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Commentary

ONE of the objects in increasing the cost of the television licence earlier this year was to make the television service self-supporting and less dependent for its income on sound broadcasting. At the time these increases were made it was announced that, as soon as possible after the completion of the television network, a start would be made on a new V.H.F. network to supplement the existing medium- and long-wave sound broadcasting services which have long been in an unsatisfactory position.

The causes which have brought about this state of affairs have been well known and so, too, have the remedies, but economic conditions and the popularity of television have both tended to prevent any steps being taken by the BBC to improve conditions.

Considerable satisfaction, therefore, will now be felt with the Postmaster General's recent announcement that he is at last able to give the BBC permission to proceed with the first stage of its scheme to erect a network of V.H.F., F.M. transmitters in this country.

Some nine V.H.F. transmitters are to be installed and, with the exception of Wrotham, they will all be erected on existing television sites.

Wrotham has been operating as an experimental station for some time past and, by May of next year, will become the first to be in regular operation, serving London and the Home Counties, to be followed by Pontop Pike and Divis (near Belfast).

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THE British Institution of Radio Engineers held a Convention at Oxford from 8 to 11 July and had as a theme, "Electronics in Industry." Over 300 persons, including many from overseas, attended and over 40 papers were presented and discussed. The Convention was wound up by an address from Sir Walter Puckey, President of the Institution of Production Engineers, and a debate, at which Sir Walter took the Chair, on the motion, "Electronics is the Key to Increasing Production in Great Britain." Many of the points made by Sir Walter were provocative, as no doubt they were intended to be, and several, perhaps, were made somewhat tongue in cheek. But, coming from one not directly concerned with electronics, but at the same time pre-eminent in the field of production engineering, they cannot be neglected.

One point in particular is worthy of special note, and that is the accusation that the electronic engineer is often guilty of wearing blinkers when dealing with industrial problems. This, of course, is partly true, though rarely is it an intentional fault on the part of the engineer. The reasons for the malady are manifold. In part it may be a case of "not seeing the wood for the trees," the old problem of becoming so involved with the intimate details that the wider aspects of a project cannot be appreciated. Enthusiasm, probably the greatest asset of any research worker or engineer, can be, too, a handicap. Over enthusiasm for electronics has doubtless accounted for many involved, and oftimes clever and ingenious, schemes to perform a task that could, to overstress the point, be performed equally well with a piece of string and sealing wax.

Probably, however, the main difficulty, and one that is inherent to the application of electronics to industry, is that the electronics engineer very often has not a deep enough knowledge of the industrial process with which he is called upon to deal. He may, for instance, be confronted with a control problem in a chemical process; he cannot, however, normally be expected to have any great knowledge of either chemistry or chemical engineering, or of the mechanical or other methods that have previously been used or tried for the control of the process. Without this knowledge it is unlikely that the problem will be solved in the most efficient manner.

There is no simple, or single, solution to the problem.

Attention must obviously be given to the training of engineers who intend to specialize in the industrial application of electronics. Their "end" must be recognized from the beginning and the whole of their training must be directed towards this end; it can no longer be considered as an offshoot or sideline to communication engineering. An adequate grounding must also be given in other branches of engineering and science. It may also be that there is the need for a new type of liaison engineer, a man who is, so to speak, a jack of all trades and a master of none. It is abundantly impossible for any normal man to have an intimate knowledge of the many branches of engineering and science that are entailed in an increase in productivity in the many industries that form our lifeblood, but, with the right type of training it should be possible to produce an engineer with a sufficiently wide range of knowledge to be able to explain, for instance, to the electronic engineer the problem and type of answer required, say, by the chemical engineer. A man, in other words, who can speak coherently and intelligently the various types of language understood by the many branches of the engineering and scientific profession.

Another approach to this problem is to train electronic engineers to serve one industry only. A considerable start on this road of approach has been made by the industrial research organizations, such as the Road Research Association, the Linen Research Association, etc., and by the larger industrial organizations who have set up their own electronic departments.

A vital need, too, is a freer interchange, and a less jealous guarding, of knowledge between the specialized types of engineer; here the professional institutions could play an important part by arranging more joint meetings and by encouraging members of one institution to read suitable papers to the other institutions.

Finally, it may be apt, if one is allowed to turn a full-circle, to remark that the main use for blinkers is to ensure that a horse runs a straight course, and there can be no more certain way of winning a race than that!

Continuous Recording of the Human Heart-Rate

By W. E. Boyd*, M.A., M.D., M.Brit.I.R.E., and W. R. Eadie*

The problems due to physical movement of the subject which arise in recording the human heart-rate are reviewed and a new cardiotachometer which overcomes these problems is described.

IN the course of hospital research on the human heart a continuous recording of the heart-rate was required from a subject under the following conditions.

(a) Confined to bed for periods of up to a week or more and engaging in normal activities, e.g. sitting up, washing, eating, being handled by attendants, etc.

(b) Carrying out controlled exercises either in bed or standing on the floor, e.g. lifting weights, the Master step test, etc.

In a previous article[1] a cardiotachometer was described for use on anæsthetized or decerebrated animals. During over two years of continuous use this design has proved entirely satisfactory for the purpose. When applied to the recording of the human heart-rate, however, and especially under the strict requirements of this particular research, it was evident that an entirely new approach was necessary. A review of the literature on the subject[2-18] showed that so far only limited success has been claimed in such recordings during exercise. This conclusion was confirmed by practical tests on a number of designs.

Detection of Heart Action

Evidence of the heart action can be classified under the two headings, "mechanical", i.e. detectable by touch or sound, and "electrical", i.e. detectable on, say, a galvanometer. Designers of cardiotachometers have, in general, tended to favour the use of the "electrical" evidence (electrocardiogram or E.C.G.). This is understandable from an examination of Fig. 1(a) where it will be seen that the E.C.G., when taken from an appropriate site on the body and under carefully controlled conditions, can provide a waveform very suitable for operating a rate-meter. Unfortunately, such conditions could not be obtained in this particular project. On the contrary the actual waveform which would be available for operating a cardiotachometer under even average conditions of the research is shown in Fig. 2(a). As will be seen the E.C.G. has practically disappeared in the background of interference. In view of this is was considered worth while investigating other methods of registering the heart beat.

Mechanical Methods

In what have been termed the "mechanical" methods a transducer is required. A simple type employs a microphone to pick up either the heart sounds from the chest wall or the pulse sounds from, say, the side of the neck[19-22]. After suitable amplification the resulting potentials operate a wave-shaping and counting circuit. A typical record of the waveform obtained from the microphone is shown in Fig. 1(c). Extraneous noise, however, precluded the use of this system as is shown in Fig. 1(d) where the subject has coughed. Other sounds which would produce artefacts are speech, breathing, friction of clothing, etc. The recently developed thermionic transducer provides a sensitive alternative to the microphone, but for present purposes suffers from the same objections.

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An elaboration of the above is to use either of them in conjunction with an inflated cuff placed around a limb or the forehead. For short recordings the method has advantages, but produces considerable discomfort after a time.

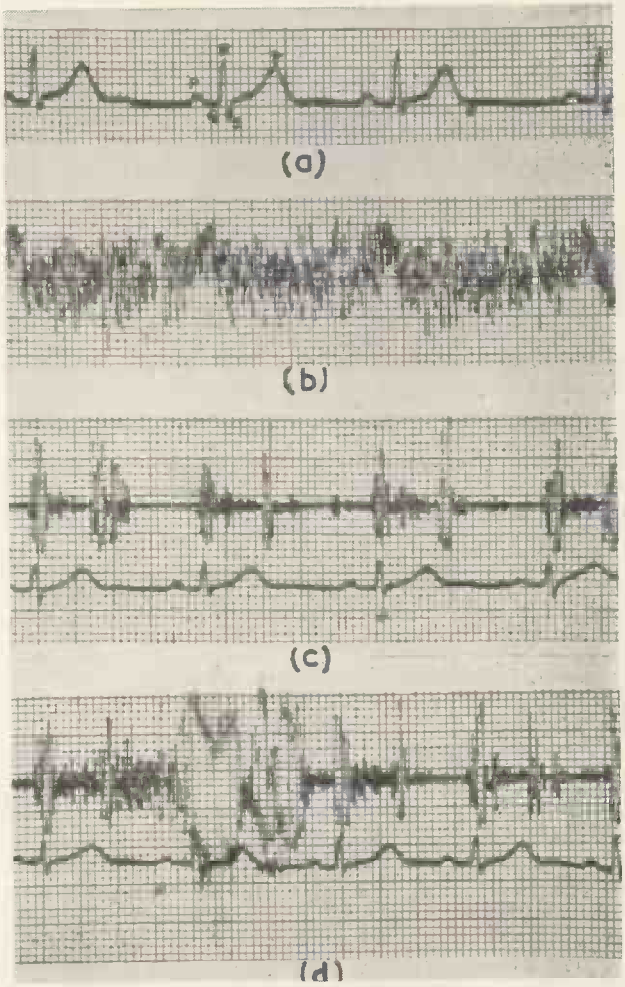

Fig. 1(a). Typical E.C.G. taken under ideal conditions, showing *P*, *Q*, *R*, *S* and *T* components. (b). Same as Fig. 1(a). but showing interference from muscle potentials produced by subject pulling with his arms. (c). Output of microphone placed on chest wall, and corresponding E.C.G. (d). Same as Fig. 1(c). but subject has coughed

There is also the disadvantage that muscle movement must be limited.

In the impedance plethysmograph[23] a section of a limb is connected as one arm of a radio-frequency bridge. The quantity of blood in the limb will vary between systole and diastole and hence the impedance to R.F. current. An out-of-balance signal is, therefore, available which can be rectified and used to operate a counter. Once again muscle movement makes this method unsuitable since it too will produce changes in the blood content of the section of limb. Similarly any method using direct current to register changes in resistance of a section of a limb suffers from this disadvantage coupled with others, such as variations in electro-chemical potentials, skin contact resistance, etc.

An ingenious method makes use of changes in the colour of the skin or tissue during each heart-beat. A beam of light is reflected from the surface of the skin, or through the web of the finger, or the ear lobe on to a photo-electric cell[24,41]. Variations in the blood content below the skin produce corresponding changes in the amount of light of a chosen wavelength reaching the photo-electric cell. For our purposes this system had two main disadvantages. The first was that unless really miniature components were used, considerable discomfort would be caused to the subject on long recordings. Such components were not available. The second was of greater importance and applies to all systems which rely on a "mechanical" indication of the heart action. In cases of disease of the circulatory system the heart frequently has a diminished action, while the arteries may also tend to lessen the mechanical effect available for registration. Such cases, unfortunately, may also be the most interesting clinically. It, therefore, appeared that the greatest possibilities still lay in using the E.C.G.

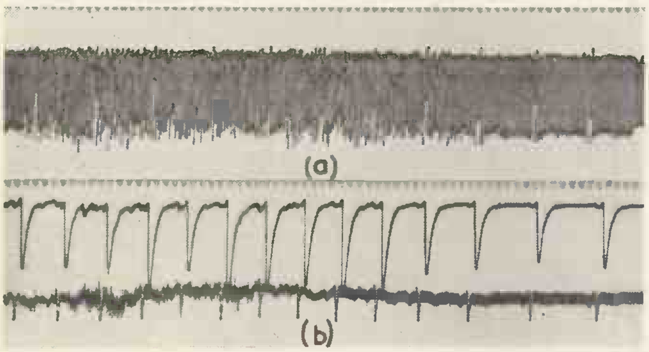

Fig. 2(a). Actual mixed waveform present at electrodes during moderate exercise and comprising E.C.G., 50c/s interference and muscle potentials. (b). Upper line—spiked output waves at selective amplifier anode of new cardiotachometer, extracted by it from mixed waveform of Fig. 2(a). Lower line—Fig. 2(a). with most of the 50c/s interference and some of the muscle potentials removed to show that above waves bear a definite time relationship to the *QRS*

(Relative amplitude and polarity should be disregarded as they have been determined by the double-beam oscilloscope)

Electrical Method

An E.C.G. like that shown in Fig. 1(a) can be obtained by attaching two electrodes to suitable parts of the body, e.g., one on each fore-arm, with a special conducting jelly interposed to reduce the electrical resistance. The subject lies on a couch insulated from ground and the electrodes are connected to an amplifier, the input stage of which is a long-tailed pair or a cross-coupled stage. The subject is, therefore, electrically balanced to ground and if the surface of the body is at a uniform potential, the in-phase components of electrical intereference from supply mains, etc., are cancelled out. The subject, however, must remain completely relaxed and refrain from movement, or interference potentials, arising from the muscle action, will become evident. The effect is seen in Fig. 1(b) where the same subject has attempted to raise himself to a sitting position by pulling with his arms.

In the case of a subject moving about a room, an analysis of the complex waveform present at the electrodes may show that it consists of the following:

(a) The E.C.G. with a frequency range of 0·3c/s to 50c/s or over, and an amplitude (peak-to-peak) of 0·25mV to 2mV.

(b) Potentials due to muscular action with a frequency range from zero to several thousand cycles per second and an amplitude of up to 10mV or more.

(c) Electrical interference from house wiring etc., with a frequency of 50c/s and an amplitude between 1mV and 20mV with occasional instances as high as 750mV. (The amplitude will also show abrupt changes if the subject is touched by an attendant.)

(d) Electrical interference from X-ray or diathermy, etc., which may be of practically any frequency and amplitude.

(e) A slowly fluctuating "D.C." potential arising from electro-chemical action in and under the skin and with an amplitude of up to 100mV.

(f) "D.C." potentials due to electro-chemical action on the metal of the electrodes, having an amplitude between 20mV and 50mV and with abrupt changes if any movement between the skin and electrodes takes place.

(g) Electrostatic charges arising from friction of clothing etc.

(h) "D.C." potentials derived from the skin of an attendant touching the subject.

Although this list may appear formidable there are a number of items which are easily removed. The steady "D.C." potentials are eliminated by a capacitance coupling in the amplifier. The abrupt changes, however, remain. These have components from zero frequency upwards and sufficient amplitude to block any normal amplifier. They are best dealt with by removing the cause as far as possible. This will be discussed more fully under the heading of electrodes. At first sight it might appear that mains and other interference could be removed by using a balanced input stage, but this is not the case since an attendant touching the subject will seriously upset the state of balance. For 50c/s interference a filter of the parallel-*T* or Wien bridge type is quite effective, although it will not necessarily deal with abrupt changes. The effect of these, however, will be greatly reduced by other means to be described. Screening can be of value in certain cases. A subject lying on an electric blanket, for example, may have as much as 750mV of A.C. appearing across the electrodes. Enclosing the blanket in a sheet of metallic cloth will reduce this to below 20mV. The reduction of interference by X-ray and diathermy can usually be done by a combination of screening and filtering, but conditions vary so widely that it is not possible to generalize.

Potentials due to muscular activity are undoubtedly the most difficult form of interference to remove. It was found, however, that a wave analysis of "muscle" potentials compared with that of the E.C.G. showed that while the spectrum of the E.C.G. rose steeply in amplitude down to below 5c/s that of "muscle" potentials fell with increasing rapidity below 20c/s. It was reasonable to assume, therefore, that by using a selective amplifier, freedom from "muscle" interference would be an inverse function of the selected frequency. An amplifier resonant at 15c/s had already been employed in the original design for use on animals, but extensive tests on human subjects over the region 10c/s to 20c/s showed that the degree of freedom from interference was not sufficient for our purposes. Frequencies below 10c/s on the other hand could not be examined with a normal L.F. selective amplifier because it tended to ring so long that interference arose between successive beats. In the heterodyne type of wave-analyser, on the other hand, where selection takes place at around 50kc/s, the decrement is very much greater and it was found possible to examine the region from 2c/s to 10c/s without difficulty. A frequency of 6c/s appeared to be the best compromise. Below this the *R*-wave output between the various types of E.C.G. varied much too widely, while above it "muscle" interference increased.

To make use of a heterodyne analyser circuit in the final

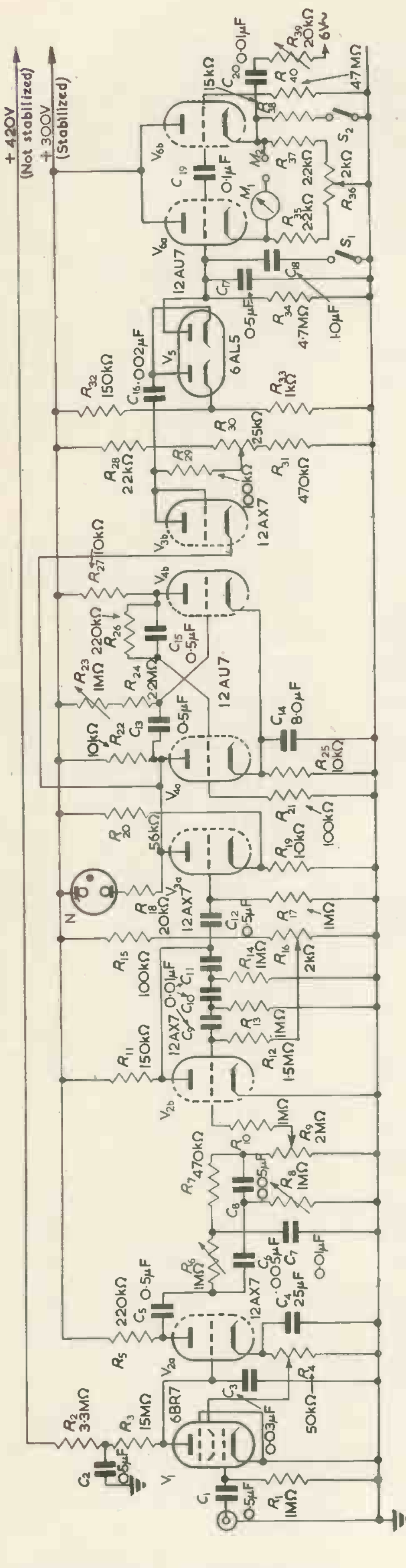

Fig. 3. The circuit of the cardiotachometer

design was, however, quite out of the question on the grounds of size, complexity and poor stability at such low frequencies. Various forms of L.F. resonant circuit were tried in which the ringings was suppressed after the counting circuit had been triggered and before the next beat was due. Considerable success was achieved but difficulties were encountered from spurious transients in the suppression circuit and unreliability. Overcoming these led once again to undue complexity and so the idea was shelved.

The circuit finally adopted is extremely simple yet has proved consistently reliable. It comprises a triode phase-shift oscillator (V_{2b} Fig. 3) damped below the oscillation point by 1·0V to 3·0V positive grid bias. When an E.C.G. waveform is applied to such a circuit, a sharp positive going spike is obtained at the anode which is eminently suitable for triggering a wave shaper. The effect is clearly shown in Fig. 2(b) where the spikes are displayed coincident with the *R*-waves from which they are derived. The E.C.G., obscured by muscle potentials, etc., is that of Fig. 2(a) obtained from an electrode on each wrist, but the subject has stooped down and raised a 5lb weight above his head. The increase in heart-rate can be easily seen. For the sake of clarity most of the 50c/s and some of the "muscle" interference have been filtered out. It should also be noted in passing that although a negative-going *R*-wave is required this does not necessarily mean that polarity at the electrodes must be observed. As will be seen presently the extreme low-frequency components of the E.C.G. are removed in the pre-amplifier and this normally results in a diphasic *QRS*. It may at times be the *S*-wave, therefore, from which the rate is derived.

The Complete Design

Rate-recorders or tachometers are already extensively used in research and industry and the basic principles are adequately described in the literature[25-36]. When these principles are applied to recording the human heart-rate, a typical design falls into five main sections.

(a) A transducer, where necessary, to provide from the heart action an electrical output of identical recurrency.
(b) A pre-amplifier to bring this output to a usable level.
(c) A wave-shaper to give one impulse of constant amplitude for each heart beat.
(d) An integrating circuit to develop a potential difference proportional to the frequency of these impulses.
(e) A voltmeter calibrated in beats per minute, to measure this potential difference.

For the special purposes of this research the following features had also to be included in the final design.

(a) Mains operated and stabilized against variations in the supply voltage and frequency.
(b) No critical adjustments and capable of continuous use by non-technical staff.
(c) Operate on an E.C.G. of 0·25mV upwards.
(d) Unaffected by considerable variations in amplitude of the E.C.G.
(e) Freedom from blocking in the amplifier.
(f) Output to give a thin easily read tracing on a 0 to 1mA pen-recorder.
(g) Suitable for use in a hospital ward as well as a laboratory and as small and light as possible.

The circuit is shown in Fig. 3.

Pre-amplifier

A peak-to-peak input of 5·0V was found satisfactory for the operation of V_{2b}. With an E.C.G. of 0·25mV this called for a gain in the pre-amplifier of 2×10^4. This is easily obtained from the "starvation" circuit of Volkers[37] and is far ahead of any other circuit tried (V_1 V_{2a}). Some values shown may appear unusual in view of the very low frequency concerned. These have been dictated by the necessity of ensuring rapid recovery from a large transient input such as might be produced by the accidental displacement of an electrode. In the worst case likely to occur it has been found that not more than one beat will be lost due to amplifier blocking. This same property also provides a satisfactory degree of automatic gain control since distortion of the waveform due to overloading is of little account.

It would have been preferable to place the 50c/s filter at the input of V_1, but variations in electrode impedance altered the null setting.

Similarly when placed between V_1 and V_{2a} it upset the stability and increased the blocking time of the "starvation" amplifier. Capacitor C_3 had, therefore, to be included to reduce the amount of 50c/s and "muscle" interference reaching V_{2a} which might cause it to be permanently overloaded.

Wave-Shaper and Delay Circuit

A convenient form of wave-shaper is the univibrator (V_3, V_4). The circuit chosen[38] is particularly free of troubles arising from leakage in the coupling capacitors. As will be seen presently, these are unusually large. In operation V_{3a} is cut off by the high bias across R_{19} and V_{4a} by the bias across R_{25}. A positive impulse from V_{2b} initiates the univibrator action in which the anode potential of V_{4a} falls. This negative going impulse charges capacitor C_{16} which operates the diode pump V_5. A diode limiter (V_{3b}) has been inserted to protect the diode pump V_5 from spurious signals which might break through from V_{3a}, but are neither large enough, nor are intended, to operate the univibrator. This limiter ensures that the anode potential of V_{4a} must fall below a certain level, determined by the setting of R_{30} before the charge on C_{16} is altered. At the same time it establishes the total potential change which will be applied to C_{16} and hence to the diode pump. The potentiometer R_{30} is, therefore, the calibration adjustment. Although the heater-cathode voltage of V_{3b} is high no trouble has been experienced from leakage.

In a typical E.C.G. (Fig. 1(a)) the *P*-wave is normally too small to be of any account, but in many cases the *T*-wave will operate the 6c/s resonator, giving an output comparable with that of the *R*-wave. This would produce a recorded rate of twice the true figure. A delay has, therefore, been incorporated in the wave-shaper so that only one or the other will operate the counter.

In an E.C.G. the *Q-T* interval obeys the formula $Q\text{-}T = K\sqrt{C}$, where $K = 0{\cdot}385$ and C = interval between beats[39]. The range of the present design has been set at 0 to 150 beats per minute to accommodate a standard paper printing. It is seldom, however, that rates below 50 beats per minute will be encountered. Considering the range, therefore, as 50 to 150 beats per minute, the *Q-T* interval will vary from 0·42sec at 50 beats per minute to 0·24sec at 150 beats per minute. These will also be suitable delay periods at these frequencies regardless of whether the *R*-wave or *S*-wave is being used. There is, in fact, an advantage in having the delay as long as possible since it reduces the time during which interference or large transient impulses can produce a false count. At 150 beats per minute it could, in fact, equal the periodicity, i.e. 0·4sec. On the other hand, at 50 beats per minute and ignoring the interference question, it need only equal the *R-T* interval which will be approximately 0·37sec. The same delay period would, therefore, be suitable for the entire range. In practice it has been found an advantage to have it variable between 0·4sec to 0·5sec. The value is controlled by R_{23}.

Voltmeter

The indicating instruments are a 75Ω 0 to 1mA panel meter in series with a 3 000Ω 0 to 1mA Evershed and Vignoles pen recorder. This has necessitated the use of a diode-pump and valve-voltmeter in the counting circuit instead of one of the more simple arrangements with a higher sensitivity meter. At the same time it has permitted the introduction of a number of valuable features. Capacitor C_{19} applies to the grid of V_{6b}, the A.C. component appearing across the integrating circuit $R_{34}C_{17}$. Cancellation of this component, therefore, takes place in the cathode circuit and removes what is in effect the "heart rhythm" from the meter. Without this the pen would swing on each heart-beat and record a broad band[5]. Pen-to-paper friction is overcome by feeding 50c/s current from the heater supply into the meter circuit via R_{39} and C_{20}. The exact amount will depend on the quality of paper used and the viscosity of the ink.

The push-switch S_2 provides a marker signal which is sharply defined and is distinctive from anything arising from a subject's heart. The range of the instrument is a matter of choice and can be readily extended by switching in alternative values for R_{34} and R_{24}. Two ranges of "probable error" are available by means of switch S_1. They enable the amount of detail shown on the record to be adapted to the paper speed. A lever on the paper-puller motor provides speeds in inches per hour or inches per minute. Convenient values are 1 inch per hour for long recordings and 1 inch per minute for exercise tolerance tests.

In an integrating instrument of this type the rate shown is not the actual rate at any particular instant, but a figure dependent on what has gone before. For a change in rate the time taken to reach, say, 95 per cent of the true reading is determined by the value of capacitors C_{17} and C_{18}, i.e. by the "probable error." Large values will give a cleaner record at low paper speeds, but the value chosen should be related to the particular information required about the subject's heart.

The neon light *N* flashes on each heart-beat, so giving a simple check on correct operation. In a larger model two "magic eyes" have been provided. The first is connected to the output of the pre-amplifier and shows the heart rhythm, while the second shows the output of the univibrator. They are placed close together so that they can be viewed simultaneously. In this way a valuable check is obtained not only in normal use but especially in difficult cases. The new Mullard DM70 miniature tuning indicator appears to be a suitable alternative which will be incorporated in the present design as soon as available. The power supply is a standard series-valve stabilized type and merits no comment.

Electrodes

The type of electrode used and the method and place of attachment, are of some importance, not only for correct operation of the instrument, but to ensure minimum discomfort of the subject. Any of the standard electrocardiograph electrodes and connexions will give good results up to a point. The electrodes must be firmly fixed, with no tension on them during movement. The connexion giving the largest E.C.G. is, of course, preferable. Two main problems, however, had to be overcome to achieve the very best results. On long recordings the electrode sites tended to become dry and contact poor, while during violent exercise, movement of the areas of skin relative to the electrodes caused large changes in the steady polarization potentials which gave rise to a false count.

The most satisfactory form of electrode so far developed to meet this consists of a 1in by 1in plate of 22 S.W.G. silver moulded into the bottom of a shallow square dish of alkathene. These are easily prepared by hard-soldering a 1in by 1in piece of ⅛in metal to the centre of a metal plate. On top of this is placed the silver electrode with an insulated lead attached and overall is placed a sheet of 1/16in alkathene. A bunsen flame is now carefully played on the alkathene, so that it melts and flows down over the metal jig. When cold it will be found that the silver plate is firmly held. The edges of the alkathene should be trimmed to leave an ⅛in flange all round. It is an advantage to make one electrode curved, by curving the jig, so that it fits more comfortably to a limb. A thin coating of silver-chloride is deposited electrolytically on the silver plates[40] and the electrodes are filled level with a paste of soft soap, KCl and glycerine.

For a bed-ridden subject the flat electrode is attached to the chest by sticking-plaster or collodion, after first cleaning the site with alcohol. By making this the earthed electrode there is a large reduction in artefacts due to handling of the subject by attendants. The curved one is attached to the left ankle by a soft strap and is the live electrode. Connexion to the recorder is made through a thin low-noise coaxial cable terminating on and securely fastened to the ankle strap. The core of this cable is attached to the ankle electrode and the outer screen extended by a thin

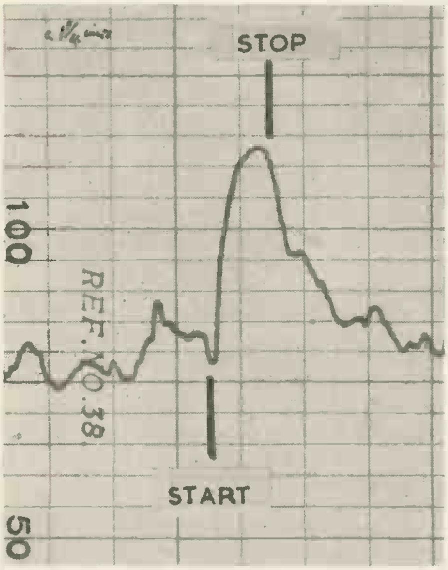

Fig. 4. Specimen record of the heart-rate of a patient suffering from heart disease, taken while pulling a 6kg weight 17 times over a pulley

Fig. 5. The Boyd Research Trust Cardiotachometer with the Evershed and Vignoles pen-recorder

flexible lead to the chest electrode. A coaxial plug and socket inserted about 6in from the ankle permits disconnexion without disturbing the electrodes. This arrangement has also been found suitable for exercise tolerance tests. In the case of step tests it will obviate tripping on the cable if it is also brought up to the shoulder and, if necessary, fastened there.

Results

The facility which the B.R.T. Cardiotachometer provides for studying the heart response during exercise opens a wide field for experiment in both normal and abnormal heart conditions. Long recordings may be made on bed-ridden subjects which show in a remarkable fashion the response of the heart to various stimuli. Emotional response, depth of sleep, response to drugs, etc., can be clearly displayed. Fig. 4 shows an example of the type of record obtained in a simple exercise test with a patient suffering from heart disease, while Fig. 5 shows the complete instrument.

Acknowledgments

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LEO

(Lyons Electronic Office)

(Part 2)

Operation and Maintenance

By E. H. Lenaerts*

PART 1 traced the history and development of LEO, built by J. Lyons and Company Ltd, and gave an outline of the design of the machine. This part discusses some of the problems that have to be faced in the daily operation and maintenance of LEO. Because most of the routine work to be done is clerical work, which has to be performed to a fairly tight time schedule, a breakdown of longer than one hour can mean a serious dislocation of the schedule of work. Testing and maintenance of this machine must, therefore, aim to reveal any potential weakness before it can give rise to such a breakdown. Adequate time must be specially set aside for this purpose. On the other hand, faults do occur during operational work and when this happens, they must be dealt with as rapidly as possible. There are, therefore, the twin problems of eliminating weaknesses so that faults do not arise, and of rectifying faults quickly when they do. The measures taken to achieve the desired standard of efficiency in maintenance will now be described, starting with the switching-on procedure and including details of the test programmes and methods of valve testing used, and a description of the marginal testing scheme developed for LEO. This will be followed by a description of the operating routine for a typical clerical job, and finally an analysis of the methods of fault tracing which are used.

Routine Machine Testing

As described in Part 1, the switching-on procedure includes an automatic delay in raising the heater voltage and an interlock prevents the H.T. being applied before this has been done. When the supplies are on, the morning test procedure starts. For approximately one hour after switching-on the calculator is given over to maintenance and testing. All the different calculating, input, and output circuits and devices are tested by means of "test programmes". This procedure only takes about 20 minutes, but adjustments and replacements, including the routine inter-change and setting-up of spare units, takes up the rest of the hour. The design of test programmes to confirm the reliability of the machine is of interest and is described below.

Test programmes are of two types. The first are programmes designed to give an assurance of the general serviceability of a large part of the machine. These are referred to as General Test Programmes. The second are designed to test one particular function of the machine. These are referred to as Action Test Programmes.

The earliest type of test programme used was derived from what we call "Action Tests." These were used with EDSAC[12], for testing one action or function of the machine at a time; for example, addition was tested with varying patterns of pulses representing both positive and negative numbers for several hundreds of repetitions. Subtraction was then tested in the same way and so the various arithmetical instructions were individually checked. Each operation was checked by comparing the actual answer obtained with the correct answer placed in the store from the data tape at the start. This method of testing was rather wasteful of machine time as it was virtually impossible to test any one action without using other actions.

A more serious disadvantage was that sometimes calculating errors occurred in jobs in which the number pulse patterns had no special peculiarities, although the action test did not show any kind of fault. Closer examination revealed that these test programmes which are by nature repetitive, produce regular patterns of waveforms, whereas jobs in which sequences of orders are repeated only after long intervals, produce irregular patterns.

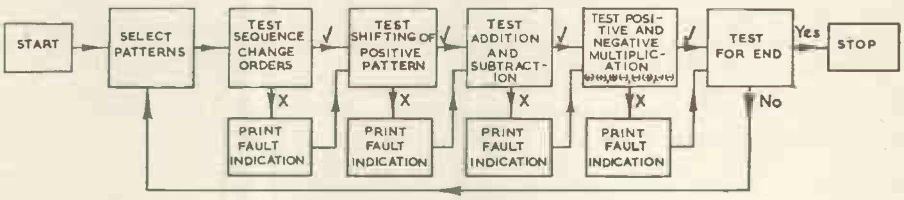


Fig. 13. General computor test programme

The most recent tests are deliberately designed to resemble normal programmes as closely as possible, although the patterns of pulses are carefully chosen in order to present the most difficult conditions for the circuits involved, and are changed periodically during the tests. Fig. 13 is a very much simplified flow chart of the general computor test now used. In fact, the programme includes 41 individual tests, each of which gives a specific indication should an error occur. The loop is intentionally made as long as necessary to give a comprehensive arithmetical test to the computing circuits.

In this test a series of arithmetical operations is performed on each pattern, testing at each stage that the operation has been carried out correctly. If at any time an error is indicated, a code number is printed by the teleprinter. Thus, if a "17" is printed, this indicates that an error has occurred when shifting a negative number to the right in the accumulator. Tests of this nature are particularly powerful in conjunction with the marginal testing technique which will be described later.

It has been found convenient to use an entirely separate test for the store in which the types of fault checked for are:

(a) Picking up extra digits in a particular mercury delay line;

(b) Dropping of digits from a particular delay line;

* *J. Lyons and Company Ltd.*

(c) Failure to extract information from one or more delay lines;

(d) Failure to plant information in one or more delay lines;

(e) Corruption of patterns in one delay line of the store by those in another.

Each compartment of the store is checked in such a way that not only is it confirmed that the correct pulses have been stacked, but also that they have not been stacked anywhere else. Because a part of the store has to be used to hold the programme for checking the remainder, the store test is, in fact, in two parts. These use different parts of the store for the programmes of orders, enabling the whole of the store to be checked in the same way. In each case the checking is done by clearing that part of the store not used for the programme, stacking a different pattern in all available compartments, and then checking that the correct pattern has been stacked.

The testing of the input and output equipment follows the form of the general computor test except that, of course, it is not possible to make an internal check of what is printed by the tabulator. The test, therefore, arranges for the printed output to be in a form that can easily be checked by inspection. The output from the card punch is tested by feeding the cards punched back into the card feed.

Summarizing the foregoing, we have found that the best plan for carrying out a routine test on the installation is to use three separate tests on:

(1) The store;

(2) Arithmetical circuits;

(3) Input and output circuits.

The tests are carried out in the order stated.

A distinction is drawn between the tests used daily as a matter of routine, and those used only when a fault has been revealed but has yet to be traced to its cause. The former can be termed "Assurance Tests" and their purpose is to prove that all parts of the machine are dependable. Such tests are not always the most effective in analysing the particular cause of a failure to pass, say, the addition checks in the general computor tests. It happens that "Action Tests" are sometimes more convenient for this purpose and they are used on some occasions. In other cases, a very simple test is often worked out by the engineer on the spot and put into the store from the push buttons. Tests of this type which repeat a particular sequence of orders fairly frequently, allow the pulses and waveforms in particular circuits to be readily examined with an oscilloscope.

Valve Testing

An analysis of the causes of the machine failures such as is presented in Table 1 shows that valve failures are by far the commonest cause. For this reason, a good deal of care is taken to see that inherently faulty valves are not introduced into the machine and subsequent tests are made at intervals to detect changes in characteristics during the life of the valve.

New valves are tested on receipt from the makers and any found faulty immediately returned. The remaining valves are aged in a special unit outside the calculator for about 100 hours, during which they draw current equal to that obtaining in a typical circuit. They are then tested again and any further faulty ones rejected. All good valves are numbered and put into store. When a valve is put into a socket in the machine, the date and socket position is noted in a log-book. When that valve ultimately fails, the date is again noted with details of failure so that accurate statistics on valve-life under various conditions can be compiled.

Valves are first tested for inter-electrode shorts in two horizontal positions, as it has often been found that an intermittent failure in the machine could not be produced until the valve was tested in precisely the same position in the tester. They are then checked for mutual conductance and peak emission at $V_g = 0$ with known potentials on anode and screen. Standards of performance for both used and new valves have been laid down. For new valves these are intended to approximate to the maker's low limits, and for used valves, to about 66 per cent of the new performance. As was mentioned in Part 1, all circuits are designed to work with valves having only 50 per cent of new performance, so even a valve that has reached the lower limit has still some margin of safety. This margin is clearly necessary, however, since it will be several months before a valve is tested again. Table 2 gives an analysis of valve failures which have occurred during an operating period of some 10 000 hours, and includes rejections as a result of intermediate tests.

TABLE 1

Analysis of the Prime Cause of Faults investigated over a Representative Period of Three Months

TYPE OF FAULT	PER CENT
Mechanical failures*	24·0
Bad connexions or dry joints	8·0
Resistors	6·0
Capacitors	2·0
Interference	1·0
Unclassified	12·0
Valve failures	47·0
	100·0

** Including faults on input/output equipment.*

TABLE 2

Analysis of Valve Failures and Rejections (Not including Diodes)

TYPE OF FAULT	NUMBER
Low emission	435
High gas current	65
Open-circuit heater	23
Other internal disconnexion	26
Inter-electrode short	381
Cracked envelope	22
Loose pins	18
Broken top cap	69
Unclassified	41
	1 080

Number of valves in machine:	
ECC 33	1 589
SP 61	824
KT 61	275
EF 50	173
EF 55	86
Total	2 947
Hours of operation	10 500
Average failure and rejection rate per 1 000 hours	= 3·49 per cent

The figures in this table do not include double-diode valves because by far the biggest cause of rejection of this type is due to the following peculiarity which cannot be considered as a normal fault, though it has been one of the most serious valve troubles on LEO. This was the gradual increase in forward resistance in thermionic diodes used in gating circuits. A new valve usually has a forward resistance of between 200 and 400Ω, but it was found that where diodes are not called upon to pass current for long periods, this forward resistance increased, sometimes to as much as several thousand ohms. This effect is not peculiar to any diodes of particular manufacture as three different equivalents of the CV140 have been used, and all show this effect.

Because of this characteristic, it was decided some time ago to change over to germanium diodes and this is being done gradually.

Valve failures have a different effect on the performance of the machine according to whether they are:

(a) Gradual;

(b) Catastrophic;

(c) Intermittent.

It is possible to guard against interruption of normal operation due to gradual failures, but little or nothing can be done to anticipate troubles due to failures of the other two types. In order to guard against gradual deterioration, one set of valves (about 20), is removed and replaced by a set of well-tested spares before the machine is switched on each day. During the day the valves removed are checked, and given a vibration test to show up possible intermittent faults, and any found to be below standard are rejected. The next morning these valves are replaced in their original positions and another set removed for testing. Where, as in the circuits of the store, there are a large number of units of the same type, a complete unit is removed for inspection and testing with its valves, and replaced by a tested spare unit.

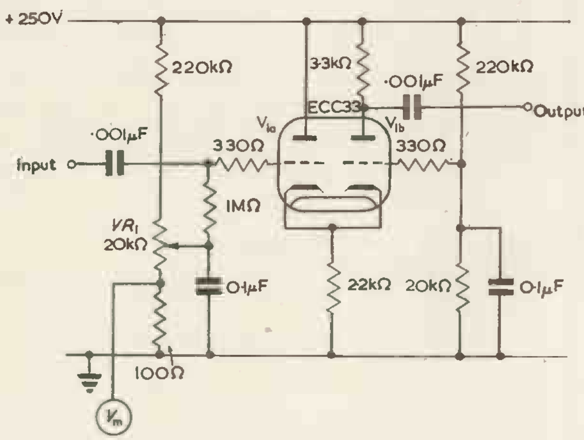


Fig. 14. Pulse amplifier

In this way, it is possible to bench-test all the valves in the machine about once in six months. In addition to this valve testing procedure, a weekly check is carried out on the current being passed by all the valves in the machine which normally pass more than 10mA and those which are normally biased off.

Marginal Testing

In order to detect whether the machine has an adequate margin for correct working at all points in the circuits, it is necessary deliberately to introduce adverse conditions while testing. On some projects this has been done by altering the H.T.[13] or filament[14] voltages generally. Such methods have the disadvantage that they do not lend themselves to the location of the circuit which is in a marginal condition, and that it is not possible to measure relative sensitivity of different circuits to these voltage changes. A more convenient method has been devised for use with LEO, but before this can be explained it is necessary to examine more closely the nature of the marginal failures that can occur. These are of two kinds:

(a) Failure of a pulse to operate a circuit because it is too small or too narrow;

or (b) Unwanted pulses (breakthrough), or interference may operate a circuit.

These effects can be exaggerated if the gain of the various pulse amplifiers in the machine is alternately increased and decreased. Fortunately, this can readily be done in LEO since the amplifier used is of the cathode-coupled type shown in Fig. 14. The current passing in V_{1b} raises the cathode of V_{1a} beyond the cut-off point. A positive pulse applied to the grid of V_{1a} brings V_{1a} into current and consequently cuts off V_{1b}, thus a pulse capable of switching the current entirely from V_{1b} to V_{1a} produces a positive pulse of a well defined amplitude at the anode of V_{1b}. Any small unwanted pulses on the input of V_{1a} are removed by adjusting VR_1 so that the unwanted pulses do not turn on any current in V_{1a}. If the potential to which the grid of V_{1a} is returned is raised, then breakthrough is amplified as well as the wanted pulses, and if it is lowered, then the wanted pulses receive less amplification. Thus, marginal testing can be applied by raising and lowering the grid bias on V_{1a} by injecting a small A.C. voltage (V_m) across the fixed resistor of 100Ω in series with VR_1. A system of this kind is believed to have been first suggested for use on the EDSAC machine. The amplification of the circuit is raised above and below normal at 50c/s to an extent determined by the amplitude of the injected voltage. The optimum setting for VR_1 is that on which both forms of circuit failure begin at the same injected voltage.

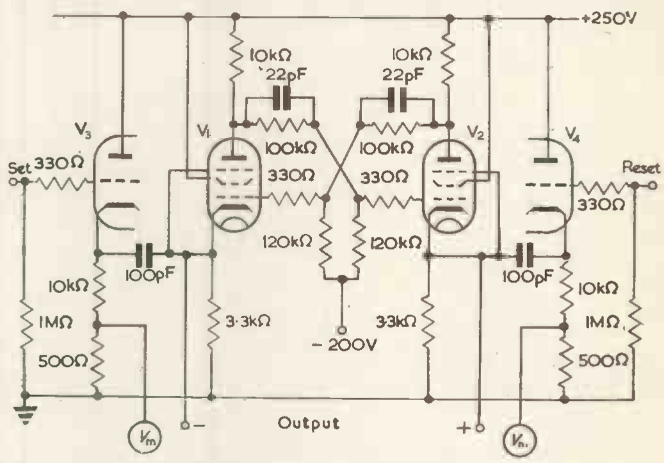
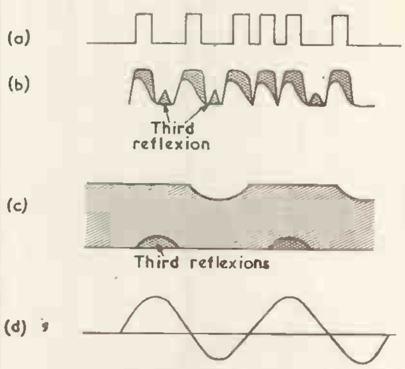


Fig. 15. Marginal test of flip-flop circuit



(a) Pulse pattern circulating in delay line. (b) Effect of marginal test voltage at video amplifier stage. Note reduced amplitude and width of pulses and appearance of the reflexion pulses. (c) Envelope of pulse pattern displayed on same timebase as (d). (d) The injected voltage

Fig. 16. Effect of marginal testing on store

A marginal test can also be applied in an analogous manner to the sensitivity of the flip-flop circuit, see Fig. 15. In this case, however, the arrangement adopted only diminishes the sensitivity to setting and resetting pulses; it does not also increase the sensitivity. This has not proved to be as serious a disadvantage as might have been expected, since when flip-flop components drift, they usually cause the performance to become asymmetrical, i.e., as setting becomes easier, resetting becomes more difficult and is revealed by the test.

Other circuits besides flip-flops and amplifiers are also subject to marginal test, but in nearly all cases the principle of A.C. variations in bias is used. A slightly different method of marginal testing is adopted with the photoelectric readers, where the voltage supply to the lamp is varied by 10 per cent up and down. This provides a most comprehensive test of the reading efficiency.

The extent to which the application of the 50c/s voltage affects the size and shape of pulses in the machine can be seen from Fig. 16, which gives a representative picture of the effect of an injection of 5 volts R.M.S. into a storage unit in which a pattern of pulses is circulating. It can be seen that not only are the required pulses reduced in amplitude and width, but also that the increased amplification at the peak of injected voltage has caused spikes to appear due to pulses which have traversed the mercury three times.

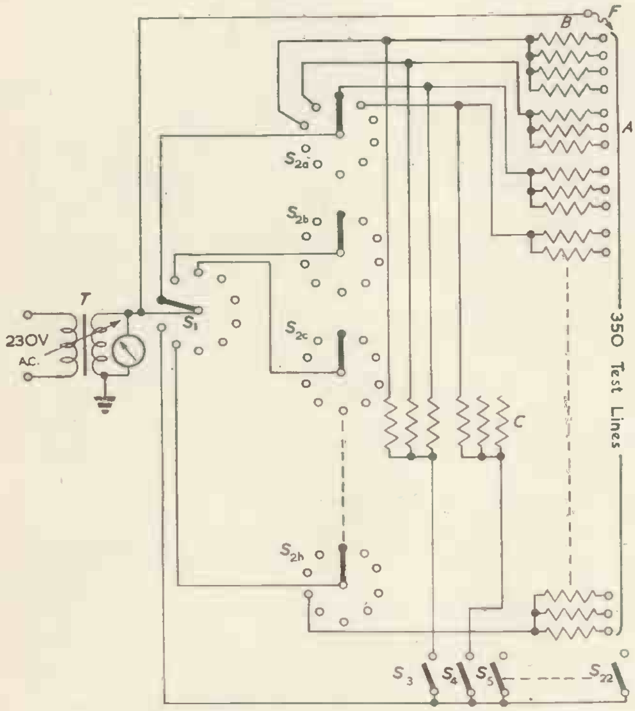


Fig. 17. Distribution of marginal testing voltages

Locating the Cause of Marginal Weakness

A separate wire is taken from each circuit subject to marginal test to a central point where the value of the injected voltage can be controlled. The sensitivities of various circuits throughout the machine are individually measured and the amplitude applied to each is so proportioned that when the marginal voltage is applied to all wires at once, all circuits fail at about the same voltage. This is done by means of series resistors in each lead, the value of which is adjusted to suit the sensitivity of the circuit served.

The marginal test voltage is distributed by a system of switching, which allows the engineer at the Monitor Desk to apply marginal tests in several ways:

1. As a direct injection to any one of some 350 points in the machine;
2. Through a series resistor to a group of related circuits (e.g., computor control circuits relating to multiplication and shifting);
3. Through series resistors to any one or any combination of larger groups of circuits (e.g., store A, store B, computor input channels, etc.).

A simplified diagram of this switching system is shown in Fig. 17 where T is a Variac transformer supplying up to 20 volts 50c/s A.C. S_1 and S_2 together form a decade switch enabling the voltage to be switched to any one of 80 lines. 79 of these lines are connected through groups of resistors (B) to a series of some 350 terminals (A). Each of these terminals is connected to one of the marginal test points similar to those shown in Figs. 14 and 15. In the 80th position of the decade switch, the voltage is connected to a series of toggle switches, S_3 to S_{22}. The other sides of these switches are connected through resistors (C) to groups of the other 79 lines. Finally, a flying-lead (F), enables the output from the transformer (T) to be connected directly to any one of the terminals (A).

When a marginal voltage is required to be supplied generally to the calculator, S_1 is set to position 9 and all the switches S_3 to S_{22} are made. This means that the voltage shown on the meter is being directed to all points in the machine through dropping resistors B and C, which have been chosen to reduce the voltage applied to each circuit to the value it can stand without failing. When a test fails under marginal conditions it can be assumed that one circuit only has deteriorated and the problem is to discover which one it is and put it right. The sensitive circuit is very easily found by removing the injected voltage from different parts of the machine in turn, starting by opening the switches S_3 to S_{22} until the failure occurs with only one of these switches made. A further narrowing-down of the area of possible failure can then be made by selecting one group of circuits through one of the terminals (A). This operation can normally be carried out within a few seconds and the ultimate discovery of the particular faulty component can be made within as many minutes.

Routine Method of Using Marginal Tests

When it has been established that the daily routine tests can be carried out with a general marginal voltage of, say, 15V R.M.S. being injected in the switching network but fail at say, 18V, then the machine is tested daily with 15V injected.

If test programmes operate correctly when all the circuits are being subjected to the standard marginal conditions, experience has shown that the small amount of gradual circuit change to be expected during the day is most unlikely to give rise to a fault.

Furthermore, if it is found that although the machine fails a test at 15V, it passes it at 12V, then it is perfectly safe to postpone the correction of the weakness until a more convenient opportunity. This is only one illustration of the convenience of the system of testing which allows a *measurement* of the safe margin of operating. If it had not been possible to vary the marginal voltage, only a Yes/No answer could be obtained and normal operation would have had to be suspended.

Marginal testing then, can be used in two ways. First, when applied generally and with the use of general test programmes it gives assurance of the overall reliability of the machine. Secondly, again using the general test programme, it enables any weakness shown up by the general test to be traced directly to an individual circuit of the machine. In this respect it is complementary to the action test programmes which can be used to localize weaknesses by calling on different parts of the machine during tests, but it is more powerful in that the locality of test is much more precise and that it can be used to test to the point of failure.

Operation of LEO

When, after the morning maintenance and testing period the engineer in charge is satisfied that there is a safe margin for reliable operation he passes control of the machine over to the operational staff.

Operating procedure when using the machine on clerical work is necessarily more complicated than when mathematical work is being done, if only because of the great volume of data and results that have to be handled. In a mathematical job, a short length of data tape may provide sufficient information to keep the machine busy for several hours whereas a typical clerical job taking two hours to complete may require as much as 200 yards of punched tape and 3 000 punched cards.

One of the first jobs envisaged for LEO was the preparation of a payroll and this job, which is now being done weekly for a staff of 2 500, will be used as an example to describe the operating procedure. The first operation is to feed the programme into the machine. This is contained in a pack of punched cards which are placed on the Hollerith card reader; reading-in is initiated by pressing the CARD START button on the control desk and takes about 30 seconds. The first two or three cards carry instructions for stacking in the store what is on the rest of the cards.

As each card is read in, the contents are summed and checked against a check total carried on the same card. This check procedure not only checks that the cards are read correctly, but also that they are in the correct order. If the calculator finds that a card has been misread or is missing or out of order, then the calculator stops and the operator must find the cause of the stoppage.

While the programme is being read in, the operator puts punched tapes representing the current data for the week on the two photo-electric readers. It simplifies the preparation of the data tapes to have the current data on two separate tapes, one of which carries amendments to the other. It is extremely important that the data tapes used should be free from all errors; methods of preparing and checking the data will be described in Part 3. The operator also ensures that the appropriate pre-printed stationery has been put on to the printer and a supply of blank cards on to the card punch.

When the last programme card has been read into the store, the machine stops. The operator now places on the card feed another pack of cards carrying brought-forward details for each man, which were recorded the previous week by the calculator. All is then ready for the job to commence.

The RESTART button is pressed and the job then carried on without further human attention—data being read from the tape-readers and the card feed, the results to be carried forward being punched on to blank cards and the results of the computation relating to each man being printed on pay-slips by the tabulator. Calculations for each man are made separately so that the operation follows the routine:

Read current data	(Tapes)
Read brought-forward data	(Cards)
Calculate	
Print pay-slips	
Punch carried-forward data	(Cards)
Read current data for next man, etc.	....

All of these steps overlap, that is to say, that printing the pay-slip and punching carried-forward data for man No. 1 goes on at the same time as calculation for man No. 2 and reading the data for man No. 3. The time taken to deal with one man is about 1·2 seconds.

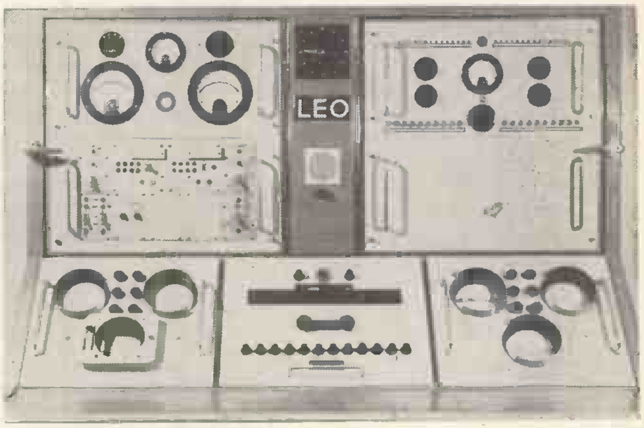
Like all programmes used on LEO, the payroll job is so arranged that the calculator will stop if the data or the result of computing become inconsistent with the criteria laid down. If this happens, it is important that work already done shall not be lost. It would be intolerable, if a data error or machine fault occurring towards the end of a job lasting several hours, made it necessary to start again from the beginning. For this reason, most programmes provide for punching intermediate results on cards so that in the event of a stoppage, the job may be picked up at a point where the results are known to be correct.

In the case of payroll, men are naturally divided into departments so that if a stoppage were to occur that called for re-feeding the programme, then it would only be necessary to restart the job from the beginning of the department where the stoppage occurred. The necessary continuity of totals is provided by a series of total cards punched out automatically at the end of each department.

Typical inconsistencies which cause the machine to stop during the payroll job are as follows:

1. Key number on current data not agreeing with that on brought-forward;
2. Data not in correct ascending order of key members;
3. Check totals in input data not agreeing;
4. Hours × Rate not agreeing with Rate × Hours;
5. Department End card not being followed by Start card of next department.

The programme is so arranged that according to the type of inconsistency discovered, an indication is given in the



Leo monitor desk: showing meter panel, frequency monitor and auxiliary equipment controls (top right), marginal test controls (top left), monitor tubes and calculator controls.

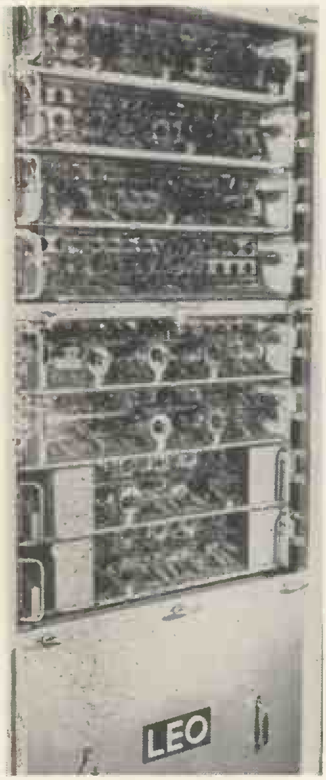
order register of the machine. The operator is provided with a schedule of operating instructions which enables him to decide what has caused the fault and what course of action he should take. For example, the current data might include no details for a man for whom brought-forward data existed. In that case, the operating instructions provide for two courses of action. If the current data is out of order, manipulation of the data tapes to re-align them is permissible. Alternatively, the accumulator may be cleared and the machine restarted; details for that man are then ignored, no totals accumulated for him, and an "exception" slip is printed to indicate an abnormality.

Where a more complex query occurs, the job would be restarted at a different point, probably at the beginning of the next department, so that the machine could continue its work while the query is being settled. Later the department in which the query occurred would be done again.

During the job, the printed results are being scrutinized so that if any obviously incorrect pay-slips are printed, action can be taken immediately.

Assuming that no inconsistencies of data are encountered the job continues until the last man has been dealt with, (an indication of this is given on the last card) and then the machine halts. On the completion of the pay-slips for the last department, the pre-printed stationery on the tabulator is replaced by plain stationery and a supplementary programme is fed in on the card feed which causes a series of totals and reconciliation accounts to be printed out. One object of these accounts is to verify as far as possible all the arithmetical calculations that have been going on by a series of cross-checks. An example of this is the account that checks that the total gross pay for all employees agrees with the sum of all the net pay plus all deductions. This illustrates the comparative ease with which programme checks can be incorporated and so draw attention to any failure, intermittent or otherwise.

In order to provide an assurance of the serviceability of the machine before and during jobs where checks are difficult, a form of test not so far mentioned is used. This consists of a short run using test-data on the programme that is about to be used. Marginal conditions are imposed on the machine and as the results expected from the test-data are known, such a test gives a good assurance that the machine is in a fit state to do the job. Where a job is a long one, consisting of several hours of work, these test-runs are done at regular intervals so that if a fault were to develop during the job, warning would be given in good time to prevent time being wasted on a doubtful machine. Where this method of testing has been successfully applied to the end of a run, no case of error in results has yet been discovered.



A rack of Leo units: showing accessibility of components; any unit can be removed and replaced by a spare in a little more than a minute.

Tracing Faults

If during operational work a stoppage occurs that cannot be explained by the operator in terms of data inconsistency, or if there should be an obvious calculator failure, then the situation is reported to the engineer in charge and a decision has to be taken on the next course of action. If it is agreed that the calculator was at fault, then the operator hands over control of the machine to the engineer.

Calculator faults can generally be classified under the same three headings as were considered in dealing with valve failures, viz:

1. Failure due to drift in characteristics of components;
2. Catastrophic failure;
3. Intermittent failure.

Failures of the first type may be due to ageing of valves or slow changes in the values of resistors. They are normally made evident during a routine marginal test, and the particular faulty component is traced by the analytical use of marginal testing switches already described.

Catastrophic failures may be caused by open-circuit valve-heaters, fuses blowing, or failures of insulation in capacitors. Although it is impossible to get any advance warning of this type of fault, it is usually fairly easy to deal with, since the circuit concerned normally fails consistently. The analytical type of test programme often provides a ready clue to the cause of the trouble.

Undoubtedly, the most difficult type of fault to deal with is the intermittent fault. In its worst form it may occur at intervals of several hours, if not days, and may be extremely difficult to locate. In such circumstances there is not much that can be done apart from collecting evidence provided by the circumstances in which the fault occurred. When it eventually becomes more frequent, as it usually does, the evidence will often indicate a point where local vibration will make the fault even more frequent, and allow it to be discovered.

When an intermittent fault is known to exist the decision as to whether to pursue the fault or to proceed with productive work is the responsibility of the maintenance engineer. If the work to be done is likely to give a clear indication of the occurrence of the fault and if it is very infrequent, he may decide to proceed and collect further evidence should a stoppage occur. If, however, the job is one the results of which are not easily checked, as in a mathematical job, then he may choose to investigate the fault using test programmes.

Fortunately, the cause of most faults is fairly obvious. For example, if the machine stops due to an order having disappeared, then it is likely that the fault is a catastrophic failure in the circuits of that part of the store, especially if the order has been used several times before in the same programme. On the other hand, the cause of some faults is not so easy to determine and for this reason it is important to have a systematic approach to the problem of tracing faults.

It has been found by analysing experience that there are, in fact, six natural stages in the process of dealing with a fault. These are, in order:

1. *Recognition*: Establishing that what appears to be a fault is in fact so, and not due to programme error or to data which is inconsistent with the requirements of the programme.
2. *Planning the attack*: Making sure that the maximum significance is extracted from the evidence provided by the fault itself.
3. *Localization of the fault*: The discovery of the particular kind of faulty behaviour of the circuits underlying the first manifestation.
4. *Discovery of the prime cause*: The discovery of the faulty valve or component.
5. *Rectification of circuit or components*: The replacement of the faulty part by a sound one. On some occasions this may most easily be done by changing the unit.
6. *Confirmation that the fault has been cured*: The proof that the fault has genuinely been cured is most important because:
   (a) The symptoms may have been ascribed to a wrong cause and the fault may not have been put right;
   or (b) There may have been more than one fault present and only one has been put right.

Each stage is best considered as a series of questions and answers to be supplied by the engineer himself. In the recognition stage, for example, the questions to be answered include:

1. Is it obviously a calculator fault ?
2. Has the programme been used successfully before ?
3. Have any alterations been made to the programme since it was last used ?
4. Are data checks incorporated in the data ?
5. Is it possible that abnormal data could cause the effect ?

Unless the answer to the first questions is " yes ", it may save time to run through the job again. If the results from the second run agree with the first then a closer examination of the programme and data is necessary.

Once the machine is suspect, there is always a danger that precipitate testing of the machine may destroy evidence held in the store, so that it is often useful to extract the contents of the store by using what is called a "post-mortem" programme which compares the programme of orders in the store with what should have been there at the commencement of the job. Any orders that differ are printed, together with the original version, with the addresses appended and these are then checked to see that the alterations are permissible ones.

When it is certain that the maximum amount of information has been obtained from the contents of the store and the registers of the machine, the next stage in the procedure is followed, making use of test programmes and the marginal testing system whenever possible.

Maintenance Team

The responsibility for maintenance and fault-finding on LEO rests upon a team of two electronic engineers, one senior and one junior. The junior engineer carries out daily tests, interpreting the results and supervising the changing of units. He attends to minor faults as they occur and makes such adjustments and replacements as are indicated by the results of the tests. The senior engineer is less directly concerned with the machine and is responsible for the maintenance policy. He studies the test and fault reports and gives such directions as are necessary to counteract changes in circuit conditions before they cause errors.

When the calculator is suspected of being faulty, control is handed over to the maintenance engineer so that he can take the necessary steps to confirm and correct the fault. His first action on taking over is to note what evidence may be available. A portable dictating machine is used for recording this and the subsequent progress of investigations. He also informs the senior engineer of the position, and then proceeds to locate and rectify the cause of the trouble using either suitable test programmes, or possibly, the particular programme on which the machine has failed. If the fault is not cured in a few minutes, the senior engineer investigates the progress made and may suggest an alternative line of approach. The senior engineer may, in a difficult case, spend some time with the junior engineer collecting evidence from the behaviour of the machine to enable him to study the problem away from the machine.

Experience has suggested that this approach on two levels is a very efficient way of putting the machine right quickly. Simple faults are put right almost at once by the man who lives with the machine, but when a complicated trouble arises, a more detailed knowledge of the logic of the machine applied to the evidence available may be required and although it is necessary to keep investigation proceeding on the machine itself, a tricky fault may often be diagnosed more quickly in the quiet of a neighbouring office.

Conclusions

Economical techniques of maintaining and operating LEO have been developed and are continually being improved.

The standard of reliability over the past year, during which a large amount of development work has been done, has improved and shows that the approach to maintenance outlined is fundamentally sound. The mercury delay lines of the store have given virtually no trouble since a reliable method of filling was found two years ago. Because marginal tests can be applied at will to individual circuits, and the magnitude of the marginal voltage can be raised, the system adopted is extremely effective both in anticipating and locating the sources of faults. It gives information that could be obtained in no other way.

A good deal still needs to be learned about methods of detecting and curing intermittent faults. It would be optimistic to hope for an easy solution to this problem, but we feel that by a study of the nature of this type of fault we may learn better methods of dealing with them.

Valves continue to be the main cause of trouble and efforts must continue to be made to provide better methods of testing these outside the circuits of the machine. Experience with thermionic diodes and crystals shows that in the circuits of LEO, the latter are far more reliable in general use but more prone to accidental damage. Our development programme provides for the replacement by crystals of many thermionic diodes now in use.

As regards operation, our experience has convinced us that routine commercial clerical work can be performed by an installation having the features described; that, provided there is a sufficient volume of work, it can be performed very economically; that provided proper measures are taken in regard to the maintenance and provision of spares, it can be carried out to a fairly exact schedule; and that above all, where such an installation is used it will in any case produce results more quickly than by other means.

Acknowledgments

The author would like to associate himself with the acknowledgments made at the conclusion of Part 1 and in particular is indebted to Mr. T. R. Thompson and Mr. J. M. M. Pinkerton for their assistance in the preparation of this article and to the LEO Maintenance and Operating Teams, without whose co-operation the present efficiency of operation would not be possible.

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(*To be continued*)

A Television Camera at Bradford Technical College

A television camera has recently been designed and constructed by the Head of the Department and members of the staff of the Electrical Engineering Department of the Bradford Technical College.

The camera is constructed around a Pye Staticon Miniature Camera Tube which operates on the photo-conductive principle and not by electron emission. The scanned area is only about 12·5mm by 9·5mm which enables a 1in $f/1{\cdot}9$ lens to be used. The standard 405 line 2/1 interlaced system of scanning is used so that the camera may be used to feed a normal television receiver. The camera itself measures 10in by 9in by 7in and is fitted with an electronic viewfinder. The camera contains a two-valve pre-amplifier and cathode-follower, with time-bases and video amplifier for the electrostatically deflected viewfinder, together with pulse amplifier for blanking the beam of the camera tube during the flyback time.

The camera feeds, through a multicore cable, a control unit fitted with 9in monitor tube. The control unit contains a pulse generator which produces correct line and frame synchronizing pulses and suitable blanking pulses for the camera, together with clamping pulses and blanking pulses for the video amplifier. It also contains the time-bases for the camera tube and monitor tube and the supply units.

Blanking signals are then introduced to suppress the picture for the required periods. Finally the line and frame synchronizing pulses are added to give a complete video waveform, which is fed to the viewfinder and, after another stage of amplification to the monitor tube. The output is also used to modulate an R.F. amplifier fed from a small oscillator. The output from this unit is very small and is used on a closed circuit to feed television receivers.

The control unit also contains a Monoscope which enables a test card "C" signal to be produced and fed to the monitor and R.F. amplifier in place of the signal from the camera.

Colour Television Broadcasting in the U.S.A.*

By C. G. Mayer†, O.B.E.

A description of the RCA system adopted for the broadcasting of colour television in the United States of America; together with a brief account of the present status of colour television in that country.

MAN has been intrigued with the possibility of transmitting colour pictures from the earliest days of television, and it has been known for a considerable time how to do it in a crude kind of way, by methods much too inefficient and wasteful to find a place in broadcasting as it serves society today. Mankind progresses, at least in a technical sense, as one learns to understand and make use of the secrets of nature. Just as sophistication follows experience, and maturity comes as a result of both; so colour pictures follow black-and-white in the orderly development of television.

The basic problem was to find a way by which colour could be added to the existing black-and-white service—a service which today reaches nearly 30 million receiving sets in the homes of the American people. Under these circumstances it was obviously highly desirable that the transition to colour should be introduced smoothly and without disrupting the good relationships between the broadcaster and the public. The challenge to our ingenuity therefore was to devise a transmission specification which would enable colour programmes to be received in colour on a colour set, and in monochrome on existing black-and-white sets at no additional cost to set owners, and without any changes or added devices. The colour set should also be able to produce black-and-white pictures from standard black-and-white transmissions. A colour television system of this kind is called "fully compatible" and has been finally adopted. In doing so, however, there was another major problem.

The Federal Communications Commission, which has the responsibility for regulating, in the public interest, the use of the ether in the United States, has established the standards for black-and-white television to operate within the 6Mc/s channel allocation structure shown in Fig. 1. These standards have given good service and as a result television broadcasting has developed rapidly.

It soon became evident that to meet the demand to establish new transmitting stations many additional channels would be required. Frequency bands are assigned by International agreement, and at Atlantic City in 1947 the Nations of the World agreed that certain bands, known as Bands I, III, IV and V, should be reserved for television broadcasting. In the United States the 12 channels available in Bands I and III are already completely in use, and the only possibility of providing the needed channels was to extend the allocation structure into the under-developed ultra-high-frequency bands above 400Mc/s, i.e. into Bands IV and V. This was done and provided a total of 70 new channels, using the same television standards as for Bands I and III, so that there are now 258 stations operating in these bands, and an additional 130 stations operating in Bands IV and V. A further total of 220 construction permits have been granted in both bands and 250 applications for new stations are pending. Most of the stations can be interconnected for network operation, and the majority of viewers have a choice of several programmes.

The importance of radio spectrum conservation cannot be emphasized too strongly. Already there is severe congestion, and with the ever-increasing uses of radio services, each interested in establishing its right to an appropriate place in the available ether space, the prospects of relief are slight. The transmission characteristics of the ether differ considerably according to the frequency used, and we certainly cannot afford to add to the congestion by any wasteful occupancy of the radio spectrum.

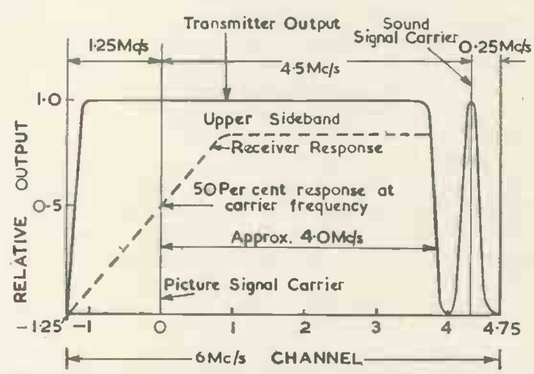

Fig. 1. Standards in United States for black-and-white television

525 lines; 30 frames; 60 fields interlaced scanning; horizontal polarization negative transmission; A.M., *video;* F.M., *audio.*

As a result of these considerations the Federal Communications Commission took the view that it would not be feasible to provide any extra bandwidth for colour. So if we were to have colour television, a way had to be found of compressing the greater amount of information required into the same channel space provided for black-and-white television.

It will be convenient to examine the solution to the problem in two parts. First, the characteristics of sight in relation to colour will be briefly reviewed; and second, the electrial techniques which make it possible to add the extra information needed to give satisfactory and pleasing television pictures in colour.

Colour printing, painting and colour photography depend on the basic principle that by mixing three suitable colours (usually green, red and blue) almost any desired colour sensation can be produced. These familiar arts use pigments or dyes, whereas in colour television coloured light is mixed. This has to be converted by a television camera into electrical signals for radio trans-

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† European Technical Representative, Radio Corporation of America.

mission and reconverted to light by a picture reproducing tube, or kinescope as it is called, in the receiver, in order to be made visible to the eye. Since the eye is most sensitive to green, less sensitive to red, and least to blue, correct brightness is obtained by mixing the colour signals together in carefully specified proportions.

Colour Vision

Human vision is a complex process involving the eyes and the brain in ways which are far from being fully understood. We experience the sensation of colour in terms of its three major attributes, brightness, hue and saturation. Brightness is a measure of light intensity or "luminance", and is the only attribute common to both coloured and non-coloured objects. Hue is characterized by the dominant wavelength of a colour, which determines

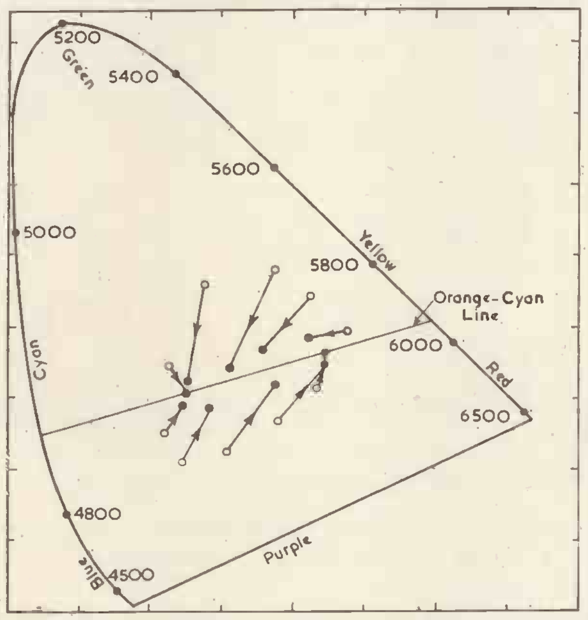

Fig. 2. The C.I.E. colour triangle and the colour matching of small pieces
The numbers are the approximate wavelengths in Angstrom units.

whether it is red or green or blue, etc. Saturation describes the vividness of colours of the same hue, and may be thought of as related to "purity", or freedom from dilution with white.

The science of colorimetry has been built up around the principles of colour mixing, and by international agreement the "chromaticity diagram" of Fig. 2 has been adopted, which enables colours to be specified as points on such a diagram in terms of mixtures of standardized primaries[1]. The location of a point completely determines hue and saturation, but indicates nothing about brightness. The visible spectrum is displayed as a closed horseshoe-shaped curve, all realizable colours being shown on the periphery at full saturation, i.e., in going round the periphery hue varies, but saturation stays constant. If we follow a quasi-radial line from a colour at the periphery into white, hue is maintained constant while saturation diminishes.

By suitable choice of primaries, three-colour presentation may be regarded as entirely satisfactory for our purpose. However, it is found that while three-colour mixing is necessary for large areas, when the area under examination is sufficiently small, adequate reproduction may be obtained with mixtures of only two colours. This fact emerges as a result of a great deal of new data on vision accumulated in recent years, and perhaps not yet widely appreciated.

In 1945, Willmer and Wright[2] reported finding that any colour in a small enough patch can be matched by mixing only two, and not three, primary coloured lights. Two Canadian scientists, Middleton and Holmes[3], performed the following experiment. They cut small pieces from colour sheets and then asked observers to match the pieces to various large sheets. It was found that the best match was with sheets of different colour from those from which the pieces were originally cut. Their results are shown in Fig. 2, where the circles represent the chromaticities of the original sheets, and the dots the chromaticities of the sheets which gave the best colour match. It should be noticed that for the small pieces the chromaticity diagram tends to become a single line; also that the two primaries needed for this line are an orange-red and a greenish-blue (called cyan). Another English worker, Dr. Hartridge[4], has also made a wide variety of investigations on colour acuity in small detail, which corroborate these findings. Further confirmation is to be found in studies of two-colour photography. Clyne notes that although other pairs of primaries are capable of giving black and grey, only the orange-cyan combination can represent adequately the hues of sky, flesh and foliage which are so familiar in nature. Add to this data the observations of sharpness of vision of colour and of brightness contrast edges made in the RCA Laboratories, and one finds all the experimental evidence in full agreement that for fine detail areas in a picture, two-colour presentation is entirely adequate. Moreover, the evidence indicates that the eye seems to have greatest acuity for colour differences when they lie along the orange-cyan axis. In passing, it is interesting to note from this that people with normal vision see small coloured objects in about the same way as people who suffer from green-purple colour blindness see all objects.

Now what happens when the detail becomes very fine? A. V. Bedford carried out tests several years ago on visual acuity to colour which established that the eye does not see colour at all in the very fine detail of a picture; only the perception of brightness remains[5]. Actually, the acuity of the eye for red is slightly less than for green, and for blue less than either. The eye is also more sensitive to changes in brightness than it is to changes in hue and saturation. It will be appreciated that as picture detail becomes finer the orange-cyan axis collapses to a point which represents white on the chromaticity diagram. It is also necessary to remember that information theory tells us that the transmission of fine detail requires more bandwidth than is needed to transmit coarse (or large area) detail. In general a transmitting channel can forget what it was doing last in one-half cycle of the highest frequency passed. Thus a 4Mc/s channel has the capacity of transmitting a maximum of 8 million fully independent amplitude values per second, although in practice the rate at which information can be passed over a given channel is determined by the prevailing signal-to-noise ratio.

At one time it was thought that the transmission of a picture in three colours would involve transmitting three times the amount of information required for a monochrome picture, and would therefore necessitate a frequency band three times as wide, but it has been realized for some time that this is entirely unnecessary. In fact, it has been determined experimentally that the bandwidth for colour information alone can be limited to approximately 1½Mc/s without the eye realizing any loss of colour in the transmitted picture.

It is known from experience with black-and-white television that the resolution of the eye for fine brightness detail at normal viewing distance is well satisfied with pictures produced with the normal 525-line scanning process. This involves a video bandwidth of about 4Mc/s, which can therefore be regarded as adequate to handle the luminance information required for all conditions of picture detail.

Summarizing the position by combining these characteristics of vision with a knowledge of electrical transmission, the signal requirements for telecasting in colour may be stated briefly as follows:

For relatively large picture areas—three-colour (green, red and blue) information, requiring a narrow band of frequencies (about ½Mc/s).

For relatively small picture areas—two-colour (orange and cyan) information, requiring a moderately broad frequency band (about 1½Mc/s).

Luminance (brightness) information for all conditions of detail, requiring the same bandwidth as for black-and-white pictures (about 4Mc/s).

It should be noted also that since nothing is gained by transmitting picture information which the eye does not appreciate, any system which attempts to provide full details of all objects, regardless of their size and chromaticity, should be deprecated as wasteful of spectrum space.

Electrical Techniques [6,7]

This brings one to a consideration of the electrical techniques needed to transmit and receive three separate signals to satisfy these requirements within the framework of compatibility and the prescribed spectrum space.

The sending of two or more independent messages together over one transmission system, yet keeping the messages separable at will, is an old problem in communications. The technique is known as multiplexing, and it is widely used. There are several methods, all requiring greater channel bandwidth than is needed for a single message. The method favoured for multiplexing the two chrominance components is by time division, which involves sharing a channel on a time basis by providing synchronous switching arrangements at the transmitting and receiving ends of the circuit.

In applying this method to colour television, an advantageous switching arrangement is to produce two carriers of the same frequency displaced in phase by 90 degrees, each of which can be independently amplitude modulated simultaneously to produce a single resultant carrier of the same frequency. The in-phase or *I*-signal is made to carry colour saturation information, and the quadrature or *Q*-signal carries information as to hue. The particular method of modulation used results in double-sideband transmission and suppression of the carrier. This becomes the chrominance subcarrier which is conveniently added directly to the main picture carrier. Since the subcarrier is suppressed at the transmitter in the interests of reducing crosstalk, it has to be re-inserted at the receiver in order to be able to recover the *I* and *Q*-signals by synchronous detection. This requires the provision of a local subcarrier oscillator in the receiver which is kept at the same frequency and in phase with the corresponding subcarrier oscillator in the transmitter. It is achieved by transmitting a sample of about 9 cycles of the transmitter subcarrier, which then serves as a reference signal in the receiver to lock the subcarriers together. Interference with other parts of the television signals is avoided by adding the sample or "colour burst" in the line retrace blanking period which follows the regular horizontal synchronizing pulse.

It is necessary now to combine the chrominance and luminance signals to produce the complete colour signal. The combining of these signals by ordinary side-by-side methods would require a minimum bandwidth of about 6Mc/s, which is still in excess of the video bandwidth available. One has therefore to resort to multiplexing again to compress the information into 4Mc/s, but in doing so one is faced with additional problems of interference, or crosstalk, between the signals, which makes it more difficult to separate them cleanly.

This crosstalk has been one of the major transmission problems in the evolution of compatible colour television systems. It can give rise to annoying defects which take the form mainly of crawling patterns in the received picture. Recent developments incorporated in the RCA system have, however, succeeded in eliminating most of this trouble.

Many years ago Metz and Grey studied the problem of transmitting two television pictures within a given channel. They discovered that the distribution of energy of signal components due to the process of television scanning, results (for most subjects) in almost all of the energy being bunched around frequencies that are whole multiples of the line scanning frequency, as shown in Fig. 3. However, at frequencies half-way between, corresponding to odd multiples of half the line frequency, the spectrum is substantially unoccupied. An additional carrier, carrying independent picture information, can fill these frequency spaces, provided that the added carrier is offset from the main picture carrier by this odd

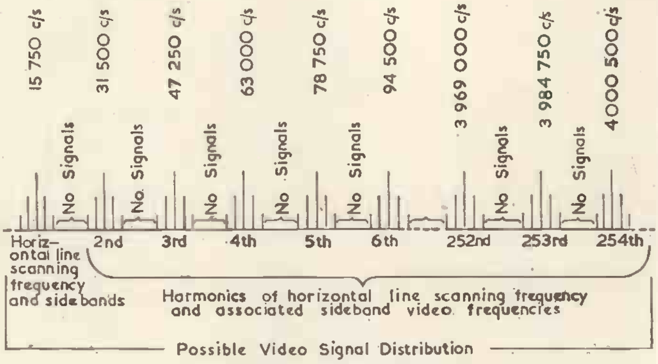

Fig. 3. Distribution of video frequencies

multiple of half the line frequency. The process is commonly referred to as "frequency interlacing" and results in the carrier and its sidebands being interlaced with the harmonics of the line and frame frequencies. In practice an additional transmitter may be avoided by using a subcarrier modulated with the extra information to be transmitted.

A useful analogy to illustrate the way the gaps in the spectrum are filled is to regard the video channel as a comb, with teeth representing the luminance signal. The chrominance signal can then be considered as the teeth of a shorter similar comb which is placed in such a way that the two combs interlace; the accurate positioning of the second comb being determined by proper choice of the subcarrier frequency.

Another way to look at this matter is to consider it from the point of view of horizontal interlaced scanning. This is known as an important band saving technique involving the interlacing of two sets of picture elements along each scanning line. If only alternate elements (or dots) of alternate lines are transmitted, in a single field scan, four such fields are required to build up a complete picture frame. Dot-interlacing reduces picture element size and also reduces visibility of flicker. The sequence of interlacing can be so arranged that successive scans are additive, or a cancelling type of interlace can be adopted. Basically cancellation occurs when provision is made for reversing polarity of the signal between successive scans of each area of the picture. Interference patterns corresponding to crosstalk between the luminance and chrominance signals then tends to cancel out through the effects of persistence of vision. Dot-interlacing is arranged by ensuring that the picture element signal occurs at a frequency that is an odd multiple of half the line frequency, which happens when the subcarrier goes through a whole number of cycles plus a half-cycle for each frame period. These are exactly the conditions for "frequency interlacing," thus it is apparent that frequency-interlace always gives rise to dot-interlace and vice-versa, so that in effect both concepts produce the same result.

Some of the main considerations of the system have now been broadly covered and, while there are still a great many details untouched, enough has been said to enable us to specify the general form of transmission signal that will provide a compatible colour television service with optimum spectrum utilization within a 6Mc/s channel bandwidth.

(1) Full 4Mc/s video bandwidth signal, representing luminance variations of the subject, transmitted as amplitude modulation of the picture carrier.

(2) Addition of a suppressed subcarrier located within the video band at a frequency determined by "frequency interlace".

(3) Simultaneous modulation of this subcarrier by two chrominance components:

(a) *I*-signal (requiring about 1½Mc/s bandwidth) representing saturation, which varies the amplitude of the subcarrier.

(b) *Q*-signal (limited to about ½Mc/s bandwidth) representing hue, which varies the phase of the subcarrier.

(4) Addition of a phase reference signal consisting of a sample burst of the subcarrier frequency transmitted as part of the conventional synchronizing signal.

(5) F.M. sound channel as transmitted for black-and-white television.

Many important details have to be considered before a specification can be written, but there is space to deal with only a few.

The choice of frequency for the subcarrier is a compromise of several factors. It is desirable to make the frequency as high as possible, so that dot-pattern will be fine and its spurious effects due to imperfect cancellation kept to a minimum. On the other hand a relatively lower frequency increases the bandwidth available for transmitting the chrominance signal. It has been found that for this purpose it is sufficient to provide a band extending in frequency to about ½Mc/s above the subcarrier frequency. Thus with the available 4Mc/s video bandwidth, a frequency around 3½Mc/s is indicated for the subcarrier. The actual frequency is determined by the "frequency interleaving" principle, and by consideration of possible interference with the sound carrier in a receiver.

Experiments have shown that any beat signal between the sound carrier and the chrominance subcarrier (due to insufficient attenuation of the sound carrier in some existing black-and-white receivers) is much less objectionable in the picture if the beat signal frequency is an odd multiple of half the line frequency. This can be arranged by separating the sound and vision carriers by an amount corresponding to a multiple of the line frequency, i.e., an even multiple of half the line frequency. It is not practicable to alter the present sound carrier because of the large number of existing receivers, and therefore to achieve the desired offset operation the line frequency and field rates have been shifted very slightly, actually about 0·1 per cent, which is within the tolerances of the existing black-and-white standard. Non-synchronous operation of the transmitter with the power supply is therefore now essential, but this had already been found necessary for black-and-white television because of network and remote operation. In order to satisfy these conditions the frequency for the chrominance subcarrier works out to be 3·579545Mc/s (with a line scanning frequency of 15 734·264c/s and field rate of 59·94c/s). The spectrum of the transmitted colour signals is shown in Fig 4.

This choice of frequency for the subcarrier results in unequal sidebands, since it allows only ½Mc/s for the upper while the lower sideband can extend to about 1½Mc/s below the subcarrier frequency. As mentioned earlier, in the process of interlacing crosstalk can be made self-cancelling, but such unbalance in the sidebands gives rise to additional crosstalk, and means have had to be devised to eliminate this. The bandwidth required for large detail areas is less than 1Mc/s and therefore involves no crosstalk problem. However, as picture detail becomes finer, unbalance occurs in the sidebands, and crosstalk would develop between the components of the chrominance signal. This is prevented by limiting the *Q* bandwidth to ½Mc/s so that in picture detail areas where there would be crosstalk if two signals were present, the *I*-signal only is transmitted and is then of course, free of crosstalk.

It has been emphasized that it would be wasteful use of the spectrum to transmit more information than the eye can see, and it is equally obvious that the same piece of

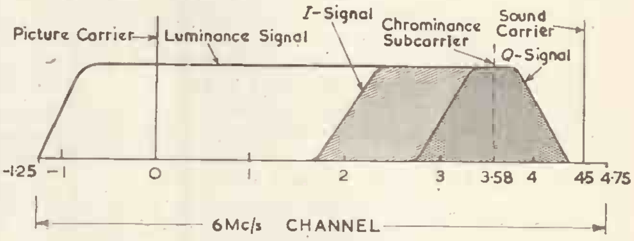

Fig. 4. Spectrum of transmitted colour signal

information should not be transmitted more than once. This would happen if each of the chrominance components of a scene to be transmitted contained information relating to brightness as well as to colour. It will be remembered that to satisfy the requirement for compatibility, brightness of the scene is transmitted as amplitude modulation of the carrier in the conventional way. Thus to avoid redundancy, the brightness signal needs to be subtracted from each of the green, red and blue colour signals. But to transmit four pieces of information when only three are required would again result in transmission of redundant information. The signal representing green minus brightness can be obtained at the receiver by subtracting the sum of the red and blue signals from the brightness signal. It is therefore arranged to transmit only signals representing red minus brightness and blue minus brightness along with the brightness signal. As a matter of interest there is no physical equivalent to the term colour minus brightness since the eye responds only to colour accompanied by brightness. In practice the colour-minus brightness signal is derived by subtracting the electrical value of the brightness signal from the electrical value of the colour signals, using a linear matrix computor. The brightness information is restored at the colour receiver, and the green, red and blue signals required to activate the tri-colour kinescope or cathode ray-tube are obtained.

In using these two colour-difference signals to modulate the subcarrier, a refinement is to mix each with the other so that the blue minus brightness contains some red, and the red minus brightness contains some blue. This does not affect the large detail areas of the picture, but for intermediate picture detail a contaminated or blended colour varying from orange to cyan is produced, which results in less noticeable distortion than when a single pure colour is transmitted. The reduction in edge distortion so obtained is due to the fact that the eye is less sensitive to colour in these edges when sharp contrast with the adjoining areas is avoided.

Having said all this about television, it is interesting to draw a parallel with the art of painting. One finds that the practice in classical art is first to create form and second to add colour. After laying the base colour, the artist usually paints in the form in monochrome, generally in black or brown and white, paying special attention to the sharp boundaries of the composition, and afterwards adds the touches of colour. This can be observed in paintings from about the 16th century onwards and may be compared with the work of some of our modern Impressionist artists who prefer to let form look after itself, and paint in colour direct from the start. In the system of colour television described the monochrome signal provides the detail or form, and the colouring is added separately, in what might be regarded as the technique of classical art.

Compatibility

Two conditions have to be considered; first, reception of colour transmissions on a conventional black-and-white receiver. It is easy to see that when there is no colour in the transmission the receiver responds fully to the luminance signal and displays it as usual, with a quality equal (or superior) to that provided by present black-and-white transmission standards. When there is colour in the original scene the chrominance information is transmitted, but self-cancellation occurs because of subtractive interlace in the colour system, and except for a residual spurious pattern due to non-linear effects in the kinescope, the receiver is not affected by the colour signal. The choice of subcarrier frequency results in the pattern being of such fine texture that at normal viewing distance where the usual scanning line structure disappears, the spurious crosstalk also disappears. The viewer seeing the picture is therefore normally unable to notice any difference from the reception of pictures from a regular black-and-white transmitter.

The second condition is reception of black-and-white transmissions on a colour receiver. This presents no problem since only the luminance signal is present. It is essential, however, that the tri-colour kinescope is carefully manufactured and capable of being adjusted to give a white field free from colour contamination due to misregistration or improper convergence of the electron beams. When properly used such a tube gives black-and-white pictures equivalent in quality to those received on conventional black-and-white receivers.

Complete Signal Specification

The complete signal specification for colour television broadcasting was recommended to the Federal Communications Commission by petitions submitted by RCA in June 1953, and shortly afterwards by the Nation Television System Committee, representing the radio industry. The practicability of the proposed specification had been checked by extensive field testing, and altogether the colour effort involved the co-ordinated teamwork of the most highly skilled electronic engineers and scientists in the United States[8]. The work represented many thousands of engineering man-hours, and the expenditure in pioneering research and development by RCA alone amounted to more than £10 million.

After witnessing demonstrations, and with due consideration of all the factors involved, the Federal Communications Commission decided to adopt the industry recommendations and in December 1953 established the technical standards for compatible colour television which are now in force.

No system is perfect at the beginning. We know that the initial cost of receivers is high, and that there are certain inadequacies, none however sufficient to spoil the enjoyment of seeing pictures in colour. Any limitations may be regarded as due to apparatus and not as inherent in the signal specifications. This was recognized in the following remarks which appear in the FCC final colour television decision:—

> "The proposed colour television signal specifications produce a reasonably satisfactory picture with a good overall picture quality. The quality of the picture is not appreciably marred by such defects as misregistration, line crawl, jitter or unduly prominent dot structure. The picture is sufficiently bright to permit a satisfactory contrast range under favourable ambient light conditions and is capable of being viewed in the home without objectionable flicker. Colour pictures can be transmitted satisfactorily over existing inter-city relay facilities and improvements in inter-city facilities may be reasonably anticipated.
>
> "The success of colour hinges on mass receiver circulation, and every effort must be made to bring the price down to the level of the mass purchaser. Every effort must also be made to design equipment to minimize the additional interference susceptibility of operations under the proposed specifications.
>
> "History has demonstrated that American industry is capable of devising practical and economical equipment on a mass production basis. We have the assurance of the industry that the enormous engineering and production ingenuity at their command will be focused on these remaining problems."

Terminal Devices

The FCC standard for colour television is the result of an evolutionary process going on over many years of systems and equipment development. The devices used at the terminal ends of the system, namely the arrangement for colour pick-up in the camera and the tri-colour kinescope in the receiver, can only be described very briefly here.

The straightforward type of camera uses three light-sensitive pick-up tubes of a type known as the image orthicon. This tube is in regular operation for black-and-white television broadcasting, and possesses the high sensitivity required for colour. The optical arrangement used is shown in Fig. 5. It will be seen that an image-dividing system splits the real image formed by the objective lens into the three colour components by means of dichroic mirrors. These are specially prepared glass plates which are colour selective and can be made to transmit one colour while reflecting another. Precision controls are provided to ensure identical scanning patterns in the three pick-up tubes, so that electronic registration of the images can match the registration of the optical system. Extensive field experience with this type of camera has proved it to be a reliable means for the transmission of high fidelity colour television pictures. Thus each pick-up tube in a camera sees its appropriate colour image and produces corresponding electrical signals. These are transformed by suitable studio equipment into the luminance signal, which modulates the transmitter in the usual way, and into the colour signal which modulates the chrominance subcarrier. Of course it would greatly simplify the camera to have only a single tube. Methods of doing this have been under investigation for some time, and recent experiments with a tri-colour pick-up tube developed in the RCA Laboratories have proved very promising. Although much work remains to be done the basic principles have been established, as well as the feasibility of manufacture, so that we can expect to have a compact tri-colour tube camera capable of replacing the present day three-tube camera.

Early receivers used three kinescopes with optical filters and mirrors for superimposing the images. Such an arrangement was far from ideal and special efforts were made to develop a single tube capable of giving natural colour reproduction. As a result several different types were evolved out of which the 3 beam tri-colour shadow mask tube was chosen for initial product development and manufacture.

In this type of kinescope the phosphor viewing screen is composed of an orderly array of small closely spaced phosphor dots arranged in triangular groups of three deposited accurately on a glass plate as illustrated in Fig. 6. Each dot of the trio is a phosphor which emits either green, red or blue light according to its characteristics when excited by an electron beam. Three separate electron guns provide the beams which activate the phosphor dots and determine their brightness. A metal shadow mask containing round holes equal in number to the dot trios is interposed between the electron gun structure and

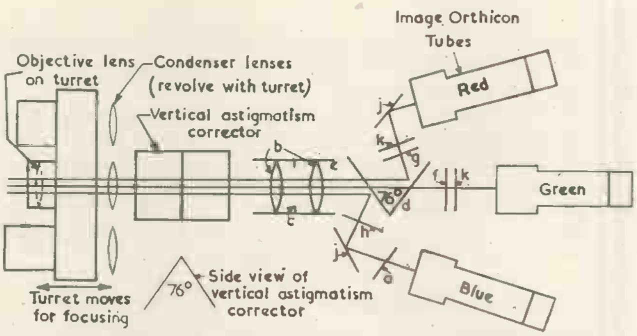

Fig. 5. Arrangement of RCA three-tube television camera

A—*Hor. Astigmatism corrector*
B—*Relay lenses both 9·5in f/4*
C—*Remotely-controlled iris*
D—*Red reflecting dichroic*
E—*Blue reflecting dichroic*
F—*Green trimming filter*
G—*Red trimming filter*
H—*Blue trimming filter*
J—*Front surface mirrors*
K—*Neutral-density filters*

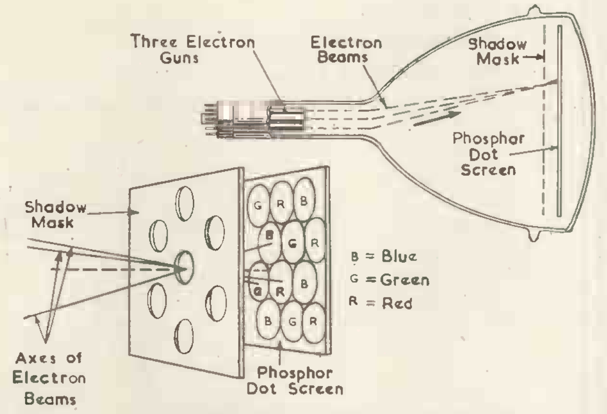

Fig. 6. Arrangement of RCA tri-colour kinescope

the phosphor dot plate. The geometry of the parts is arranged so that electrons from the red gun reach only the red emitting phosphor dots, and similarly the electron beams from the green and blue guns strike only the dots corresponding to those colours. Thus the colour signals controlling the electron beams produce independent pictures in the primary colours. Because of the small size and close spacing of the dot pattern, each trio blends into a single picture element with the result that the eye sees a full colour picture; a 15in tube of this type has nearly 600,000 dots, each approximately 0·014in in diameter, and gives a 12in wide picture. The dot structure, at normal viewing distance, is less visible than the usual scanning line structure, and the tube adequately meets the requirements for black-and-white standards.

There has been steady improvement in colour kinescope performance, evidenced by increased light output, better colour rendering, registration, etc., and also in methods of manufacture, so that the tube now in production gives excellent results. There is no doubt however that because of the prevalence in America of receivers with larger black-and-white kinescopes, it is necessary to produce larger colour tubes. Preparations are therefore in hand for production of a similar 19in tube which will incorporate still further improvements to simplify manufacture and increase efficiency. The 19in tube gives a picture about 15½in wide and has over a million dots. This is expected to be followed next year by the demonstration of a 21in tube of rectangular form, using a different principle of operation giving still brighter pictures.

The colour tube is really the heart of the system because its cost mainly determines the cost of the receiver, and therefore the price which the public has to pay to see pictures in colour. Everything else may be regarded as of secondary importance. Active development is therefore going forward in many places to bring down the cost of the colour kinescope, and the success of this effort will largely determine the rate of development of broadcast colour television.

Conclusion

In conclusion, a brief account of the present status of colour television in America is given. Colour programmes are being radiated by the NBC station in New York several times a week, and the programme time will be gradually increased. These programmes are available for network operation. Colour equipment is in production, and stations and studios in many parts of America are being equipped to broadcast in colour. RCA has offered to modify existing RCA transmitters free of charge, and its broadcasting subsidiary, NBC, is making available colour programme time without extra charge, so that sponsors can gain experience in the use of this new medium.

Colour receivers and tri-colour kinescopes are in production at a rate of several thousands per month, and receivers are now on sale to the public at prices around $1000 (about £350). It is estimated that demand for sets will exceed supply this year and next year, and that by 1957 the industry will be selling about three million colour sets annually, rising to five million annually in 1958. To install and maintain these colour receivers, which have more than twice the complexity of a black-and-white receiver, service engineers are being trained in large numbers. Already over 30 000 have attended special "colour clinic" courses conducted in 65 major cities.

Coast-to-coast radio relay circuits have been equalized for colour and are in regular use. Many more such transmission circuits will be available shortly so that by the end of 1954 over 100 stations across the country will be interconnected for network operations in colour, and colour signals will be within the range of 75 per cent of the nation's homes.

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The Selenium Rectifier in Digital Computor Circuits

By A. D. Booth*, B.Sc., Ph.D., and A. D. Holt†, M.Sc.

A brief discussion of the types of element required in a modern computing machine is followed by an examination of possible physical embodiments. The selenium disk rectifier is shown, as a result of physical measurements, to be reliable and economical and to have a wide application to computors where the frequency of operation does not exceed 30kc/s.

IN many fields of electronic application, the presence of an intermittent source of error will not be accompanied by any serious consequences. This is usually due, either to the presence of gross redundancy in the information which is being processed, or, alternatively, to certain "reasoning" facilities inherent in the receptor.

As an example, the transmission of the message

"He walked down the street"

might, in the presence of fault or noise, be received via radio telegraph as:

"He wilked den tee street"

but the message would still be comprehensible to a human recipient.

On the other hand, the information which is used in a digital computor is not normally redundant so that the presence of a single error at any stage will invalidate the whole operation of the machine from the point of disturbance onward.

It is, of course, possible to design an electronic computing machine in such a way that it can recognize errors in the numbers with which it is operating. Possibly the simplest scheme of this type, for use in a binary based machine, is to insert at the end of each word a check digit which is such that the sum of all digits (including the check) is an odd number. As an example:

Word	Check
11011	1
00100	0
11100	0

This method of error detection is limited in scope to the *certain* detecting of a single digit error. It will not indicate the particular digit which is at fault and gives no indication of the correct version of the number to which it is applied.

More complex codes exist[1] which can not only detect errors, but also correct them in certain circumstances[1]. Generally a high degree of redundancy is necessary and often the coded representation of a given number is not in a satisfactory form for the performance of arithmetic operations.

It has long been the opinion in this laboratory that in order to obtain accurate and fault-free operation of an electronic digital computing machine it is necessary to minimize the number of thermionic valves. The justification of this approach is found in the performance of A.P.E.(X).C.[2,3,4], where the "mean free path" between errors is between one and two weeks.

Quite apart from the question of reliability, it is highly desirable to reduce, as far as possible, the power consumption of the computing machine. Even on A.P.E.(X).C., with less than 500 valves, nearly 2kW of power is needed and the 175 amperes of heater current at 6·3 volts is a considerable embarrassment.

With the object of eliminating as many valves as possible a survey has been made of the various possible replacements having computor applications. Two chief lines of development have emerged, semi-conductor elements and rectangular loop magnetic cores. It is the purpose of the present article to describe some of the work carried out on the former class of material.

Some Computor Elements

Chief among the basic units required in the A.P.E.(X).C. are:

(1) The single digit store,

(2) The invertor-amplifier,

(3) The shift diode,

(4) The diode buffer,

(5) The 2_2 gate,

(6) The coincidence sensing unit,

(7) The matrix function table.

Of these (1), (2), and (5) are not directly amenable to

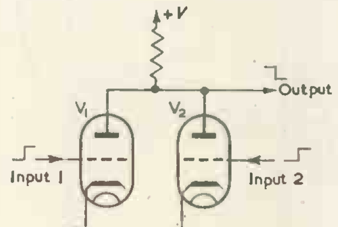

Fig. 1. Circuit for positive input and negative output

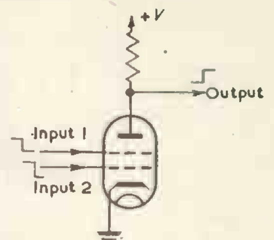

Fig. 2. Circuit for negative input

substitution by semi-conductor diode elements; although, in the case of (5), an immediate application exists when the frequency and impedance levels of associated circuits are suitable, and some indication will be given of these possibilities. The function of shift diodes is considered in an earlier article published in this journal[3] and it is proposed to hold over the discussion of the element until later in this article.

Buffer isolators are used when it is necessary to trigger a unit from one or more independent sources, they may be required to receive, or emit, either positive or negative pulses. A typical circuit, for positive input, negative output, is shown in Fig. 1. Here, both triodes are normally cut off, and a positive pulse, of sufficient magnitude, applied to the grid of either (or both) valves will lead to conduc-

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tion. Thus a negative pulse is produced at the common anode output, and no interaction will occur between the pulse sources themselves or between either source and the receptor. It is evident that the circuit can be extended to any number of inputs.

For negative pulse input the circuit of Fig. 2 can be used. The valve used is a tetrode, the anode of which is at a low potential since the two control grids are held at zero voltage and the valve is fully conducting. If negative pulses, of sufficient amplitude, are applied to either or both grids the valve will be cut off and its anode potential will rise. This new anode potential will be maintained until both grids are returned to their normal potential. An undesirable feature of this circuit lies in the fact that the rise time of the output pulse is determined by the value of the anode load resistor and the capacitance of the driven circuit. The former cannot be reduced too far without overloading the valve.

A typical diode buffer isolator circuit, for negative pulses, is shown in Fig. 3. If the D.C. levels of the input and output lines are suitably matched the capacitor C and the resistor R can be omitted; should these components be necessary, however, values must be chosen so that the time-

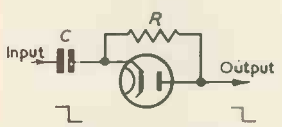

Fig. 3. Diode buffer isolator for negative pulses

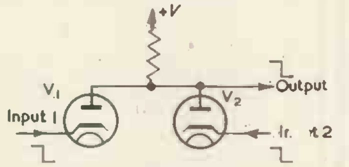

Fig. 4. Circuit for more than one input

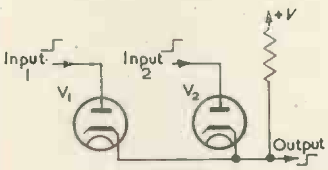

Fig. 5. Circuit for positive input

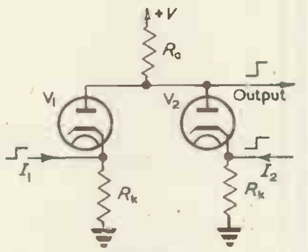

Fig. 6. Modification as 2-gate circuit

constant, RC, is suitable for the pulse repetition rate in the circuit for which the element is designed.

When more than one negative input is required, the circuit shown in Fig. 4 can be used. The diodes are normally non-conducting since their cathodes are at higher potential than their anodes. A negative pulse, of sufficient amplitude to cause the cathode potential to fall below that of the anode, and applied to one or more cathodes, will cause conduction. Thus a negative pulse of the same duration as the envelope of the applied pulses will be produced at the output point.

For positive input pulses the analogous circuit is shown in Fig. 5, the operation is identical with that just described except that both diode and pulse sense is reversed.

With only a very small modification, the diode buffer circuits just described can be made to serve as 2 gate elements. Consider the situation shown in Fig. 6 and assume that $R_a \gg R_k$ and that the internal resistance of the diodes is less than that of R_k. Under these circumstances the application of a positive pulse to either I_1 *or* I_2 separately leads to a voltage of $R_k/(R_k+R_a) \cdot V$ at A compared with $R_k/(R_k+2R_a) \cdot V$ normally obtaining, that is, to a step of approximately $R_k/(2R_a) \cdot V$ volts. When both I_1 and I_2 receive simultaneous positive inputs, however, the voltage at A rises to V (or to the positive pulse input height if this is less than V. For reasonable component values this type of gate can be seen to offer signal to breakthrough ratios of better than 10 to 1 over a reasonable frequency range.

In the past 15 years many improvements have been made in the properties of diodes (or "rectifiers") made from semi-conducting materials and it is evident that, in the case of the circuits just described, there exists the possibility of using these as replacements for the thermionic elements. It is clear that to justify a change a number of requirements must be met, for example:

(1) The ratio of forward to reverse resistance must be large.

(2) The reverse resistance must be high compared with that of any resistance used in the circuit.

(3) The forward resistance should be low compared with that of any circuit element used in series with the diode.

(4) The capacitance, especially in the reverse direction, must be low.

(5) The tolerance on any batch of the units must be within the normal 20 per cent limit.

Types of Semi-Conductor Diodes

The earliest semi-conductor rectifier to be developed was that employing copper oxide, and its discovery, in 1920, was the result of an investigation into possible replacements for the electromagnetic relay in railway signalling. The smallest copper oxide rectifier which appears to be available at present is a 1/16in diameter disk. This has a reverse resistance of the order of 1MΩ and a forward resistance of a few thousand ohms, considerable variations occur between specimens, and there is a large variation with temperature. In view of the small area, the capacittance is low, but unfortunately the maximum continuous reverse voltage appears to be only 6 volts.

Second in order of appearance as a commercial rectifier is that constructed from selenium. This has been in use in power applications for some years, it has recently become available in sizes suitable for computor work and will be discussed in greater detail later.

Germanium has many advantages over copper oxide as a rectifier material since it is less susceptible to temperature variations, has (in the point contact rectifier at least) an extremely low capacitance, and will withstand over 50 volts in the reverse direction. The resistance in the forward direction is only a few hundred ohms and that in the reverse direction a few hundred thousand ohms. Outweighing these advantages are considerations of size, cost and uniformity. The size of a germanium rectifier is roughly the same as that of a (British) half watt resistor. The cost does not differ appreciably from that of a thermionic diode, and in a test of 100 samples of the type IN38 carried out in this laboratory the back resistance, at 20 volts, was found to vary between 5kΩ and 1MΩ. Furthermore, although the back voltage rating was stated to be in excess of 50 volts, a number of the specimens would not stand more than 30 volts in this direction. Table 1 gives an analysis of the batch characteristics.

TABLE 1

Analysis of a Batch of Type IN38 Germanium Rectifiers

RESISTANCE RANGE	NUMBER	BACK VOLTAGE RANGE	NUMBER
5kΩ – 10kΩ	9	30V – 50V	7
10kΩ – 100kΩ	60	50V – 75V	80
100kΩ – 500kΩ	22	75V – 100V	5
500kΩ – 1MΩ	9	100V – 120V	8
Total	100		100

It is perhaps only fair to state that these tests were conducted on specimens of American origin made in 1948 and that no systematic tests have been carried out on an adequate sample of recent British production.

Recent reports[5] suggest that the new type of diffused silicon rectifier may have characteristics which are superior even to those of the thermionic diode, at least as far as back resistance is concerned. Too little is known about these new developments, however, to justify speculation as to their possibilities in any currently envisaged computor.

To return to the selenium rectifier, this is now commercially available in the form of small disks (¼in diameter by 1/16in thick) at an extremely low cost (about 1d). As in the production of larger units, the selenium is sprayed on to an etched, or sandblasted, metal base and then heat treated. A paper mask having rows of holes, each equal in size to the required rectifier area, is then stuck on to the selenium layer. A metal mask having holes corresponding to, but slightly larger than, those in the paper is now placed over the plate, and the whole is then sprayed with the selected counter electrode material. After spraying, the mask is removed and replaced by a flat metal plate which touches all of the circles of counter electrode material sprayed on to the selenium through the two masks. A pulsating unidirectional voltage is now applied

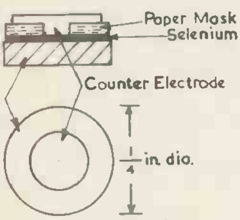

Fig. 7. Selenium disk rectifier

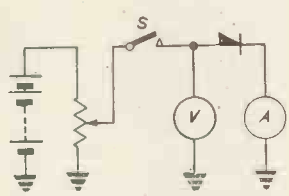

Fig. 8. Static characteristic measurement

between this plate and the base to "form" the whole unit, finally the disks are so punched out of the plate that the outer part of each is a circular annulus, enclosing a circular area of counter-electrode beneath which is the selenium actually used for the rectification. The assembly is shown in Fig. 7. It may be mentioned that the counter electrode has a low melting point, and any overloading of the rectifier may cause it to melt and to flow over the edge of the paper disk and thus short-circuit the rectifier.

A number of sources of variation are inherent in a manufacturing process of this type. The area of rectification is small (as determined by the hole in the paper disk), any flow of the adhesive holding the paper may reduce the effective rectifier area and thus cause large differences in resistance between members of the same production batch. Poor contact between counter electrodes and the plate used in the forming processes may lead to varying degrees of "formation".

While the forward resistance is relatively high (5kΩ to 10kΩ) the capacitance is small and the back resistance, as will be shown later, is phenomenally high; finally, the units will withstand a continuous back voltage of 50V.

Physical Characteristics of the Miniature Selenium Rectifier Disk

It was the opinion of the authors that, of the available rectifier elements, the selenium type, despite its disadvantages, was the most suitable for A.P.E.(X).C. type machines.

Unfortunately, very little published data was available regarding the characteristics of the ¼in diameter disk rectifier (basis of the S.T.C. Type M.1.), and that which has appeared was not particularly useful for assessing the performance of the unit in pulse operated computor applications. It was thus decided to make some measurements under the conditions obtaining in our machine.

In the usual methods of rectifier measurement a plot is made of the voltage-current characteristic. This can be determined by means of the basic circuit shown in Fig. 8, where it is assumed that the voltmeter has an impedance which is high compared with that of the rectifier. Since creep may occur with time, three current values are of interest:

(1) Immediately after application of voltage.

(2) The maximum current reached.

(3) The steady current.

Alternatively, a voltage-current curve can be obtained under dynamic conditions and presented upon the screen of a cathode-ray oscilloscope. This is most conveniently arranged by using a 50c/s supply of suitable voltage in the circuit of Fig. 9. An advantage of a presentation of this

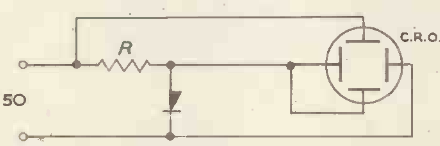

Fig. 9. Dynamic measurement

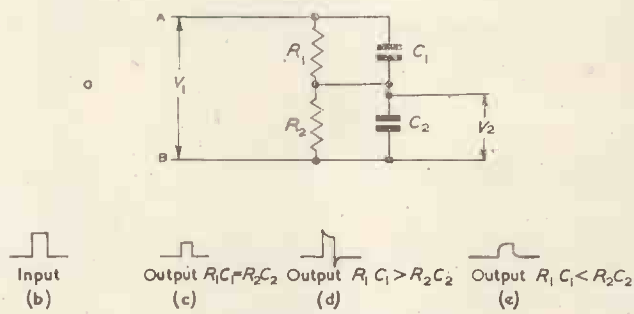

Fig. 10. Pulse characteristic measurement

type lies in the fact that it is dynamic and gives an indication of the presence of hysteresis effects.

Rectifier capacitance is normally measured by a bridge circuit using A.C. of a moderate frequency, this method has the advantage of giving resistance at the same time.

For the present investigation it was decided to use the straightforward voltage-current method for measurement of resistance and to investigate the capacitance by means of a circuit which exposed the rectifiers to conditions similar to those under which they are used in a computing machine.

The effective resistance of the rectifier can be readily determined under pulse conditions, by using the circuit shown in Fig. 8, the D.C. potential being applied and removed by means of the switch S. The reading of the current immediately after application of the voltage is required and the system has the disadvantage that the current meter has a relatively slow response. Any variation would be caused by a change occuring in the barrier layer, however, and this would also affect the capacitance. Other experimenters[6] have shown that for short time intervals such changes are negligible and are independent of the pulse repetition rate, the simple method was therefore considered suitable for this work.

For the capacitance measurement the circuit of Fig. 10(a) was used. It can easily be shown that if a rectangular pulse is applied across the points AB, then an output of the same shape will be obtained if:

$$R_1C_1 = R_2C_2$$

this is shown in Figs. 10(b) and 10(c). On the other hand, if:

$$R_1C_1 \neq R_2C_2$$

the outputs shown in Figs. 10(d) and 10(e) will result in the two possible cases.

A similar output will be obtained when a rectifier, which has a resistance R_{eff} and a capacitance C_{eff} in parallel, is substituted for the resistance and capacitance R_2 and C_2 so long as:

$$R_{eff}C_{eff} = R_2C_2$$

Thus, if R_1 and C_1 are known and R_{eff} is measured, the value of C_{eff} can be calculated.

Prior to making these measurements the selenium recti-

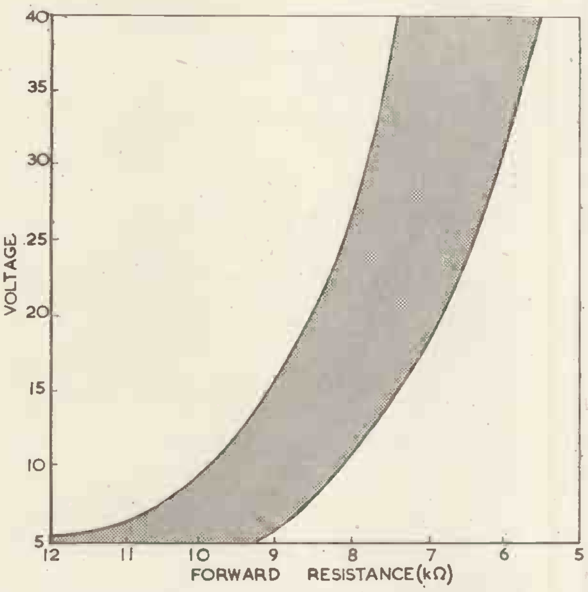

Fig. 11. Forward resistance/applied voltage for M.1 disks

fiers were subjected to 40V pulses, in the reverse direction, and applied at the 25kc/s repetition rate of A.P.E.(X.)C. This treatment was continued for 3 hours to allow for any changes which might take place through forming in the initial operating period of normal operation[7]. Changes taking place during this short period could not be attributed to ageing. An increase of approximately 15 per cent in the D.C. resistance was noted.

The measurement of forward resistance was made with the circuit of Fig. 8, voltage being recorded on a valve voltmeter and current on a multi-range milliameter. Both instruments were calibrated against substandards.

In the forward direction only a few volts are normally applied across the rectifier; however, no damage was caused by the momentary application of up to 40V since all readings were repeatable, even at lower applied voltages where damage would be expected to alter the current readings. The results of these measurements are given in Fig. 11.

Since the reverse resistance is very high difficulties arose when a similar method of measurement was attempted. As mentioned above, the reverse resistance increases by about 15 per cent during forming, this change was measured using a galvanometer having a sensitivity of 1cm/μA, and to obtain a readable deflexion 5 rectifiers had to be connected in parallel. The group resistances, on several such batches of 5, varied between 20 and 25MΩ, which suggests an individual resistance of 100 to 125MΩ. The identity of component units was checked by removal and replacement of the units in each group.

The apparatus used for capacitance measurement is shown in Fig. 12 (a), (b) and (c). A flip-flop, triggered from a free running multivibrator operating at 25kc/s generated the voltage pulses of Fig. 12(a). These were clipped by means of a biased diode and then fed to the

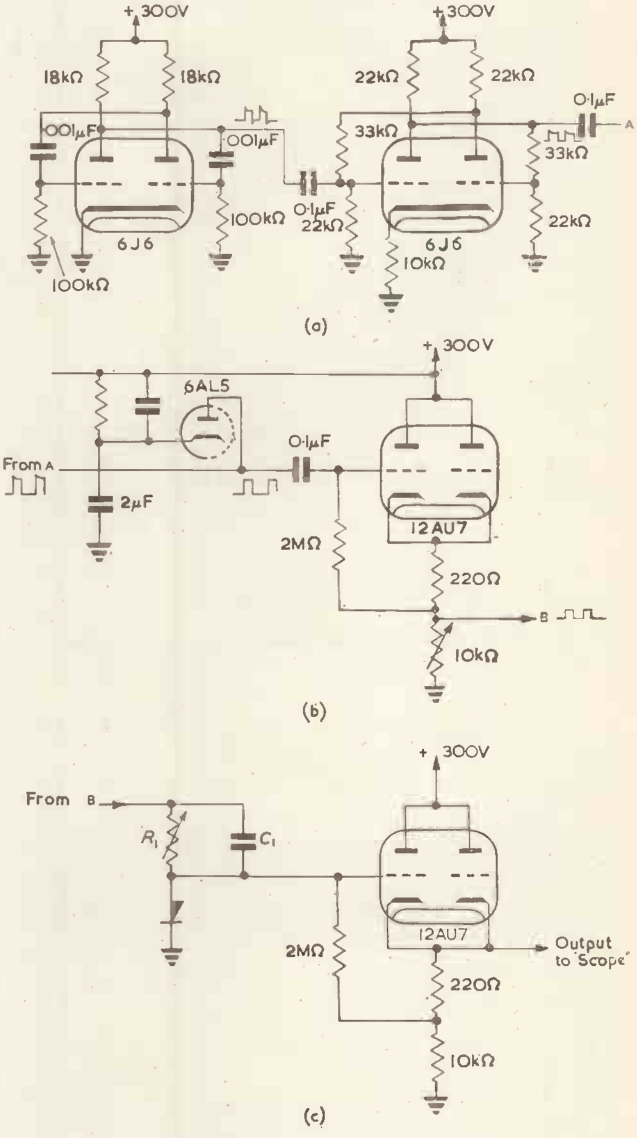

Fig. 12. Pulse measurement circuits

grid of a cathode-follower; from the tapped cathode resistor of the latter a variable output amplitude could be obtained (Fig. 12(b)). This output was then applied across points AB. of the circuit shown in Fig. 10(a), C_1 being a fixed capacitor and R_1 a variable resistor. A rectifier having equivalent parameters R_{eff}, C_{eff} was substituted for R_2, C_2 and the output was observed via a cathode-follower connected directly to the Y plates of a Cossor double beam oscilloscope (Fig. 12(c)).

The apparatus was checked before use by connecting the output of the first cathode-follower to the grid of the second and observing both outputs on the oscilloscope. No measurable variation was noted and both waveforms were rectangular at all signal amplitudes. Since the voltage applied to the rectifiers was also required the system was first calibrated by the application of a known D.C. potential to the input and the oscilloscope deflexion/input voltage characteristic obtained.

For the measurement of the forward capacitance, R_1 and C_1 (Fig. 10) were made equal to 5kΩ and ·001μF respectively, the rectifier under test replacing R_2C_2. By

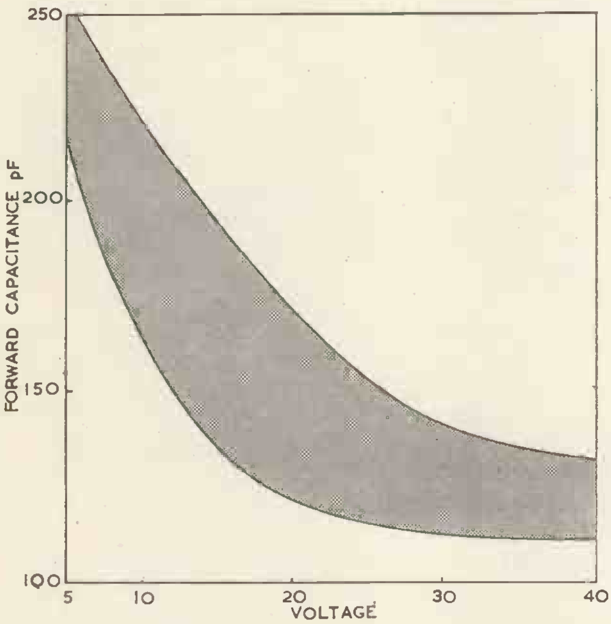

Fig. 13. Forward capacitance/applied voltage for M.1 disks

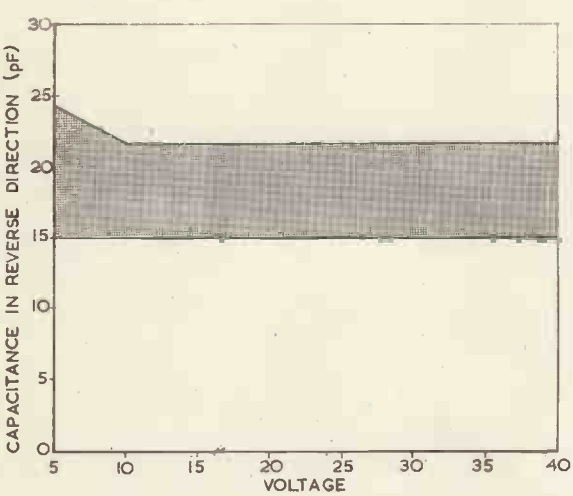

Fig. 14. Reverse capacitance/applied voltage for M.1 disks

adjusting R_1 and observing the point of identical wave shape between input to the network and output across the rectifier, both being observed via cathode-followers, the capacitance of the rectifier was calculated for various values of the applied voltage pulse height. The results of these measurements are shown in Fig. 13.

The same basic circuit was used to measure the reverse capacitance except that, since the reverse resistance of the rectifiers is very large, the latter was shunted with a 1MΩ resistor. The effect of this is to make the resistance of the unit 1MΩ within 1 per cent. In this case the resistor R_1 was taken as 100kΩ (variable) and the value 270pF adopted for C_1. The results of the measurement of reverse capacitance are shown in Fig. 14. To check the accuracy of the method it was used to determine a standard capacitor, of about the same magnitude as that of the rectifiers, the experiments were also repeated on the rectifiers themselves. It was concluded that the limits of error, due to measurement, did not exceed 2 per cent.

To summarize the results:

(1) The forward resistance is higher than that of hard valve, or of germanium diodes, but is adequately low compared with the back resistance.

(2) The "time-constants" of the selenium rectifier are 2μsec in the forward direction, and 2 000μsec in the reverse direction.

(3) The tolerance between various rectifiers is approximately ±20 per cent. From this it can be concluded that the units will be useful, for full voltage swings, at frequencies of up to 25 to 30kc/s. The high reverse time-constant implies that a biasing network of the same type as that used on thermionic diodes is necessary and that the leak method which is available with germanium diodes cannot be used. This is shown in Fig. 15.

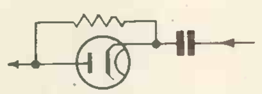

Fig. 15. Biasing network for diode

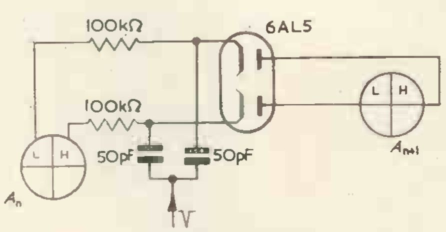

Fig. 16. Shifting register unit

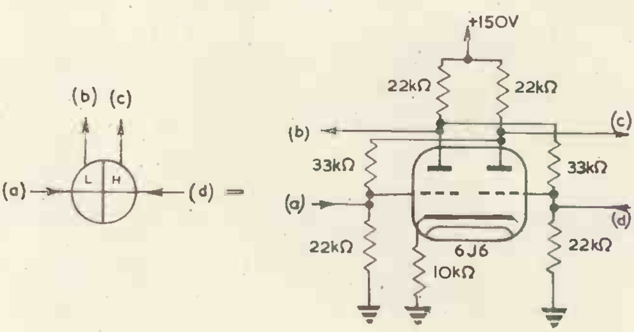

Fig. 17. Detail of flip-flop

Shifting Register Units

Details of the shifting register unit used in this laboratory have been given elsewhere[3]. The circuit is essentially that shown in Fig. 16, where the function desired is the setting of the flip-flop unit A_{n+1} to the state previously occupied by A_n. The flip-flop units are illustrated in Fig. 17 and it is assumed that a series $A_1A_2 \ldots A_8$ of these are simultaneously to transfer their contents to the next neighbour. The suggested use for selenium rectifiers in this circuit is to replace the 6AL5 valve. It was found, upon investigation, that the M.1 disks were effective when new, but rapidly became inoperative; this was traced to the forming which occurs under the static back voltage of 40 volts which, in turn, causes a rise in the forward resistance. Reliable operation resulted from replacing the M.1's by "Unistors", type Q3/5. In effect this unit lowers the forward resistance by connecting 3 M.1 disks in parallel and at the same time, decreases the applied back voltage per disk, by connecting 5 in series. (It should be remarked that the Unistor is not actually constructed of 15 M.1 disks, as would be suggested by this functional description.)

This application of the selenium rectifier lends itself to a neat circuit layout for the register since the Unistor is roughly the same in size and appearance as an American 2 watt carbon resistor.

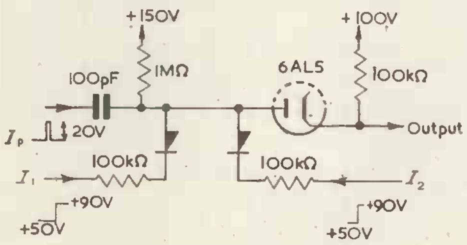

Fig. 18. Multiple gate

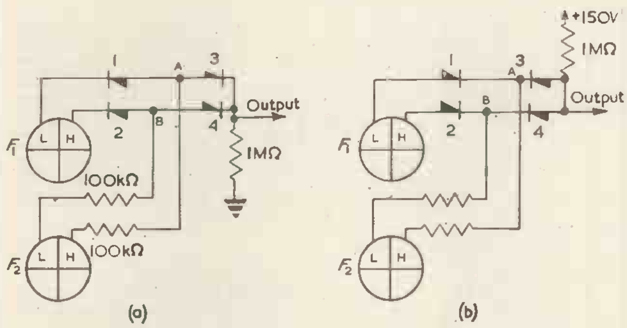

Fig. 19. Coincidence sensers

The Diode Buffer

It is not necessary to detail the manner in which the selenium rectifier can replace the thermionic valve in Figs. 3 and 4. At sufficiently low frequencies direct substitution is possible, as a general rule it has been found that the upper limit is at repetition rates of about 30kc/s. On the other hand, a useful gate can be constructed, by using additional thermionic elements, which although *set* by the selenium diodes, will transmit sharp (1μsec) pulses derived from elsewhere. An example of this is given in the next section.

The Gate

Several applications of the selenium rectifier to gate circuits have proved successful. The simplest is shown in Fig. 18; here the selenium rectifiers are used to set a potential at the anode of the hard diode. Up to this point no conduction of the latter occurs, and the slow operating time of the circuit (20μsec) does not matter. When the sharp test pulse, I_p, is applied, however, the 6AL5 conducts and passes the pulse to the external circuit.

Other types of gate are equally possible, the principle being that the slow selenium elements must set a potential so that a fast pulse can then pass through a hard valve.

Coincidence Sensing Units

In certain units of a computing machine it is necessary to detect coincidence (or anti-coincidence) between the states of two flip-flop units.

A possible method is to use a pair of 2_2 gates, the first to detect the states (0, 0) and the second, (1, 1). Electronic variants of this method have been described, in detail, elsewhere[3,8] and it is proposed to deal, here, only with the problem of coincidence detection between single valve pairs. With the notation given in Fig. 17 two selenium coincidence sensers which have proved satisfactory, are shown in Fig. 19(a) (b). In the first circuit (a) it will be seen that point A will be at low potential when the anode potentials are as shown, because the forward resistance of the selenium element 1 is small compared with 100kΩ. Likewise the potential at B will also be low since the back resistance of selenium element 2 is high compared with 100kΩ. The output point will therefore remain at a low potential nearly equal to that at A and B. It is seen, from the symmetry of the circuit, that reversing the state of both F_1 and F_2 will not alter the output. On the other hand, suppose that F_2 changes state. Point A will again be at low potential, but point B will be a high potential; rectifier 4

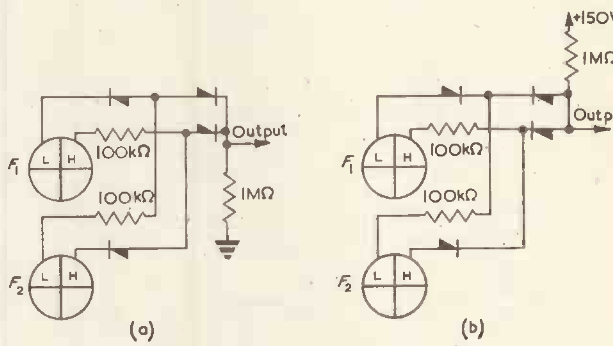

Fig. 20. Unsymmetrical coincidence sensers

therefore conducts and maintains the output point at high potential. Again the situation can be replaced by its symmetry twin in which F_1 has changed state and F_2 is as shown, the output still being at high potential.

Thus the circuit gives a low potential output for coincidence between the states of F_1 and F_2 and a high potential for anti-coincidence The circuit shown in Fig. 19(b) is the same as that just described, except for reversal of the connexions of all rectifiers and return of the output resistor to high potential. The analysis is as before and it will be seen that a high output potential is produced for coincidence and a low output potential for anti-coincidence.

Unsymmetrical versions with the same functions are shown in Fig. 20(a)(b). By an analysis of the type given above it can be seen that in Fig. 20(a) a high output potential will be produced in coincidence between F_1 and F_2 and a low output potential otherwise, similarly the circuit of Fig. 20(b) reverses the situation.

These circuits have proved extremely reliable over long periods; they have one disadvantage, however, in the fact that the rise (or fall) time of the output waveform varies with the particular element (F_1 or F_2) being switched.

Matrix Decoding Circuits

In an automatic computing machine instructions are represented, in coded form, by numbers[8]; it is necessary to transform the voltage settings of a number of flip-flops into unique outputs representing the individual orders. This is normally performed by means of a decoding matrix, or function table.

A simple example of this unit is shown in Fig. 21, in which the dots, at intersections, represent resistors or diodes. Suppose that the left-hand anodes of the flip-flop units are at a low voltage V_L and the right-hand anodes at a high voltage V_H; assuming equal resistive connexions and no output loads the output voltages are:

(1) V_L

(2) $\frac{1}{2}(V_L + V_H)$

(3) $\frac{1}{2}(V_L + V_H)$

(4) V_H

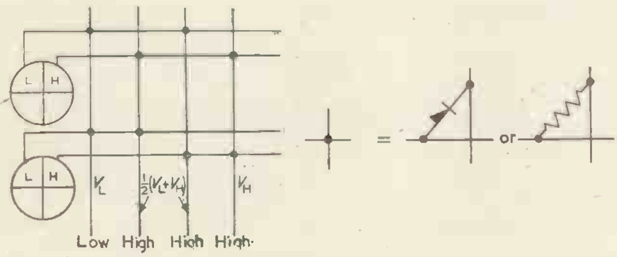

Fig. 21. Simple matrix decoder

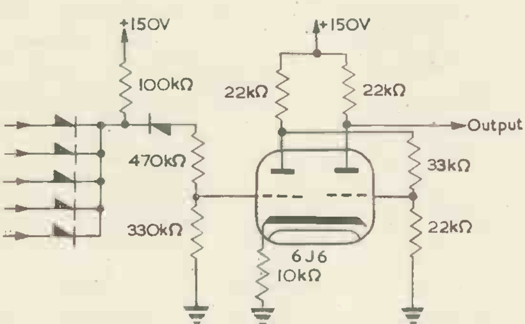

Fig. 22. Schmidt output circuit for matrix

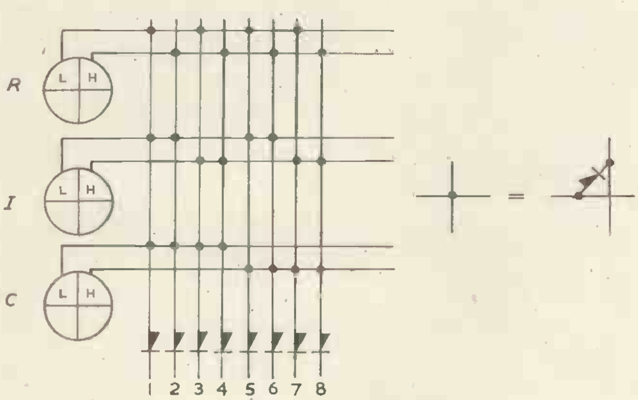

Fig. 23. Three input adder matrix

Thus only one output is at the lowest (or highest) potential and it is easily seen that this varies with and is uniquely related to, the states of the flip-flops.

The above circuit can be extended so that n double inputs control 2^n outputs only one of which is at low (or high) potential for each input configuration. The disadvantage of this resistance matrix is that high values of resistance must be used to avoid inter-action between the sources; this leads to a slow rise time for the output waveform. A second consequence of the resistance connexion is the fact that the discrimination between the lowest output and its nearest neighbours is V/n where V is the total voltage swing at the input. Thus with an anode swing on the input flip-flops, of 50V a 5 input resistance function table will produce a discrimination, at the output, of only 10V.

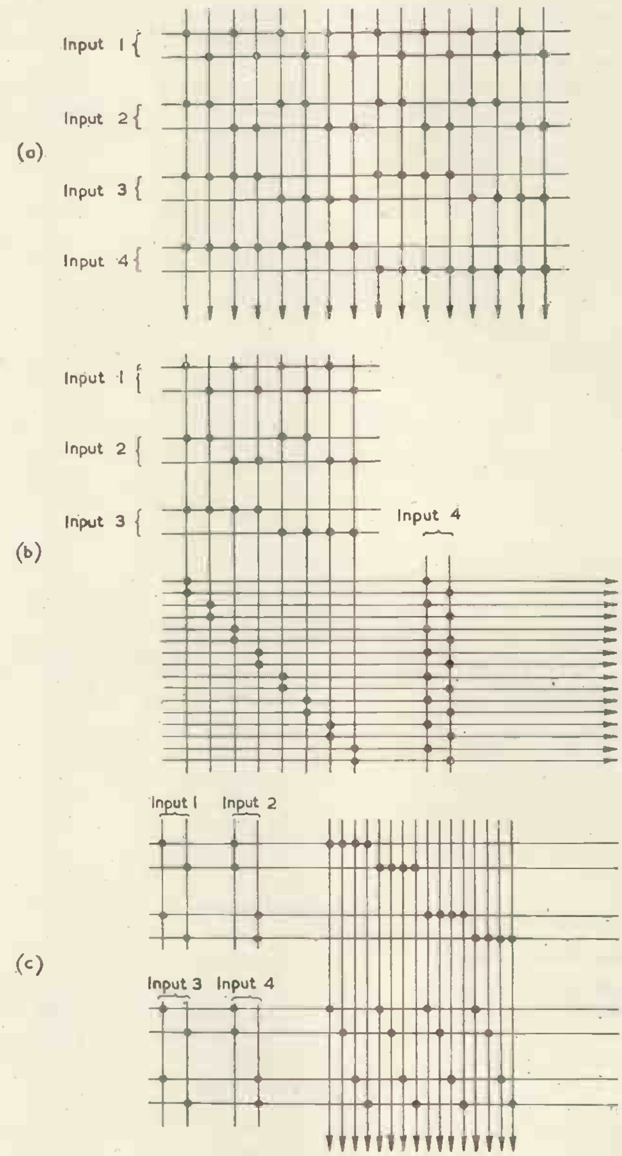

Fig. 24. Possible 4-input, 16-output matrices

By the use of diodes in the matrix both of the above disadvantages can be largely overcome, but the 5 × 32 table mentioned above would require 160 diodes and the cost, if not prohibitive, is still an appreciable fraction of the total valve cost of any reasonably well-designed machine.

Apart from its relatively high self capacitance the selenium rectifier offers an ideal solution to the problem of constructing function table matrices. To determine the performance of such a unit, an experimental section of a 5 × 32 function table was constructed using the type M.1 disks and the circuit parameters shown in Fig. 22. The inputs were fed, via cathode-followers, from the anodes of five flip-flops of the type shown in Fig. 17, and the output actuated a Schmidt trigger circuit of the type shown. Rise and fall times were measured at the output point when one of the input flip-flops was cyclically triggered and it was found that the delay was about 3μsec for switching on and 10μsec for switching off.

Quite apart from the main function table of A.P.E.(X).C.[8], where a 5 × 32 matrix of the above type has been in successful use for nearly a year, smaller assemblies of the same type are useful in binary addition. A network for three input addition is shown in Fig. 23, it will be seen that, if *R* represents the binary digit storage flip-flop, *I* the incident digit flip-flop and *C* the store for any carry which may have arisen from a previous addition, the outputs 1 to 8, will be at low potential for the combinations shown in Table 2.

TABLE 2

R	*I*	*C*	OUTPUT	SUM DIGIT	CARRY DIGIT
0	0	0	1	0	0
0	0	1	5	1	0
0	1	0	3	1	0
0	1	1	7	0	1
1	0	0	2	1	0
1	0	1	6	0	1
1	1	0	4	0	1
1	1	1	8	1	1

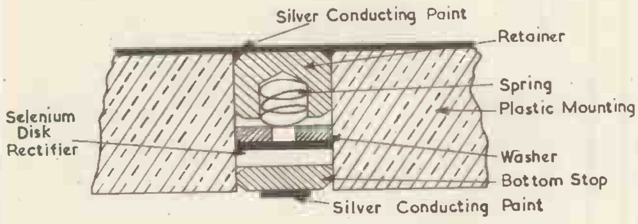

Fig. 25. Aiken disk mounting

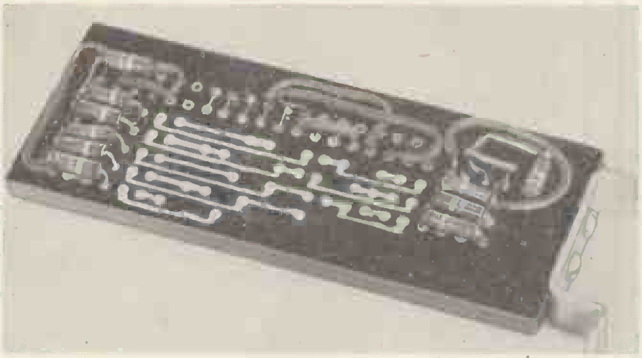

Fig. 26. A complete unit

Thus, if output lines 2, 3, 5 and 8 are connected together via buffer rectifiers they will produce the correct sum digit combination for all inputs, and, in a like manner, the connection of 4, 6, 7, and 8 will produce the correct carry.

In designing decoding circuits of any size it is useful to remember that the simple scheme outlined above is not, in general, the most economical. Thus Fig. 24 shows three of the possible four input, sixteen output matrices, and it will be seen that the straight-forward scheme given in (a) requires 64 rectifiers, whereas scheme (b) requires 56 and scheme (c) only 48. For really large units the saving is even more remarkable, thus, an 8 × 256 decoder of the normal matrix type has 2 048 rectifiers, whereas the most economical version has only 608.

The disadvantage of the optimal schemes lies in the fact that rectifiers have to be connected in series and this leads to an increase in resistance, capacitance and resultant time-constant.

Constructional Details

One of the most important features of any circuit element in relation to a computing machine, is the ease with which the element can be packaged in large numbers. Several American computing machines[9] have used selenium disks of 1/12in to 1/16in diameter. These have been mounted in a plastic panel by means of a plug and spring assembly as shown in Fig. 25; and the necessary connexions are inserted by painting the surface of the mount with conducting paint. A unit of this type is shown in Fig. 26.

For the work of this laboratory, where the ¼in diameter M.1 type disks are the only variety available, a somewhat

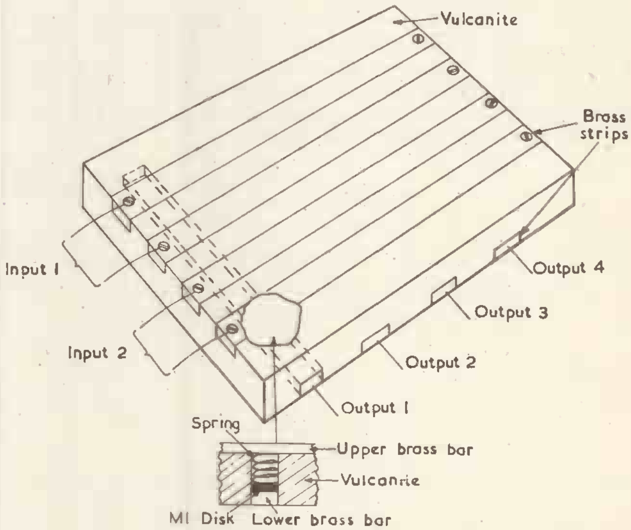

Fig. 27. Construction of unit using M.1 disks

different mounting technique has been used. A plastic plate, ¼in thick, has holes drilled through it in positions to receive the rectifiers. Inlaid into the top and bottom surfaces are sets of 1/16in thick brass strip, ¼in wide and of suitable length. To make up a given matrix the 2*n* output strips are fixed into position and rectifier disks are placed in the appropriate holes to rest on the output strips. A small phosphor bronze spring is next placed over each rectifier and finally the 2*n* input strips are placed in position and fixed. To date no ill effect due to moisture or chemical attack has been observed. The units are neat and compact in appearance as will be seen from Fig. 27.

Acknowledgments

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A Count-Rate Meter

Having Automatic Correction for Losses Caused by Finite Resolving Time

By E. W. Pulsford*

A count-rate meter circuit is described, having automatic correction for count-rate losses caused by the finite resolving time of the input circuits of the counting equipment. It is necessary that the resolving time is known in order that the circuit may be adjusted to apply the appropriate correction.

The chief sources of error are discussed, and the performance of an experimental model is quoted.

IN any experimental determination of the mean rate of arrival of random-in-time pulses from a detector of radioactive disintegrations in conjunction with electronic circuits, it is always found that some pulses are uncounted because of the finite resolving time of the system. When the resolving time is short compared to the mean time interval between pulses, it is possible to compute the true mean count-rate from the observed count-rate, the usual simple relationship employed being

$$N = \frac{n}{1-nt} \qquad \text{(Appendix)}$$

where

$N =$ true mean count-rate; pulses per second.
$n =$ observed mean count-rate; pulses per second.
$t =$ resolving time of the counting system.

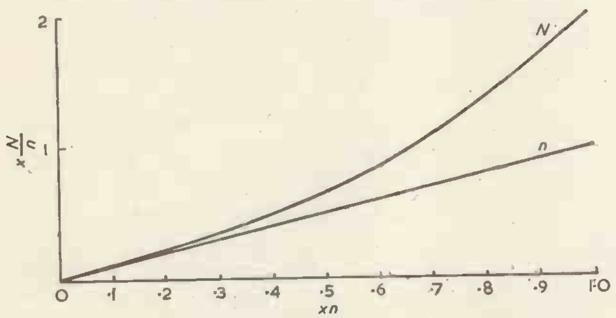

Fig. 1. Correction of observed count rate

Resolving time such that for an observed rate n, the true mean rate (N) is 2n.

In those experiments where accurate values of N are required, it is necessary to employ this relationship to compute N from each observation of n. This can absorb time and labour, especially where there are many results to adjust, therefore it would be an advantage if the computation could be performed by the electronic circuits of the counting equipment. It is possible to do this in the circuits of a count-rate meter, similar in principle but of slightly different design to the linear count-rate meter described by E. H. Cooke-Yarborough and the present author[1].

Characteristic of an Auto-Correcting Count-rate Meter

Compared to a linear instrument, whose output is directly proportional to the input pulse-rate n, an auto-correcting count-rate meter must have an output $n/1-nt$ for the same pulse rate. This represents a rising characteristic, whose shape is shown in Figs. 1 and 2. It should be noticed that the curve nowhere approximates to a straight line, consequently a simple readjustment of the scale of a linear instrument cannot be used as a method of compensation for counting losses.

Generation of the Characteristic

In order to produce this rising characteristic it is necessary to make the count-rate meter progressively more and more sensitive as the count-rate increases. The way

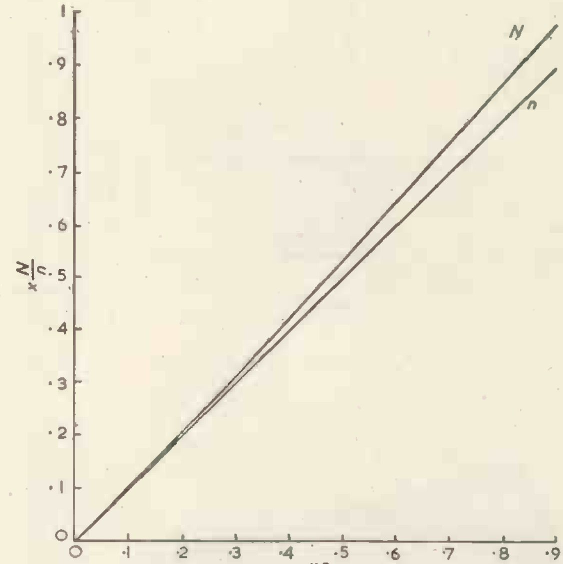

Fig. 2. Correction for resolving time over the range 0 to 10 per cent losses

which has been chosen to do this is to increase the charge-per-pulse fed to the tank circuit by the appropriate amount for the correction required. This increase is effected by adding an appropriate fraction of the count-rate meter output voltage to the amplitude of the rectangular wave, which charges and discharges the feed capacitor of the diode pump circuit. The operation of the system may then be described mathematically, as follows:—

In the linear count-rate meter the relation between the equilibrium output voltage and the count-rate is

$$v = VC_fR_tn.$$

where

$v =$ output voltage of count-rate meter.
$V =$ effective amplitude of restangular wave applied to C_f.
$C_f =$ capacitance of diode-pump feed capacitor.
$R_t =$ resistance of the count rate meter tank circuit.

If a fraction p of the output voltage is added to V this becomes

$$v = (V + pv)C_fR_tn$$

*A.E.R.E.

whence $v = VC_tR_t \dfrac{n}{1-npC_tR_t}$

If pC_tR_t is made equal to the resolving time, t, of the counting system, we have

$$v = VC_tR_t \frac{n}{1-nt}$$
$$= VC_tR_tN$$

and the output voltage is now a linear function of the count-rate corrected for resolving time losses.

Circuit of the Auto-correcting Count-rate Meter

The basic circuit is shown in Fig. 3.

V_1 is the output stage of an amplitude discriminator[2] at the anode of which rectangular voltage changes occur in synchronism with the incoming pulses. The A.C.-D.C. coupling network from the anode of V_1 to the grid of V_2 is so proportioned that the anode current of V_2 is alternately cut-off and saturated. In the latter condition the anode voltage of V_2 is but a few volts above its cathode voltage, and, therefore, the anode swing of V_2 is from this lower limit to an upper limit set by the cathode voltage of the cathode-follower, V_3. This cathode voltage is a few volts above the grid voltage of V_3, consequently the magnitude of the anode swing of V_2 is approximately the same as the voltage difference between the grid of V_3 and earth. For simplicity it is taken to be exactly equal; any error introduced by the inaccuracy of this assumption is one of scale rather than principle of circuit operation. The amplitude of the anode swing of V_2 is the voltage V of the previous paragraph, and it is defined at the grid of V_3 partly by potential division from the stabilized H.T. supply (by the network R_6, R_7, VR_1) and partly by potential division from the anode voltage of V_5 (by the network R_8, VR_2 to which must be added the impedance of the network R_6, R_7, VR_1 as seen from VR_2).

The circuits of V_5 and V_6 form a feedback D.C. amplifier. In the absence of any pulse input to the count-rate meter, VR_3 is adjusted so that the grid of V_6 is at earth potential and the output meter is made to read zero, by adjusting VR_4. Because the grid voltage of V_6 is at earth potential and because the same current flows in R_{10} and R_{11}, the anode voltage of V_6 is $|B-| \times R_{10}/R_{11} = q\,|B-|$. The current in the chain R_6, R_7, VR_1 is adjusted (by VR_1) so that the voltage at the junction of R_6 and R_7 is the same as this, so that at low count-rates, when the correction for resolving-time losses is negligible, there shall be no change of calibration of the instrument with change of degree of compensation, as determined by the position of the slider of VR_2.

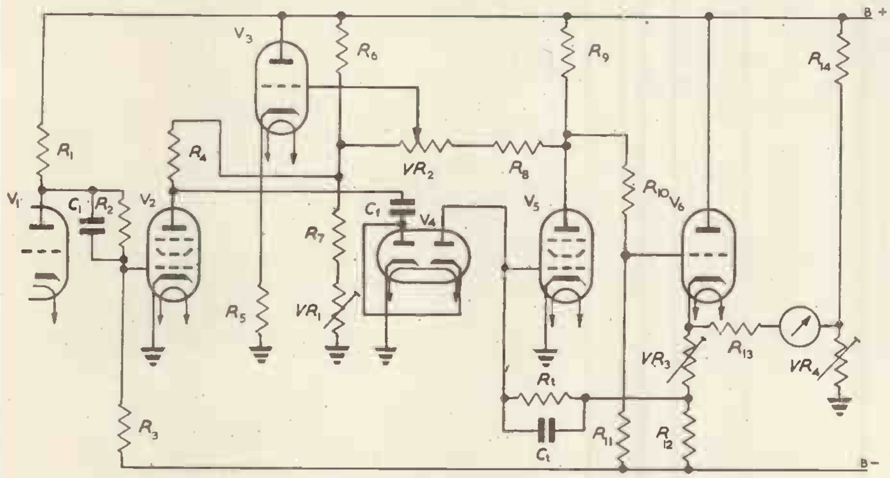

Fig. 3. Basic circuit of count-rate meter with auto correction

The degree of compensation is calculated as follows: Suppose the output voltage of the circuit, as measured at the cathode or grid of V_6 is v. Then the change in voltage at the anode of V_5 is $v(q+1)$ and the corresponding change at the grid of V_3 is an adjustable fraction of this depending in a simple manner on the values of R_8, VR_2, R_6, R_7 and the position of the slider of VR_2. Let us suppose that this fraction is m; then the voltage at the grid of V_3 is

$$q|B-| + mv(q+1).$$

This is the voltage $V + pv$ of the basic treatment, and the corresponding solution for v becomes

$$v = q|B-|C_tR_t \frac{n}{1-n(m(q+1)C_tR_t)}$$

The magnitudes of m and q must be such that $m(q+1)$ C_tR_t is equal to the resolving time of the counting equipment: then compensation for resolving time losses is achieved. In practice q is fixed at a value of 0·5, leaving the variable m to be adjusted to give the required compensation. The usual value of $|B-|$ is 105 volts; setting these figures in the equation yields

$$v = 52{\cdot}5\ C_tR_t \frac{n}{1-n(m\,.\,3C_tR_t/2)}$$

The application of this relationship in the design of an auto-correcting count-rate meter having full scale reading of 10 000 pulses per second and a resolving time of 10 microseconds is illustrated in the design of a practical circuit, shown in Fig. 4. The conditions quoted are typical when working with scintillation counters, the losses at the highest count-rate being about 10 per cent.

Practical Circuit

This differs from the basic circuit in three respects:—

(1) The method of connecting the output meter between the cathodes of two cathode-followers.

(2) The inclusion of switch S_1.

(3) The inclusion of switch S_2.

These modifications render the circuit easier to set up, which process is carried out as follows:—

(1) S_1 is closed and VR_4 adjusted until the meter reading is zero.

(2) S_1 is opened and VR_3 adjusted until the meter reading is again zero. The grid of V_{6a} is then at earth potential, and the anode of V_5 at +52·5 volts.

(3) A sensitive high resistance voltmeter is connected between the anode of V_5 and the junction of R_6 and R_7; then VR_1 is adjusted until this meter reads zero. The voltage of the junction is now 52·5 volts, and the amplitude of the square wave at the anode of V_2 is also 52·5 volts for reasons given previously.

The output meter reaches full scale for a 50 volt change on the grid of V_{6a}, and, therefore, the current flowing in R_t is 50 microamperes. This settles the value of C_t, for we require

$$52{\cdot}5 \times 10\,000\,C_t = 50 \times 10^{-6}$$

C_t is seen to be rather less than 100pF, which value is covered by the range of the pre-set capacitor, the only variable element provided to take up component tolerances and other linear errors affecting the accuracy of the instrument scale.

To compensate for the resolving time of 10 microseconds we require, as explained,

$$m \cdot \frac{3C_t R_t}{2} = 10 \text{ microseconds}$$

$C_t R_t$ is, as already determined by the sensitivity of the count-rate meter, very nearly 100 microseconds; we see, therefore, that m should be 0·067. The use of the values shown for R_8, VR_2 enables m to be adjusted to this figure. This is done in a subsidiary experiment using a variable frequency source of evenly spaced pulses. First the scale accuracy of the instrument is checked against the frequency of these pulses, C_t being adjusted as necessary with the switch S_2 open so that there is no compensation. Then a suitable pair of values of N and n are computed, for example, $N = 10\,000$, $n = 9\,100$p/s. The frequency of the pulses is adjusted until the count-rate meter reads 9 100, switch S_2 is closed, and VR_2 adjusted until the meter reads 10 000. The circuit is now set up to perform the computation of N from n at all points on the scale.

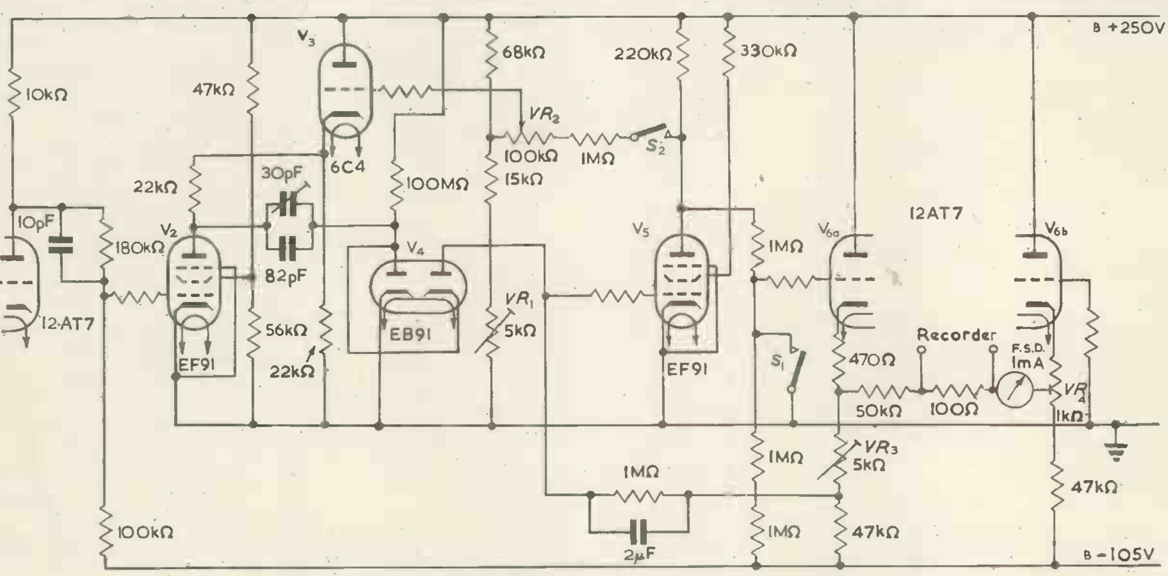

Fig. 4. Practical circuit of count-rate meter with auto correction

Stability and Accuracy

Stability of Zero

In the absence of any pulses arriving at the input of the count-rate meter, the reading of the output meter (ideally a constant zero) is affected only by the behaviour of the circuits of V_5 and V_6, where changes of valve parameters with age or with change of cathode temperature (because of mains voltage changes) may affect the zero. These changes are of the order of a few tens of millivolts, and amount to only a few parts in a thousand of the full scale deflexion (50 volts). In an experiment where the mains voltage varied from 210 to 240V, the movement of the meter needle was barely perceptible: the circuit may, therefore, be relied on to maintain its zero setting in a satisfactory way.

Stability of Calibration

When no resolving time correction is used, the calibration stability depends on the accuracy with which the relation

$$v/n = V \cdot C_t R_t$$

is held. The chief causes of error involve the stability of C_t and R_t with time, and that of V which may be affected by mains voltage changes, ageing of the valves and the stability of the potential dividing networks which define it. The use of high stability types of resistors and reliable capacitors disposes of, as far as possible, the component stability point. The changes affecting the performance of V_2 and V_3 may be divided into long-term changes, which are usually rectified by occasional resetting adjustments, and short-term changes which result from mains fluctuations. A reduction in mains voltage, resulting in a lowering of the cathode temperature and emission in V_2 and V_3 causes a fall of cathode potential in V_3 (which is readily observable) and probably a small reduction in saturation current in V_2. Both of these effects result in a reduction of the magnitude of V by an amount which is small, but not negligible for work of the highest accuracy. For example, in a check of an experimental instrument, the meter reading fell by 1 per cent for reduction of 10 volts from the normal mains voltage. This represents the sum of inaccuracies from all points affected by mains voltage changes, but there is little doubt that most of the observed error results from changes in these valves: this is confirmed by observation of the cathode voltage of V_3, where a voltage change is found sufficient to account for the greater part of the observed error. If the mains voltage can be relied on to ±10 volts, the errors introduced are not much greater than the standard deviation of the counting rate from the mean (with integrating time 2 seconds, this is ±1 per cent at 2 500c/s, ±½ per cent at 10 000c/s[1]) and so may be just tolerable. For better accuracy than this, steps should be taken to stabilize the heater temperature of these valves, preferably by stabilizing the mains supply to the whole instrument.

When the compensation of resolving time losses is in use, the additional sources of error are drifts in the resistors of the network defining the feedback factor from the anode of V_5. These errors are minimized by the use of high stability components; this, together with occasional performance checks should reduce these additional sources of error well below the tolerance level.

Linearity of Scale

The most likely factor affecting the linearity of the scale is the time-constant of charge and discharge of the feed capacitor to the diode pump. When the anode current of V_2 is flowing, C_t is discharged into the tank circuits; since the saturation current available in the anode circuit can be quite large, the 100pF of C_t is discharged very rapidly, certainly in a shorter time than that in which it is charged after V_2 is cut-off. The time-constant of charging is $2{\cdot}2 \times 10^4 \times 10^{-10}$ seconds, or 2·2 microseconds, which is only about 1/50 of the mean pulse spacing at 10 000c/s. Consequently losses resulting from incomplete charging or discharging of C_f are so small as to be negligible.

A test of the linearity of the circuit performance against regularly spaced pulses of known frequency showed that there was little, if any, detectable non-linearity at any part of the scale; certainly it was less than ½ per cent everywhere in the experimental model used for the test.

It may, therefore, be concluded that, provided the mains voltage is reasonably steady, the overall accuracy of performance of this instrument is good, and may be relied on with confidence to better than 1 per cent. This has been confirmed by a prolonged run, using a self-balancing potentiometer recorder on the output, when overnight (16 hours) the reading remained constant, the errors being unreadably small. In this test the pulses were crystal controlled at a repetition rate of 5 000p/s.

Conclusion

The instrument described should be useful in counting experiments, where the accuracy requires the computation of the losses caused by finite resolving time, and especially in long-term experiments where recording is used. Provided the voltage of the power line is kept reasonably constant, and occasional calibration checks are made, the accuracy of the instrument should be adequate for the majority of purposes where count-rate meters are employed.

Acknowledgments

The author is indebted to Mr. R. B. Owen, who suggested that an auto-correcting count-rate meter might be designed, and to Mr. J. R. Gibbs, who constructed the experimental model which provided the quoted performance data.

Appendix

Correction of Observed Count-Rate for Resolving Time

We assume that the pulse duration is negligible compared with the resolving time and the mean pulse spacing.

Let N be the true mean count rate.
n be the observed mean count rate.
t be the resolving time.

Suppose a certain pulse initiates a resolving time, and that, following the end of the resolving time there is a waiting time until the arrival of another pulse, which starts the next (similar) sequence.

The interval between counted pulses is, therefore, resolving time + waiting time.

Now we count n of these intervals per second, therefore, the mean duration of one of them is $1/n$ seconds; each mean interval contains N/n pulses, of which one is counted, and $N/n - 1$ are lost.

The lost counts occur in the resolving time, t, their mean number being $N\,t$.

We have, therefore,

$$N\,t = N/n - 1$$

whence $N = n/1 - nt$.

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A Simple Glare Meter

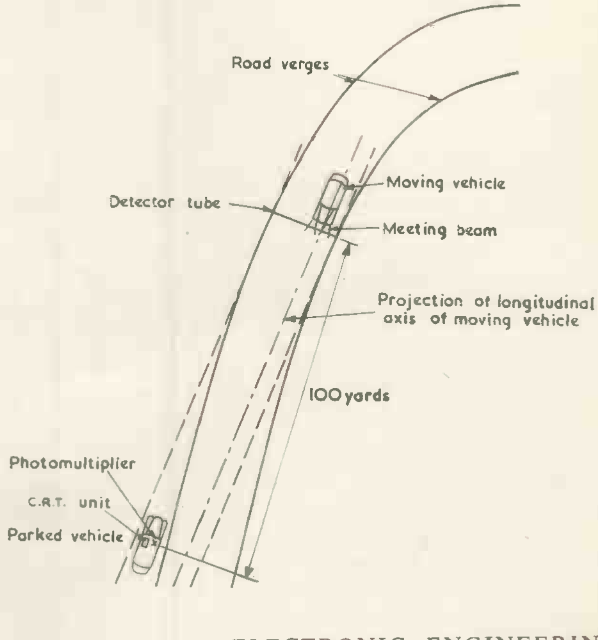
By V. J. Jehu*, M.Sc., A.Inst.P.

Surveys of the dazzle situation arising from the use of vehicle headlights at night have been carried out by the Road Research Laboratory from time to time. The assessment of dazzle has been based on a visual glare assessment made by the observers. While any one survey can give a fairly reliable comparison of the dazzle from different types of lamp or the lamps used by different classes of vehicle, such surveys are not well adapted to revealing changes which may take place over a period of time, since an observer's criterion of dazzle will not necessarily remain the same from one survey to the next. Headlight intensities were therefore measured with a photo-electric cell, as described in this article.

Method

The glaring intensity of approaching headlamps and passlamps was found by measuring the illumination received 100 yards from the lamps by a multiplier photocell mounted in a stationary car. The car was parked on the grass verge facing towards a right-hand bend in the road, and 100 yards from a detector tube which was placed across the road in such a position that at the instant of passing over the tube the lamps of oncoming traffic were aimed slightly to the offside of the stationary car (Fig. 1). In this way it was possible to obtain a close approximation to the glare condition when two vehicles are 100 yards apart on a straight road. The bend in the road also enabled measurements to be made from denser traffic than would otherwise have been possible, because light from the lamps on following vehicles was not

Fig. 1. Layout for measurement of glare of vehicle meeting beams



* *Road Research Laboratory, D.S.I.R*

directed at the photocell until the vehicles were close to the detector tube.

Apparatus

The multiplier photocell was mounted in a position which approximated to that of the driver's eyes; it was connected directly to a cathode-ray unit so that the output of the photocell was measured by observing the deflexion recorded on the cathode-ray tube. The passage of the front axle of a vehicle over the detector tube on the road closed a contact which actuated a relay chain arranged to brighten momentarily the spot on the long persistence screen of the cathode-ray tube. The deflexion of the spot could readily be measured by means of a millimetre scale graduated on perspex, which was mounted over the face of the cathode-ray tube, and which was internally illuminated by a torch bulb. Horizontal and vertical shift controls enabled the zero setting of the light spot to be adjusted and periodically checked.

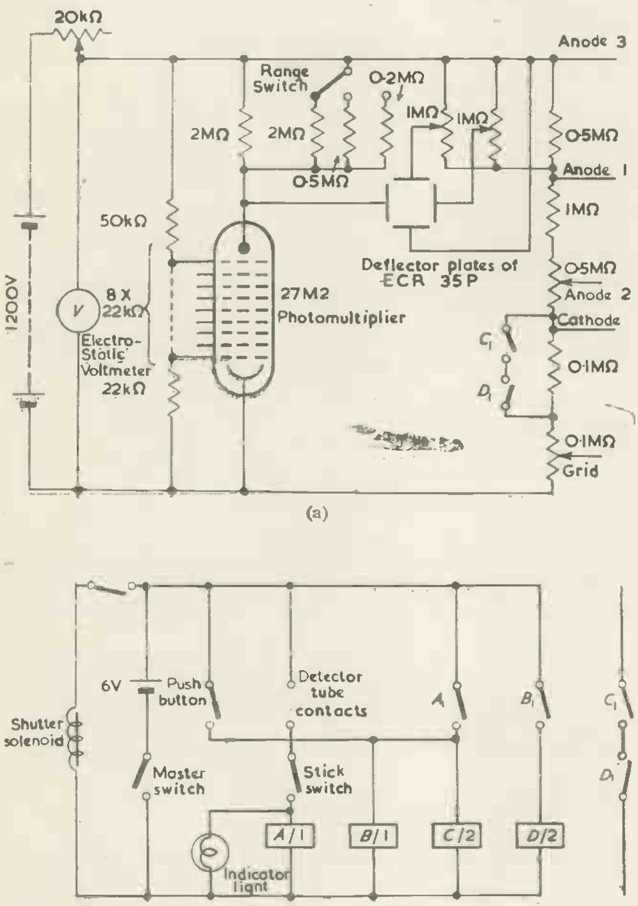


Fig. 2. Circuit of the glare meter

(a) Photomultiplier and cathode-ray tube circuit.
(b) The trigger circuit.

The sensitivity of the instrument could be varied by altering the anode load of the photo-electric cell; three ranges were provided having sensitivities of about 7×10^{-4}, 3×10^{-3}, and 6×10^{-3} lm/sq ft/mm respectively. These sensitivities corresponded to full-scale deflexions (50mm) for intensities of about 3 700, 16 000 and 32 000cd, when the light source was 100 yards from the cell. Allowance was made in the calculation of intensities for the transmission factor of the windscreen of the car. The spectral response curve of the photocell was corrected to that of the average human eye by means of a colour filter. The filter reduced the sensitivity of the cell to light from an incandescent filament to less than one-tenth, so that without the filter the maximum deflexion sensitivity of the instrument would be about 7×10^{-5} lm/sq ft/mm.

The multiplier photocell and the cathode-ray tube were supplied from a common high-voltage source, a vibrator pack energized from a 6-volt car battery. An adjustment was provided so that the supply voltage indicated by an electrostatic voltmeter could be kept constant. This was necessary because the sensitivity of the multiplier photocell depended on the supply voltage and increased rapidly as the voltage increased. The sensitivity of the cathode-ray tube also depended on the supply voltage; it decreased as the voltage increased, but not sufficiently to counteract the increased sensitivity of the photocell. Circuit diagrams of the measuring apparatus and the relay chain are given in Fig. 2.

To measure the glaring intensity of a meeting beam the operator selected the appropriate range of the instrument and closed a switch as the vehicle approached the detector tube. The switch energized the relay chain and opened a shutter which normally covered the photocell. Finally the operator noted the position of the light spot on the screen of the cathode-ray tube.

Estimated Accuracy of Results

Measurements of the intensity of a light source require a knowledge of the distance between the light and the measuring instrument. In the present arrangement there are two sources of error in the determination of distance. The first is the delay between the passage of the front wheels over the detector tube and the switching on and off of the electron beam of the cathode-ray tube. The second is the distance between the lamps on a vehicle and the vertical plane containing the front axle.

The delay is made up of the time for the initial pulse to travel along the detector tube, and the time of operation of the relay chain. High-speed relays are used in the trigger circuit, and it is estimated that the total delay between the initiation of the pulse in the tube and the dimming of the cathode-ray tube is about 25msec. During this time-interval a vehicle travelling at 60 m.p.h. would move about 2ft, which in 100 yards corresponds to a maximum error in the measurement of beam intensity of about 1 per cent. The maximum distance between the lamps and the front axle is of the order of 6ft to 7ft for modern public service vehicles, and this corresponds to an error of 5 per cent in the determination of beam intensity. For the majority of vehicles, however, the error will be less than 5 per cent. Because of the smallness of these errors it may be assumed in calculating the intensities that the distance is 100 yards in all cases.

The largest source of error appears to be the variation in the calibrations of the instrument, which were carried out in the laboratory with a 100 watt sub-standard lamp source. The maximum variation observed in calibrations made at a specified supply voltage over the six-month period during which glare measurements were made was about 17 per cent.

Considering all three sources of error, therefore, the values of the intensity are estimated to be subject to maximum errors of about +15 per cent and −8 per cent. The inequality of the positive and negative errors arises because the errors in the distance tend always to increase the calculated intensity.

Acknowledgments

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An Audio Frequency Phase Meter

By F. P. Moss*, B.Sc.

A direct reading instrument for the measurement of the phase difference between two signals in the 30c/s to 30kc/s frequency band is described.

The meter incorporates an automatic squaring control circuit[1,2], which renders the reading substantially independent of variations of level of 20db and up to 20 per cent total even harmonic distortion, and a thermionic diode meter shunt which reduces errors due to variation of the mains supply voltage.

THE instrument was originally developed for use in conjunction with phonic wheel generators to measure the torque of rotating shafts. In this application two phonic wheel type of alternators are mounted a known distance apart on the shaft. Twist in the shaft causes a phase displacement of one signal relative to the other which is proportional to the angle of twist and which may be measured by the phase meter here described.

The phase meter also has many uses in the study of vibrational and acoustical problems and in testing audio frequency apparatus such as amplifiers and filters. The instrument was finally designed with such applications in mind and has a frequency range of 30c/s to 30kc/s and a range of permissible input levels of 40mV to 400mV R.M.S. The design also ensures that accuracy is unimpaired by up to 20 per cent total even harmonic content.

Basic Circuit

A block diagram showing the waveform at various points in the circuit is shown in Fig. 1. The two signals are amplified by separate amplifiers and converted into square waves by separate limiters. Unity mark-space ratio of the square waves is maintained under conditions of varying input level and harmonic content by means of the automatic mark-space ratio control circuits.

One of the square waves is applied to the control grid and the other to the suppressor grid of a short grid and suppressor base pentode. Anode current will only flow during the period for which both square waves are positive and thus rectangular pulses of anode current are obtained. The width of these pulses will depend on the phase difference between the two square waves, that is to the phase difference between the input signals from which the square waves are derived. The relationship between pulse width and phase difference is given by the equation:—

$$x = 180 - \phi$$

where x = pulse width (degrees)

ϕ = phase difference (degrees)

Since the amplitude of the pulses is constant, the mean anode current will be proportional to the pulse width and a D.C. milliammeter in the anode circuit of the valve will indicate the phase difference between the input signals, the law being a linear one.

The input signals are amplified approximately 32db before being fed to the limiters. The exact gain of the amplifier is not critical as the subsequent circuits are designed to accommodate variations of 20db corresponding to 40mV to 400mV input signal level. A single stage triode amplifier employing one half of a 12AX7 is used.

Limiter

The function of this part of the circuit is to convert the amplified signal into a square wave of unity mark-space ratio. A number of squaring circuits were considered, but most of them suffered from the defect that the mark-space ratio depended upon signal level and in all of them the mark-space ratio varied with the harmonic content of the signal, so that a manual control was necessary.

The simplest circuit is a triode or pentode limiter, capacitively coupled from the amplifier. The coupling

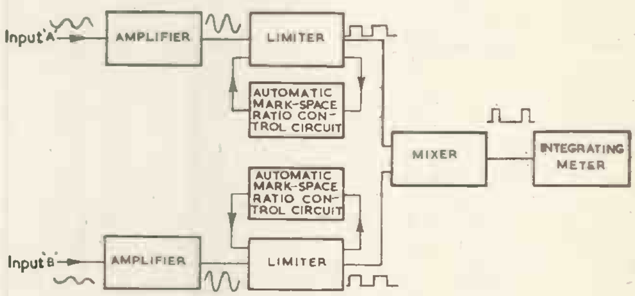

Fig. 1. The phase meter

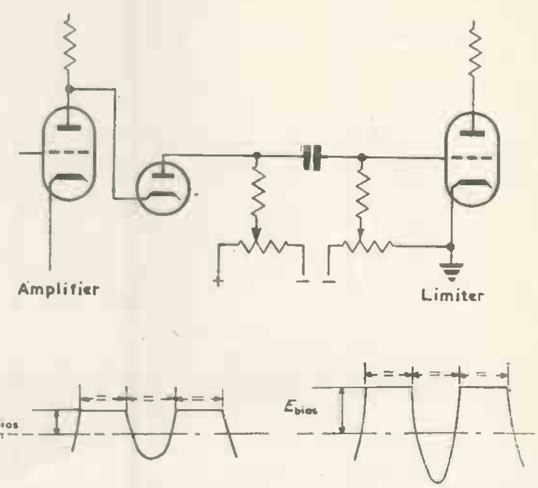

Fig. 2. Relative grid bias of limiter required to obtain equal mark-space ratio with different signal levels

capacitor will, however, become charged by grid current and will thus change the grid bias of the limiter and hence alter the mark-space ratio. D.C. coupling the amplifier to the limiter overcomes this defect, but the grid bias of the limiter is then affected by drift in the amplifier and highly stabilized H.T. and heater supplies will be required.

An alternative approach is to insert a diode between the

* *Saunders-Roe Limited.*

amplifier and the limiter as shown in Fig. 2 so that the grid of the limiter is never driven positive. The grid bias is chosen to give unity mark-space ratio, but as the value required will depend on the signal level this circuit is not a solution of the problem.

A diode may be employed as shown in Fig. 3. to prevent the grid of the limiter being driven positive, the mark-space ratio in this case being controlled by the bias on the diode. Charging of the coupling capacitor will, however, effect the bias, but may conveniently be prevented by means of a second diode inverted with respect to the first as shown in Fig. 4. The circuit shown in Fig. 4(b) was employed with

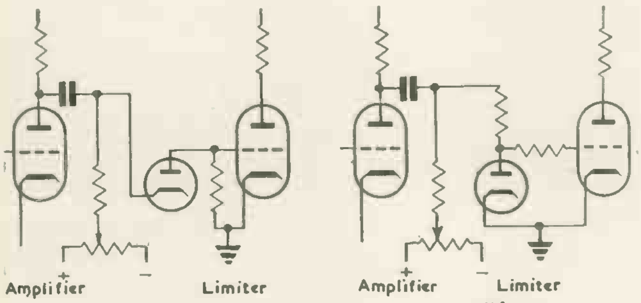

Fig. 3. Use of diode to prevent grid of limiter being driven positive

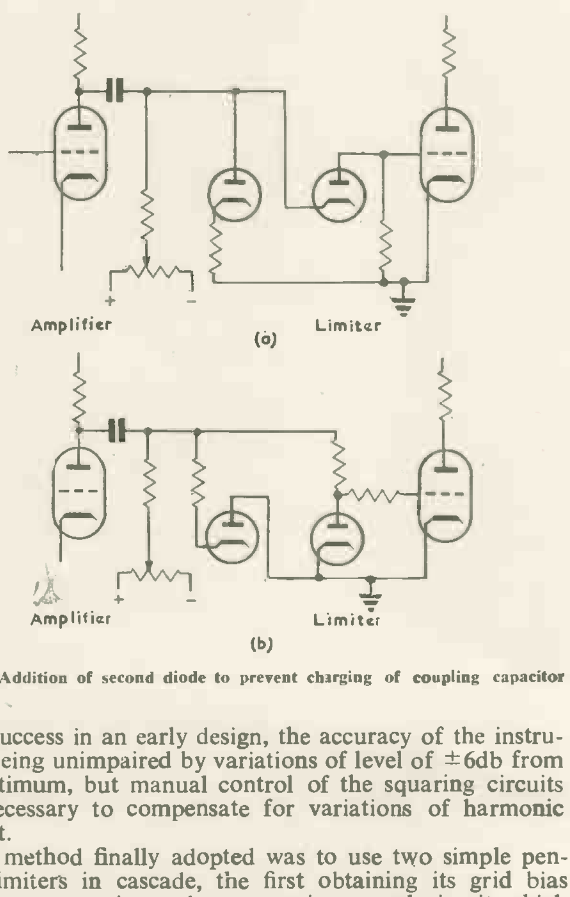

Fig. 4. Addition of second diode to prevent charging of coupling capacitor

some success in an early design, the accuracy of the instrument being unimpaired by variations of level of ±6db from the optimum, but manual control of the squaring circuits was necessary to compensate for variations of harmonic content.

The method finally adopted was to use two simple pentode limiters in cascade, the first obtaining its grid bias from an automatic mark-space ratio control circuit which measures the mark-space ratio of the square wave and automatically controls the limiter bias to maintain this ratio at unity[1,2].

MIXER

The Mazda 6F33 pentode, which has short cut-off control grid and suppressor grid characteristics and a diode internally connected to the suppressor grid to permit this electrode to be driven positive, is suitable for use in the mixer stage. The H.T. supply for both anode and screen is 70 volts and is obtained from a neon stabilizer tube, type QS70/20. Under these conditions the effective cut-off for the control grid when the suppressor grid is connected to the cathode is −2·5 volts and that for the suppressor grid when the control grid is connected to the cathode is also −2·5 volts. The low value of H.T. not only ensures that the rectangular pulses of anode current have very short rise and decay times compared with their duration, but also ensures that the value is not over-run.

INTEGRATING DETECTOR AND HEATER SUPPLY COMPENSATION CIRCUIT.

Basically the detector consists of a D.C. milliammeter connected in the anode circuit of the mixer valve. In the final design a circuit which compensates for variations of heater supply voltage was incorporated. This consists of a double diode in series with a resistor, connected as a meter shunt of value dependent upon the heater supply voltage. A fall of heater voltage causes an increase of the diode resistance

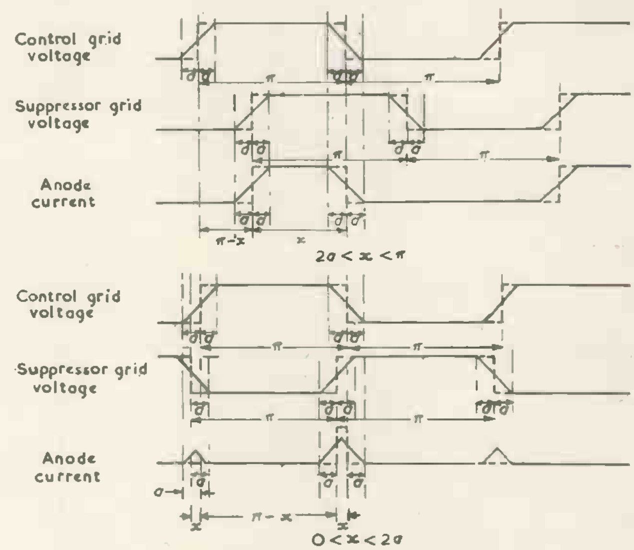

Fig. 5. Circuit waveforms

and thus an increase of the fraction of the anode current carried by the meter which compensates for the fall of total anode current.

Possible Sources of Measurement Errors

To achieve a high degree of accuracy of measurement it is necessary for the square wave to have exactly unity mark-space ratio and for its rise and decay times to be as short as possible. The former is achieved by means of the automatic mark-space ratio control circuit and is dealt with more fully elsewhere[1,2].

The error due to the square wave having finite rise and decay times will now be considered.

In Fig. 5 the ideal square waves fed to the control grid and suppressor grid of the mixer are shown dotted and the corresponding trapezoidal waves obtained in practice by solid lines. It is seen that whereas the anode current corresponding to the square waves is a rectangular pulse that corresponding to the trapezoidal waves will be either trapezoidal or triangular depending upon the relative phase of the input waves.

It is seen that for a phase difference of $(\pi - x)$ for $0 < x < \pi$, the area of the rectangular pulse is equal to hx where h = height of pulse and is thus a measure of the phase-angle. The area of the trapezoidal or triangular wave will also be a function of x. This function $f(x)$ will now be considered.

Let $2a$ = rise time of trapezoidal wave whose period is 2π then, provided $2a < x < \pi$, the pulse of anode current is trapezoidal and is of area hx., i.e., is the same as that of the ideal rectangular pulse and there is thus no error.

$$\text{i.e., } f(x) = hx \text{ for } 2a < x < \pi$$

When $x < 2a$ the anode current consists of two triangular pulses π radians apart as seen in Fig. 5 and $f(x)$ is equal to the combined area of these.

$$\text{i.e., } f(x) = \tfrac{1}{2}\frac{(2a + x)^2 h}{4a} + \tfrac{1}{2}\frac{(2a - x)^2 h}{4a}$$

$$\text{i.e., } f(x) = h(a + x^2/4a) \text{ for } 0 < x < 2a$$

Thus $f(x) > hx$ and the measuring error e is given by:—

$$e = h(a + x^2/4a) - hx$$

$$\text{i.e., } e = h[a - x(1 - x/4a)]$$

Now $1 - x/4a$ is positive for $x < 2a$ and the error is therefore less than ha.

Maximum error occurs at $x = 0$ and is equal to ha.

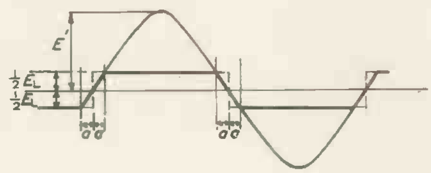

Fig. 6. Analysis of error

Full-scale deflexion occurs when $x = \pi$ and is equal to $h\pi$.

Thus the zero error is $ha/h\pi \times 100$ per cent of full-scale deflexion.

i.e., zero error $= a/\pi \times 100$ per cent of full-scale deflexion.

Referring to Fig. 6, the rise time $2a$ is given by $\sin a = \frac{1}{2}E_L/E'$.

For the early design of phase meter which employed diode limiters:—

$$E_L = 2{\cdot}5 \text{ volts and } E' = 50 \text{ volts.}$$

$$\therefore \sin a = \frac{\frac{1}{2} \times 2{\cdot}5}{50} \text{ i.e., } a = 0{\cdot}025$$

The error is zero for $x > 2a$, i.e., $x > 0{\cdot}05$ radians (or 3°)

i.e., zero error for phase angle of between 0° and 177°.

Maximum error occurs when $x = 0$, i.e., at 180° and is given by

$$e_{180°} = 0{\cdot}025 \times 100 \text{ per cent of full-scale deflexion.}$$

$$\therefore e_{180°} = 0{\cdot}78 \text{ per cent of full-scale deflexion.}$$

i.e., error at 180° is 1·4°.

The meter reading and corresponding error for phase angles of between 177° and 180° are tabulated below:

PHASE-ANGLE	METER READING	ERROR
0 – 177°	Correct	0
178°	177.9°	0.1°
179°	178.4°	0.6°
180°	178.6°	1.4°

For the final design of phase meter which employs two pentode limiter stages in cascade, the rise time will be considerably less than for the earlier instrument, i.e., $a \leqslant 0{\cdot}025$, and hence the error due to this cause will be much less than 1·4° for a phase difference of 180°.

Another possible source of error is the variation of the height, h of the pulses of anode current of the mixer, caused by valve ageing or drift in the supply voltages. Since, however, the meter deflexion is directly proportional to the pulse height, this error can readily be eliminated by means of a variable meter shunt adjusted to give the correct meter reading for a known value of phase difference. In practice, a single 50c/s supply of suitable amplitude is provided, which is applied to both channels when the USE CALIBRATE switch is set to CALIBRATE. The variable meter shunt SET ZERO control is then adjusted for zero phase reading of the instrument.

Further errors may be caused by phase shift in the amplifiers or limiters, but by making the two channels identical and by careful attention to time-constants this source of error may be minimized.

Calibration

In order to check the calibration of the instrument it is necessary to feed it with two signals having a known phase difference. No method of measuring phase to the required degree of accuracy (better than 1 per cent) is known to the writer. It was, therefore, decided to use a resistance-capacitance phase shift network to provide the pair of signals of known phase.

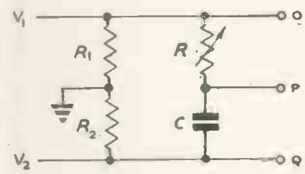

Fig. 7. Calibration network

The series resistor and capacitor R and C are fed from a balanced low impedance source as shown in Fig. 7. The phase of the voltage between point P and ground will depend upon the value of R, C and the frequency. Its amplitude will, however, be constant and equal to the input voltages V_1 and V_2 provided the load impedance between point P and ground is large compared with R and C. The resistors R_1 and R_2 must be small enough to ensure that V_1 and V_2 are unaffected by changes of R and C.

In practice, the resistor R was a 2kΩ helical potentiometer, calibrated 0 to 1 000 and linear to better than 0·1 per cent. The capacitor C, and frequency, were then chosen so that the reactance of C was equal to the maximum resistance of R. The phase-angle between points P and O was then 90° and that between points P and Q also 90°. As R is reduced in value the phase-angle between P and O will be reduced and the complementary phase-angle between P and Q increased. The law relating phase-angle to C, R and frequency f is:—

$$\phi_{PO} = 2 \tan^{-1} 2\pi fRC$$

$$\phi_{PQ} = 180 - 2 \tan^{-1} 2\pi fRC$$

thus by feeding one input of the phase meter from point P and the other from point O or point Q a complete range of phase of 0 to 180° was obtained.

Acknowledgement

The author wishes to express his thanks to Saunders-Roe Ltd., for permission to publish this article.

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1. JOHNSON, A. B., A Clipper with Automatic Mark-Space Rate Control. *Electronic Engng. 26*, 364 (1954).
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A Clipper with Automatic Mark-Space Ratio Control

By A. B. Johnson*, B.Sc.

It is sometimes convenient to be able to produce from a given periodic waveform a rectangular wave with a mark-space ratio (M.S.R.) independent of the amplitude and harmonic content of the input wave. This object can be achieved by means of a special feedback device[1]. The basic principle is shown in Fig. 1.

The input voltage is a periodic time function $V(t)$. The output is a rectangular wave whose M.S.R. is a function of $V(t)$ and e_c, the control bias. For a given $V(t)$, the M.S.R. is determined by the bias level of the first clipping stage of a limiting amplifier. It is compared in a discriminator circuit with a standard and a voltage proportional to the departure from the assigned value is used to modify this bias in a degenerative sense. With sufficient open-loop gain the error in the M.S.R. can be made very small.

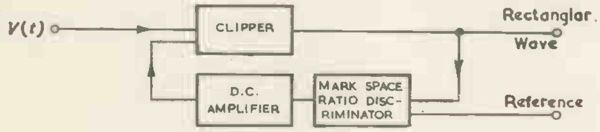

Fig. 1. The basic principle

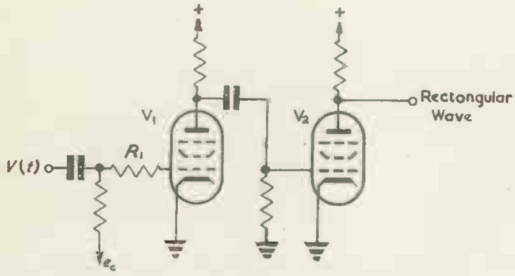

Fig. 2. Two pentode clipping amplifier

Consider a clipping amplifier consisting of two pentode stages as in Fig. 2. Anode current cut-off in the first valve produces the flat top of the clipped wave appearing at the anode of V_1. The upper few volts of this wave are then amplified in V_2 to produce a rectangular wave (Fig. 3). The M.S.R. is thus determined by the level at which the input wave is clipped by anode current cut-off in V_1. R_1 is present to prevent the wave being clamped on the positive-most part by grid conduction, which would result in e_c losing control.

The M.S.R. is defined here as $x = \theta / \pi$ (Fig. 4).

Consider the system of Fig. 1 in equilibrium with a certain $V(t)$ and value of e_c producing an M.S.R. x_0. Now let $V(t)$ change in amplitude or waveform so that x becomes $x_0 + \delta x$ in the absence of any change in e_c.

Let the output of the discriminator be $K(x_0 - x)$. Then $e_c = AK\,(x_0 - x)$, and with this change in e_c operating on the clipper.

$$x = x_0 + \delta x + \partial x/\partial e_c\, AK(x_0 - x)$$

$$\text{Whence } x = x_0 + \frac{\delta x}{1 + \partial x/\partial e_0 \,.\, AK} \quad \ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where $\partial x/\partial e_0$ is the rate of change of x with e_0 for the new input $V(t)$.

Hence the presence of the feedback loop reduces the change δx by a factor $\dfrac{1}{1 + AK\ \partial x/\partial e_c}$

Consider a waveform at the relevant clipping level shown in Fig. 5.

$\theta = \theta_0 + (1/m_1 + 1/m_2)\,.\,\delta e_c$, where m_1, m_2 are the slopes of tangents to the wave in the region of the clipping level, with appropriate signs,

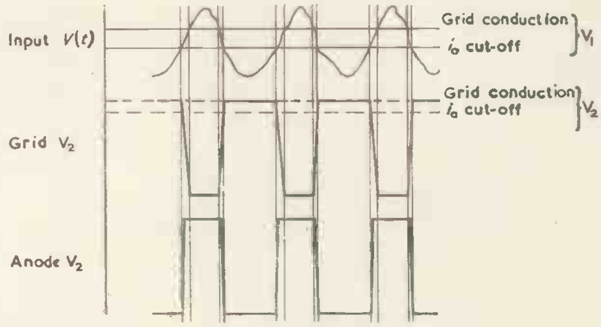

Fig. 3. Circuit waveforms

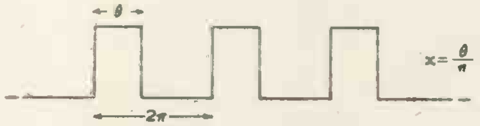

Fig. 4. Definition of mark-space ratio

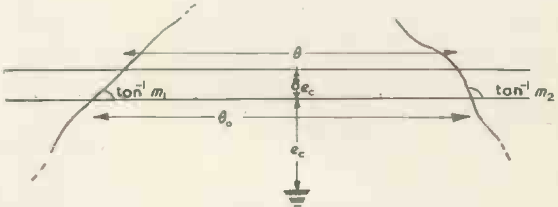

Fig. 5. Waveform at clipping level

$\therefore\ \delta x = \delta e_0/\pi\,.\,(1/m_1 + m_2)$ and $\partial x/\partial e_0 = 1/\pi\,(1/m_1 + 1/m_2)$ substituting in equation (1)

$$x = x_0 + \frac{\delta x}{1 + AK/\pi\,(1/m_1 + 1/m_2)}$$

Now δx is determined by the nature of $V(t)$, the changes it undergoes and the characteristics of the clipping circuit. It is least, for pure amplitude variations in $V(t)$, when the clipping level is arranged to be at the average value of the waveform.

For a large error reduction factor, A,K should be large, m_1, m_2 small. When m_1, m_2 are both infinite, i.e., the wave has vertical sides in the vicinity of the clipping level, e_0 has no control.

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Practical Application:

Fig. 6 shows a simple embodiment of the principle outlined above. Pentodes V_1, V_2 constitute a clipping amplifier operating as shown in Fig. 3. The M.S.R. discriminator is basically a pair of clamping circuits followed by averaging and summing networks. Waveforms are shown in Fig. 7. The M.S.R. is readily changed by variation of E_R or the tap position of point A. The M.S.R. discrimination can be achieved in numerous ways but that shown is probably the easiest to realize practically.

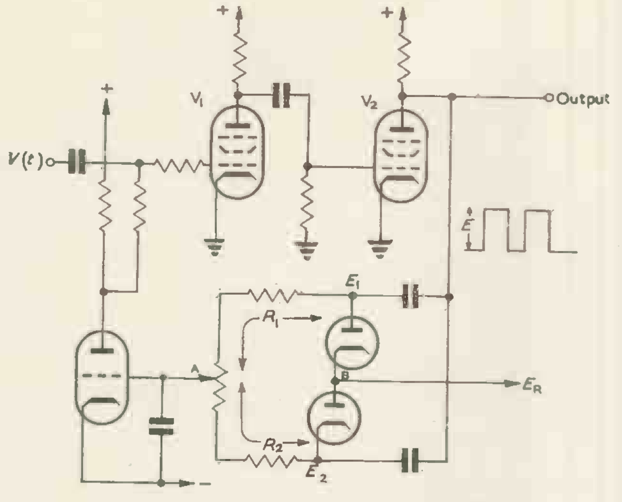

Fig. 6. Simple embodiment of principle described

Neglecting the output impedance of V_2,

$$E_1 = Et/T = Ex/2 \qquad E_2 = E(T - t/T) = E/2\,.(2 - x)$$

$$E_1 - E_0/R_1 = E_0 - E_2/R_2 \qquad \therefore E_0 = \frac{E_1R_2 + E_2R_1}{R_1 + R_2}$$

$$E_0 = E/2.\left[\frac{x(R_2 - R_1) + 2R_1}{R_1 + R_2}\right]$$

Comparing with the above, $E/2$ corresponds to K. It is an advantage if the pulse input to the discriminator is as large as possible.

This device has been found very useful in phase and torque measurement where a 1:1 square wave is required from an arbitrary input: this application is treated in detail elsewhere[2].

An interesting application suggested by Mr. P. G. S. Jackson is the use in conjunction with a sinusoidal oscillator to obtain a pulse generator of conveniently variable pulse width and good frequency stability.

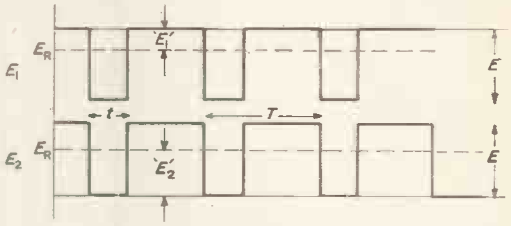

Fig. 7. Waveforms of Fig. 6.

With a sawtooth input it can be used to obtain pulse width modulation with good modulation linearity, the reference voltage E_R being varied in accordance with the information.

Acknowledgment

Acknowledgment is due to Messrs. Saunders-Roe Limited for permission to publish this article.

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2. Moss, F. P. An Audio Frequency Phase Meter. *Electronic Engng.* 26, 361 (1954).

A New Infra-red Photocell

An important contribution to the numerous applications of infra-red radiations in science and industry is made by a new photocell recently introduced by the Communications and Industrial Valve Department of Mullard Ltd. This cell, the 61SV, is of the photo-conductive lead sulphide type, and is characterized by extreme sensitivity to infra-red radiations and an unusually high speed of response. It has the additional advantages of a high signal-to-noise ratio, small size and robustness.

For example, it makes possible advances in radiation pyrometry, enabling very small temperature variations to be detected in low temperature sources down to 100°C. This means that the 61SV cell can be used for such typical applications as controlling and monitoring the work in radio-frequency heating and similar industrial applications such as measuring the temperature resulting from severe braking in wheels on railway carriages, and for detecting hot axle bearings, etc.

The 61SV lead sulphide cell depends for its operation on the photo-conductive effect. In practice, the cell is given a polarizing voltage, and the change in resistance is made to produce a voltage change across an external resistive load.

The electrical resistance of the lead sulphide layer in the 61SV lies between 2 and 7MΩ. It is, however, normal to use the cell with a load resistance of between 1 and 2MΩ, thus making it possible to use the cell with conventional amplifiers.

The spectral sensitivity of the 61SV to long-wave, infra-red radiations represents an improvement on that given by existing photocells of the caesium-oxidized-silver photo-emission types. Its sensitivity is also a considerable improvement on previously available photo-conductive and photo-voltaic cells. When compared with thermal infra-red detectors, such as the thermopile and bolometer, the 61SV not only shows better sensitivity, but, what is more important, great improvement in the speed of response. The short response time of this cell has the distinct advantage that it enables transient phenomena, i.e. fluctuating temperatures, to be studied and, where necessary, observed on the screen of a cathode-ray tube.

The spectral response of the 61SV cell is from about 0·3μ (3 000Å) in the visible spectrum to about 3·5μ (35 000Å) in the infra-red. The peak response occurs at 2·5μ (25 000Å). By comparison, it is interesting to note that the useful spectral sensitivity of emission photocells of the caesium-oxidized-silver type stops at about 1·2μ (12 000Å).

Cells of the lead sulphide photo-conductive class have an inherently large ambient temperature coefficient of resistance. In order to minimize the effects of these changes in the cell output, it is usual to operate the cell with an interrupted or "chopper" disk, holed disk or similar device. The output of the cell is then fed into an A.C. coupled amplifier, the time-constants of which are so chosen that only the rapidly changing signals, resulting from the chopping of the radiation from the temperature source under observation are passed on to the subsequent amplifier stages. For critical measurement applications, best results are achieved by using an interruption or "chopper" frequency of about 800c/s, the amplifier being of the tuned type, having a bandwidth such that all necessary information in the cell output is utilized. A typical amplifier bandwidth for such purposes is 50c/s.

The ultimate detection limit of the cell is usually derived by using an interrupted radiation source at the optimum chopper frequency (800c/s) and an amplifier having a theoretical bandwidth of 1c/s. With such a circuit arrangement it is possible to detect radiation energies as low as 0·003 microwatts (3×10^{-9} watts). The radiation source for this particular measurement is a 200°C black body, having a 3·0mm diameter aperture, situated 8in (20cm) away from the cell. Some idea of the sensitivity may be judged from the fact that the cell will detect directly without any optical system the heat radiation produced by such hot objects as an ordinary soldering iron (approximately 350°C) placed at a distance of 100 yards or more away.

Induced Charges and Currents

(Appreciable Space Charge Present)

By W. E. Benham, B.Sc., F.Inst.P.

It is rigorously established, starting with Green's Theorem, that the potential function appropriate to the calculation of induced charge must satisfy Laplace's equation. This means that existing methods of arriving at induced charge are valid even when space charge distorts the field, i.e., the "cold" potential function for this purpose is vindicated, whatever the degree of space charge present.

THE correct way of regarding electronic currents in any kind of vacuum tube is not merely to say that one electrode emits, or another collects so many electrons per cm^2/sec, but to reason as follows. All the time a milliammeter is indicating anode current, electrons are in motion between the electrodes of the device considered. It is this motion of electrons which induces (electrostatically) a varying anode charge. When the electrons actually become collected they no longer contribute current in the same way as they did while freely travelling, and since they are slowed down (sensibly to zero velocity) on impingement at an electrode, one can understand that the anode current (due to electrons at the moment of impingement) falls to zero just at the time that the older conception of electron collection would have indicated that the current would first occur. The current in the wiring to the electrodes is produced by the (sensibly, but not quite) zero motion of electrons after collection, and not merely one group but a number of already collected groups, all moving with velocities of the order of a fraction of a centimetre per second only.

Since, owing to space charge neutralization by positive nuclei in the metal, enormous densities of electrons are possible, we obtain the same current per cm^2 in the metal by virtue of the relation (applicable, at any rate, to direct currents)

$$i_c = p_c v_c = p_m v_m$$

Where i_c convection current in valve; p,v are space charge density and electron velocity; the suffix c corresponds to convected electrons, while m denotes the values in the metal. Thus, if v_c should be (as is typical) as high as $10^9 v_m$, p_m will be $10^9 p_c$—a state of affairs which suggests very high local internal fields inside the metal (as modern physics in fact teaches, contrary to the older simplifying doctrine of zero field inside a conductor).

Since the induced charges on the electrodes, by their variation in time according to changes in electron positions and densities (i.e. in $dr/dt = v_c$ and in p_c) gives rise to induced currents, it is all important to be able to calculate these induced charges and currents, for the latter virtually specify the performance characteristic of the device at any frequency of operation. By far the greater part of published work starts out by neglecting the effects of mutual repulsions, so that in cases where mutual repulsions of electrons must be considered, the question arises, does the expression used for induced charge depend upon the space charge density, or can one continue to use an expression based upon a potential distribution in the device in the absence of space charge? The purpose of the present article is to establish rigorously that the answer to the second question framed above is, indeed, in the affirmative.

The necessary mathematical details are relegated to the Appendix, and it only remains to comment here upon what is being done there, for the benefit of those not prepared to spend the time to scrutinize the proofs. In the first section (equations (1) to (8)) it is shown that if by means of Green's theorem due allowance is made for the existence of two potentials, one, ψ the potential in the absence of space charge and the other, ϕ that in the presence thereof, then the expressions for induced charge (equation (5)) and induced current (equation (8)) both come out in terms of ψ rather than of ϕ. Note here that v differs from ψ only in that it contains a constant multiplier, $1/\log(b/a)$.

In dealing with a cylindrical geometry we can at any time reduce to a plane geometry by letting a tend to b. A spherical geometry has also been worked out.

In the next section 'Potential Function appropriate to the calculation of Induced Charge', instead of specifying at the outset that ψ shall be the 'cold' potential function, we leave ψ open and, in a more general approach, reach the conclusion that, if ψ (whatever its value) shall now be regarded as the potential function appropriate to the induced charge, then (equation (5))

$$\psi = \psi_b \log(r/a)/\log(r/b)$$

(with ψ_b at our disposal) is reached as a sufficient (but not yet necessary) condition for the satisfaction of the equation (4b) which is that corresponding to Green's theorem after certain legitimate manipulations have been effected.

Further steps taken are directed towards establishing that the above condition is necessary as well as sufficient. To this end we let ψ differ from the cold potential function by the amount ψ_p and in taking an assumed power series expansion for ψ_p find that all the coefficients are zero.

The inference from this work, believed novel at any rate in respect of publication, is that expressions in current use are valid even when space charge is important.

Appendix

1.—Induced Charge on Anode of Cylindrical Diode: Induced Current

It is convenient to start with the following well-known form of Green's theorem

$$\int dS(\phi\partial\psi/\partial n - \psi\partial\phi/\partial n) = \int dv(\phi\triangle^2\psi - \psi\triangle^2\phi) \quad \ldots\ldots\ (1)$$

and make ϕ the actual potential at any point in the diode, while ψ will be chosen as $\log(r/a)$, for reasons which will later be seen to be valid. The boundary surfaces are: cathode $2\pi al$ anode $2\pi bl$, while $2\pi r dr$. l represents the appropriate volume element dv. The normals being directed out of the cathode-anode space, we shall have $\partial/\partial n = -\partial/\partial r$ at cathode and $+\partial/\partial r$ at anode. Equation (1) becomes, after making these substitutions and cancelling the common factor $2\pi l$, and remembering that $\triangle^2\psi = 0$

$$a(-\phi_a/a - O) + b\left\{\phi_b/b - (\partial/\partial r)_b \log(b/a)\right\}$$

$$= -\int_a^b dr \log(r/a)\partial/\partial r\,(r\partial\phi/\partial r) \quad \ldots\ (2)$$

or $\phi_b - \phi_a - b\log(b/a)\,(\partial\phi/\partial r)_b$

$$= -\left|r\log(r/a)\,\partial\phi/\partial r\right|_a^b + \int_a^b r\partial\phi/\partial r\,.\,dr/r \quad \ldots\ldots\ (3)$$

On inserting limits on the right-hand side, and integrating the last term, we see that it becomes identically equal to the left-hand side.

If we write equation (2) in terms of the space charge density p and of $p_1 = 2\pi r p$ (so that $p_1 dr$ element of charge per unit length of dv)*

$$\phi_b - \phi_a - b \log(b/a)\,(\partial\phi/\partial r)_b = 4\pi \int_a^b pr \log(r/a) dr$$

$$= 2 \int_a^b p_1 \log(r/a) dr \quad \ldots\ldots \quad (4)$$

Now consider the significance of the left-hand side. Division by $b \log(b/a)$ gives us the potential gradient $(\phi_b - \phi_a)/b \log(b/a)$ at the anode of the empty diode, while $(\partial\phi/\partial r)_b$ is the actual potential gradient at the anode when space charges p are present. The difference, with the sign changed, gives the charge induced electrostatically on unit area of the anode $\times\ 4\pi$, that is, it gives the induced charge per unit length $\times\ 2/b$. Thus the equation is (reversing the signs)

$$-(\phi_b - \phi_a)/\left\{ b \log(b/a) \right\} + (\partial\phi/\partial r)_b = 2q_1 \ldots\ldots \quad (5)$$

where $q_1 = -\int_a^b p_1 v\, dr$, with $v = \log(r/a)/\log(b/a)$

When q_1 varies with time t, it gives rise to the induced current (reckoned positive in direction of electron flow)

$$i_{nd} = dq_1/dt = -\int_a^b (p_1 dr)\, dv/dt \quad \ldots\ldots \quad (6)$$

$$= -\int_a^b (p_1 dr/dt) dv \quad \ldots\ldots \quad (7)$$

$$= \int_a^b i_c dv \quad \ldots\ldots \quad (8)$$

Where i_c = electron convection current $-p_1 dr/dt$ reckoned per unit length, and v is the 'cold potential function' $\log(r/a)/\log(b/a)$.

2.—Potential Function appropriate to the Calculation of Induced Charge

Let us now leave ψ completely open, and apply Green's theorem to the same cylindrical diode as before. We have, instead of equation (2) $a\phi_a(-\partial\psi/\partial r)_a + b\phi_b\,(\partial\psi/\partial r)_b + a\psi_a\,(\partial\phi/\partial r)_a - b\psi_b\,(\partial\phi/\partial r)_b =$

$$= -\int_a^b dr\, \partial/\partial r\,(r\partial\phi/\partial r)\psi + \int_a^b dr\; r\phi\triangle^2\psi \quad \ldots\ldots \quad (2a)$$

Integrating by parts the right-hand side of this gives

$$\left|\phi r\partial\psi/\partial r - \psi r\partial\phi/\partial r\right|_a^b + \int_a^b dr(r\partial\phi/\partial r\partial\psi/\partial r) - \int_a^b dr(r\partial\psi/\partial r\ \partial\phi/\partial r)$$

the first two terms of which cancel the four terms on the left-hand side of equation (2a) while the last two add up to zero. We get no information this way except that Green's theorem is satisfied for all scalars ψ, ϕ having radial symmetry. If, however, we specify that ψ, whatever its value, shall be the function appropriate to the induced charge, then some information can be gleaned. First we take both ϕ_a, ψ_a to be zero (no loss of generality involved here). Secondly, write $\partial/\partial r\,(r\partial\phi/\partial r) = p_1$ where $p_1 dr$ is the charge per unit length of cylindrical shell of thickness dr and obtain

$$b\ \left\{ \phi_b(\partial\psi/\partial r)_b - \psi_b(\partial\phi/\partial r)_b \right\}$$

$$= \int_a^b 2p_1\psi dr + \int_a^b \phi\partial/\partial r(r\partial\psi/\partial r)dr \quad \ldots\ldots \quad (2b)$$

Now since, by hypothesis, ψ is the function appropriate to the calculation of induced charge, the latter will satisfy the condition

$$(\partial\phi/\partial r)_b = \int_a^b dr\,(-2p_1\psi)/b\psi_b + (E_o)_b \quad \ldots\ldots \quad (3a)$$

where $(E_o)_b$ is the cold field at the anode, and ψ_b has to be placed as shown in order that the cylindrical element $2p_1 dr$ shall, when very close to the anode, induce an equal and opposite (hence negative sign) charge thereon. Division by $2\pi b$ converts the induced charge per unit length (the integral term) to surface density of induced charge.

Comparing equation (2b) with equation (3) we find

$$-b(\phi\partial\psi/\partial r)_b + b(\psi E_o)_b = -\int_a^b \phi(\partial/\partial r)\,(r\partial\psi/\partial r)\,dr$$

$$= -(\phi r\partial\psi/\partial r)_b + \int_a^b r(\partial\psi/\partial r)\,(\partial\phi/\partial r)\,dr$$

$$\text{or } b\psi_b(E_o)_b = \int_a^b r(\partial\psi/\partial r)(\partial\phi/\partial r)\,dr = \int_a^b r(\partial\psi/\partial r)d\phi \quad \ldots\ldots \quad (4)$$

But $(E_o)_b$ is known to have the value

$$(E_o)_b = \phi_b\left[\partial/\partial r\left\{\log(r/a)\right\}\right]_b \log(b/a) = \phi_b/b\log(b/a) \quad \ldots\ldots \quad (4a)$$

$$\text{Thus } \psi_b\phi_b/\log(b/a) = \left[\phi r\,\frac{\partial\psi}{\partial r}\right]_a^b - \int_a^b \phi\partial/\partial r(r\partial\psi/\partial r)\,dr \quad \ldots\ldots \quad (4b)$$

This equation is seen to be satisfied if ψ satisfies Laplace's equation. Thus, a sufficient condition that the equation be satisfied is

$$\psi = \left\{\psi_b/\log(b/a)\right\}\log(r/a) \quad \ldots\ldots \quad (5)$$

where ψ_b would obviously be taken as unity. In order to try and ascertain whether the condition is also a necessary one, let ψ differ from the above quantity by the quantity ψ_P which (as will presumably be produced as the result of space charge P) then satisfies

$$0 = \int_a^b \phi\partial/\partial r(r\partial\psi_P/\partial r) + b(\partial\psi_P/\partial r)_b\ \phi_b$$

$$= \int_a^b r(\partial/\partial r)\ \psi_P\ .\ d\phi, \text{ for } \phi_a \text{ zero} \quad \ldots\ldots \quad (6)$$

Now $\phi > 0$ over the vast majority of the range $a \rightarrow b$ under typical operating conditions. Hence for the integral to vanish $(\partial/\partial r)\psi_P$ would either have to vanish or be negative over part of the range and positive over the rest.

Consider the latter possibility and, to simplify investigation, take a very simple expression for ϕ namely $\phi_b(r-a)/(b-a)$. Then $d\phi = \phi_b dr/(b-a)$. We then require to find a value for ψ_P other than zero, which satisfies

$$0 = \int_a^b r(\partial\psi_P/\partial r)dr = \int_0^b (x+a)\ (\partial\psi_P/\partial x)\ (\partial x/\partial r)dx$$

where $x = r - a$

Try $\psi_P = (\alpha x + \beta x^2 + \ldots)$

$\partial\psi_P/\partial x = (\alpha + 2\beta x + \ldots)$

Condition is

$$0 = \int_0^{b-a} (x + a)\ (\alpha + 2\beta x)\ dx$$

$$= \left[\alpha(\tfrac{1}{2}x^2 + ax) + 2\beta\ (\tfrac{1}{3}x^3 + \tfrac{1}{2}ax^2 + \ldots)\right]_0^{b-a}$$

Hence $\alpha a = 0$, and since $a \neq o$ this means $\alpha = 0$. Similarly $\frac{1}{2}\alpha + \alpha\beta = 0$, which leads to $\beta = 0$.

Thus all coefficients α, β, .. in an assumed power series expansion for ψ_P turn out to be zero. We thus infer that $\psi_P = 0$ and that equation (5) is both necessary and sufficient.

For planes, condition corresponding to equation (4), section 2 is

$$\phi/d = \int_0^d \psi'\ (x/d)\ \phi'\ (x)\ dx,$$

satisfied alone by $\psi'(x/d) = 1/d$. Thus $\psi(x/d) = x/d$, as used in accepted treatments of the plane case.

* p_1 and p carry their own signs.

Short News Items

Cable and Wireless Ltd announce that two Canadian youths will join their Engineering School at Porthcurno, Cornwall, in January next. They will be the first two students chosen from applicants from Canadian high schools to undergo an eighteen months' all-expenses-paid course in telecommunications engineering under a new scheme financed by the Canadian Overseas Telecommunication Corporation. If the experiment is successful it will be repeated annually for the next five years. On completing their training successfully and passing their final examinations, the students will join the permanent engineering staff of the Corporation at one of its offices in Montreal, St. John's (Newfoundland), Halifax (Nova Scotia), or on the Canadian West Coast.

The General Electric Co Ltd is to supply microwave radio relay equipment to carry television programmes in Canada between London and Windsor, Ontario. The order has been obtained by the Canadian General Electric Co Ltd the main contractor for the scheme, jointly from Canadian National Telegraphs and Canadian Pacific Telegraphs.

The Northern Polytechnic, Department of Telecommunications Engineering, are holding three new courses, commencing on 27 September, to assist present television servicing engineers in the understanding of aerial and receiver problems in connexion with the introduction of band III television and F.M. broadcasting. Approximately 50 per cent of each course will be devoted to lectures and the remaining time to practical experiments and measurements on current television and F.M. receivers. Full details and enrolment forms, which must be completed by 7 August, may be obtained from the Northern Polytechnic, Department of Telecommunications, Holloway, London, N.7.

The British Thomson-Houston Co Ltd announce that a third contract for Mobile Fire Control Radar, Type A.A. No. 3 Mk7, valued at $5 700 000 (£2 020 000) has been placed with them by the U.S. Army European Headquarters Command. This brings the total value of the three orders to over $14 000 000 (£4 975 000).

The British Instrument Industries Exhibition next year will be held at Earls Court from 28 June to 9 July. The response from exhibitors has more than justified the decision when it was agreed to select Earls Court, where all stands are to be sited on the same floor.

Mr. John Clarricoats, for the past 24 years general secretary of the Radio Society of Great Britain and, since 1945, a member of the Southgate Borough Council, has been elected an Alderman of that Borough.

Solartron announce that, as the next stage of a planned programme of expansion, they are forming a holding company, to be known as the Solartron Electronic Group Ltd. This company will co-ordinate the overall activities of the existing companies, Solartron Laboratory Instruments Ltd, and Solartron Engineering Ltd, together with a new company to be known as Solartron Research and Development Ltd. The holding company will have responsibility for joint administrative services, and all sales and purchasing functions for the member companies of the group.

Johnson, Matthey and Co Ltd have joined the International Telex service, at present providing direct foreign teleprinter communication and to be extended later this year to include transmissions within the United Kingdom.

The Plessey Co Ltd announce that a new division has been established, to be known as the Swindon Components Division. It will be responsible for the development, manufacture and sale of electrolytic and paper capacitors and moulded track potentiometers. Mr. O. G. Cox, previously in an executive position in the Components Division at Ilford, has been appointed general manager. The address of this new division is, The Plessey Co Ltd, Swindon Components Division, Kembrey Street, Swindon, Wiltshire.

Pye Canada, in competition with other manufacturers, have received an order for a large quantity of radio telephone equipment from the Highways Branch of the New Brunswick Department of Public Works. This is a province wide scheme on 152-174Mc/s to provide communication to snow ploughs and other road maintenance vehicles, plus a separate point to point network on 72-76Mc/s.

The Fourth Annual Eastern Joint Computor Conference and Exhibition will be held in the Bellevue-Stratford Hotel, Philadelphia, from 8-10 December. The theme of the conference, which is jointly sponsored by the American Institute of Electrical Engineers, The Institute of Radio Engineers, and the Association for Computing Machinery, will be "Design and Application of Small Digital Computors." Further particulars may be obtained from Mr. R. G. Lex, chairman, Publicity Committee, Leeds and Northrup Company, 4901 Stenton Avenue, Philadelphia 44, Pa. U.S.A.

Mullard Ltd, in accordance with their policy of providing valve users with comprehensive technical information on valve applications, have designed a five valve, ten-watt high quality amplifier circuit. This circuit enables the fullest advantage to be taken of the latest Mullard audio valves and will help home constructors and equipment manufacturers to build a high performance amplifier at a comparatively low cost.

Gresham Transformers Ltd have recently conducted considerable research into the design of transformers to U.S. specification incorporating materials made in this country. This has been necessary in order to implement the policies of the North Atlantic Treaty Organization where new problems of standardization have had to be solved, ranging from major equipment down to small components.

Pye Ltd of Cambridge have developed a new miniature television camera which was used recently at the inaugural meeting of the British Association of Pediatric Surgeons when about 100 surgeons from all over the world watched a series of operations on television at the Hospital for Sick Children, Great Ormond Street, London. The new camera is designed for use in all branches of industry, particularly for remote viewing of dangerous or inaccessible processes. The weight of the camera is only 30lb.

The Seventeenth French Radio and Television Exhibition, organized under the auspices of the National Federation of the Radioelectric and Electronic Industries will be held from 2 to 12 October at the Musée des Travaux Publics, Place d'Iéna, Paris.

Standard Telephones and Cables Ltd will be exhibiting equipment at the British Trade Fair to be held in Baghdad from 25 October to 8 November.

Hilton Electric Company Ltd are now manufacturing a range of A.C. solenoids designed for industrial applications where efficiency, reliability and compactness are of paramount importance. These solenoids are supplied for operation on any voltage from 6-600V A.C. giving a linear pull or push up to 1¼in with a maximum continuously rated power of 7lb. A laminated silicon iron magnetic circuit with shaded pole faces ensures silent operation and the riveted steel frame assembly provides for side or back mounting within a little over a 2in cube.

Errata. The following amendments should be made to the article, "A Simplified Circuit and Conductimetric Tube for Chemical Analysis at Low-Frequency" by G. G. Blake which appeared in the July issue.

In the summary on page 316, line 2, for "operation" read "operator".

Page 317, clause (3), for "0·1/42" read "0·1/4A".

Page 317, second column, line 10, for "4·18mm³" read "4·16mm³".

LETTERS TO THE EDITOR

(We do not hold ourselves responsible for the opinions of our correspondents)

Frequency Shift Diplex

DEAR SIR,—The keying distortions described in the article by S. C. Heward in the June issue can be, as the author mentions, overcome by synchronizing the two sets of signals.

Some twenty years ago I brought out a D.C. diplex system in which the two tape controlled transmitters were mechanically coupled together so that the signals were in phase. If the two signal sources were received over separate lines, these were equipped with receiving perforators to furnish the two tapes.

About the same time F. G. Creed used the same idea for a diplex system in which the voltage on one channel was three times that of the other. When manually operated this system was liable to signal distortion of the type shown in Fig. 4 of the article. When however tape controlled transmitters coupled together were employed, this form of distortion disappeared.

Yours faithfully,

H. H. HARRISON,
Ewell, Surrey.

In reply:

DEAR SIR,—Perhaps you would permit me to reply to Mr. Harrison in the absence of the author, Mr. S. C. Heward, who is abroad.

Mr. Harrison's letter on the question of synchronization in the Frequency Shift Diplex System is of great interest, and the writer remembers very well the D.C. system which Mr. Harrison brought out.

Frequency shift diplex systems have been operated with synchronized five-unit transmitters, synchronization being achieved by using a common driving motor with a consequent reduction of distortion. In practice, however the two channels are often controlled from quite different telegraph offices and used for different purposes; the introduction of synchronization would mean a tape relay at the terminals of the radio circuit. This would increase the technical complication and operating costs. As the distortion is not excessive, synchronization is not usually considered worth while.

In some cases the channels may carry different forms of signalling and it is not unusual to have high speed morse operation on the first channel with start-stop five-unit working on the second channel.

Thus, although I agree with Mr. Harrison that synchronization is technically preferable, in practice the flexibility obtained through operating the channels independently is normally an over-riding consideration.

Yours faithfully,

A. W. COLE,
Marconi's Wireless Telegraph Co., Ltd.

D.C. Amplifiers

DEAR SIR,—In their valuable review of D.C. amplifiers, Messrs. Yarwood and Le Croissette[1] mention the use of mean level feedback in push-pull amplifiers. I should like to draw attention to an unwelcome feature of these circuits, which renders their utility open to question. It is that mean-level feedback increases the non-linear distortion of the push-pull input-output characteristic.

The explanation of the phenomenon is that there is a hidden push-pull feedback, which may be traced as follows. Suppose a push-pull signal is applied to the input stage. This results in a push-pull output from the output stage. If the output stage is not perfectly balanced, it also results in a change of mean-level of the output, (i.e. in a "push-pull" output). If mean-level feedback to the first stage is incorporated, there is consequently a change of push-pull input to the first stage. If the first stage is not perfectly balanced, this produces a push-pull output from the first stage. This output thus constitutes a form of spurious signal feedback (not to be confused with the intentional push-push feedback). The feedback may be positive or negative according to the relative signs of the unbalances in the first stage and output stage. Indeed, since unbalance is affected by small non-linearities in each half of a push-pull stage, the feedback may change from positive to negative over parts of the output range. Such changes can make for gross non-linearity of the resultant input-output characteristic, especially when the forward gain of the amplifier is high.

The effect becomes emphasized when the output stage is driven nearly into saturation since its sign of unbalance will depend on which valve shows more saturation, and this in turn depends on the sign of the output signal. In fact an amplifier I hopefully made some years ago, having mean-level feedback over three push-pull stages, showed instability (D.C.) at one end of its characteristic and very poor sensitivity at the other.

The most that mean-level feedback can do is to reduce the push-push gain of the amplifier to about unity. Yet the same result can be achieved by the alternative method of designing each stage to have a push-push gain of about unity, i.e., using long-tailed pairs with sufficiently large cathode resistances). Can we not, therefore, dismiss mean-level feedback as being, at best, a redundant technique?

Yours faithfully,

A. T. FULLER
Godalming, Surrey.

REFERENCE

1 YARWOOD, J. and LE CROISSETTE, D. H., D.C. Amplifiers. Part 3. *Electronic Engng.*, 26, 114 (1954).

The authors reply:

DEAR SIR,—Mr. Fuller is correct in showing that there is a path through the amplifier causing positive or negative feedback according to the relative signs of unbalance in the two stages which are acting as links in the feedback chain. In order to determine whether the effect which he mentions is sufficiently great to warrant the dismissal of 100 per cent mean level feedback as redundant, it is advisable to consider the value of the amount of unbalance which is normally found in such an amplifier.

Balanced directly coupled amplifiers are usually built with selected valves and balancing controls are fitted in the anode circuit. The balance control may be adjusted until, with no input, the potential difference between the two anodes is zero. This adjustment means that the ratio of the potential divider formed by the anode load of the first valve and the direct current resistance of that valve is accurately set to equal the corresponding ratio for the second valve. Any small change in the H.T. potential to the stage will produce a change in voltage which will be the same at both anodes. Since the input voltage to such an amplifier is generally low and the two valves are initially well matched, any second order effects creating unbalance may be neglected in comparison with the inaccuracies in setting the balancing control. This adjustment may be varied as the valves age.

The in-phase voltage produced between the anodes of the output stage is not compensated for by adjusting the anode loads since this procedure does not take into account any unbalance in the valve parameters determining the amplification in the stage.

The product of the out-of-phase gain through the amplifier and the reduction in the signal due to passing through the two stages slightly out of balance, must be appreciably less than unity in order to be able to neglect the feedback. It can be seen that this condition will not be satisfied when the amplifier gain is high (greater than 10^4 say) and the valves in the output stage are not well matched. In this case, as Mr. Fuller says, discrimination against in-phase signals is best achieved by designing each stage to have a low in-phase (or push-push) gain.

In the more simple low-gain amplifiers, however, 100 per cent mean level feedback may surely still be justified? Good discrimination against in-phase signals can usually only be provided in each stage by the use of a common cathode resistance of high value, used in conjunction with a very stable negative bias supply. This complication may be avoided by the simple connexion providing mean level feedback.

Yours faithfully,

D. H. LE CROISSETTE,*
J. YARWOOD,†

* *The Physics Department, The University of Southampton.*

† *The Mathematics and Physics Department, The Polytechnic, London, W.1.*

ELECTRONIC EQUIPMENT

A description, compiled from information supplied by the manufacturers, of new components, accessories and test instruments.

Infra-red Spectrometer

(Illustrated below)

THE main feature of the Mervyn spectrometer is the manochromator which consists of a Merton-N.P.L. grating which is considerably cheaper to produce than the more conventional optical systems. The source is a Nernst filament, the light output of which is interrupted 800 times per second. A filter is used to absorb unwanted orders and a lead selenide cell is used as a detector.

A high gain amplifier followed by a special correlation detector and an adjustable integrator network combines adequate sensitivity with a control of signal-to-noise ratio at the output.

A high order of overall long term and short term stability for quantitative measurement, comparable with that of a null method balanced double beam spectrometer is obtained on this instrument by means of a novel and patented system of compensation. By this system the light

output from the source is continuously monitored through the detector and the gain of the amplifier is adjusted automatically so that variations in output of the source, the sensitivity of the detector or drifts in the amplifier characteristics appear as negligible variations in the output.

The normal scanning range is 2·8 to 3μ with provision for locking at one wavelength for control work.

Mervyn Instruments,
Copse Road,
Woking, Surrey.

Field Strength and Radio Noise Measuring Equipments

(Illustrated above right)

MARCONI Instruments Ltd can now supply two alternative equipments for the quantitative measurement of both transmitter and noise field strengths, types TF 1054 and TF 1055. These two equipments, each supplied mounted with its own A.C. power pack, are virtually identical with the exception of the essential internal differences occasioned by their respective frequency ranges: Type TF 1054 covers from 0·15Mc/s to 2·4Mc/s with an intermediate frequency amplifier operating at 100kc/s, while type TF 1055 covers from 2·4Mc/s to 30Mc/s with an I.F. of 1·6Mc/s. Each receiver is supplied complete with the necessary loop

and rod aerials, aerial coupling unit and aerial supporting tripod, and comprises an input attenuator, two R.F. stages, a local oscillator and mixer, a multistage I.F. amplifier with attenuator, and a diode detector followed by a moving coil output indicator. Gain standardization is obtained by reference to the output of a saturated noise-diode.

In the design, particular attention has been paid to the maintenance of a specified bandwidth over the whole frequency range, so obtaining freedom from spurious responses, and to the provision of adequate overload factors to cater for random noise pulses of large amplitude.

Marconi Instruments Ltd,
St. Albans,
Hertfordshire.

Polarograph

(Illustrated below)

THE Polarograph Minor is another addition to the range of the Tinsley polarographs and has been introduced to meet the demand for a less expensive

instrument for use where the volume and scope of the analytical work does not warrant the outlay for the larger recording instrument.

Although non-recording, the Minor retains many features of the larger model including the derivative circuit: this inclusion is made possible by the use of a motor-driven potentiometer, and the Minor is claimed to be the only non-recording polarograph to have this important circuit. The derivative circuit is used to identify substances which fall close together on the potential scale, by giving more distinct readings and hence increasing the sensitivity of the method. With this polarograph it is possible to detect changes in current of 100 micro-microamperes; this amplification is achieved without the use of any thermionic valves or additional attachments.

Evershed and Vignoles Ltd,
Acton Lane Works,
London, W.4.

Meter Tester

(Illustrated above)

THIS instrument is designed to test meters for any "stickiness" in the movement.

On joining the meter to the test terminals, a small backwards current flows, to take the needle to a slightly negative reading. Then, on pressing the button, the meter current rises to full scale and then returns to the start. The rise of current is completly smooth. Thus, if there is the slightest hesitation in the motion of the needle the operator can be perfectly sure that there is a tendency to stick at that point. Three speeds are fitted, to cover the meter scale in 10, 30 and 100 seconds. Naturally, the slower the motion the finer is the test. The recommended speed is 30 seconds for all normal meters. The maximum current is 10mA and the maximum voltage is 100V.

When testing numbers of meters, one can join a whole batch at once to the tester and set a switch to REPEAT. Now, the test cycle is continued indefinitely, so the operator can look at each meter in turn without having to restart the tester.

Servomex Controls Ltd,
Crowborough Hill,
Jarvis Brook, Sussex.

Television Signal Generator

(Illustrated below)

THE Radar television signal generator type 405 is a portable instrument which provides both sound and vision R.F. signals for injection into the aerial socket of a receiver, the complete video signal also being available for connexion to the video stage. The generator covers all channels in Bands I and III and tuning is continuously variable over each band. Sound and vision carriers are independently tuned and may be used simultaneously. The output of the combined signals is continuously adjustable by a variable output attenuator over the range of $10\mu V$ to 10mV. The video modulation allows a choice of patterns affording facilities for the rapid checking and adjustment of line and frame hold, picture width and height, linearity and contrast

gradation. Fine vertical rulings with a short time-rise allow "ringing" and overshoot to be checked. A plain raster with correct blanking is available at peak white or black level enabling the interface to be readily inspected. The syncronizing waveform is to BBC standards with correctly interlaced frame sync. The half-line pulses and the correct front and back porches are included.

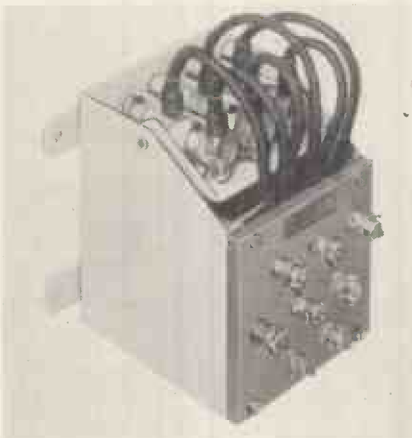
Waveforms Ltd,
Radar Works,
Truro Road,
London, N.22.

Mercury Switch Relay

(Illustrated above right)

IN the Tiltray relay the mercury switches are mounted in a pivoted tray and the relay is designed so that the heavy weight of the switches is operated very smoothly without over-critical adjustment of the operating power. Controlled acceleration gives splash free movement of the mercury so that even highly inductive circuits can be switched without any difficulty. The maximum switching capacity is 3-pole 60A. The coil consumption is 5 to 15VA A.C., or 0·5 to 2W D.C.

Besson and Robinson Ltd,
6 Government Buildings,
Kidbrook Park Road,
London, S.E.3.



Automatic Voltage Regulator

(Illustrated below)

THE Airmec type P.857 5kVA automatic voltage regulator is designed to provide a constant output voltage independent of mains supply fluctuations and changes in load current. Providing the operating range of the equipment is not exceeded, the output voltage is unaffected by variations in load, load power factor or normal changes in frequency.

The equipment consists essentially of an auto-transformer, the ratio of which is varied by means of motor-driven brushes. Automatic control is effected by two thyratron-operated relays which control the supplies to the motor, the thyratrons being triggered by a voltage sensitive circuit.

A special feature of the equipment is that it may be controlled by low-value external A.C. or D.C. signals instead of the normal output voltage. Hence alternating voltages derived from step-up or step-down transformers or a D.C. output of a rectifier circuit may be stabilized.

The stabilized output voltage may be adjusted by means of a preset control to any value between 210 and 240 volts providing the input voltage variations lie within the range of the input tappings. If desired the automatic control may be disconnected by operation of a switch on the front panel and the output controlled

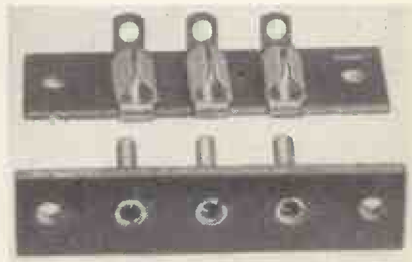
manually by means of two push-button switches.

Airmec Ltd,
High Wycombe,
Buckinghamshire.

Multiple Strip-Connectors

(Illustrated below)

THESE multi-way strip connectors are designed for the direct interconnexion of chassis and sub-assemblies. They are manutactured from too grade Bakelite sheet, with rolled butt-jointed hollow pins for tip-soldering and fully floating self-aligning sockets with integral solder tags.



Both pins and sockets are electrolytically tinned. They are available in 3, 4, 5, 6, 8, 10 and 12-way models. The maximum continuous current rating is 5A per pole.

A. F. Bulgin and Co., Ltd,
Bye Pass Road,
Barking, Essex.

Lightweight Transceiver

(Illustrated below)

THE Venner Transceiver is an entirely self-contained transmitter and receiver, operated from small dry batteries, which has been developed by Venner

Electronics Ltd to meet specific industrial requirements. With an aerial of approximately 50ft it has a useful range of 5 miles.

One of the first uses of this new product will be for the inter-communication of barges on the Dutch canal system.

Transmission is by hand microphone with switch depressed, normal conversation level giving adequate modulation.

Receiving, normally by loudspeaker, can be taken by headphones, which when plugged in, automatically mute the loudspeaker.

The complete unit measures 12¼in by 8¼in with a depth of 9in and weighs 23lb.

Venner Electronics Ltd,
New Malden,

BOOK REVIEWS

Industrial Electronics

By R. Kretzmann. 227 pp., 266 figs. Demy 8vo. Philips Technical Library, Holland. Elsevier Press, Inc., New York. Cleaver Hume Press, London. 1953. Price 25s.

THIS book is written primarily around Philips' practice, both as regards valves and apparatus. There is no objection to this provided the fact is made clear, but the preface leads the reader to expect a more comprehensive account. The work does not present a truly general treatment, and many details described are at variance with the practice of other manufacturers.

In the 227 pages of text, the book accommodates a wide variety of subjects including electronic relays, counting circuits, rectifiers, dimmers, welding control, motor control, and H.F. heating of metals and dielectrics. In addition there is a chapter devoted to small and high power valves and cathode-ray tubes. The treatment is thus necessarily condensed, and it is unfortunate therefore that there has been an injudicious choice of a full page of reproduction photographs which have little direct bearing on the industrial application of valves.

The book can be recommended provided only it is supplemented by other sources of information. Some loose wording is noted in several places, as for instance under "rectifier circuits" where the statement is made that with a rectifier having a capacitor-input filter, ". . . . the current flow is distributed over the whole cycle." Also the accompanying diagrams showing ripple for various rectifier connexions are manifestly incorrect, and may puzzle the careful reader.

The book deals briefly with saturable core reactors, a desirable feature in view of the close associaion between electronics and magnetic amplifiers. Unfortunately from the text on page 117 and the diagram on the preceding page, it is evident that the author does not understand the mode of operation of the saturable reactor as now commonly used in magnetic amplifier circuits. The fact that the saturated core gives a "gating" action somewhat analogous with that of a thyratron, is entirely omitted.

Electronic motor control is dealt with at some length and some applications are briefly described. While some useful information is given, there is a notable lack of information with regard to the causes and prevention of "hunting." The author's use of the word "stabilizing" to indicate the achievement of accuracy of control is unnecessarily confusing having regard to the fact that in this art "stabilization" is quite generally accepted as meaning prevention of hunting.

The treatment of high frequency heating and the accompanying application photographs are at a much better level than the rest of the book.

Many readers will find it difficult to agree with the terminating paragraph in the book that "the books of Philips' Technical Library are on a rather high level."

A. L. WHITELEY.

Electronics—Physical Principles and Applications

By A. O. Williams. 306 pp., 192 figs. Demy 8vo. D. Van Nostrand Co., New York. Macmillan & Co., Ltd., London. 1953. Price 34s.

THIS book is intended to form the basis for a short course on electronics for students specializing in other sciences. As such, it describes the uses of electronics as a tool rather than as an art in its own right.

Based on the properties of static and current electricity the circuit elements necessary for the development of electronics are described. Interwoven with this description the thermionic valve is introduced and the design and analysis of D.C. and A.C. amplifiers. Further chapters describe the generation of oscillations by means of valves, the techniques available for the transmission of information and the mathematical treatment of electromagnetic waves, both guided and free. In the final chapters, a broad view of physics is taken and the uses of electronics in many diverse fields are described. Two chapters are devoted to radiometric and spectroscopic measurements, while the two concluding chapters deal with the manipulation of electron and ion beams with special reference to the generation of high energy particles.

The book contains a good selection of diagrams and illustrations and in addition numerous arithmetical examples of an essentially practical character.

The early part of the book describing electronic methods in general is on the whole rather more satisfying than the later part. In the latter a wide survey of practical applications is compressed into a very small space. It might be that the object of the book would have been better achieved by describing fewer experimental applications rather more fully.

In one or two places, the excellence of the illustrations is marred by an unfortunate handling of the subject matter. An instance of this occurs in a diagram of the performance of a diode demodulator for amplitude-modulated waves. Here justified diagrammatic exaggeration is so carried out that the result has lost much of the significance that could have been given to it.

Again, diagrams of the appearance of amplitude-phase- and frequency-modulated waves are shown, but by choosing a modulating waveform which is different in all three cases the full significance of the comparison is lost. One cannot help feeling that if this diagram had been more carefully constructed the author himself would not have described as frequency modulated a wave referred to later on (constructed by vector addition) which could better be described as phase modulated.

In a book of this broad intent it is inevitable that some sections should appeal to a particular reader more than others, but in the main this volume covers the ground intended well.

H. A. DELL.

Rotating Amplifiers

By B. Adkins, A. W. Blackhurst, E. A. Binney, K. F. Raby and A. L. Whiteley. Consulting Editor: M. G. Say. 152 pp., 62 figs. Demy 8vo. George Newnes Ltd. 1954. Price 17s. 6d.

THIS book is a co-operative effort of which the aim is to present information about the theory, maintenance, testing, applications and elements of design of the more important types of cross-field machines used for regulating purposes, namely the Amplidyne-Metadyne, the Magnicon and the Magnavolt.

The sections on the individual machines are preceded by a chapter on cross-field machine theory and followed by chapters on elementary control theory as it applies to these machines and on their industrial applications.

In the chapters on the individual machines the authors—perhaps not unexpectedly, since they represent the manufacturing companies involved—sometimes tend to boost their own products. One rather glaring instance occurs in the chapter on the Magnicon (which incidentally lacks the lucidity of the others), where we are told that, because the total current carried by each slot is the same round the machine periphery "armature heating is uniform round the machine . . . and hence the cooling is very efficient." Surely in any other machine, say the Metadyne, the *non*-uniformity of spatial current distribution is averaged out as far as conductor heating is concerned by the rotation of the armature?

There is also some non-uniformity of convention: one chapter shows brushes drawn in the physical position, others in the "symbolic" position, which cannot but be confusing to the layman reader.

But these weaknesses of team-work, to which may be added a tendency to theoretical tautology, should have been eradicated by more forceful editing and detract only a little from the wealth of information given by the individual contributors. One only wonders in retrospect whether there could not have been a chapter on the relative merits of the various machines by that *rara avis*, a disinterested expert. Or would that, to coin a phrase, have been to set the pigeon among the cats?

J. M. LAYTON.

The Amplification and Distribution of Sound

By A. E. Greenlees. 300 pp., 115 figs. Demy 8vo. 3rd. Edition. Chapman & Hall. 1954. Price 35s.

NO engineer could fail to be enthusiastic over this work. It bears the stamp of the practical expert, who knows exactly what his less experienced colleagues need help with. Every paragraph is packed with concise information and indeed the style of writing is unique in that the book consists almost entirely of very short, direct paragraphs.

This lucidity in condensation is an art which Mr. Greenlees has in full measure. What makes the book so attractive is the wealth of information not to be found elsewhere and the direct approach to every problem. Tests have shown that whatever the circumstances, a workable answer will be forthcoming.

Naturally, the whole subject matter must be viewed from the P.A. angle, and data on high-fidelity equipment is meagre. But, since this is to be found in abundance in other publications, it only enhances the value of the contents to the P.A. Engineer.

The drawings are clear and to the point, although perhaps Messrs. Wente, Neumann and Thuras might stir uneasily if confronted with the capacitor and moving coil microphone response curves on page 125; and there is a curious little motif of commas and full stops interchanging with each other in sections of the book.

This reviewer has been through the mill of maintenance on cables, impedance matching and related problems in the motion picture recording field, which only serves to underline his appreciation of Mr. Greenlees' countless hints

The book is unreservedly recommended to the practising engineer, in fact it seems ungrateful to suggest that the bibliography is scant, haphazard, and gives no indication of publishers or dates for the books mentioned.

ALAN DOUGLAS.

High Voltage Laboratory Technique

By J. D. Craggs and J. M. Meek. 404 pp., 369 figs. Demy 8vo. Butterworths Scientific Publications. 1954. Price 65s.

HIGH Voltage Laboratory Technique is a book concerned with the generation and measurement of high voltages and heavy currents, and not with the applications of these techniques. It comprises well edited and collected digests of papers written by about 500 authors. There are in all 702 references, listed in groups at the end of each of the eleven chapters. Almost every figure in the book is reproduced from previously published papers.

The first two chapters are concerned with the generation and stabilizing of high voltage direct current. The latter topic is especially important when precise and measurable high voltages are required for experiments in particle physics. Many techniques are described for generating high voltage D.C. using either rectifiers or an electrostatic process.

The next two chapters, of interest in connexion with testing the insulation of electrical power plant, describe methods of generating high voltage alternating current and impulse voltages. A thorough survey is made of the many circuits for generating high voltage alternating current and impulse voltages based upon Marx's original multi-stage generator. Factors which affect the impulse wave shape are discussed in detail.

Circuits for generating high current impulses are briefly described, but much useful information is given about resistance shunts and magnetic links for measuring current impulses.

The chapter on generating square pulses at high voltages surveys the many devices which have been developed primarily for supplying modulated power to very short wave oscillators for radar. Although there is some discussion on pulse forming "cable" units and methods of recurrently charging them, the subject is treated mainly from the point of view of the discharge switch. Spark gap devices, thyratrons, ignitrons and pulsators are the types of switch which are discussed.

The final chapters are about measuring instruments and techniques for high voltage D.C., A.C., and impulses. Separate chapters are devoted to potential dividers and to high speed oscillographic techniques. Much useful data has been collected together concerning the breakdown voltages of various shapes of spark gap. The knowledge of critical energies at which certain nuclear reactions occur can be used to calibrate a high voltage scale in nuclear physics experiments, and interesting data and references on this topic have been presented by the authors.

There has long been a need for a book such as this in English. The problem of making such a compilation readable has been ably met by the authors, who have composed the work of many others together with their own comments into smoothly running chapters. The book is thus suitable as both a manual containing surveys of various topics and a handbook for referring to specific techniques.

JOHN D. HARMER

BOOK REVIEWS (Continued)

Progress in Nuclear Physics Volume 3

Edited by O. R. Frisch. 279 pp. Demy 8vo. Pergamon Press. 1953. Price 63s.

THIS third volume of the series edited by Professor O. R. Frisch presents nine articles which survey varying aspects of modern work in nuclear physics.

Two of the sections, "Stripping Reactions" by R. Huby, and "The Collision of Deuterons with Nucleons" by H. S. W. Massey, are predominantly mathematical in nature, and are outside the range of interest of the average electronic engineer.

Two other articles, "Orientated Nuclear Systems," by Blin-Stoyle, Grace & Halban, and "The Annihilation of Positrons" by M. Deutsch, are also highly specialized, but have a general interest in that they demonstrate the dependence of nuclear physics on progress in electronic instruments. This is particularly emphasized by the work on positron annihilation which involves the measurement of time intervals of the order of 10^{-10} seconds.

The larger part of the volume contains five sections of more specific interest to the electronic engineer.

M. Snowden gives a succinct account of the diffusion cloud chamber, which is continuously sensitive, as contrasted with the intermittent activity of the more conventional device. The limited depth of sensitivity renders the diffusion chamber of more utility in conjunction with high energy particle accelerators than in cosmic ray work. It is just in this latter field, however, that the Cerenkov radiation detector, described very fully by J. V. Jelley, finds particular application. The "electron's supersonic bang," as Cerenkov radiation is so graphically described in the Editor's foreword, depends on a particle moving faster than the velocity of light in the medium, and is emitted at an angle and of an intensity which depends on the velocity. For work with very high energy particles, therefore, the Cerenkov detector provides a powerful tool, and Dr. Jelley has given adequate design data for such devices.

The measurement of particle energy by proportional counters is discussed by D. West in a rather complete article. These instruments are particularly powerful in the low energy field, where their ability to give adequate resolution at a few keV make them superior to the scintillation counter.

The conduction counter has had a rather brief career as an effective tool of nuclear physics, being rapidly superseded by the scintillation counter for almost all applications. The survey by Dr. Champion of this instrument does indicate the limitations of the device, but appears unduly optimistic about future applications.

A most interesting summary of methods of producing intense focused ion beams is provided by P. C. Thoneman. A great deal of information is packed into this article which is, however, unduly condensed for the type of review in which it appears. The standard of book production is high, as is the price.

J. SHARPE.

Fields and Waves in Modern Radio

By S. Ramo and J. R. Whinnery. 576 pp., 84 figs. Demy 8vo. 2nd Edition. Chapman & Hall Ltd., 1953. Price 70s.

THIS book has been a great help to the reviewer over the past few years, and consequently he found it a pleasure to review the second edition. He is convinced that the aim in the teaching of electrical engineering should be to teach a method of tackling new problems rather than the solutions to the problems themselves. The book is particularly successful in this respect; it gathers together in one volume a vast amount of information on modern electromagnetic theory, and presents it in a clear and comprehensible way which appeals to the practising engineer and to the student.

The principal differences from the first edition are the use of rationalized M.K.S. units, the introduction of a new chapter on microwave networks, and the expansion of the chapter on aerials and radiation. The new chapter is useful, and much of the network theory worked out there is of general application at all frequencies. The second edition also refers to the "Smith" impedance chart for transmission lines, but the explanation is not as clear as it might have been.

The book sets out with a chapter on wave fundamentals, two chapters on static fields, and a really excellent treatment of Maxwell's equations. From this foundation, it builds up the chapters on applied electromagnetic theory, dealing with circuit concepts, skin effect, propagation, guided waves, resonant cavities, microwave networks, and radiation, all in considerable detail. The authors have deliberately avoided reference to practical techniques; in a field where current practice is changing so rapidly, this seems a wise decision.

The text is well illustrated with charts, graphs and diagrams, and the tables listing the characteristics of various types of transmission lines, and various modes of waveguide propagation are complete and lucid. Unfortunately, the mode nomenclature in rectangular waveguides does not conform to common practice in this country. For example, Ramo and Whinnery's TE_{10} mode in rectangular would here be known as TE_{01} or H_{01}. Each chapter is well provided with examples, and the book is finished off with an appendix containing references to a selection of textbooks.

J. W. SUTHERLAND.

PUBLICATIONS RECEIVED

PROCEEDINGS OF THE EASTERN JOINT COMPUTER CONFERENCE contains papers and discussions presented at the joint conference sponsored by The Institute of Radio Engineers Professional Group on Electronic Computers, The American Institute of Electrical Engineers and The Association of Computing Machinery, held in Washington, in December, 1953. The Institute of Radio Engineers, Inc., 1 East 79 Street, New York, 21. Price $3.

LIST OF U.K. EQUIPMENT CSA APPROVED contains the names of manufacturers of electrically-operated equipment in the United Kingdom, with addresses, approved by the Canadian Standards' Association. Copies of the booklet, which also includes names and addresses of Canadian representatives, can be obtained free from the BSI/CSA Approvals Agency, 2 Park Street, London, W.1.

A MATTER OF LIGHT OR DEATH is a booklet on better street lighting of special interest to municipal lighting engineers, members of local authorities, and all concerned with street lighting. The British Electrical Development Association, 2 Savoy Hill, London, W.C.2.

MARCONI INSTRUMENTS 1954 is a catalogue of the telecommunication measurement equipment and industrial electronic instruments manufactured by Marconi Instruments Ltd., St. Albans, Hertfordshire. Over 70 different equipments are dealt with and a list of associated companies and agents is included in this new bound catalogue.

STAINLESS, CORROSION AND HEAT-RESISTING STEELS. In this brochure, combining both corrosion and heat-resisting alloys, recognition is made of their common basis of composition and physical properties. Darwins' special alloys are listed separately according to present convention. Other products of the Darwins Group are also mentioned. Darwins Ltd., Fitzwilliam Works, Sheffield.

TELEVISION, WHAT THE FUTURE HOLDS is a booklet produced by "His Master's Voice" to answer some of the questions that existing and potential televiewers are asking themselves at the present time. The booklet is distributed through the company's dealers, or direct to any inquirers. The Gramophone Company Ltd., Hayes, Middlesex.

BEAMA ANNUAL REPORT, 1953-54, recently published mentions that the electrical industry was again the second biggest exporter among British industries. In 1953 its exports reached nearly £212 million in value, despite fierce competition from foreign firms. The report discusses the effect of export incentives and subsidies operated by continental competitors, and states that intense foreign competition for export orders must be expected to continue this year. The British Electrical and Allied Manufacturers' Association, 36 and 38 Kingsway, London, W.C.2.

THE RADIO AMATEUR'S HANDBOOK 1954 is the 31st edition and contains a considerable amount of new equipment in all categories. It is the standard manual of amateur radio communication and has long been considered an indispensable part of the American amateur's equipment. The American Radio Relay League, West Hartford, Conn. Price $3.

VARLEY ACCUMULATORS AND BATTERIES describes the advantages of Varley equipments and sets out the various battery type numbers together with their sizes. Varley Dry Accumulators Ltd., By-Pass Road, Barking, Essex.