, Hamid Aschar. *Lalamuska, W. Pakistan.*
MOHANTY, Sudhanshu Sekhar, B.Sc. *Cuttack, India.*
RAIF, Faiz Avni. *Huddersfield, Yorkshire.*
READ, Peter George. *London, S.E.3.*
SMITHERS, Peter Alan. *Redhill, Surrey.*
STEELE, Brian Frederick. *Seaton, Devon.*
STEPHENS, Robert John. *Plymouth, Devon.*
TIBBENHAM, William Percy, *Dovercourt, Essex.*
TURPIN, Edwin Dealtry Depree. *London, E.4.*

Transfer from Student to Graduate

ALEXANDER, Vaidian Thayil Mathew, B.Sc. *Bombay.*
RENGARAYALU, Captain Subbarayalu, B.A. *Agra Cantt, India.*
RING, Hans Chanan. *Givatayim, Israel.*
TEMBE, Shivram Ramchandra. *Thana, India.*

STUDENTSHIP REGISTRATIONS

The following students were registered at the 29th June meeting of the Committee.

ASGILL, Julius James. *London, N.7.*
BAPAT, Dinkar Ramchandra. *Poona, India.*
BENJAMIN, Eniola. *London, E.7.*
BHAGAVAN, Rangaswany Iyenar. *Bangalore.*
BINZAGR, Faisal Saeid M. *Loughborough.*
BLACKBAND, Alexander Graham. *Birmingham.*
BLICK, John Spencer. *Eastleigh, Hampshire.*
BLOOMFIELD, Raymond J. *Saffron Walden.*
BROWN, Barry Keith. *Romford, Essex.*
CHAKRAPANI RAO, Ramchandra Rao, B.Sc. *Bangalore.*
CHANDRASMEKARA, Kantharajapura Lavappa, B.Sc. *Bangalore.*
CHAWLA, Hari Mohan, B.Sc. *Kangra, India.*
COLEMAN, Frederick John. *London, W.9.*
COLES, Ronald David Charles. *Plymouth.*
COONEY, George G. *U.S. Forces Europe.*
CRAWFORD, David Owen. *London, W.5.*
*DAVIES, Alan Terrell. *London, S.W.19.*
DAVIES, Colin Howell. *B.F.P.O. 23.*
DIVEKAR, Krishna Vaman, B.Sc. *Bangalore.*
*FINLAY, John C. *East Boldon, Co. Durham.*
FRANCIS, Thalakkattore Mathew, B.Sc. *Kerala State, India.*
FREEMAN, Terence A. *Edgware, Middlesex.*
GIBSON, Roger Edward. *Chatham, Kent.*
GOPALKRISHNAN, Kollengode Sangameswara, B.Sc. *Bombay.*
HASLOP, Dennis. *London, N.5.*
*IYER, Rama Padmanabha, B.Sc. *Delhi.*
KATHERGAMANATHAN, Ponnambalam. *Ilavalai, Ceylon.*
KATRAK, Behram Jamshedji. *New Delhi.*
KRISHNASWAMY, C., B.Sc. *Madras.*
*KUNDU, Sushyamal. *Calcutta.*
LABAN, Herbert Maxwell. *Doncaster, Yorks.*
LEWIS, Philip James. *Brighton, Sussex.*
McLAUGHLIN, Alexander W. *Hamilton, Lanarkshire.*
MAHADEVAN, Perunkolam Ramier, B.Sc. *The Nilgiris, India.*
MANN, Donald Cedric. *Banwell, Somerset.*
MICHAELIDES, Michael Charalambous. *Kyrenia, Cyprus.*
NAGABHUSHANA, Harnahalli Mylariah, B.Sc. *Bangalore.*
NAIRN, Leslie Leonard. *Lagos, Nigeria.*
NARASIMHA-PRASAD, Belagur Srikantaiah, M.Sc. *Bangalore, India.*
NEWBERY, Francis G. *Stockport, Cheshire.*
NEWTON, George Alban, M.Sc. *Lucknow.*
NICHOLAS, Anthony Michael. *Plymouth.*
O'BYRNE, John R. *Weston-super-Mare, Somerset.*
OJI, Dickson Egwounwu. *Onitsha, Nigeria.*
ONG, Swee Jin Samuel J. *Singapore.*
OSUWAH, Goodwill Chukwuma. *Lagos.*
PAJNOO, Sl Om Kar Nath. *Srinagar, India.*
PARTHASARATHY, Rajagopala, B.Sc. *Bangalore.*
POLANOWSKI, Antoni. *London, W.2.*
PREMA-KUMAR, Ramaswamy, B.Sc. *Bangalore.*
*PRITAM-SINGH, Saund. *Jullundur, India.*
RAGHAVENDRA-RAO, Channakeshavapura Krishnamurthy. *Bangalore.*
RAJAGOPALAN, Pootheri, B.Sc. *Kerala, India.*
RAO, Addanki, Lakshmi Prasad, B.Sc. *London, S.W.7.*
RICHARDS, John Charles Thorpe. *Plymouth.*
SEAH, Cheng Huat. *Singapore.*
SELF, Thomas Albert. *London, W.4.*
SEONG, Tan. *Kuala Lumpur, Malaya.*
SMITH, Arnold Moses D. *London, S.W.5.*
SUBRAMANIAN, P. K., B.Sc. *Madras.*
SWAMINATHAN, C. V., B.A. *Bangalore.*
TAM, Shun Kwong. *Hong Kong.*
THOMPSON, Anthony Ben. *London, N.22.*
TOMBS, Donald Ivor. *B.F.P.O. 53.*
VAN DER MEULEN, Frans J. *Arnhem, Holland.*
WARRICK, David. *Belfast.*
WILSON, Duncan Ferguson. *Glasgow.*

The following students were registered at the 28th March meeting of the Committee but were not included in the list published on page 456 of the May *Journal.*

BLACKWELL, Leslie Charles. *Ilford, Essex.*
DAVIES, Garnett Burne. *Swansea, Glam.*
DRIVER, Anthony David. *London, S.E.*
ELWOOD, David Victor. *Redhill, Surrey.*
FATIMILEHIN, Olawolfe. *Lagos, Nigeria.*
FINN, Edmond. *Ilford, Essex.*
MAKSHMINARAYAN, N. *Bangalore, India.*
MORGAN, David Hambry. *Port Talbot, Glam.*
MORTON, Alan. *Chelmsford, Essex.*
RABINDRAW, A. *Bangalore, India.*
JAI RAM RAJ, Sarikonda, *Bangalore, India.*

*Reinstatements.

U.D.C. 535.37 : 681.2.3

The Electroluminescent Matrix for Pattern Display and Recording

By

D. C. JEFFREYS, M.Sc.†

AND

G. R. HOFFMAN, Ph.D.†

Presented at the Computer Group's Symposium on Alpha-Numeric Display Devices held in London on 18th January 1961.

Summary: Construction techniques for electroluminescent matrix systems, namely photographic etching and vacuum evaporation through masks, are described in detail. A method of extending the lifetime of electroluminescent layers is put forward which offers easier construction of the electroluminescent device. Selection problems in electroluminescent matrix systems are considered. Electro-mechanical systems are shown to be very slow and a description is given of a high-speed, economical, electronic selection system, which may use either valves or transistors.

1. Uses of Electroluminescent Matrices

1.1. *Graphical Plotting*

The electroluminescent matrix has been considered as a graphical output unit for a digital computer in a paper by Kilburn *et al.*,[1] and also as a permanent storage device for use in a digital computer, in a paper by Hoffman *et al.*[2] It is the purpose of this paper to describe in detail the construction and operation of these electroluminescent matrices.

An electroluminescent matrix consists of a sandwich of electroluminescent phosphor between orthogonal sets of conducting strips deposited on a glass substrate (Fig. 1). A pair of conducting strips, one in the X direction, and one in the Y direction, may be selected by a co-ordinate selection system, and on the application of anti-phase voltages $\hat{E} \sin \omega t$ to X, and $-\hat{E} \sin \omega t$ to Y, there will be a voltage of $2\hat{E} \sin \omega t$ at the intersection of X and Y. At all other intersections of the selected X with non-selected Y conductors, and the selected Y with non-selected X conductors, there will be a voltage of $\hat{E} \sin \omega t$. This method of selection of a single point within a matrix is discussed in reference 1. If the brightness-voltage characteristic of the electroluminescent phosphor is sufficiently steep, then with this 2 : 1 difference in voltage there will be sufficient difference in the brightness of the electroluminescent light output for a photographic film to record the light from the spot at the intersection of the selected conductors but not the light output from the intersections between selected and non-selected conductors. Electroluminescent layers have now been developed which are sufficiently bright for a photographic record to be made of each selected co-ordinate position in 1–2 ms. With suitable high-speed co-ordinate selection circuitry, fast and accurate graphical plotting may be accomplished.

When this recording time is compared with that of a cathode-ray tube plotting device[11] the electroluminescent matrix is slower. However the electroluminescent matrix is inherently accurate. A 512 × 512 line graphical plotting matrix has a built-in drift-free accuracy of 0·2% (i.e. 1 line in 512) and all matrices manufactured to the same specification will be absolutely identical from one to another.

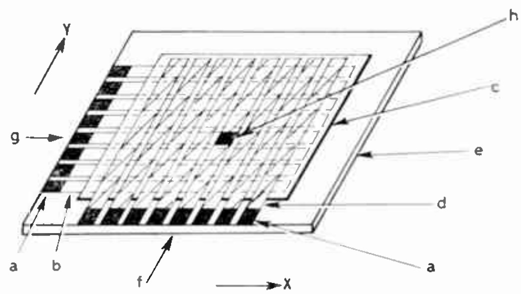


Fig. 1. An electroluminescent matrix.

a silver contact
b transparent conducting lines
c electroluminescent phosphor layer
d copper lines
e glass plate
f selected X line
g selected Y line
h selected spot.

Compared with mechanical plotting systems, the electroluminescent matrix is at least as accurate, but considerably faster, so a graphical plotting system, incorporating an electroluminescent matrix combines the high accuracy of a mechanical system, but with high recording and selection speed. Such systems will be of considerable use in connection with computing machine installations where the rate of data output requiring accurate plotting, may be high. An example is shown in Fig. 2.

† Computing Machine Laboratory, Manchester University.

1.2. *Alpha-Numeric Displays*

The electroluminescent matrix may be used as an alpha-numeric display or recording device by programming the co-ordinate selection so that numerals or letters are sequentially plotted (see Fig. 4 in reference 11). In this way, a plotting speed of 10–20 ms per character may be achieved, which compares favourably with the 16 ms per character required by a high-speed tape punch.

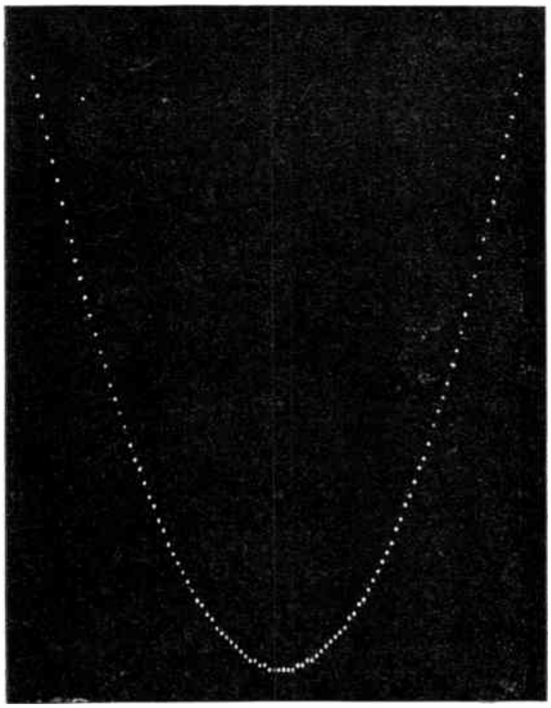


Fig. 2. Solution of the equation $y = kx^2$ plotted on an electroluminescent matrix.

As the display on an electroluminescent matrix is essentially sequential, then in order for the eye to perceive a steady or readable image it is necessary to build in some form of image storage mechanism. The simplest storage mechanism is a phosphor with a long afterglow, but as electroluminescent phosphors are in general not of this type, a standard long-afterglow photoluminescent phosphor may be mixed with the electroluminescent phosphor to produce the required effect.

If the display is plotted in less than 100 ms, i.e. the maximum time before the eye observes flicker, then the display may be continuously recycled to produce a steady image. This system is particularly useful in conjunction with a radar system where the co-ordinates of the objects under surveillance are being continuously scanned.

2. Construction of Electroluminescent Matrices

2.1. *The Simple Electroluminescent Cell*

This consists of a sandwich of electroluminescent phosphor between conducting plates (Fig. 3). When an alternating voltage is applied to the two plates then an alternating electric field is established across the electroluminescent layer. If the electroluminescent phosphor is suspended in an insulating dielectric, then light will be emitted due to intrinsic electroluminescence.[3] To allow the luminescence to be observed, one of the conducting plates must be transparent. Therefore, electroluminescent cells are generally constructed on glass which has been given a transparent conducting coating. The electroluminescent phosphor, suspended in a plastic dielectric, is then spin coated or sprayed on the conducting surface of the glass, and finally a metallic back-conductor is evaporated or sprayed on to the phosphor layer. An alternative method of construction may be used where the electroluminescent phosphor in a low melting point glass binder is coated on a metal plate, fused, and then a hard transparent conducting layer formed on the surface. Although this second method of electroluminescent cell construction gives a very robust cell it is not easy to use it for matrix construction.

2.2. *Matrix Line Width and Spacing*

In the electroluminescent matrix, the conductors are long narrow parallel lines, each line being insulated from its neighbours (Fig. 1) and each having an independent electrical connection. The transparent conducting lines on the front of the matrix are arranged to be orthogonal to the opaque conducting lines at the back of the matrix.

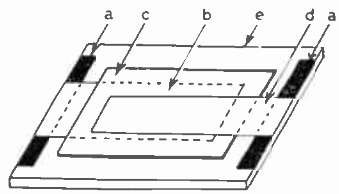


Fig. 3. A simple electroluminescent cell.
- a silver contact
- b transparent conducting film
- c electroluminescent phosphor layer
- d copper film
- e glass plate.

The lines in one set may be placed as close together as the insulation properties of the glass and resin dielectric allow, providing that they are not so close that the electric field created by exciting adjacent lines in one co-ordinate set is sufficient to cause electroluminescence. The width of the lines is basically determined by the phosphor particle size. In order to obtain uniform light output from each individual electroluminescent element at the line intersections in the matrix, then there must be a large number of phosphor particles per element so that random distribution of phosphor particles during deposition of the layer will only have a small effect within the area of the element.

Using a phosphor with a particle size distribution in the range 20–40 μm, a line width of ⅓ mm with a spacing of 2 lines per mm has given uniform results.

2.3. *The Choice of Transparent Conducting Films*

The range of transparent conducting coatings available falls into three classes:

(1) Reactively-sputtered or evaporated metallic oxide films, e.g. CdO.[4]

(2) Chemically-deposited metallic oxide films, e.g. SnO_2.[4]

(3) Evaporated or sputtered noble metal films, sufficiently thin to be transparent, e.g. Au.[5]

The simplest method of producing transparent conducting films is by vacuum deposition. This allows a wide choice of coatings for the glass and does not subject the layers to any high temperature stress.

Films prepared in the first two classes generally have an optical transmission of the order of 90% with a resistivity in the range 50–200 Ω per square (the resistance measured between opposite sides of a square area of the film). Furthermore, they are very hard and difficult to remove or etch.

Evaporated gold films using the high bulk conductivity of gold, as opposed to the semi-conduction of the oxide films, have a low resistivity of the order of 5 Ω per square, with an optical transmission of 60%. These films are very soft but harden on ageing, and may easily be etched.

The most important factor governing the choice of conducting coating is the resistivity of the film. Considering a matrix with a fixed number of lines, and a fixed line-width/spacing ratio (say 2 : 1), then the total resistance of one line is independent of the width of the line, and dependent only on the resistivity in ohms per square of the conducting film. This is because if the width of the line is increased, the length will also be increased to accommodate the increased width of the orthogonal set of conducting lines. For example, a 512 × 512 square matrix, using a gold transparent conducting film of resistivity 5 Ω/square, will have a transparent line resistance of at least 4 kΩ, i.e. 512 × 1·5 × 5. In a practical matrix, the line length must be extended to allow connections to be made and the total resistance may be 6 kΩ.

This becomes important when the capacitance of the matrix is also considered. The distributed capacitance and resistance of the transparent line becomes an electrical diffusion line, causing a phase change and attenuation of the voltage waveform down the line. As it is desirable to use high excitation frequencies,[1] this attenuation and phase change may become considerable. Using a 512 × 512 matrix, with a transparent gold line width of 12 mils, and a capacitance of 1100 pF/in^2, the phase change is of the order of 60 deg at 250 kc/s, and 15 deg at 50 kc/s and the attenuation is 0·7 at 250 kc/s and 0·9 at 50 kc/s. These effects are discussed in Appendix 1.

The conductivity of the transparent conductor is a major factor in determining the maximum size, and operating frequency of the matrix for uniform light output. A 512 × 512 matrix has been successfully operated up to 50 kc/s sinusoidal excitation frequency, and a 128 × 128 matrix has been operated up to 500 kc/s excitation frequency, each of these matrices having a gold transparent conducting film. Conducting films with a higher resistivity would necessitate the use of lower excitation frequencies, or lower resolution matrices.

No effects due to phase change or attenuation in the backing electrodes need be considered because these may be thick, opaque layers of high conductivity copper.

2.4. *Techniques for the Formation of the Line and Contact Pattern*

Two techniques have been developed to form the line patterns with a high positional accuracy. The first technique is based on photo-etching as in printed circuitry and the second is based on evaporation through masks.

2.4.1. The photo-etching method

The photo-etching method involves initially the manufacture of a "master" photographic negative, upon which will depend the accuracy of the final electroluminescent matrices. The negative defines the straightness and positional accuracy of the lines, the arrangement and position of the contacts to the lines, and the orthogonality of the two sets of conducting lines. A typical master negative for a 128 × 128 matrix is shown in Fig. 4. The line pattern is derived from a line screen as used in the printing industry. Original line screens are ruled to a high degree of accuracy, and are available to various specifications of resolution and mark/space ratio. They may be copied by contact printing on to photographic film with a dimensionally stable base to preserve the accuracy.

The contact pattern may now be drawn on the line pattern by hand. In order to obtain contacts sufficiently large for soldering or making pin connections,

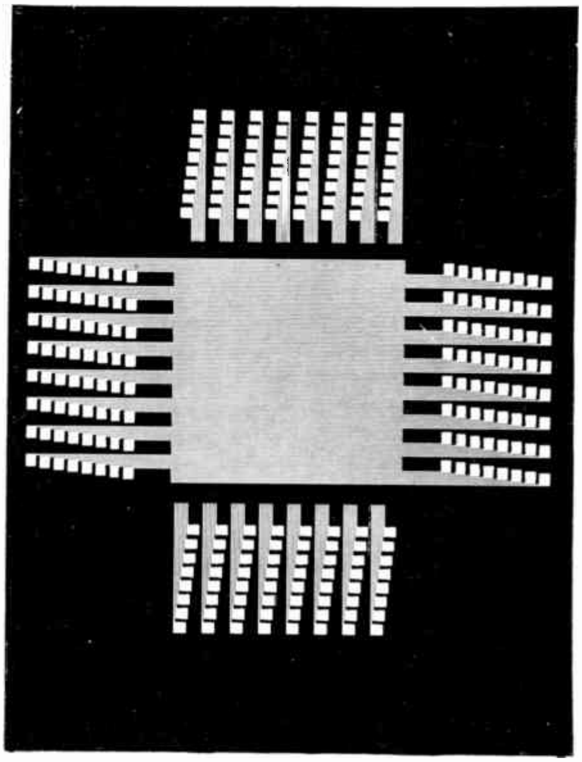


Fig. 4. A print of the 128 × 128 line master negative.

the lines are extended alternately at either end of the matrix in blocks of eight (Fig. 4) and each line terminated with a contact. This is called the "flag" pattern of contacts. Finally in order to define the orthogonality of the line patterns, the negative consisting so far of the 128 lines plus contacts is placed in a contact-printing machine, printed down, then turned through 90 deg exactly and the contact ends of the lines are printed down again giving the complete pattern of Fig. 4.

The production schedule for a matrix using such a negative is as follows:

(1) Select a sheet of best-quality plate glass which must be free from surface defects and then etch the surface of the glass with hydrofluoric acid over the area where the contacts are to be deposited.

(2) Spray silver paint over the contact area of the glass and bake into the surface to form a good bond.

(3) Etch the contacts into the silver paint, using photo-resist printed in contact with the master negative.

(4) Clean the glass central area very thoroughly and evaporate a high-conductivity transparent bismuth oxide–gold film[4, 5] over one set of contacts and the central area of the matrix. It is essential at this stage to evaporate a narrow band of silver over the junction of the transparent gold and silver contacts to act as a reinforcement layer. (Silver is used because it can be etched independently of the gold.)

(5) Etch the line pattern in the gold layer and the silver reinforcing layer using the master negative and photo-resist. The negative may be readily registered with the contacts if it is manufactured sufficiently accurately because when one line is in register then all the others will be also. The exposure is carried out in a vacuum printing frame to ensure accurate contact between the matrix and the negative.

(6) Deposit the layer of electroluminescent phosphor. This is best carried out on a spin-coating machine which is also used for the photo-resist coating. The most efficient layer is obtained by coating the phosphor in a binder of high-viscosity nitrocellulose, and then coating a second layer for the dielectric consisting of resin heavily loaded with barium titanate.

(7) Evaporate a thick layer of copper over the second set of contacts and the back of the dielectric layer.

(8) Etch the line pattern in the copper layer using photo resist printed in contact with the master negative. The line pattern on the negative may again be

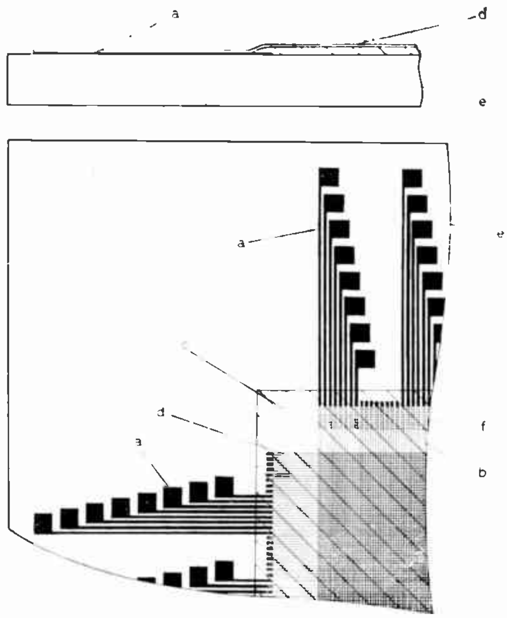


Fig. 5. Section and plan of an electroluminescent matrix produced by photo-etching.

a silver contact "flag"
b transparent gold lines
c electroluminescent phosphor layer
d copper lines
e glass plate
f reinforcement silver, over a junction between a gold line and a contact.

readily registered with the second set of contacts on the matrix panel to make the copper lines orthogonal to the gold lines.

(9) Thoroughly dry, then seal the panel against moisture ingress to ensure a long reliable life.

Figure 5 shows the section and plan of a matrix produced by etching. Etching solutions, etc., are given in Appendix 2.

2.4.2. The mask method

The method using a mask in the evaporating process to form the lines derives its accuracy from the accuracy of fabrication of the mask.

The simplest method to construct an accurate mask is to stretch fine wires across a rigid framework, the wires being positioned by an accurately-turned screwed rod, one wire being placed in each groove in the screw thread. To maintain tension when the glass baseplate of the matrix is brought into contact with the wires, each wire must be separately sprung, in tension, and the wire should preferably be made of the same material as the support frame to avoid differential expansion problems. Steel is a suitable material. Round wires must be used to avoid unwanted effects due to the wire twisting, but this allows only a single line of contact between the wire and the glass surface. Thus, penumbra effects in the vacuum evaporation can reduce the effective spacing between the lines, by evaporated material scattering between the mask wire and the glass. The penumbra effect may be overcome by using a high vacuum and a large source to substrate distance in the vacuum evaporator. A suitable mask structure is shown in Fig. 6.

In order to make contact to the lines, it is necessary in this case to make a soldered connection directly to each line, within the line width. If the lines are 50 mils wide or more, this is comparatively simple, but with lines down to 10 mils in width, it is more difficult. The contacts are prepared by evaporating chromium through the mask and then merging an evaporation of copper with the chromium on the glass substrate at 200° C. At this temperature the chromium forms a good bond to the glass and the copper evaporation then provides a surface keyed with the chromium to which wires may be soldered. After allowing the glass to cool down, the transparent bismuth oxide–gold layer may be evaporated with the mask still in position and the lines will be in register with the contacts.

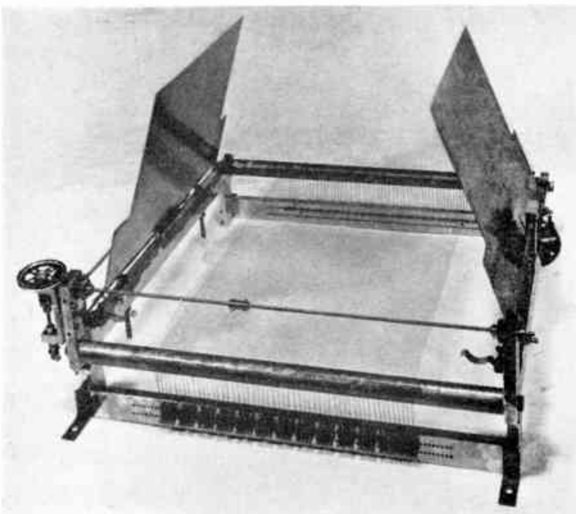


Fig. 6. Photograph of a wire mask, used for direct evaporation of a matrix.

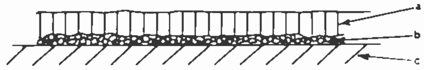


Fig. 7. Section of an electroluminescent layer.
a dielectric resin, heavily loaded with barium titanate
b phosphor particles, bound in nitrocellulose
c glass plate.

When the phosphor has been deposited the back conductors may also be evaporated through the mask, orthogonality being ensured by the accuracy of construction of the mask.

Soldering to the contacts is made comparatively easy if the contacts are first coated with a resin fluxing-agent. A solder-coated copper wire may then be positioned using a micro-manipulator, and the soldering operation performed by passing a heavy pulse of current through the wire from a bank of capacitors. By careful design of the micro-manipulator, a rapid automatic technique may be developed.

Using these manufacturing techniques many matrices have been produced of different size, resolution and line spacing. The techniques have proved sufficiently versatile to produce matrices of different specifications for various applications.[2]

3. The Electroluminescent Phosphor Layer

This consists of a layer of electroluminescent phosphor embedded in a plastic dielectric binder.[6] To ensure the maximum efficiency of the electroluminescent layer, the binder plastic may be loaded with a material of high dielectric constant, say barium titanate, so that most of the electric field forms across the phosphor particles, the dielectric layer preventing breakdown (Fig. 7).

When such a layer is subject to an electric field, then the brightness and excitation voltage are related by the expression[7]

$$B = a \exp - \frac{b}{\sqrt{V}} \qquad \ldots\ldots(1)$$

where B = integrated light output from the electroluminescent device,

V = peak to peak amplitude of the excitation voltage.

a and b are parameters depending on the electroluminescent layer, and applied voltage frequency and waveshape.

This expression has proved true over eight decades of brightness measurements.[1] Reference 1 also discusses the significance of this expression in connection with the discrimination ratio between selected and non-selected spots in the matrix. When a sinusoidal excitation voltage is applied to the selected lines in X and Y and all the other lines are earthed, there will be a difference between the electric field at the selected spot and the field at non-selected spots along the selected X and Y lines of 2 : 1 (Section 1). For the satisfactory operation of the matrix it is essential that this 2 : 1 difference in field gives sufficient difference in brightness for the selected spot to be easily visible and the non-selected spots invisible or hardly visible. Where photographic recording is used, the total amount of light emitted from any one spot will be integrated, as far as the reciprocity failure of the photographic emulsion allows. Thus a spot which has received the half maximum field excitation voltage many times, without having been subject to the full excitation voltage, may emit sufficient total light to expose the photographic emulsion as would a spot which had received the full excitation voltage. In order to prevent this from happening then the discrimination ratio[1] must be high. A simple method for increasing this is to reduce the excitation voltage. This reduces the brightness of the selected spot and so a greater photographic exposure time is required.

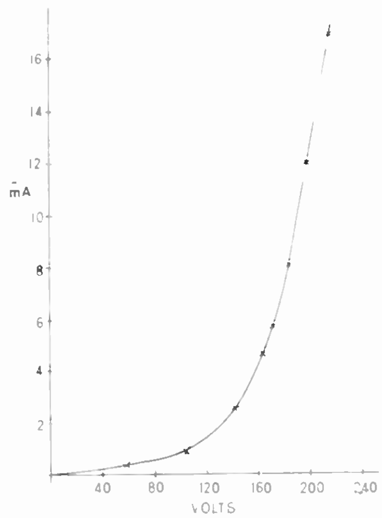


Fig. 8. Characteristic curve of a typical silicon carbide layer.

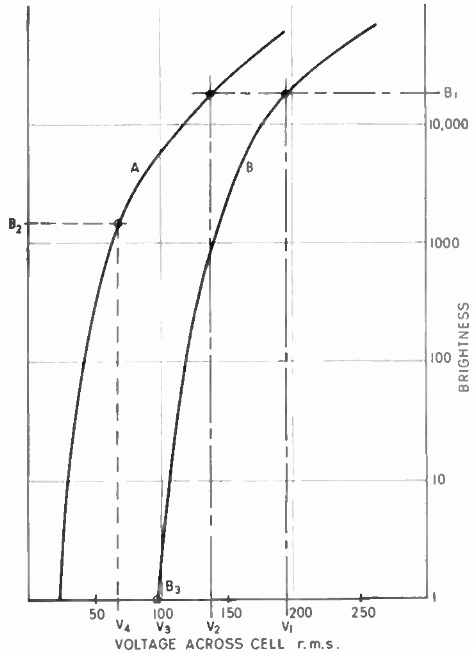


Fig. 9. Characteristic curves of electroluminescent cells.
A simple electroluminescent cell
B electroluminescent cell with a silicon carbide layer.

By using the finer phosphor particles only from a batch of phosphor, or by dissolving away the larger phosphor particles, the discrimination ratio may be slightly increased.[8]

However, a considerable increase in discrimination can be brought about by incorporating a non-linear resistive layer in series with the electroluminescent layer, silicon carbide or cadmium sulphide being suitable materials. The resistance of a silicon carbide layer reduces with increase of applied voltage as the slope of the curve in Fig. 8 indicates. If a correctly-designed layer is incorporated in an electroluminescent matrix, then at the spot receiving full excitation voltage the resistance of the silicon carbide will be low, and there will be a high field across the electroluminescent phosphor. At the spots receiving half excitation voltage, the resistance of the silicon carbide will be high and there will be a low field across the electroluminescent phosphor. The brightness-voltage characteristic of an electroluminescent cell incorporating a silicon carbide layer is shown in Fig. 9. At a brightness corresponding to 2×10^4 units on the arbitrary scale (B_1), there is a discrimination ratio of 2×10^4 : 1, i.e. (B_1/B_3) for a 2 : 1 discrimination ratio of field (V_1/V_3), whilst, for a similar normal type of electroluminescent layer at the same maximum brightness, the brightness discrimination ratio is 10 : 1, i.e. (B_1/B_2).

Unfortunately silicon carbide being a resistive element, tends to dissipate power. Under high brightness conditions therefore the layers become hot and the matrix could be destroyed. However, the silicon carbide layer enables the brightness of the electroluminescent layer to be increased whilst retaining an adequate discrimination ratio so that a photographic record can be made in 1 ms. Provided that the duty ratio of any individual spot or small area on the matrix is kept low, then the matrix will not overheat.

Matrices incorporating silicon carbide layers may be constructed either by bonding a sintered slab of silicon carbide non-linear resistor material to the phosphor layer before the formation of the back electrodes, or by coating the phosphor layer with a suspension of silicon carbide powder in a suitable binder. As it is difficult to obtain flat thin silicon carbide sintered layers on a large size scale (above 4 in. diameter disks), the sintered layers can only be used for small matrices. Powder suspension silicon carbide layers are still being developed for this application, and the results are very promising.

Essentially the silicon carbide layer obeys the law[9]

$$i = av^n \qquad \ldots\ldots(2)$$

where i = current,

v = applied voltage,

a = parameter of the particular layer,

n = 4 to 5.

As this is such a high power law, the silicon carbide layer can be considered as a switch in series with the electroluminescent cell, which is ON when its impedance is lower than that of the electroluminescent cell, and OFF when its impedance is higher than that of the electroluminescent cell. The impedance of the silicon carbide layer will alter very rapidly with voltage and so for any fixed impedance, say that matching the impedance of the electroluminescent layer, the switch-on voltage is fixed. The switch-on voltage of the device may be altered by modifying the characteristics of the silicon carbide layer. A thicker layer of silicon carbide, or the use of finer grade material will increase the switch-on voltage. Work is proceeding to enable the characteristics of layers to be calculated and predicted.

4. Extension of Lifetime of Electroluminescent Layers

Electroluminescent light output rapidly deteriorates if electroluminescent cells are excited or exposed to light in the presence of moisture. If the moisture is removed then this mechanism of decay is eliminated. The normal production procedure for electroluminescent devices must therefore be very strict in the removal and exclusion of moisture. The preferred method of drying and sealing is to bake the device under vacuum for several hours, and then to prevent moisture ingress with a layer of wax or impervious resin. A positive moisture barrier consisting of a sheet of glass or metal on the back of the device must also be considered essential. Using these techniques, useful electroluminescent lifetimes of the order of 3000 hours may be obtained under normal excitation conditions. Even so, it is possible for moisture to obtain access to the device along contacts or through edge layers and destroy the luminescence in certain areas.

Incorporation of an efficient moisture absorber in the layer can reduce the severity of these problems and even in some cases remove the necessity to perform the initial drying process of the layer.

Unfortunately in the etching method for matrix production, aqueous etching and photo-resist processes are involved on the back of the phosphor layer, after it has been deposited. This would destroy the properties of most moisture absorbers incorporated in the layer. However, there are some organic compounds, having a great affinity for water, which can have the water-seeking molecular structure surrounded by other molecular structures so that without destroying the water affinity its rate of reaction is considerably hindered. Thus the presence of a large quantity of moisture in the etching processes would not destroy all the active material in the electroluminescent layers. When the aqueous etching processes are finished, this remaining active material will remove all the moisture from the layer over a period of a few hours after the matrix has been sealed.

Suitable materials are found in the range of sterically-hindered isocyanates, for example

3 : 3′ : 5 : 5′-tetramethyl-4 : 4′-diisocyanato-diphenylmethane

This is a solid which is soluble in the solvents used in the preparation of the phosphor layers, and in the presence of water decomposes to produce carbon dioxide and a poly-urea. Although the rate of reaction is slow, any water present will be absorbed by the

Table 1

Time (hours)	Brightness (foot-lamberts): Control cells without isocyanate		Cells with isocyanate	
	1	2	1	2
0	1	1	1	1
400	$\frac{1}{3}$	$\frac{1}{10}$	$\frac{1}{2}$	$\frac{1}{2}$
1 000	$\frac{1}{10}$	$\frac{1}{30}$	$\frac{1}{2}$	$\frac{1}{2}$
10 000	$\frac{1}{100}$	$< \frac{1}{100}$	$\frac{1}{4}$	$\frac{1}{4}$

isocyanate. Generally the quantities involved are so small that the carbon dioxide evolved is negligible. About 0·3% by weight of isocyanate-phosphor mix is sufficient to remove the need for drying the cells before sealing to prevent further moisture ingress. Table 1 shows the result of life tests on electroluminescent cells incorporating the isocyanate.

The cells received ½ hour soaking in water before sealing, and were then excited at 250 V r.m.s., 50 c/s for the duration of the test. This represents 2×10^9 cycles during which time the light output from the treated cells has decreased to 25% of its initial value. The isocyanate has enabled this figure to be achieved over a long excitation period after having taken no other special precautions to dry the electroluminescent cells.

5. Selection Problems in Electroluminescent Matrix Systems

5.1. *Simple Selecting Systems*

The minimum time required for recording the light output from an individual element on an electroluminescent matrix is 1–2 ms with the most efficient types of electroluminescent layers. The selection time for any particular co-ordinate must be at least as fast as this for efficient use of the matrix. The selection time must also include any necessary decoding time of input information.

In the case of a 512×512 matrix, the problem is to select one line from 512 in the *X* direction, and one line from 512 in the *Y* direction, and then apply voltages to these two lines. This problem is easily solved using relays or rotary switches, but the operating time of such devices is too long to enable high-speed plotting to be carried out. For example, a suitable relay selection system has been tested in which, on selection of any particular co-ordinate, 20 ms had to be allowed for reliable contacts to be made. Similarly the search time for a high-speed rotary switch with sufficient contacts to operate a large matrix is of the order of 2 seconds.

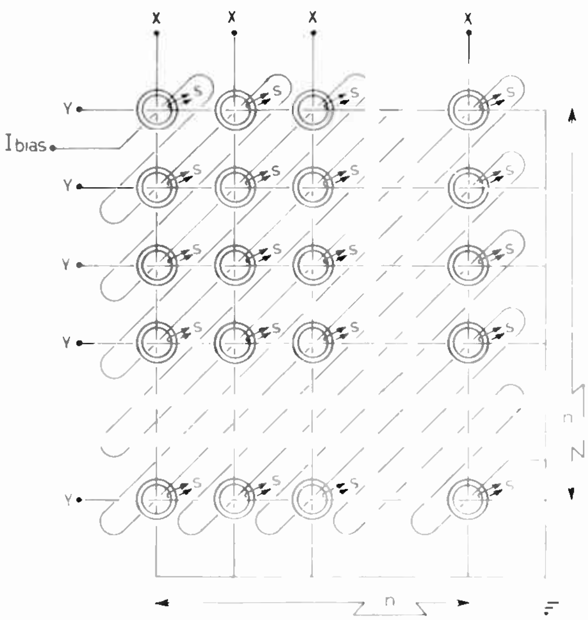


Fig. 10. Matrix of selection transformers.
S secondary winding connected to a line on the electroluminescent matrix
X, Y selection-valve connections.

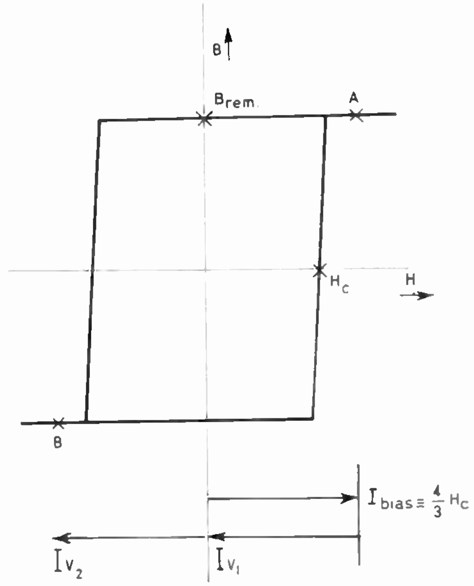


Fig. 11. Hysteresis loop of the transformer core material.

Higher speed selection systems must therefore involve electronic methods (and may be expensive). In the simplest case, a selection system replacing each relay contact by a valve or transistor switch, would require at least one valve per line or as many as 1024 valves in the case of a 512×512 line matrix. A method of reducing this uneconomically large number of valves would clearly be valuable.

5.2. *Transformer Matrix Selection System*

A matrix of transformers as shown in Fig. 10 is a much more economical method of line selection. Each transformer has one secondary winding, which drives a corresponding line on the matrix and three primary windings wound on a magnetic core having a rectangular hysteresis loop. The primary windings are connected in a matrix array as shown in Fig. 10, one set of windings connected in rows, another set in columns, and the third connected in series throughout the matrix. Each row and column set of windings is connected to the anode of a current switching valve, and the common series set of windings is connected to a bias current source. The use of this selection system to drive an $n \times n$ line matrix, would require a total of $2n$ transformers for (X, Y) selection, but the number of selection valves required has been reduced to $2\sqrt{n}$. For example a 512×512 line electroluminescent matrix could be driven by two 32×16 transformer selection matrices requiring a total of 96 valves.

In operation, a bias current (I_{bias}) of such a magnitude to create a magnetizing field of approximately 1·3 times the coercive field (H_c) of the core is passed through the common series set of primary windings (Fig. 11). This current is sufficient to saturate all the transformer cores in the matrix. If two of the valves are now switched on by identical pulses on their grids, one valve associated with a row and another with a column set of primary windings, and each valve current is adjusted to be equal to the bias current, then the transformer core at the intersection of the selected row and column is driven to saturation with a reversal of magnetization, i.e. transition from state A to state B. The valve currents must flow in the primary windings in opposite sense to the bias current. All other cores along the selected row and column will receive current pulses cancelling the magnetizing field due to the bias current, but because of the rectangular hysteresis loop properties of the core, only a minor hysteresis loop will be traced and there will be a small flux change. Thus the core at the intersection of the selected row and column of primary windings suffers a reversal of magnetization whilst all other cores are virtually unaffected. When the driving pulse is removed from the grids of the driving valves, then the bias current returns the selected core to the original state of magnetization. In practice a train of such current pulses is used to excite the selected transformer. Each change of magnetization will induce a voltage in the secondary winding depending on the rate of change of flux in the core, and this induced voltage has proved adequate to excite the lines on an electroluminescent matrix.

5.3. *The Nature of the Output Voltage Pulse*

The output voltage from the transformer secondary winding depends on the number of turns and on the rate of change of flux in the transformer core. The rate of change of flux, in turn, is a function of the driving current giving rise to the magnetizing fields.[12, 13]

It is found that the time for the flux to change is a function of the overdrive of the applied field:

$$t = \frac{S}{H - H_c} \qquad \text{......(3)}$$

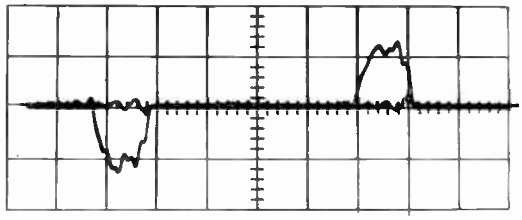


Fig. 12. Photograph of the output-voltage of a transformer.
Vertical scale—100 volts per division.
Horizontal scale—2 μs per division.

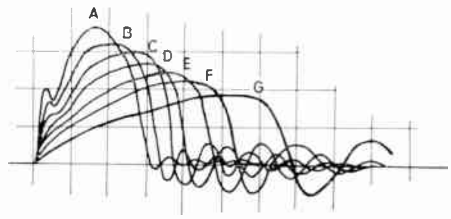


Fig. 13. Output voltage waveform with capacitive load.

A = 0 pF
B = 18 pF
C = 47 pF
D = 68 pF
E = 120 pF
F = 220 pF
G = 440 pF

Vertical scale = 50 volts per division.
Horizontal scale = 0·5 μs per division.

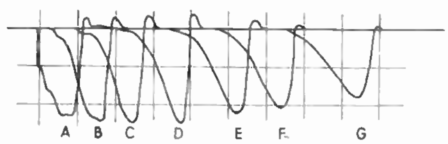


Fig. 14. Output voltage waveform with various rates of rise of driving current.

A = 1·3 amps per μs
B = 1·50 mA per μs
C = 80 mA per μs
D = 40 mA per μs
E = 29 mA per μs
F = 22 mA per μs
G = 14 mA per μs

Vertical scale = 50 volts per division.
Horizontal scale = 2 μs per division.

where t = flux reversal time (μs),
H = driving field (oersted),
H_c = threshold field for irreversible domain wall movement (oersted),
S is a parameter of the material
$\simeq$ 0·6 oersted μs for ferrite and thin metal cores.

The mechanism of flux reversal commences by the creation of small domains of reverse magnetization at grain boundaries throughout the core. Above the critical field strength necessary for domain wall movement to occur, reversal of magnetization takes place by the growth of these small domains at the expense of the others, by domain wall movement at right angles to the direction of magnetization. The voltage output will therefore be proportional to the rate of change of cross-sectional area of the growing domains of reverse magnetization. Since the applied field is constant (H) the output voltage should show an initial rise to a maximum followed by a decline as the growing domains encounter each other and begin to merge. This gives rise to the roughly triangular shape of the output voltage shown in Fig. 12, the amplitude of which is a function of the driving field intensity arising from the driving currents.[12]

When the transformers are used to drive the capacitive load of the matrix, the output voltage may be expected to change. Figure 13 shows the output voltage waveform with various values of capacitive load up to 440 pF. There is a considerable reduction in peak output voltage as the load capacitor is increased, but it is found that for a constant load, the output from all selected transformers is sensibly similar.

As the rate of change of driving current is varied, the output voltage waveform changes as shown in Fig. 14. The area of the pulse and the peak amplitude vary only a little, but for the slower rates of change the output voltage pulse is considerably delayed. Thus to ensure coincidence of the driving pulses on the X and Y co-ordinates of the electroluminescent matrix, the rate of change of driving current in the transformer selection matrix must be carefully controlled. As can be seen from pulse A in Fig. 14, at a pulse excitation frequency of approximately 200 kc/s, the output pulses will merge together to give a waveform approximating to a sine wave of 200 kc/s.

The transformers were made using ferrite ring cores, having a total cross sectional area of 8 mm^2, and were wound with three 20-turn primary windings, and one 70-turn secondary winding.

Testing each transformer in turn along a row or column showed little variation in output due to relative transformer position in the matrix, but it was found that non-selected transformers, on a selected column or row gave an output pulse, approximately $\frac{1}{10}$th of the amplitude of the main pulse (Fig. 12). Not only is this interference pulse $\frac{1}{10}$th of the peak amplitude of the main pulse but its duration is restricted. The effective value of this interference pulse on the electroluminescent matrix is therefore negligible, but the presence of the non-selected cores producing these small interference-voltage pulses causes distortion or "ringing" of the current driving pulses along the rows and columns.

A prototype selection system designed to drive a 128 line electroluminescent matrix, has been built, tested and found adequate.

6. Conclusion

The matrices described have many applications where the high accuracy is of advantage. These include pattern representation, fixed storage,[2, 14] selected co-ordinate marking, and digital computer graphical output.[1] The relatively high recording speed, even for random co-ordinate selection, together with the advantage that digital-analogue conversion is unnecessary, make it especially attractive for applications where information is available in a digital form. It has been demonstrated that it is feasible to construct 512×512 line matrices which accurately specify over a quarter of a million discrete electroluminescent elements, by methods which allow identical units to be manufactured.

7. Acknowledgments

The authors would like to thank Professor T. Kilburn of the Computing Machine Laboratory, and Professor F. C. Williams of the Electrical Engineering Department at Manchester University for the provision of the research facilities enabling this work to be carried out. They also acknowledge the work of Mr. J. K. Birtwistle in connection with the transformer matrix selection system, Mr. P. L. Jones in connection with work on various applications of electroluminescent matrices, and Mr. D. Sutton for his valuable assistance in the construction of the matrices.

8. References

1. T. Kilburn, G. R. Hoffman and R. E. Hayes, "An accurate electroluminescent graphical-output unit for a digital computer", *Proc. Instn Elect. Engrs*, **105B**, pp. 136–44, March (I.E.E. Paper No. 2441M.).
2. G. R. Hoffman, D. H. Smith and D. C. Jeffreys, "High speed light output signals from electroluminescent storage systems", *Proc. Instn Elect. Engrs*, **107B**, pp. 599–605, November (I.E.E. Paper No. 3217M.).
3. G. Destriau and H. F. Ivey, "Electroluminescence and related topics", *Proc. Inst. Radio Engrs*, **43**, pp. 1911–40, December 1955.
4. L. Holland, "Vacuum deposition of thin films" (Chapman and Hall, London, 1956).
5. A. E. Ennos, "Highly conducting gold films prepared by vacuum evaporation", *Brit. J. Appl. Phys.*, **8**, pp. 113–7, March 1957.
6. G. Siddall, "The preparation of electroluminescent panels", *Vacuum*, **7**, pp. 61–71, 1957–58.
7. G. F. Alfrey and J. B. Taylor, Discussion on Paper 7, Supplement 4. *Brit. J. Appl. Phys.*, **6**, 1955.
8. P. Goldberg and S. Faria, "On the physical characteristics and chemical composition of electroluminescent phosphors", *J. Electrochem. Soc.*, **107**, No. 6, pp. 521–6, June 1960.

   W. Lehmann, "Voltage dependence and particle size distribution of electroluminescent phosphors", *J. Electrochem. Soc.*, **107**, No. 1, pp. 20–6, January 1960.

9. R. W. Sillars, "Metrosil", *Metropolitan-Vickers Gazette*, **20**, pp. 304–12, July 1944.
10. W. A. Thornton, "Electroluminescence maintenance", *J. Electrochem. Soc.*, **107**, No. 11, pp. 895–907, November 1960.
11. R. L. Grimsdale and M. Barraclough, "A cathode-ray tube output for a digital computer", *J.Brit.I.R.E.*, **21**, pp. 497–501, June 1961.
12. C. H. Lindsey, "The square-loop ferrite core as a circuit element", *Proc. Instn Elect. Engrs*, **106C**, pp. 117–25 (I.E.E. Monograph No. 327M.).
13. N. Menyuk and J. B. Goodenough, "A theory of flux reversal in polycrystal ferromagnetics", *J. Appl. Phys.*, **26**, p. 8, January 1955.
14. G. R. Hoffman and D. H. Smith, "The light waveforms emitted from electroluminescent cells, energized by square waves and pulses of voltage", *J. Electronics & Control*, **9**, No. 3, pp. 161–216, September 1960.

9. Appendix 1

The gold lines on the electroluminescent matrix may be represented as electrical diffusion lines (Fig. 15), so that the electrical performance of the line may be predicted. Five-section lines have proved sufficiently adequate for most calculations.

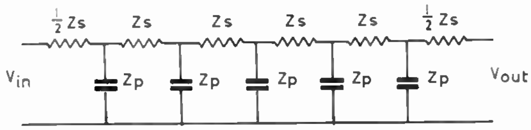


Fig. 15. Electrical analogue of gold line.

Let Z_s = series impedance of line,

Z_p = shunt impedance of line,

Z_0 = characteristic impedance of line.

For one section of the line, the following equations may be written:

$$Z_0 = \sqrt{Z_s Z_p\left(1+\frac{Z_s}{4Z_p}\right)} \quad \ldots\ldots(4)$$

$$\cosh\gamma = 1+\frac{Z_s}{2Z_p} \quad \ldots\ldots(5)$$

$$Z_p = \frac{Z_0}{\sinh\gamma} \quad \ldots\ldots(6)$$

Therefore $\frac{1}{2}Z_s = Z_0 \tanh\frac{1}{2}\gamma$ ......(7)

A line having N sections may be converted into an equivalent single section line by modifying eqns. (6) and (7):

$$Z'_p = \frac{Z_0}{\sinh N\gamma} \quad \ldots\ldots(8)$$

$$\tfrac{1}{2}Z'_s = Z_0 . \tanh\tfrac{1}{2}N\gamma \quad \ldots\ldots(9)$$

Table 2

ωCR	ϕ	x
0·000	0	1·0000
0·001	0·7°	1·0001
0·002	1·4°	1·0003
0·003	2·1°	1·0006
0·004	2·9°	1·0011
0·005	3·6°	1·0018
0·006	4·3°	1·0025
0·007	5·0°	1·0035
0·008	5·7°	1·0045
0·009	6·4°	1·0057
0·010	7·1°	1·0071
0·020	14·1°	1·0279
0·030	20·7°	1·0618
0·040	26·8°	1·1074
0·050	32·4°	1·1634
0·060	37·5°	1·2282
0·070	42·2°	1·3006
0·080	46·3°	1·3792
0·090	50·0°	1·4630
0·100	53·3°	1·5510
0·200	73·8°	2·5479
0·300	84·3°	3·5884
0·400	91·7°	4·5775
0·500	97·7°	5·4721
0·600	103·4°	6·2420
0·700	109·0°	6·8635
0·800	115·0°	7·3194
0·900	121·6°	7·6014
1·000	129·4°	7·7162

However, over one section the open circuit output voltage is

$$V_{oc} = \frac{Z_p . V_i}{Z_p + \frac{1}{2}Z_s} \quad \ldots\ldots(10)$$

Substituting eqns. (8) and (9) we have

$$V_{oc} = \frac{V_i}{1+2\sinh^2(\frac{1}{2}N\gamma)} \quad \ldots\ldots(11)$$

Evaluating eqn. (11) for $N = 5$ gives the results shown in Table 2, where

ω = line excitation voltage frequency,

C = $\frac{1}{5}$th total capacitance of a line as measured at low frequency,

R = $\frac{1}{5}$th total resistance of a line measured by d.c.

Measurement of these three parameters enables the phase change and attenuation of the voltages down a gold line to be readily determined. Let the phase change = $\phi°$.

If the X and Y co-ordinates are excited with voltages $\hat{E}\cos\omega t$, and $-\hat{E}\cos\omega t$, then the voltage at the selected intersection (X, Y), neglecting the attenuation, will be

$$T' = \hat{E}\cos\omega t + \hat{E}\cos(\omega t + \phi)$$

$$T' = 2\hat{E}\cos(\omega t + \tfrac{1}{2}\phi).\cos(\tfrac{1}{2}\phi) \quad \ldots\ldots(12)$$

i.e. there has been reduction in the effective peak voltage at the selected intersection from $2\hat{E}$ to $2\hat{E}\cos(\frac{1}{2}\phi)$.

Considering the attenuation separately from the phase change, the voltage at the selected intersection, due to an attenuation of $1/x$, will be

$$T'' = \hat{E}\cos\omega t + \frac{\hat{E}}{x}\cos\omega t$$

$$T'' = \hat{E}\left(1 + \frac{1}{x}\right)\cos\omega t \quad \ldots\ldots(13)$$

Combining eqns. (12) and (13) gives a final approximate equation for the voltage at a selected intersection, (T), due to small phase changes and attenuation caused by a transparent conducting line:

$$T_1 = \hat{E}\left(1 + \frac{1}{x}\right)\cos(\tfrac{1}{2}\phi)\cos(\omega t + \tfrac{1}{2}\phi) \quad \ldots\ldots(14)$$

Under optimum excitation conditions where there is no attenuation or phase change then $x = 1$, and $\phi = 0$ then the excitation voltage

$$T_2 = 2\hat{E}\cos\omega t \quad \ldots\ldots(15)$$

If these values (T_1 and T_2) of excitation voltage are now substituted in eqn. (1), the brightness ratio for selected spots in optimum and adverse selected positions on the matrix, may be calculated.

10. Appendix 2

Etching Solutions Used in the Photo-Etch Method of Matrix Preparation

(1) The solution used to prepare the surface of plate glass to receive the silver paint contacts:

Hydrofluoric acid 58/60° w/w	200 cm^3
Phosphoric acid	25 cm^3
Distilled water	300 cm^3

Etching time is 1 minute, to leave the glass surface slightly roughened.

(2) The solution used to etch the silver paint contacts:

Chromium trioxide	1 g
Distilled water	60 cm^3
Concentrated nitric acid	40 cm^3

Etching time: 1½ minutes.

(3) The solution used to etch the evaporated silver layer reinforcing the connection between the gold film and the silver paint contact (this solution must be alkaline to prevent destruction of the bismuth oxide layer beneath the gold film):

Sequestrol-iron complex C.P.2 (Geigy)	60 g
Sodium carbonate (anhyd.)	5 g
Potassium bromide	30 g
Sodium thio-sulphate (anhyd.)	140 g
Potassium thiocyanate	10 g
Distilled water	to 1000 cm^3

Etching time: 1½ minutes.

(4) The solution used to etch the gold lines:

(A)	Potassium cyanide	5 g
	Distilled water	100 cm^3
(B)	Ammonium persulphate	5 g
	Distilled water	100 cm^3

Immediately before use, mix equal parts of solution A, and solution B, and then dilute with 8 parts of distilled water. Etching time: 5 seconds.

(5) The solution used to etch the copper lines is 45° Be ferric chloride solution, as is used for the preparation of copper printing rollers.

Manuscript received by the Institution on 7th March 1961 (Paper No. 651).

U.D.C. 681.2.085

An Electronic Tabular Bay with Automatic Printing of Data

By

KENNETH H. SIMPKIN
(*Associate Member*)†

Presented at the Computer Group's Symposium on Alpha-Numeric Display Devices held in London on 18th January 1961.

Summary: A novel form of tabular display of printed data designed for use in air traffic control is described. The equipment is intended to fulfil the functions of the existing manually-operated tabular bay, using flight progress strips, but by an electronic scanning system using a magnetic matrix it provides for automatic indication of data strips between control consoles and also for automatic amendment of the data displayed, by binary coded messages from a keyboard or data processor. Other possible applications of the equipment are discussed.

1. Introduction

The "Tabtrol" tabular display is a data-handling component embracing three essentially independent functions:

(*a*) The display of data cards in individual, removable card holders, up to 24 cards being allowable per bay.

(*b*) High speed location and reading of a binary code set into the card holders, the complete set of cards being read in 2 milliseconds.

(*c*) The printing of alpha-numeric data on to an addressed card, any of 64 characters being printed anywhere in a 20-by-4 character area, at an average rate of 3 characters per second.

At the present time, the presentation of information to Procedural Controllers on the progress of flights within an Air Traffic Control complex makes use of slips of paper, known as Flight Progress Strips. These strips which contain data on the proposed flight plan of the aircraft, such as identity, height, speed, route and estimated times of arrival at reporting points, are printed at the A.T.C. centre, distributed to the controllers, and inserted in suitable holders. These are placed in vertical columns on a console, each column being normally associated with a particular reporting point. The information on the strips is subsequently amended in pencil by the controller as the flight progresses.

The prime function of the Tabtrol is to eliminate the manual operation of amending the strips; this involves two basic problems, the location of the strip position in the bay and the printing of data upon it. By making both these operations automatic, control of the Tabtrol by an A.T.C. digital data processor or from a keyboard becomes possible and the routine work load of the controller is thereby considerably relieved.

The equipment is associated with a separate Flight Progress Strip Printer which, located near to the Controller's console, initially produces the strips from data arising from the processing of input flight plans and loads them into holders for insertion into the Tabtrol bay. The system forms a powerful tool with which some of the problems of handling high traffic densities may be solved. The F.P.S. printer will not be considered further in this paper, although suitable printers are under development both in the U.S.A. and the United Kingdom.

A secondary function of the Tabtrol arises when it is operated in conjunction with a Data Entry Keyboard. The magnetic coding system used for locating the position of strips can equally well provide a means whereby data entered by the keyboard can be associated with a particular strip in communicating with a data processor or with other Tabtrols. Thus a set of Tabtrol consoles with Data Entry Keyboard can not only fulfil the display function but can also provide a communication channel between controllers, assisting to eliminate unnecessary use of the telephone.

Apart from its application to Air Traffic problems, the tabulation of data into files, which are subsequently searched and the data amended, is a function common to most forms of data processing. It is apparent, therefore, that the Tabtrol has applications outside the field of Air Traffic Control, some of which will be examined later.

2. General Description

The Tabtrol display consists of a tiltable rack containing 24 metal strip holders, located vertically one above the other, each holder retaining a card approximately one inch wide and eight inches in length upon which data are printed. The rack is

† General Precision Systems Ltd., Aylesbury

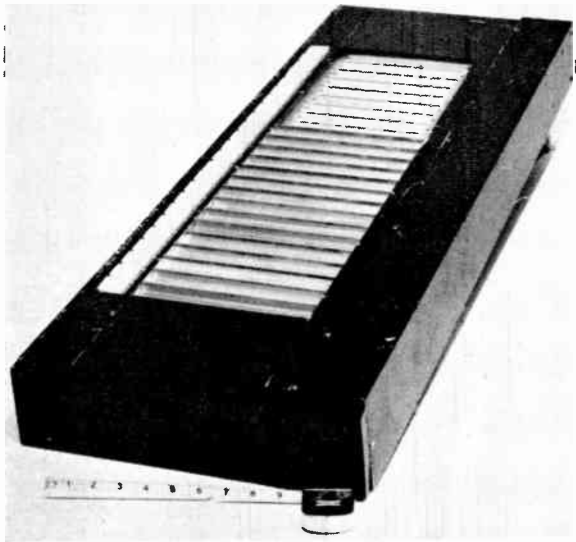


Fig. 1. The Tabtrol tabular bay.

about 3 ft in length, 1 ft wide and 4 in. deep and weighs about 35 lb; it can be tilted through an angle of up to 60 deg. Each holder is magnetically coded in binary code, enabling its position in the rack to be rapidly located by means of a scanning matrix of coils located beneath the assembly of holders. This search process is very fast, approximately 2 ms being required to locate any holder.

To print new information on a card, the desired holder is automatically selected and driven to the side of the rack, where it slides beneath a continuous metal loop belt carrying a type fount. The lateral position of the holder is chosen to locate the column of the card to be printed over the vertical type coordinate of the belt. The belt is driven until the desired character is in position and the holder is then raised and pressed, via an inked ribbon, against a back plate, resulting in an exceptionally quiet and legible form of printing. Four characters may be printed along one line in this manner to complete a message.

A choice of 64 alpha-numeric characters is available on the belt and these may be printed in groups of four at each print cycle in any of four separate lines and twenty columns at the right hand side of the card, at a rate of approximately two seconds per character.

Down the left side of the rack, adjacent to the holders, is a row of lamps, each of which may be automatically illuminated by inserting the code of the holder adjacent to it into the input register. Each lamp is associated with a button switch which, when depressed, places the code of its adjacent holder into an output register and also illuminates the lamp. Since, however, the connection between the switch and the lamp is through the search systems, subsequent movement of the holder in the rack will be followed by the lamp illumination.

The logic circuits associated with the rack consists of about 35 printed circuit cards which may be mounted either in the console or in an associated rack. Transistors are employed throughout and only three types have been used.

Individual Tabtrol assemblies may be combined to form multiple rack consoles, five to seven racks being normal for Air Traffic Control applications. The extent to which the logic circuits can be shared depends upon the requirement of simultaneous operation at each rack. It is however normal to time-share the logic associated with input to the racks but not that associated with holder location or print control.

If required, a cross-out symbol at the datum position of the belt can be used to cross out the previous line of data by minor modification of the logic. Messages of more than four characters can be handled by appropriate increases of the input storage and modification of the logic. The mechanical design of the printer is such as to maintain at low speed those motions requiring accelerations, resulting in low wear and a low noise level. This particularly applies to the print operation, which departs from the normal hammer technique. The reduction of noise is of the utmost importance in Air Traffic Control applications.

A single error detection code is used with odd parity. If the holders are coded so that a single error in the matrix read-out will result in an even code, no holder search can be made until the matrix reads correctly, and since this search controls the printing cycle, no print can occur on the wrong holder.

The interrogation matrix is fully encapsulated and due to the low impedance of the windings and the d.c. isolation between primary and secondaries, gating is achieved in the matrix without using semi-conductor logic.

Correct alignment of the holders is achieved without the use of critical mechanical tolerances. With the normal length of coding bars, correct read-out is possible with vertical misalignment of 0·1 in. and skew angles of up to 5 deg, the read-out system having high tolerance in this respect. When the holder is shifted to the print position, it is mechanically indexed to ensure correct registration of the print on the card. Since, however, the holders are not normally held rigidly in the rack but pack down by gravity, additional precautions are taken to ensure that they are sufficiently well positioned for the mechanical registration to take control when required.

Since the Tabtrol is equipped with its own data input registers, the control logic associated with input is particularly simple. The requirement is to enter into the input registers the holder code, the column, the line and the four characters to be printed. This can be achieved at data processor rate in a 7-bit parallel mode using a control counter to sequence the data into the correct registers and two binaries to sense the duration of each character, and of the whole message. The binaries derive control pulses indicating, to the data processor, readiness for the next character and the correct reception of a message. Parity checking is carried out on each character received before entry into the input registers, the latter being completely cleared and the message repeated from the beginning in the event of a parity error being detected.

The input logic is asynchronous and will operate as fast as the logic circuits will allow. The present system is designed for a bit rate up to around 250 kc/s, but higher rates can be accommodated by using faster binaries. Since the data input operation is entirely separated from the printing and scanning systems, it is apparent that a multiplicity of Tabtrols may be fed with information at data processor speed and left to print at their own convenience, the only limitation being that not more than one message can be handled by one Tabtrol every 8 to 10 seconds.

The output logic is normally associated with a Data Entry Keyboard, the latter being limited to function and numeric keys only, since identity can be established by the Tabtrol button associated with the holder into which it is desired to write in a message. This facility is outside the scope of the paper, and will not be described further.

3. Further Applications

In fields of traffic coordination other than for air traffic, the Tabtrol system may be used to display at a number of coordinating points information on traffic movements throughout the system and, with a small data entry keyboard, to communicate data from all control points to all others. In the industrial processing field, the Tabtrol has possibilities in the display of data in printed form, subject to automatic and manual amendment, and retaining a permanent record.

The scanning system of the Tabtrol has by itself a wide variety of applications. It provides a robust and reliable form of data or programme store, capable of holding and reading out up to 24 fourteen bit words of data per rack, the choice of among 16 000 words being by manually inserting coded holders or keys in the matrix unit. For example, by gating 24 gates with the matrix interrogation pulses, 24 fourteen bit instructions may be routed out to 24 separate channels, the instructions being modified on any channel by simple replacement of a holder or key. Alternatively, by making the interrogation scan asynchronous and conditional upon the completion of an operation, 24 sequential operations can be controlled from the matrix in any one complex of keys, a choice of up to 16 000 types of operation being available by a change of key code. As a method of controlling a set of operations which vary in nature from time to time over a wide variety of forms, the Tabtrol matrix has much to commend it, particularly in view of the inherent reliability of the system arising from its designed freedom from tight tolerances, its fully magnetic logic and complete encapsulation. Because of its overall dimensions of approximately 82 in. × 1 in. × 24 in. for a 24-key matrix, it provides an economical and space-saving method of process switching.

In the field of business data processing, the Tabtrol is capable of fulfilling the requirement of data storage and presentation with automatic file search and updating and, by association with suitable sensors, may provide an automatic record, for example, of the dispatch of orders or movements to and from a materials store.

4. Conclusions

A form of data storage and display system, with automatic facilities for printing amended information and with high speed communication with data sources, has been described. Although designed initially for Air Traffic Control applications, the facilities afforded are of value in all fields where the storage and continuous display of changing data is desired.

5. Acknowledgments

It should be emphasized that all credit for this development should be given to Mr. D. Goldman and his associates at the General Precision Laboratories, Pleasantville, New York, and that the author has been concerned only with its development and applications in the United Kingdom.

The author also wishes to express his thanks to the management of General Precision Systems Ltd., Aylesbury, and of the General Precision Laboratories in the U.S.A. for the permission and facilities afforded to present this paper.

Manuscript received by the Institution on 23rd February 1961 (Contribution No. 35).

Further Development of the Independent Television Network

Post Office Links to I.T.A. Television Stations in South-West England

With the extension of the Independent Television service to the South West of England in April last, five new Post Office vision links came into operation.

Two of these links are major engineering projects: the first connects London and Bristol by coaxial cable and the second connects Bristol and Plymouth by line-of-sight radio link. Two shorter links, using line-of-sight radio transmission, connect Plymouth with the new I.T.A. broadcasting stations at Stockland Hill in Devon, and Caradon Hill in Cornwall. Finally, the studios of the programme company are connected by coaxial cable to the national television network at Plymouth.

The link from London to Bristol is provided in a coaxial cable containing six tubes, two of which are used for television and the remaining four for the telephone trunk service. The vision circuit, which is 140 miles in length, is equipped with carrier line equipment to operate in the $\frac{1}{2}$–4 Mc/s frequency band.

The main radio link between Bristol and Plymouth is 125 miles long and has four intermediate repeater stations. The radio equipment used on these links operates on frequencies of about 4000 Mc/s. Each radio link is provided with protection equipment which will be automatically switched into service in the event of breakdown. The intermediate radio stations are unusual in that the radio signals are amplified directly at microwave frequency.

Improvements to the I.T.A.'s Transmitter Stations

The new 1000 ft mast and directional aerial system at the Independent Television Authority's Black Hill station in Central Scotland is now complete, and programme transmissions from it began on 10th July. The Authority's field strength measuring unit has been touring Central Scotland studying the performance of the new aerial, and reports of reception in the service area of test transmissions from the new system indicate that the signal strength throughout the region has been greatly increased, the average strength in many parts of the coverage area being about double that provided by the previous aerial. Owing to the fact that the signal in some parts of the area, notably Ayrshire, has so far been in part horizontally polarized, some receiving aerials have been installed in a horizontal position. The new transmitting aerial will radiate in the vertical plane with no significant horizontal component, the removal of which was necessary in order to conform to national and international technical agreements.

Work will start soon on the dismantling of the original 750 ft mast at Black Hill which has stood since August 1957. This mast will be cleaned and checked by its makers, British Insulated Callenders Construction Ltd., and will then be re-erected at Selkirk, where it will support the new aerial and feeder system of the Selkirk transmitter, an unattended automatic satellite of the station that the I.T.A. has recently completed at Caldbeck, near Carlisle. Selkirk will start programme transmission around the end of 1961.

This is the first time that the Authority has improved the performance of one of its stations by "twinning" old and new masts. The building of a new mast alongside a fully-powered aerial without interrupting the service presented two new and unknown difficulties. When the new structure reached the height of the powered aerial, some "shadowing" effect on reception might have been expected. This effect was, in fact, detected, but it did not prove to be serious in extent. Work had to be stopped on the new mast when it approached the height of the working aerial so that a careful study could be made of the strength of the radiated field through which it would have to pass and it could be established that there was no danger to men erecting the new mast. The study revealed that there would be no such danger and construction of the new mast was able to proceed without interruption of broadcasting from the old one.

Similar problems had to be faced at the Authority's station at Lichfield, where a new 1000 ft mast is nearing completion alongside the original 450 ft tower. Here also it was found that men could work in the field radiated by the powered aerial without risk and that the "shadow" cast by the rising structure was limited in extent. The old mast in this case is to carry the aerials of the Channel Islands station in Jersey, scheduled for operation at the end of 1962.

The new Lichfield mast will carry a new directional aerial system, having a maximum e.r.p. of 400 kW to the south, 200 kW to the north and west, and 100 kW to the east. As well as extending the coverage of the station, particularly to the south-west and north-west, the new mast and aerial will improve reception throughout the area.

Another improvement which has been recently introduced at Lichfield has been the addition of high-power amplifiers to the stand-by transmitter. Previously, if a fault occurred in the main transmitter, programme transmissions had to continue on reduced power. In future, if a fault should occur, programme transmissions from the stand-by transmitter will continue, without reduction of power, while the fault on the main transmitter is being rectified.

U.D.C. 535.37 : 681.2.385

Electroluminescence and Alpha-Numeric Indicators

By

P. J. CLEWER†

Presented at the Computer Group's Symposium on Alpha-Numeric Display Devices held in London on 18th January 1961.

Summary: The basic properties of electroluminescence are first discussed and the paper then describes the construction of "organic-on-glass" and "ceramic-on-metal" lamps. Typical performance figures for these lamps as given. A description of the various types of alpha-numeric indicators that have been proposed follows. In particular, the "8-bar" digital indicator, and its variants, is compared with other types not requiring coding. Types of alphabet indicator are also discussed.

1. Introduction

First discovered in 1936 by Destriau,[1] electroluminescence is the emission of light by certain materials, generally known as phosphors, when placed in an electric field. Thus an electroluminescent lamp consists essentially of a parallel plate capacitor, with the phosphor as the dielectric material, and one transparent electrode to release the light generated within the dielectric. While some phosphors are known which will emit light in a constant electric field, most of the commercially important ones require a changing field for excitation, i.e. an alternating voltage is applied to the capacitor.

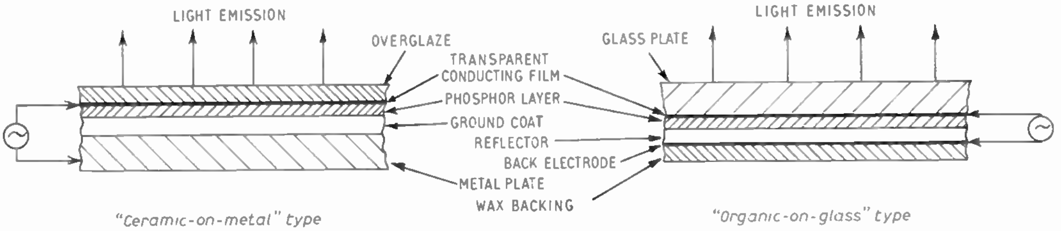


Fig. 1. Constructions of electroluminescent lamps.

2. Construction of Lamps

There are two main types of construction in use today, the "organic-on-glass", and "ceramic-on-metal", the words "organic" and "ceramic" referring to the organic resin and ceramic frits, respectively, used to construct the lamps, as in Fig. 1. The "organic-on-glass" lamp is built on a glass plate having a transparent conducting film of tin oxide on one face. This conducting surface is first coated with the phosphor layer, followed by a layer of barium titanate, which serves to scatter light forward out of the lamp, and to increase the effective dielectric constant, enabling more current to be passed, and hence a greater brightness to be obtained. The capacitor is completed by a second electrode of, say, evaporated aluminium, or a conducting "dag" (colloidal graphite) paint. Finally, the assembly is completed with a wax backing to exclude all moisture. This is vital to obtaining a long life of the lamp. The "ceramic-on-metal" lamp is built in the reverse order, starting with a steel plate forming the back electrode. The ground coat, a ceramic frit (or glazing enamel), serves mainly to bond the subsequent layers to the metal plate. Being white in colour, it also helps to scatter light forwards out of the lamp. Next is applied the phosphor layer, and the second transparent electrode, again of tin oxide. The lamp is finally protected by a transparent overglaze.

Other possible constructions include an all-plastic flexible lamp, and a "ceramic-on-glass" type, both being similar in construction to the "organic-on-glass" lamp described above. One form of all-plastic lamp recently described,[2] consists of a suitable flexible plastic base upon which a transparent conducting film of gold is evaporated to form the front

† Thorn Electrical Industries Ltd., Lighting Laboratories, Enfield, Middlesex.

electrode. Following the above construction, of phosphor and reflector layers, and back electrode of evaporated aluminium, the lamp is completed by a second plastic layer to seal and protect the lamp. Being flexible, and only about 0·050 in. thick, this lamp offers interesting possibilities, but both this and the "ceramic-on-glass" type are in the development stage at the moment.

The only phosphors of commercial importance at the moment are zinc sulphides and zinc sulpho-selenides, containing low proportions of activators such as copper and chlorine to give blue and green light, and the further addition of manganese to give a yellow emission. Many of the green phosphors change to blue at supply frequencies above about 1000 c/s, due to a blue band which increases rapidly in intensity, compared with the green band, at higher frequencies. Other phosphors stay green at all frequencies. It is unfortunate that there is no red phosphor in existence at the moment which is comparable in brightness with those mentioned above. An approximation to white can be obtained by blending the blue, green and yellow phosphors, but the colour tends to change on running, due to differential ageing of the components.

3. Characteristics

Table 1 shows the characteristics of electroluminescent lamps under various operating conditions. It is interesting to note that although the efficiency of these lamps is very low compared with, say, an incandescent lamp of 12 lumens/watt efficiency, the saving in power by using an electroluminescent sign, as compared with a sign using a stencil lit from behind with incandescent lamps, is considerable. This is because in an electroluminescent lamp, most of the light generated is usefully employed to convey the information. By way of example, a sign having a dozen $\frac{3}{4}$-in. high letters will consume about 2 watts of power, when operated at 350 V, 400 c/s.

Table 1

Characteristics of Green Electroluminescent Lamps

Characteristics	Ceramic type (a)	Ceramic type (b)	Organic type (a)	Organic type (b)
Voltage	240	350	240	350
Frequency (c/s)	50	400	50	400
Brightness (foot-lamberts)	2·5	20	3	25
Current (mA/in²)	0·125	1·6	0·2	1·6
Capacitance (μF/in²)	0·0017	0·0021	0·003	0·003
Impedance (MΩ/in²)	1·92	0·22	1·15	0·14
Power factor (cos φ)	0·15	0·48	0·28	0·39
Efficiency (lumens/W)	0·8	0·65	1·55	0·70

A typical brightness maintenance curve for 400 c/s operation is shown in Fig. 2. The brightness rises over the first 100 hours to about 115% of its initial value, and then decays roughly exponentially. It is customary to define the "life" of a lamp as the time for the brightness to decay to 50% of its initial value. For supply frequencies up to at least 10 kc/s, approximate working rules are that the brightness is proportional to the frequency, and the life inversely proportional to frequency. This leads to the conclusion that the life is a constant number of cycles of the supply. This figure has been given as 10^{10} cycles. It has also been suggested that the life is nearly independent of the applied voltage.[3, 4] Hence for maximum life a lamp should be run at its full working voltage, and at the minimum supply frequency consistent with the required brightness level.

A salient feature of all electroluminescent lamps run under normal conditions is their complete freedom from catastrophic failure. A visual warning of the need for a lamp change is given by it merely becoming too dim to read under normal conditions, but at no stage will the lamp suddenly fail.

Various equations relating the brightness to the applied voltage have been proposed, but the relation

$$\text{brightness} = A \exp\left(-\frac{b}{V^{\frac{1}{2}}}\right)$$

applies over a wide range of variables. The parameters A and b depend on the exact lamp construction, and the type of phosphor used.

The rise and decay times of the brightness on switching is usually quoted as a few cycles of the applied frequency. Recent work has shown that for lamps having very low resistance electrodes (the transparent film being of gold), rise and decay times of the order of microseconds can be obtained for voltage pulses a few microseconds in width. The rise and decay times observed seem to depend on the immediately previous excitation of the lamp, and the time interval between pulses, etc.[5, 6, 7]

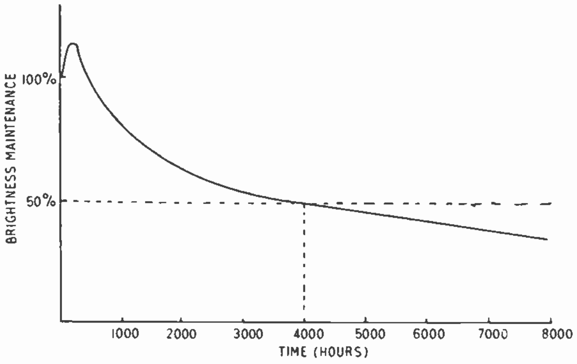


Fig. 2. Brightness maintenance at 400 c/s.

A useful property of electroluminescent lamps is the ease with which lamps having many individually illuminated areas can be made, especially with the "organic-on-glass" construction. Here it is only necessary to divide the back electrode into the required shapes, and connect individually to each one. With the "ceramic-on-metal" construction, it is the transparent front electrode that must be divided, and connecting "tails" used for electrical connection, which will appear illuminated, unless suitably masked off. This technique is under development, and numeric indicators have already been made in this way.

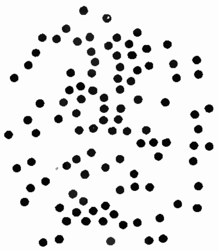


Fig. 3. "Dot" type digital indicator.

Clearly, the "ceramic-on-metal" lamp is very robust, especially to mechanical shock, and will withstand a higher ambient temperature than the "organic-on-glass" type. It is also thinner, about 0·030 in. compared with 0·250 in. for the glass type. Further, the "ceramic" lamp is suited to semi-automatic production methods, reducing the cost considerably as compared with the "organic" type. At the moment, however, it cannot be regarded as a complete substitute for the "organic-on-glass" type.

4. Alpha-Numeric Indicators

The problem here is to design an alpha-numeric indicator, such that any one of the digits 0–9, or the letters A–Z can be displayed in a given window. There are two main methods of approach, either to use separate lamp areas for each character, or to have a smaller number of suitably shaped areas that can be used in various combinations for the required characters. With digital indicators, both methods have been used, though the latter is now generally used, and is, to the author's knowledge, the only one used for electroluminescent alphabet indicators.

4.1. *Digital Indicators*

One of the early types of electroluminescent digital indicator consisted of a panel having about 100 dots (Fig. 3), separate dots being used for each digit. The advantage of this type is that only simple single pole switching is required, each digit having its own connection. The disadvantages are poor visibility, due to the relatively low area of lamp actually illuminated, difficulty and high cost of manufacture, and non-centring of the various digits.

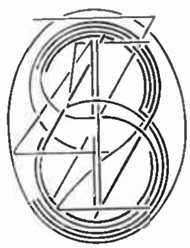


Fig. 4. A proposed form of digital indicator.

Another proposed form is shown in Fig. 4. Again, each digit has its own individual connection, but the manufacturing difficulties are considerable, and there is a large variation in the height of each digit.

These types of digital indicator become more practical in larger sizes, say above 6 in. in height, especially where a simple mechanical switch is all that is required for digit selection.

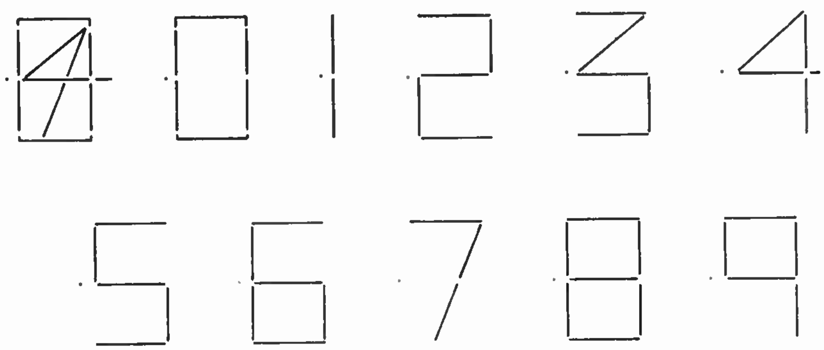


Fig. 5. "11-bar" digital indicator.

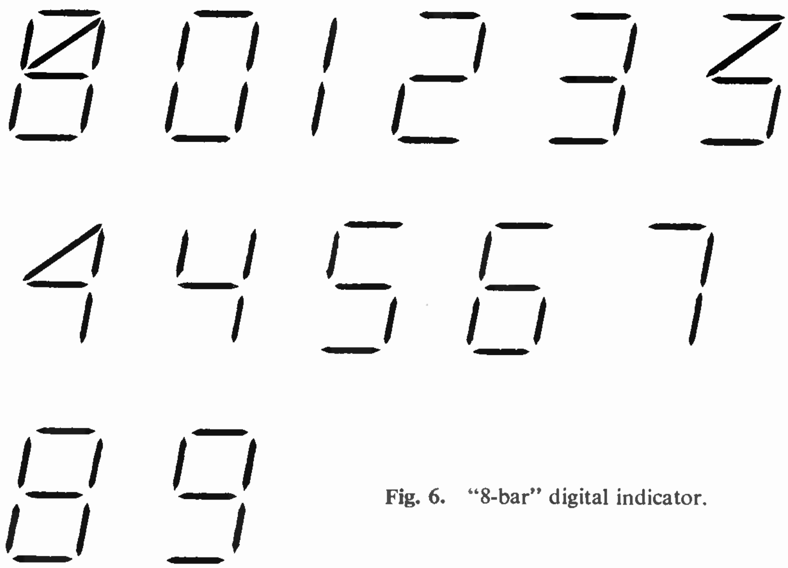


Fig. 6. "8-bar" digital indicator.

Considering now digital indicators using combinations of lamp elements, an early design using 11 bars is shown in Fig. 5, together with the digits formed by this system. Decreasing the number of bars to 8, and making them thicker (Fig. 6), gives simpler switching, together with improved visibility. Alternative forms of "3" and "4" are shown. If these alternative forms are acceptable, the number of bars can be reduced to 7, with further economy in switching. This is current American practice.

Having decided on the number of bars to be used, there is still need to consider carefully the exact shape and position of the bars, and the way the corners are to be mitred, etc. Even quite small changes in design can have a large effect on the visual presentation. The above general layout should by no means be considered as final, and recently some other designs, based on the above idea, have appeared.

Where mechanical switching is permissible, the normal type of rotary switch can be used, as the fairly high operating voltage, combined with low current consumption gives a long contact life with no "contact cleaning" problems. Where the switching has to be electronic, some form of coding matrix will be required, and can be built up of non-linear resistors of, say, silicon carbide.[8] This type of matrix can be used to convert decimal information to the code required for the indicator. A technique of switching and decoding at low voltages suitable for transistorized equipment is being developed.

The present size range of digits is from 6 in. to $\frac{7}{16}$ in. high, and there is no basic reason why a $\frac{1}{4}$ in. high indicator should not be made. This could be used for photographic read-out, an exposure of 0·02 seconds through a normal lens being quite adequate.

Perhaps the greatest advantage of electroluminescent indicators is their wide angle of viewing, since all the digits are displayed on the same plane.

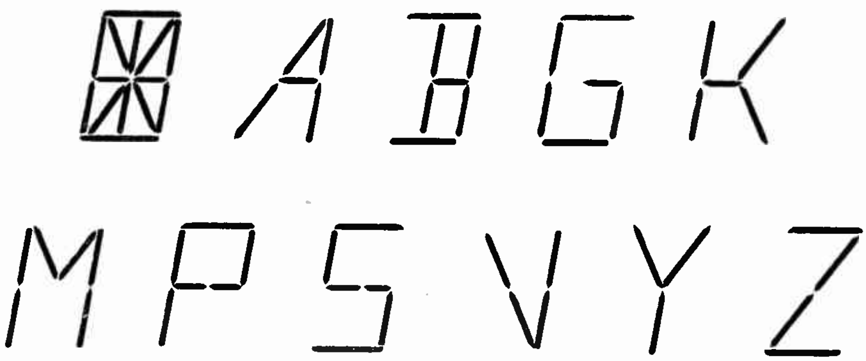


Fig. 7. "14-bar" alphabet indicator.

4.2. *Alphabet Indicators*

Present alphabet indicators are built upon the same idea as the last mentioned digital indicators, except that more bars have to be used. Figure 7 shows a 14 bar design, with some typical letters. This appears to be the minimum number required, and several designs using 20 or more bars have appeared, the extra bars being used to improve the shape of the letters. Because of the greater number of bars, many small variations in design are possible, and clearly there must be a compromise between simplicity of switching and the departure from conventional shape of the letters that is acceptable.

5. Conclusions

The foregoing remarks concerning the switching and coding of digital indicators again apply. Because of their complexity, the minimum size may have to be increased a little over that for digital indicators. It is interesting to note that the above alphabet indicator can also display the digits 0–9.

While digital indicators in various forms have been in use for many years, little use seems to have been made of alphabet indicators, possibly because in the past they would have been very complex. With the increased use of business computers, no doubt in the near future there will be an increased demand for indicators of this type.

6. Acknowledgment

The author wishes to thank the directors of Thorn Electrical Industries Ltd. for permission to publish this paper.

7. References

1. G. Destriau, "Experimental studies on the action of an electric field on phosphorescent sulphides", *J. Chim. Physique* **33**, p. 320, 1936.
2. R. J. Blazek, R. W. Wollentin and H. B. Bullinger, "Multi-layer and flexible single layer electroluminescent lamps", *Illum. Engng (N.Y.)*, **61**, p. 195, March 1961.
3. S. Roberts, "Aging characteristics of electroluminescent phosphors", *J. Appl. Phys.*, **28**, pp. 262–5, February 1957 (Paper 11).
4. W. A. Thornton, "Electroluminescence maintenance", *J. Electrochem. Soc.*, **107**, pp. 895–907, November 1960.
5. T. Kilburn, G. R. Hoffman and R. E. Hayes, "An accurate electroluminescent graphical output unit for a digital computer", *Proc. Instn Elect. Engrs*, **105** B, p. 136, 1958.
6. G. R. Hoffman, D. H. Smith and D. C. Jeffreys, "High-speed light output signals from electroluminescent storage systems", *Proc. Instn Elect. Engrs*, **107** B, p. 599, 1960.
7. G. R. Hoffman and D. H. Smith, "The light waveforms emitted from electroluminescent cells energized by square waves and pulses of voltage", *J. Electronics & Control*, (first series) **9**, No. 3, p. 161, 1960.
8. D. H. Mash, "An electroluminescent digital indicator with a silicon carbide coding matrix", *J. Sci. Instrum.*, **37**, pp. 47–50, No. 2, February 1960.

Manuscript received by the Institution on 1st March 1961 (Paper No. 652).

News from the Sections . . .

West Midlands Section

At the meeting held on 8th March in Wolverhampton College of Technology, Mr. L. Kay gave an account of experiments which have been carried out at Birmingham University and elsewhere on the echo-location system used by bats.

The acuity achieved by the bat is much better than that of any radar or sonar system. In certain experiments, bats were made to fly across a room containing wires of diameters down to 0·28 mm; less than 10% of the wires were struck. Even with a noise level 40 dB above the bats' transmission, their performance was still very good.

To explain these facts, Mr. Kay put forward the following theory. All bats vary the frequency of their transmission, at least during some part of each pulse; a typical frequency sweep might cover the range 80–40 kc/s. When the echo returned, it would therefore differ in frequency from the tone then being sent out. Since the ear is non-linear, the two sounds would produce a beat note, whose frequency would be determined by the range of the target. Also, if the target were not dead ahead, the two ears would be at different distances from the target, and would therefore produce slightly different beat notes; this would indicate the bearing of the target.

The basis of the theory was well illustrated by means of tape recordings of bat transmissions, suitably translated into an audible frequency range.

D. H. A.

Scottish Section

"Measuring the Stability and Spurious Modulation Spectra of High Quality Oscillators" was the title of a paper read by Mr. A. L. Whitwell, B.Sc. (Associate Member) at Edinburgh on the 8th February and at Glasgow on the following evening. Improvements in the performance of microwave oscillators demanded by the general advance of microwave technology in various fields were described with reference to some of the major applications. These included Doppler and m.t.i. (moving target indication) radars, v.h.f. communication and microwave spectroscopy.

The nature of the output spectrum of typical oscillators was considered in detail. The spectrum was seen to comprise two distinct regions; the first a relatively small band of frequencies in which the major power is concentrated and the second a wider band of frequencies in which the significant total power output lies, including the contribution from undesirable noise components. In both regions it was shown that the output spectra have the nature of a continum, although line frequency components derived from various sources may exist and be superimposed on a basic noise spectrum. The significance of oscillator performance in terms of long and short term stability, the relative width of the frequency band containing the major power components and the nature and distribution of the noise skirts of the response, were considered in relation to the requirements of narrow-band systems incorporating oscillators and requiring a high degree of frequency resolution in the associated apparatus. A typical example of such requirements is the Doppler Radar System.

Other equipment described and demonstrated included a swept r.f. spectrum analyser, a noise analyser and a video spectrum analyser used in conjunction with a superheterodyne receiver.

W. R. E.

North-Western Section

For its last two meetings of the 1960–61 Session the Section Committee selected topics biased towards management and production problems in industry and the way in which computers are being applied to their solution. On 2nd March, Mr. C. W. Blaxter spoke on "Some typical uses of Electronic Data Processing Systems" and explained how commercial applications can, in many cases, be readily grouped for integrated data processing, e.g. wages and labour costing. One of the main problems of integration is the change-over period when it may be necessary to run the new system partially in parallel with existing methods and the importance of the initial planning was stressed. An integrated system has to give managements only the data they would require for immediate action.

At the final meeting on 6th April, Mr. K. J. McCarthy (Associate Member) read a paper on "Plant Investigation and Control Using Digital Techniques", in which he reviewed industrial information systems. The data logger/alarm scanner was pioneered in this country some six to seven years ago and the original and the majority of present day systems are built from relays and uniselectors. Mr. McCarthy said that at least one organization had already developed a completely transistorized system which gave extreme reliability for such equipment. The use of computer systems for process control was then discussed with particular emphasis on the principle of progressively increasing automatic control. In concluding, Mr. McCarthy pointed out that the hardware of such systems was already well in advance of the knowledge of how to use them to the best advantage. He suggested, however, that the limiting factor at present was the natural reluctance of industrial organizations in this country to consider their use seriously despite the fact that British systems are now being considered and installed by other countries.

F. J. G. P.

U.D.C. 621.382.232

An Introduction to the Tunnel Diode as a Circuit Element

By

P. M. THOMPSON, M.A.
(*Associate Member*)†

AND

J. BATESON‡

Based on a paper presented at the South Western Section's Convention on "Aviation Electronics and its Industrial Applications" held in Bristol on 7th–8th October 1960.

Summary: The theory of operation of the tunnel diode is discussed with reference to energy levels. Its function as a negative resistance element is considered and a simple oscillator circuit and a computer logic circuit are given. The advantages of the device for aviation electronics are assessed.

1. Introduction

As electronic engineers we have been familiar with the single *p-n* junction as a rectifier for many years. More recently we have learned of the useful properties of *p-n* junctions such as avalanche or Zener breakdown, and voltage variable capacitance, and more recently still we have begun to hear about the "tunnel diode". As it is probable that this device will become increasingly important, it would seem timely to consider some of its basic properties and uses, and how it differs from the *p-n* junction diodes we already know.

2. Tunnel Diode Operation

Figures 1(a) and (b) show a typical rectifier diode characteristic, with forward conduction starting at about 0·3 V. There is also avalanche conduction, shown here as starting at about − 10 V. The avalanche voltage is controlled by the degree of doping, or the impurity content, so that as the semi-conductor is doped more heavily, the avalanche voltage will be reduced, and at about 6 V Zener conduction will take over from avalanche. In a tunnel diode the degree of doping is very high indeed and Zener conduction starts almost at zero voltage. Also there is another kind of conduction, called tunnel conduction, which, as the forward voltage increases, causes the current to rise and then fall again. The current voltage curve of a typical tunnel diode is shown in Figure 1(c). The fall of current with increase of voltage may be described in terms of negative resistance, and it is this property of the tunnel current which makes the diode useful as a circuit element.

The choice of the term quantum tunnelling is unfortunate from the point of view of most engineers as it tends to suggest an incorrect physical picture. Tunnelling is a process by means of which a current can leak through an insulator from one conductor to another. If the current is to be significant the layer of insulator must be very thin indeed. Also the electrons or carriers must gain or lose no energy in the process. In a tunnel diode the tunnel current flows across a very narrow *p-n* junction between heavily doped, or "highly degenerate" *p* and *n* regions. Since the electrons, when crossing the junction, must gain or lose no energy, there must be a source of available electrons on one side, and states which can accept electrons with this energy on the other. A change of bias voltage across the junction causes the energy

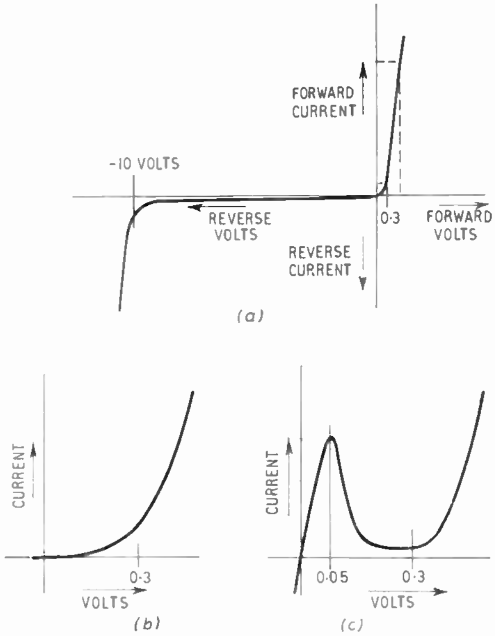


Fig. 1. (a) The current-voltage curve for a typical *p-n* rectifier diode.
(b) The section of (a) within the dotted line redrawn with a magnified voltage scale.
(c) A tunnel diode current-voltage curve drawn on the same scale as (b).

† The Plessey Company Limited, Roke Manor, Romsey, Hants.
‡ Eastern Ontario Institute of Technology, Ottawa, Canada.

levels in the p and n regions to change with relation to one another causing the current to increase and then decrease again.

Figure 2(a) shows an energy level diagram of such a p-n junction. The degenerate p material is shown on the right and the n material on the left, and the energy levels are shown one above the other. The dotted areas represent levels at which electrons exist, and the cross-hatched areas levels at which electrons cannot exist, and this is called the forbidden gap. The areas on either side of the junction left unshaded represent empty but allowed energy states, and at zero bias the energy level between the filled and empty states (the Fermi level) is the same on both sides of the junction, i.e. filled states on the p side of the junction are opposite filled states on the n side, and empty states are opposite empty states. Under these conditions there will be, on the average, no current flow in either direction.

A bias voltage across the junction will cause the energy levels on one side of the junction to shift with relation to those on the other, so that the Fermi level will no longer be the same on both sides. Filled states will now be opposite empty states, and electrons can leak across the junction. Provided the bias voltage is small, the current will be proportional to both the magnitude and sense of the voltage. A forward bias will cause the levels on the n side of the junction to be raised with respect to those on the p side, and the forward current will increase to a maximum when the filled band on the n side is exactly opposite the empty states on the p side, as in Fig. 2(b). A further increase in the forward bias brings the filled band on the n side opposite the forbidden band on the p side, and the empty band on the p side opposite the forbidden band on the n side, as in Fig. 2(c). Under these conditions the tunnel current is turned off again, and the diode is at its current minimum. If the forward bias is increased still further the diode is brought into its normal forward conduction region and the current increases again.

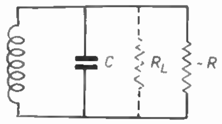


Fig. 3. The circuit will oscillate when the negative resistance is lower than the equivalent shunt loss resistance R_L.

For clarity, Fig. 2 shows the Fermi level as being sharply defined, a condition which is only strictly true at very low temperatures. However, the principle of operation at higher temperatures is basically similar.

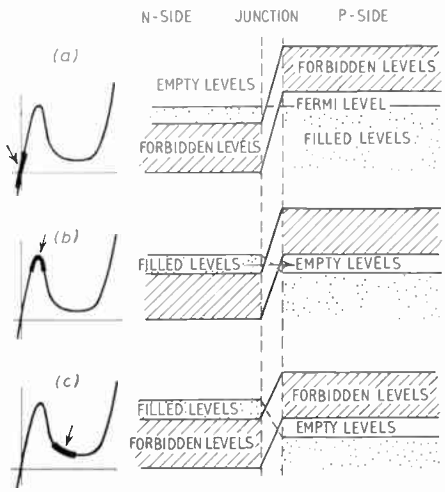


Fig. 2. There is a peak of current in the tunnel diode characteristic when the filled energy levels on the n-side of the junctions coincide with empty but allowed energy levels on the p-side.

(a) There is no current at zero bias.

(b) The tunnel current peak is when the filled levels are opposite empty levels.

(c) The current falls again, because the filled levels are opposite forbidden levels.

3. Negative Resistance

The usefulness of the tunnel diode is due to the negative resistance part of its characteristic curve. A negative resistance results in signal power being increased, just as a positive resistance results in signal power being dissipated or reduced. If a negative resistance is connected across a tuned circuit, as in Fig. 3, and the increase of signal power due to the negative resistance is greater than the loss due to damping, the circuit will oscillate, i.e. any small noise signal in the circuit will be amplified more than it is attenuated and it will build up as an oscillation. The loss in the tuned circuit can be represented as a resistance R_L, and the condition for an oscillation to build up is that R_L is greater than $-R$, so that the total value of the two resistances in parallel is negative. The way in which a negative resistance may be used as an amplifier can be seen as follows. Consider a signal from a source (such as a line) at characteristic impedance R_0, as in Fig. 4(a). If we are to obtain the maximum power from this signal we must match the line to a load which is also R_0, and any deviation from this will result in a reduction of power. It is possible to increase the effective value of a resistance, as seen across its terminals, by placing a negative resistance in parallel with it (just as a positive resistance would reduce the value). Thus we may reduce the value of the

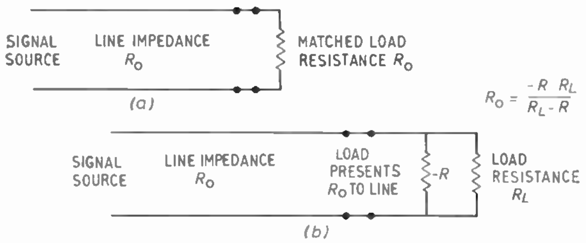


Fig. 4. (a) A line matched by load resistance R_0 equal to its characteristic impedance.
(b) The load resistance is reduced in value and placed in parallel with a negative resistance.

load resistance R_L in Fig. 4(b) while still presenting a load of R_0 to the line, by placing a negative resistance in parallel with R_L, as in Fig. 4(b). As the load presented to the line is unchanged, the signal voltage will be unchanged. However, the value of the actual load resistance is decreased, and the current, and therefore the signal power, in the load is increased.

4. Bias

If a tunnel diode is to be used as a negative resistance element it must be biased so that it operates on the negative resistance part of its characteristic. The way in which a negative resistance device may be biased depends on the particular type of negative resistance, i.e. on whether it is voltage stable or current stable. The line AB in Fig. 5(a) represents a negative resistance, because as the voltage increases the current decreases, or similarly, as the current increases the voltage decreases. If we had a device with this characteristic, we could bias it to a required working point on its characteristic, say at C, with either a current or a voltage. However in practical devices the negative characteristic ceases at some point and becomes positive. (See Fig. 5(b) and (c).) In most devices in general use, e.g. the arc, neon bulb, thyratron, four-layer diode, etc., the end of the negative characteristic

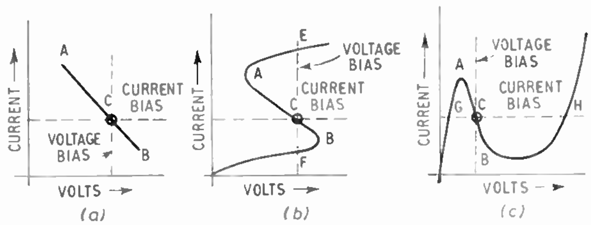


Fig. 5. The classification of negative resistance devices.
(a) Simple theoretical negative resistance.
(b) Current stable device.
(c) Voltage stable device.

marked B is returned to the origin (Fig. 5 (b)), but in the tunnel diode it is the end marked A (Fig. 5(c)). The dynatron† circuit also exhibits this type of negative resistance. The type of negative resistance shown in Fig. 5(b) is called current stable, because a current bias defines only one operating point C, while a voltage bias could also define points E and F. Similarly the operating point C of the tunnel diode (Fig. 5(c)) is voltage stable, and a current bias could also define G and H.

A practical tunnel diode oscillator may be constructed by using a circuit such as that shown in Fig. 6. This is similar to the circuit of Fig. 3 with the negative resistance replaced by a tunnel diode and a resistor across which a bias voltage can be generated. The resistor R must have a small value, considerably less than the value of the negative resistance of the tunnel diode, because R is the effective source resistance of the bias voltage, and a too high resistance would result in an uncertain operating point. There is no attempt to decouple R since its presence is useful in damping spurious resonances in the circuit. A practical negative resistance amplifier can be constructed by loading the oscillator to a point where it just ceases to oscillate. If a signal is then fed into the tuned circuit, an amplified version of the signal may be absorbed by a load, as illustrated in Fig. 4.

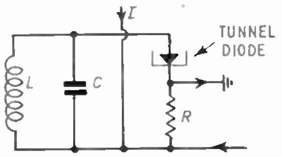


Fig. 6. A tunnel diode oscillator circuit. The bias voltage for the diode is generated by a current I through resistor R.

5. Pulse Circuits

In pulse circuits the tunnel diode is used quite differently from the way in which it is used in the linear circuits discussed above. Rather than being biased with a voltage from a small source impedance, so that it can be represented in circuits as a negative resistance, in most cases it is biased from a high impedance similar to the current bias G-H of Fig. 5(c). Under these conditions the diode has two stable states G and H, and it can be switched from one to the other by injecting current pulses. A typical computer logic circuit is shown in Fig. 7. In a computer logic system, bistable tunnel diode circuits (i.e. flip-flop circuits) are triggered from similar circuits through resistors. In

† See, for instance, M. G. Scroggie, "Radio Laboratory Handbook," pp. 60–2, 6th edition (Iliffe, London, 1954).

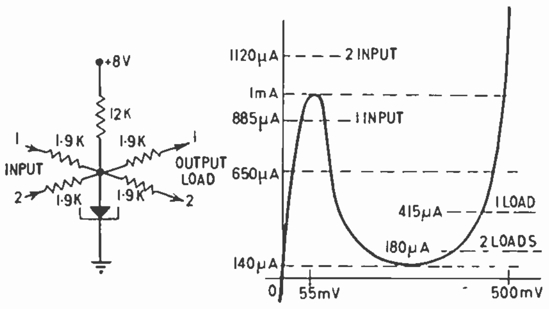


Fig. 7. A tunnel diode computer logic circuit.

the particular example, two simultaneous inputs are required to trigger the flip-flop; and in turn the flip-flop is capable of providing similar inputs to two more diodes. The diode shown is a General Electric 1N2939 which has a current peak of 1 mA, and a current minimum of 140 μA or less. When it is in its low voltage state, on the part of the characteristic marked G, each input will contribute 235 μA. Thus if the bias current is 650 μA one input will raise the diode current to 885 μA, which is below the current maximum where it will trigger, while two inputs will raise the current to 1120 μA where it will trigger, and switch to the high voltage part of the curve marked H. Here two output loads will reduce the current to 180 μA, which is 40 μA greater than the current minimum. A third load would switch the diode back to its low voltage state. A limitation of the circuit in the particular form shown is that if one of the input voltages were reduced to zero, after the diode had switched, it would act as another load, and may switch the diode. The circuit was designed as part of the decoding arrangement for a computer memory where this did not matter. However the limitation may be removed at the expense of designing the circuit to withstand four loads, which would impose severe tolerance restrictions on both the diode and resistors.

The tunnel diode, then, has at least two fundamentally useful characteristics; it has negative resistance, and as a result of this it can be made bistable. Although there are other ways in which tunnel diodes can be used in both linear and non-linear circuits, the examples show ways of using these two characteristics of the device.

6. Acknowledgments

We wish to thank the Directors of The Plessey Company Limited, and the Eastern Ontario Institute of Technology for permission to publish this article.

7. Appendix

An Assessment of the Position of Tunnel Diodes in Aviation Electronics

Assessing the future usefulness of tunnel diodes in the field of aviation electronics is a very dangerous exercise, at the moment, because if we are to judge by drawing a parallel with the growth of transistor applications it will be at least three years before they are used in practical aircraft equipment. It is not ever very safe to draw this parallel because, except in a few well known instances, transistors do not fit happily into valve circuits, so the introduction of transistors into aviation electronics had to wait until a whole equipment could be transistorized. With tunnel diodes we have a very different situation for two reasons. The characteristics of tunnel diodes are such that they will fit readily into transistor circuits, and also they do not appear to be as flexible in application as transistors, so it is unlikely that we shall see the tunnel diode take over all the electronics in an equipment, as we have seen with the transistor. Rather we shall see the tunnel diode become part of solid-state electronics, and be used along with transistors and other solid-state devices where their special characteristics make them the most appropriate device for a particular application. We should, then, look at the advantages claimed for tunnel diodes, and see where they coincide with the special requirements of aviation electronics.

The main requirements of aviation electronics are four. There are "the two R's", ruggedness, and reliability. There is the ability to operate over a wide temperature range, and low power consumption. It is too early to say much about ruggedness and reliability except that present day tunnel diodes, which we must remember are early tunnel diodes, are better than the early transistors. Furthermore, the nature of the tunnel diode is such that it would lead us to expect reliability, and stability of its characteristics. They are essentially low power devices because the important part of the tunnel diode characteristic is at voltages lower than that required for normal forward conduction. The temperature range over which they will operate depends largely on the circuit chosen. It has been shown that there is a negative resistance over a temperature range from that of liquid helium to well above the temperature at which transistors made from the same semi-conductor will operate, and for this reason, it is possible for some circuits to work adequately over a very wide range of temperature indeed. However, many tunnel diode circuits require great stability of the diode characteristic, and will have a much more limited working temperature range. An example of such a circuit is the resistor-coupled tunnel diode logic circuit discussed earlier which has been considered widely for computer applications.

Advantages which have been claimed for tunnel diodes are as follows:—

(a) They are simple two terminal negative resistances.

(b) High frequency operation.

(c) Fairly low noise.

(d) A resistance to neutron bombardment which is greater than that of transistors.

The simplicity of some tunnel diode circuits is perhaps their most attractive feature. They will almost certainly find application as low power oscillators, and particularly as high frequency oscillators. A simple way of making a transistor bistable is to add a tunnel diode to the emitter base circuit. There are simple level discriminator circuits, harmonic generating circuits, and many others. Their reported noise figure and gain-bandwidth product should make them attractive as ultra high frequency pre-amplifiers in applications where parametric amplifiers are disqualified by their complexity. Resistance to neutron bombardment has been given as an advantage now that nuclear motors are being considered for aircraft. However it may be difficult to make use of this advantage, as it is expected that tunnel diodes will be used in circuits along with other more neutron-sensitive semi-conductor components.

It appears probable, then, that with improvements in tunnel diode technology, and more experience of the stability of their characteristics with time, we shall see their use, in aircraft electronic equipment, along with other semi-conductor components. However, design engineers will incorporate tunnel diodes in aircraft equipment only if manufacturers are prepared to back further development effort to improve the device characteristics, and to reduce the cost to approximately that of other low-power diodes.

Manuscript received by the Institution on 11th February, 1961
(Paper No. 653)

Radio Engineering Overseas . . .

The following abstracts are taken from Commonwealth, European and Asian journals received by the Institution's Library. Abstracts of papers published in American journals are not included because they are available in many other publications. Members who wish to consult any of the papers quoted should apply to the Librarian, giving full bibliographical details, i.e. title, author, journal and date, o, the paper required. All papers are in the language of the country of origin of the journal unless otherwise stated. Translations cannot be supplied. Information on translating services will be found in the Institution publication "Library Services and Technical Information".

HIGH VOLTAGE PULSE GENERATOR USING TRANSISTORS

Transistors of the *p–n–p* type are especially suitable for the generation of steep-front positive pulses; unfortunately, these pulses are usually limited to small amplitudes because of the low voltage rating of suitable transistors. A Canadian engineer has described a method of cascading transistors to produce steep-front positive pulses of any desired amplitude. The circuit produces pulses of 100 volts amplitude, with rise times of 0·05 microseconds and fall times of 0·5 microseconds.

"Cascaded transistors produce high voltage pulses", F. C. Creed. *Canadian Electronics Engineering*, **5**, No. 3, pp. 51, 55, March 1961.

TRANSISTOR CIRCUIT DESIGN

A technique has been developed by a lecturer at the University of Melbourne for the design of transistor feedback amplifiers, based on the use of impedance mismatches between stages. Expressions are derived from the transmittance of the four basic building blocks—the series and shunt single stage feedback amplifiers and the current and voltage feedback pairs—and methods of interconnection which achieve the mismatch are considered. The expressions for the transmittance are both simple and highly accurate, yet they involve no quantitative information about the transistors at all. Three examples in the use of the design technique are given, covering the audio and video frequency ranges up to 20 Mc/s.

"An engineering approach to the design of transistor feedback amplifiers", E. M. Cherry. *Proceedings of the Institution of Radio Engineers Australia*, **22**, pp. 303–20, May 1961.

VESTIGIAL SIDEBAND FACSIMILE

A vestigial sideband system for the high-speed transmission of facsimile signals has been described in a recent Japanese paper. The system uses simple methods of performing homodyne detection and eliminating quadrature distortion. In the transmitter, the maximum modulation factor is set at a small value, and the carrier frequency is constantly transmitted. In the receiver, the even symmetry components around the carrier frequency of the received signal pass through a band-pass filter in which the phase-modulated components are eliminated. The amplitude components are then suppressed by a limiter, the output of which is used as the carrier frequency for homodyne detection. Thus homodyne detection can easily be performed without resorting to an a.f.c. system.

"A new type of vestigial-sideband fascimile system", K. Kubota and K. Kobayashi. *Review of the Electrical Communication Laboratory (NTT)*, **9**, pp. 85–90, January/February 1961. (In English).

NANOSECOND PULSE GENERATOR

A pulse generator built by members of the High Temperature Laboratory of the Stuttgart Technical High School has recently been described which supplies a square-wave pulse with an amplitude of 280 V and a duration that can be continuously controlled between 20 ns and 1·4 μs. Rise and decay, as measured between 10% and 90% of the pulse amplitude, takes place within 10 ns. The ripple of the pulse top is less than 5% of the pulse amplitude. The shape of the composite pulse is found by adding three individual pulses of different characteristics. The first of these rises steeply, the second has a horizontal top, and the third has a steep trailing edge. The generating circuit for the composite pulse is assembled with electron tubes, for they permit better synchronization than do transistors.

"The production of controlled square wave pulses in the nanosecond range", F. Maisenhalder, H-D. Purps and E. Pfender. *Archiv der Elektrischen Ubertragung*, **15**, pp. 253–6, May 1961.

TUNNEL DIODE POWER SUPPLY

Tunnel diodes, being very low impedance devices, require low impedance power sources but conventional supplies are bulky and inefficient. Introduction of new thermoelectric materials makes it feasible to build supplies with desirable characteristics, and designers at the National Research Council of Canada have employed bismuth telluride thermocouples heated by nichrome ribbon. Advantages derived are: (1) very low output resistance at reasonable efficiency (about 2½%); (2) negligible ripple when operated from an a.c. source; (3) ability to vary output potential smoothly and continuously over the entire range; (4) ability to operate from a source of a.c. or d.c. power at almost any impedance level.

"Low impedance thermoelectric device powers tunnel diodes", E. L. R. Webb and J. K. Pulfer. *Canadian Electronics Engineering*, **5**, pp. 38–43, February 1961.

DIELECTRIC LENSES

Using Luneburg's spherical dielectric lens theories, the authors of a French paper show how a complete dielectric system can be adjusted by focusing individually and collectively the component lenses or reflectors, the latter being lenses metallized over part of their surfaces. Many experimental results and methods of measuring the electrical characteristics of lenses and reflectors are given. The design principles of an omni-directional dielectric reflector are mentioned and the performance of an ordinary metallic reflector is compared with that of a dielectric one to demonstrate the advantages of the latter.

"Experimental studies of spherical dielectric lenses and reflectors", B. Chiron and F. Holvoet-Vermaut. *L'Onde Electrique*, **41**, pp. 481–9, May 1961.