The Journal of

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

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# THE VALUE OF CONVENTIONS

TWENTY-FIVE years ago the Institution held its first Convention. Held in the Winter Gardens, Blackpool, it was a modest affair compared with subsequent Conventions; the programme stated that it was not only the first Convention held by the Institution, but the first Television Convention ever to be held, and that the Council of the Institution " . . . has been actuated by a desire to place on record that which is actually a historical event."

Again, by comparison, the papers presented seem few, but they covered much of the radio art as it then existed. Although broadcasting of television programmes had not then started, a subsequent Institution report said that after the meetings "visits were paid to the Blackpool "Television Theatre." An image 12 in. wide by 28 in. with wonderful definition, was demonstrated. The image was . . . speeded up gradually (*sic*) until the full picture of the entertainer was clearly discernible. These practical demonstrations were combined with facilities for the examination of the transmitter and receiving gear."

Commenting on this Convention, "The Manchester Guardian" (June 5th, 1934) reported "Television is destined to be of the greatest value to civilisation. Not only will it increase the facilities of business and ordinary communication, but should have far reaching effects upon . . . our friendship with other nations. . . ."

Television engineering, in popular concept, has undoubtedly had far reaching effects upon our domestic and public life. In promoting its scientific and engineering development, the Institution has played a major part. Even during the war years the Institution reported on post-war television activity and promoted meetings and discussion on the development of colour television.* Indeed, the first post-war Convention (1947) gave practical and theoretical demonstration of some of the applications of television technique. The 1951 Convention was really a series of six Conventions, the part devoted to Television Engineering being held in the University of Cambridge.

In the intervening years, the development of television has stretched far beyond facilities of business and ordinary domestic communication. As an important tool in varied fields of scientific research, as an integral feature of diverse material production, and as an instrument of education and entertainment, television engineering is increasing in its impact on individual and industrial development.

Such thoughts doubtless inspired those members of the Council who successfully urged that the theme of this year's Convention should be Television Engineering. Members of the Institution are well aware of the many reasons which dictated the venue of the 1959 Convention. The attendance will again be of an international character, a growing feature of Institution Conventions, and typified this year in the fact that for the first time the Clerk Maxwell Memorial Lecture will be given by a scientist from abroad —Dr. V. K. Zworykin—and that among the members will be the first Chairman of one of the earliest Sections to be established overseas—Professor S. K. Mitra, F.R.S.

Attendance at an Institution Convention has always been well rewarded. The arrangements made for accommodation in the various colleges and the overall plans of the Convention Committee augur well for the success of the fifth post-war Convention of the Brit.I.R.E.

G.D.C.

* John Logie Baird gave a paper and demonstration on colour television before a meeting in London in October 1943.

# INSTITUTION NOTICES

### Dinner of Council and Committees

As announced in the February *Journal*, the dinner in honour of the Immediate Past President, Mr. G. A. Marriott, and Mrs. Marriott, will be held on Thursday, 23rd April, at the Savoy Hotel, London.

Some 150 members are attending and only a few more tickets can be allocated. Members who wish to attend the dinner, therefore, should apply immediately. Tickets are £3 3s. each and this covers all costs except drinks at dinner.

Mr. Marriott, who was recently appointed Managing Director of the M.O. Valve Company, is proceeding to America and Canada soon after the dinner. During his tour, Mr. Marriott will take the opportunity to meet members in those countries, and particularly to explore the possibility of setting up Sections of the Institution in Canada.

### New Institution Premiums

The Council announces that it has decided to establish four additional Premiums for the authors of outstanding papers published in the *Brit.I.R.E. Journal*. It is intended that two of these Premiums shall take account more especially of the extensions in the field of electronics and its applications which have taken place during the last decade.

In addition, the Council has decided to increase the value of the Clerk Maxwell Premium; with effect from 1958, its value will be 25 guineas. The new Premiums are as follows:—

*Charles Babbage Premium:* This Premium is for an outstanding paper on the design or use of electronic computers, and its title recognizes the pioneer work of Babbage in first formulating the requirements for a calculating machine. (*Value 15 guineas.*)

*Lord Rutherford Premium:* Electronics plays an ever increasing part in control and instrumentation associated with atomic physics and nuclear engineering. The Premium commemorates the fundamental work carried out by Lord Rutherford at the Cavendish Laboratory, Cambridge. (*Value 15 guineas.*)

*Arthur Gay Premium:* The importance of efficient methods of production in the electronics industry led to the establishment of this Premium for an outstanding paper on production techniques. The late Arthur Gay was a production engineer associated with H. J. Leak (Member) who has endowed the Premium. (*Value 10 guineas.*)

*Hugh Brennan Premium:* This Premium is to awarded annually to the author of the most outstanding paper read before the North Eastern Section of the Institution, and subsequently published in the *Journal*. The Premium has been endowed by a Past Chairman of the Section. (*Value 15 guineas.*)

Papers published in the *Journal* during 1959, will be eligible for these awards. The total of Premiums awarded annually is now thirteen; and details of the terms of reference are given inside the front cover of this issue.

### Circulation of the Journal

The latest certificate issued by the Audit Bureau of Circulations shows that for the period July-December 1958 the average circulation of the *Journal* was 6,947. This does not, of course, include sales of back numbers during this period.

### Correction

The following corrections to the paper "A Comparison between Pulse and Frequency Modulation Echo-ranging Systems," published in the February issue of the *Journal*, were received too late for incorporation.

Page 106: Equation (1) should read:—

$$P_{t_1}=P_{t_0}+\int_0^{t_1}\frac{\mathrm{d}P}{\mathrm{d}t}\,\mathrm{d}t$$

Page 107: In equation (10) the term $2P_{t_0}$ should be multiplied by $t_1$. The expression should be differentiated with respect to $\mathrm{d}t_1$ instead of $\mathrm{d}t$.

Equation (11): This expression should be differentiated with respect to $\mathrm{d}t_1$ instead of $\mathrm{d}t$.

Equation (13): Delete $(q_r\, t_1+\theta_r)$.

Page 109, col. 1, line 10: Substitute $y_r$ for $f_r$.

# A Low-drain Distress Beacon for a Crash Position Indicator†

*by*

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**Summary:** A new, light, simple and inexpensive radio distress beacon has been developed to survive airplane crashes. A special long-life pulsed transmitter with trickle-charged batteries and an internal capacitor antenna is potted in shock-absorbing foam which is transparent to radio waves and formed to a high-lift wing section. The device is held on the tail of the aircraft and releases automatically upon detection of any structural deformation. It tumbles away from the aircraft in time to clear the danger zone, slows down to a safe landing and transmits a distress signal from any position, under wide environmental conditions, and over any terrain.

## 1. Introduction

A method of locating aircraft crashes by means of a completely automatic radio distress beacon has been sought for the past thirty years to supplement the visual search method now in use. Crash scenes must be located with all possible speed in order to bring medical assistance to survivors who may be too seriously injured to operate manual distress equipment. In other cases, where there are no survivors, this fact must be established, and possible causes of the crash investigated. The problem has been gaining in urgency in recent years as high speed aircraft, carrying more people than ever before, have become a widely used means of transportation, both in commercial and military fields.

A radio beacon which can survive an aircraft crash and then automatically radiate a useful distress signal, poses a large number of design problems not encountered in personal beacons or conventional distress and communications equipment. The beacon must be safely separated from the crashing aircraft at the earliest symptom of disaster, because at present no practical equipment can be designed to withstand the tremendous forces and temperatures encountered in a direct crash. The beacon must then be transferred to a safe operational position not too far from the wreck, and should transmit a sufficiently strong signal over any terrain, such as swamp or water, flat open country or narrow, densely vegetated valleys.

Systems previously designed as a means of locating crashed aircraft are complex and require considerable equipment[1-4]. They fulfil only a part of the stringent requirements satisfactorily and do not represent a simple solution to the problem.

A simple Crash Position Indicator has been developed[5] which offers a promising solution. It consists of a tumbling aerofoil and a battery-operated radio beacon specially designed to meet the weight, size, and ruggedness limitations which are the requisite for successful operation. The "tumbling aerofoil" is an enclosure about 2 ft. × 2 ft. × 6 in., shaped somewhat like a short section of an aircraft wing (see Fig. 1), inside of which the antenna, transmitter, and batteries are potted in plastic foam. The total weight is 11·3 pounds, and it floats 85 per cent. out of water. This unit is placed on the tail of the aircraft (see Fig. 2) and held by a slim metal ribbon passing through a spring-loaded knife. The knife is operated by a change in tension of the tightly stretched trigger wires connected to the extremities of the aircraft structure. Any abnormal structural change in the aircraft as a result of a crash or other emergency is transmitted through the wires and releases the aerofoil, which thereupon lifts upwards, hits the airstream, and tumbles away. Because of the shape and the suitable placement of the centre of gravity, the aerofoil slows down by a factor of

† Manuscript received 9th October 1958. Based on a paper read at the 1958 I.R.E. Canadian Convention and published in the Convention Record. (Paper No. 491.)

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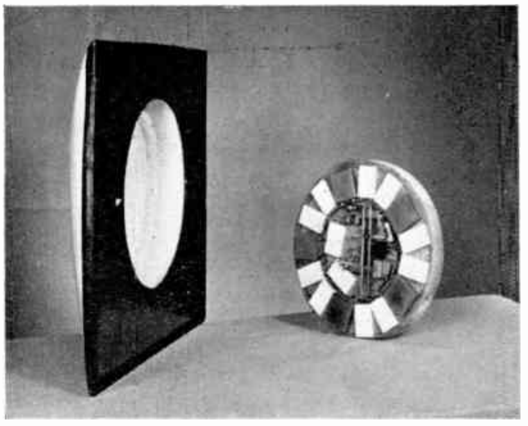


**Fig. 1.** (*left*) A low-drain radio beacon ready to install in the tumbling aerofoil.

**Fig. 2.** (*above*) "Expeditor" aircraft with the Crash Position Indicator mounted externally on the tail (see arrow).

two for every 35 feet it travels, thus greatly reducing the landing velocity. It also curves away on a 100 foot radius, thereby increasing its flight distance and landing sufficiently far from the aircraft to escape the dangers of the wreck.

In order that the tumbling aerofoil can perform the above function successfully, its total weight should be small and all parts, including the transmitting antenna, should fit inside the unit. Thus the total weight of the batteries, which represent the major load of the unit, must be limited to less than four pounds. Also the small size of the unit restricts antenna dimensions to a fraction of a wavelength, which unfortunately reduces the efficiency of transformation of the generated to the transmitted r.f. power. On the other hand, to ensure a high probability of success in a search, the radio beacon should be designed to operate under a wide range of environmental conditions found in all parts of the world from the Arctic to the Tropics, and the range should be at least 5-10 miles, so that a significant improvement over visual search is obtained. Since the beacon will be called upon to operate after having received a considerable impact shock, the electronic components should have a high shock rating. As the unit may be carried on the aircraft for periods of several years before being brought into use, reliability is also a major objective. Thus simplicity of design represents a preferable solution over more complex circuitry, even if certain performance features have to be sacrificed.

In the beacon designed, the problems discussed are overcome in as simple a manner as possible. Since continuous wave transmission is not necessary, advantage is taken of the well-known fact that oxide-coated cathodes have the unique and valuable property of being able to give very high electron emission when a relatively high voltage, well in excess of the rated value, is applied to the anode of the valve in the form of short pulses. In addition, the filament drain of the transmitter, which constitutes a major fraction of the battery drain, is considerably reduced by periodic on-and-off switching of the filament. A very light capacitor antenna which has relatively high efficiency has been designed to fit inside the unit, and its performance is not affected by the shock-absorbing foam or skin of the aerofoil. The propagation pattern obtained takes advantage of the most likely orientation of the unit upon landing, but in any case provides a useful signal in other positions. So that the system may be compatible with the available search equipment, the output should consist of groups of pulses of r.f. energy. A simple transistor circuit has been developed to generate the required number of pulses per group, form the groups themselves, and at the same time transform the output to a higher voltage. This makes possible the use of low voltage batteries with more rugged construction.

This crash position indicator beacon provides a means of locating crashed aircraft in a short time, and experiments carried out to date indicate that it will fulfil its intended function in a useful number of cases.

## 2. The Beacon System

Two approaches are possible to the problem of generating a radio distress signal:

(*a*) A triggered or interrogated beacon, which is brought into operation by external stimulation, and

(*b*) a beacon which starts to operate at the time of crash, and continues until the available power is consumed, preferably not less than 100 hours.

A triggered or interrogated beacon has several advantages over a continuously operating beacon. The maximum battery drain would take place only when a search aircraft is within range of the signal, thus greatest battery economy could be obtained and probably the range could be extended.

However, the disadvantages are great enough at the present time to outweigh the benefits of the use of this type of beacon. These disadvantages include the added circuitry of the low-drain transistorized receiver which would be required; the lack of transistors which operate reliably at v.h.f.; design complications due to the antenna for the receiver; and the danger that an extraneous interference signal may trigger the beacon before the search aircraft are within range. Also, the interrogating transmitter on the search aircraft represents additional cost and complication.

A beacon operating continuously from the time of crash simplifies the design considerably. In this case the problems presented are how to obtain a maximum r.f. output for the required period of time from the limited battery supply. The weight and extreme environmental variations expected limit the battery capacity to less than 40 Whr (see Section 7, The Power Supply). The desired time of operation is 100 hours. A c.w. system offering compatibility with aircraft communications receivers was ruled out because of the necessity of crystal control and the added drain of the multiplying stages required to reach the chosen distress frequency of 243 Mc/s. A pulsed carrier system was therefore regarded as the correct approach since it resulted in greater battery economy, could be made compatible with the widely used "Sarah" search receiver[6], and required no crystal control. However, even a pulsed carrier system using known circuitry would require more power than that available.

The problem thus becomes an attempt to maximize the r.f. output and minimize the battery drain. Several unconventional methods have been used to reach this objective and are described in the following sections.

## 3. Choice of Carrier Frequency

The choice of frequency is determined by the size of the device which is closely coupled with the type of antenna to be used. A directional antenna can not be employed because the beacon should radiate a useful signal in all directions. The order of magnitude of the received power, $P_r$, using omnidirectional half-wave dipole antennas for transmission and reception, can be roughly approximated using the plane earth equation (see eqn. 1). This equation holds for the region below the first interference lobe and transmitting and receiving antenna heights greater than or equal to the minimum effective antenna heights.[7]

$$P_r = 0{\cdot}345 \left(\frac{h_r\, h_t}{d^2}\right)^2 P_t\, 10^{-14} \qquad \ldots\ldots\ldots(1)$$

where

$P_r$ = received power in watts
$P_t$ = transmitted power in watts
$h_r$ = receiving antenna height in feet
$h_t$ = transmitting antenna height in feet
$d$ = distance in miles.

It can be seen from the equation that the received power and range are independent of the wavelength. This would permit a low frequency of operation, which is preferable because the transmitted power can be generated more efficiently, and wave propagation is not affected by physical obstacles such as hills, trees and dense vegetation. However, a low carrier frequency requires antenna dimensions considerably larger than the size of the "tumbling aerofoil." The lowest frequencies of operation used for distress signalling for which small antennas[8] can be designed are 121·5 and 243 Mc/s. At 243 Mc/s an efficiency of 80 per cent. and an antenna $Q$ of 50, corresponding to a bandwidth of about 5 Mc/s, can be realized. High accuracy of tuning, and therefore crystal control of the beacon carrier frequency, is not essential. At the next lower frequency of 121·5 Mc/s, the efficiency is considerably lower and the $Q$ of the antenna increases eightfold for the same dimensions, as will be shown later. If this frequency was chosen, tuning would be much more critical and crystal control desirable.

The choice of 243 Mc/s for the carrier frequency of the beacon was also influenced by the existence of the commercially available "Sarah" receiver, which was specifically designed for search and rescue operations in connection with a personal beacon operating with a pulsed carrier at this frequency. The "Sarah" receiver is electronically tuned over a band of ±1·5 Mc/s during each 10-second period. It also fulfills favourably the requirements for identification, homing, and precise location of the transmitting beacon. Furthermore, it had been approved for use in search and rescue operations by the Royal Canadian Air Force at the time the tumbling radio beacon project was initiated.

### 4. Antenna and Antenna Matching Unit

The antenna for the crash position indicator must fit the inside of the tumbling aerofoil and should have dimensions which would permit an adequate layer of foam between the antenna and the skin of the aerofoil. This requirement leads to the choice of a small antenna of the capacitor type.

The fundamental limitations of antennas with reduced dimensions are twofold.[8] The $Q$ of the antenna becomes excessively high as the dimensions of the antenna are reduced, which in turn requires a high frequency stability of the oscillator and makes tuning critical. The efficiency of the antenna also decreases. Both are the result of the fact that the radiation shunt conductance $G_R$ (see equation 2) decreases rapidly with the ratio of the area of the capacitor plate to the square of the wavelength.

$$G_R = \frac{8\pi^3 G K_a^2}{3}\left(\frac{A}{\lambda^2}\right)^2 \qquad \ldots\ldots\ldots(2)$$

where $G = 1/R$ = wave conductance in free space $= 1/377$ mhos
$A$ = area of capacitor plate
$\lambda$ = wavelength
$K_a$ = shape factor of capacitor
= effective area/actual area $A$
$K_a$ magnifies the area $A$ to account for the field outside the cylindrical volume and ranges between unity (for $b \ll a$) and $1{\cdot}27\, b/a$ (for $b \gg a$). $K_a$ is determined experimentally from $C = K_a \,.\, a/b$, where $a$ is the radius of the circular capacitor plate, and $b$ is the spacing between plates.

The radiation $Q$ of the antenna, which is the inverse of the radiation power factor $p$, is found to be, for negligible losses,

$$Q = \frac{1}{p} = \frac{\omega C}{G_e} = \frac{3c\varepsilon\lambda^3}{8\pi^3 G K_a A b} \qquad \ldots\ldots(3)$$

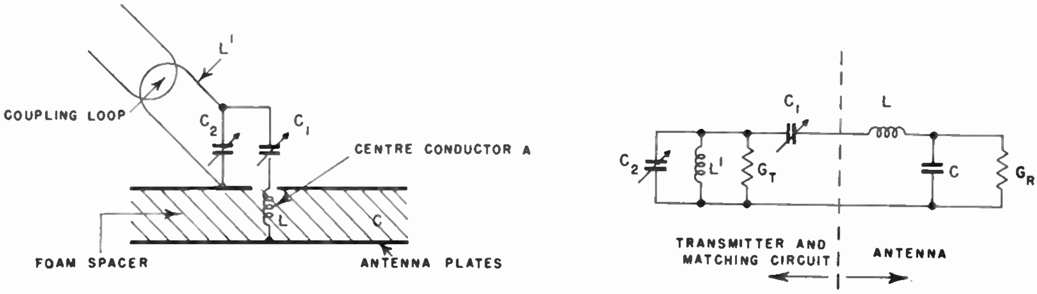
(where $c$ = velocity of light)

and is proportional to the third power of the wavelength and inversely proportional to the volume, $V = Ab$, enclosed by the capacitor plates. For a given volume, doubling the wavelength increases the $Q$ eightfold. A 30 per cent. reduction in volume however, necessitates only a 10 per cent. reduction in wavelength. This is of interest when considering designs of smaller units.

The circuit efficiency, $e$, of the antenna is given by

$$e = \frac{G_R}{G_R + G_T} \qquad \ldots\ldots\ldots(4)$$

where $G_T$ is the shunt conductance looking towards the transmitter which matches the ohmic




(a) (b)

**Fig. 3.** Cross-section through the antenna and the equivalent electrical circuit.

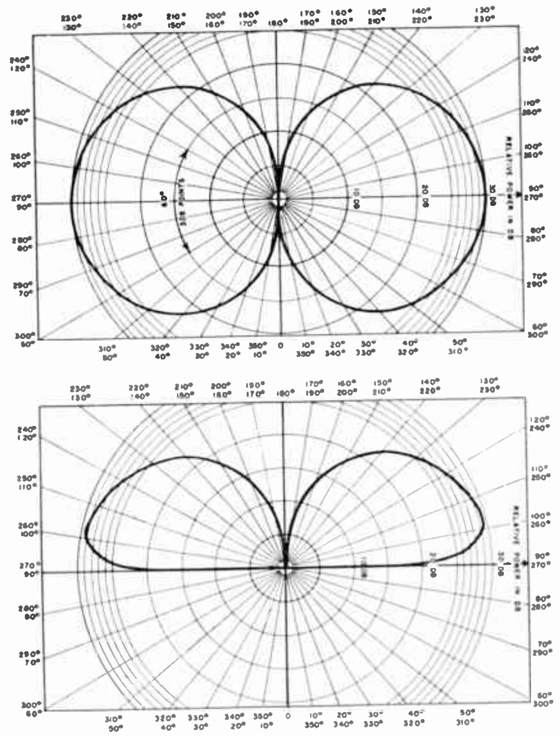


**Fig. 4.** Radiation patterns for the capacitor antenna. (a) free space (b) on the ground.

losses of the antenna. Dielectric losses are neglected.

Figures 3(a) and (b) show respectively the cross-section through the capacitor antenna and the equivalent electrical circuit. The matching capacitors are represented by C1 and C2; the inductance L consists of a single wire, and L′ is the coupling loop and the reflected primary inductance. For an efficient antenna, $G_R$ should be many times greater than $G_T$. Since $G_R$ is determined by the dimensions of the antenna and the operating frequency as given by (2), $G_T$ should be as small as possible for high efficiency, but should still allow efficient coupling to the transmitter. The value of $G_T$ can be controlled by a trimmer capacitor C1, which detunes the resonant circuit consisting of C and L to the desired value of $G_T$. Then L′, together with the adjustable trimmer C2, tunes out the reactance introduced by this detuning. The antenna plates consist of two circular aluminium discs, 14 in. in diameter, 0·002 in. thick, and $1\frac{1}{2}$ in. apart. The skin depth at the operating frequency should be a small fraction of the thickness of the discs. Foam spacer was used to provide a fixed separation between them.

Measurements on the antenna at 243 Mc/s indicate a value of $Q = 50$, and an efficiency of 80 per cent. The measured free space radiation pattern is shown in Fig. 4 and has an angle of 60 deg at the 3 db point. When the antenna is placed on the ground, the pattern is equal to the upper half of the curve shown in Fig. 4(a), in the case of perfect ground conductivity. Otherwise the pattern is given by Fig. 4(b) and the grazing angle depends on the conductivity of the terrain.

## 5. The Transmitter

### 5.1. *The oscillator*

The primary consideration given to the design of the transmitter for the tumbling radio beacon is the transformation of the available d.c. power into the highest possible r.f. power. It has been found that for pulse operation, the maximum anode voltage values on a valve can be considerably exceeded. Also, if the pulse width is short and separation intervals are long[9, 10] unusually high peak power outputs can be obtained by using valves with oxide-coated cathodes. The choice of valve types was therefore confined to oxide-coated filamentary types with high mutual conductance and anode current values, low filament drain, and small interelectrode capacitances. In addition, the valve to be used had to withstand a relatively high impact shock. The CK 5971, a subminiature triode, was found to fulfil favourably all the above requirements. The rated anode voltage value for this valve is 90 volts. However, with a 7 microsecond pulse of 300-400 volts applied, two of these valves in a push-pull oscillator circuit generate 2-3 watts of r.f. power. This is about 10 times the power obtainable at 90 volts.

A parallel line resonator offers many advantages at 243 Mc/s. Mechanically it is cheap and simple to construct. Tuning can be accomplished with a shorting bar or sliding line section. Mechanical stability and ruggedness is reflected in very good frequency stability, even when subjected to vibration and impact shock. Electronically, the stability of the parallel line resonant circuit is high, with frequency changes of less than 1,000 parts in $10^6$ for temperature

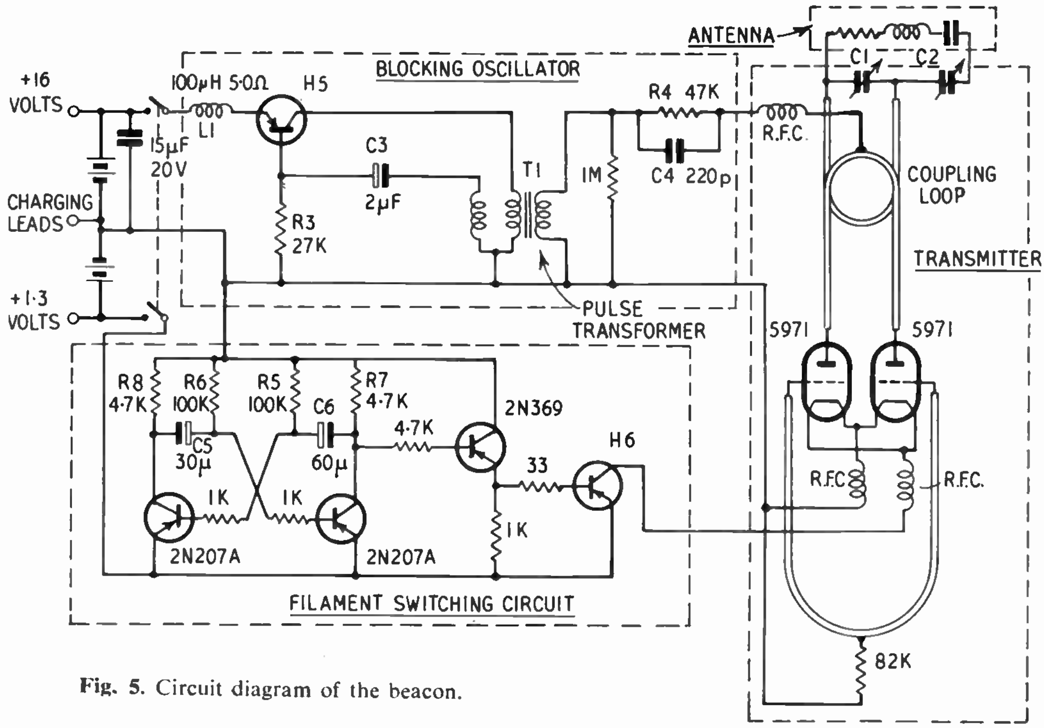



Fig. 5. Circuit diagram of the beacon.

changes from −40° C to +40° C, and anode voltage variations of ±10 per cent. These frequency variations are well within the limits set by the $Q$ of the antenna and the frequency sweep of the "Sarah" receiver. Furthermore, the parallel line resonator permits short connections to the valve terminals and these connections then become parts of the resonant line system. In the choice of a circuit, a push-pull design is preferable to a single valve, as its efficiency is higher. Also in push-pull circuits, the grid and anode parallel line resonators make it possible to feed the anode and grid supply voltages at low r.f. potentials, thus simplifying decoupling.

The input impedance of a parallel line is given by

$$Z_{in} = Z_0 \tan \theta \qquad \qquad \ldots\ldots\ldots(5)$$

where $Z_0$ = characteristic impedance of the line

$\theta$ = electrical length of the line, in degrees

Since this impedance resonates with the input capacitance of the tube, it must be inductive in nature. The length of the shorted line is therefore less than $\lambda/4$. The length is also influenced by the value of $Z_0$ which is in turn determined by the dimensions of the line:

$$Z_0 = 276 \log_{10} 2S/d \qquad \qquad \ldots\ldots\ldots(6)$$

where $S$ = spacing between the lines

$d$ = diameter of the lines

For a given input impedance, short lines with a high $Z_0$ or longer lines with a small $Z_0$ are possible. A longer line permits a higher operating $Q$ because of larger energy storage and improves the frequency stability of the oscillator, while a shorter line may be advantageous in oscillators with wideband modulation. A high operating $Q$ is advantageous in the present case, since the modulation bandwidth is small, and high frequency stability is desirable. However, the length of the lines is limited by the available space in the unit. Also the value of $Z_0$ is influenced by the mechanical features of the lines, such as ruggedness. In a compromise solution, dimensions of the lines were chosen with $S = \frac{3}{4}$ in. and $d = 3/16$ in. resulting in a value of $Z_0 = 250$. The calculated values of line length for given values of interelectrode capacitances for the CK 5971 are found to be much larger than those obtained in actual practice because the inductance and capacitance of the connections to the valve electrodes as well as the vicinity of the antenna plates are not included in the calculations. The length of the anode and grid lines were found to be 5 in. and $2\frac{1}{2}$ in. respectively, easily fitting into the available space.

The coupling between the oscillator anode circuit and the antenna is carried out by means of a small coupling loop placed over the shorted end of the parallel line. The size of the coupling loop and distance from the shorted end were adjusted experimentally for maximum power output, which indicates a matched condition. A margin of safety was allowed from the point at which oscillation ceased due to overloading. The inductance of the tuning loop is tuned out by means of a matching trimmer capacitor C2, shown in Fig. 3 and explained in the description of the antenna. Radio frequency chokes were used to earth the filament lead electrically and prevent r.f. currents from flowing into the filament and h.t. supply. The grid resistor was adjusted experimentally for maximum power output with a value of 50 kΩ-100 kΩ found to be most suitable.

The circuit diagram of the transmitter is shown in Fig. 5. The oscillator valves have a filament drain of 80 mA and peak anode current of about 16 mA each during the anode pulse. The valves operate reliably in pulsed operation with the excessive voltages applied. It has been found to withstand an impact shock of at least 700*g*.

### 5.2. *Modulation of the transmitter*

Pulse modulation on the anode of the oscillator is used as stated previously in order to obtain a relatively high output peak power by greatly exceeding the rated plate voltage of the valves during the pulses. In addition, anode pulsing offers several advantages over grid and cathode modulation. For example, no separate anode voltage supply is required, since the oscillator will oscillate by applying voltage pulses of sufficient amplitude to the anode. These voltage pulses can be generated in a transistorized blocking oscillator, using a step-up transformer in the output. A relatively low voltage supply can be used thus avoiding a d.c. converter or high voltage batteries, which are less rugged.

Anode modulation of the push-pull circuit of the transmitter introduces some grid modulation due to voltage divider action between the anode-to-grid interelectrode capacitance of the valve and the grid resistor. A positive voltage is thus applied to the grid, which increases the flow of anode current when the anode pulse is applied. Simultaneous grid modulation is quite desirable in this case since a given anode current can be obtained with less anode voltage than would otherwise be required.

The modulation waveform is influenced to a considerable extent by the properties of the "Sarah" receiver which is used for the receiving equipment on the search aircraft. In the "Sarah" receiver, the incoming signal is displayed on a c.r.t. screen. The transmitted signal consists of pairs of pulses. The first pulse triggers the time-base in the display circuit, thus establishing synchronization, and the second pulse is displayed on the screen. As a result of synchronization of the time-base with the incoming pulses, the displayed pulses appear stationary, improving considerably the rejection of noise and interference pulses which are not stationary. The "Sarah" receiver has a sensitivity of 10 microvolts for a 2 : 1 signal-to-noise ratio at the output and a signal-to-noise receiver factor of 8 db.

Optimum receiver performance is obtained when the product $\tau B$ of the pulse width $\tau$ and i.f. bandwidth $B$ is about 1·2. For values of $\tau B$ much larger than this, the signal threshold power increases linearly as the receiver-noise figure, and for much smaller values the signal threshold power is inversely proportional to $\tau B$ (see Ref. 11). Although the i.f. bandwidth of the "Sarah" receiver is 800 kc/s at the 3 db points, the pulse width of the C.P.I. beacon has been chosen to be about seven microseconds. A narrower pulse width would theoretically permit an improved resolution, but it would show up on the receiver screen as a narrow spike, and it would not stand out in noise as well as the seven-microseconds pulse. Four pulses in a group were considered to be the best solution, since this permits three pulses to be displayed on the screen. The advantages of having three pulses displayed, rather than one, are considered to be the following.

In weak reception areas, in the presence of interference and noise, the observer may not be sure of the presence of the single signal on the screen. It is very reassuring to find two more pulses of the same shape displayed at the expected positions. Also, if the first pulse should fail to trigger the sweep, the second or the third pulse in the group may accomplish it, thus enabling two or a single pulse still to be displayed. The r.f. output, therefore, consists of a group of four pulses, each about seven microseconds wide at the 3 db point (see Fig. 6a), and separated from each other by about 75 microseconds (see Fig. 6b). The group repetition frequency is 65 groups per second (see Fig. 6c).

The choice of group repetition frequency is a compromise between sensitivity of reception, anode power drain, and effectiveness of display. The signal threshold power is nearly proportional to the inverse square root of the pulse or group repetition frequency as shown in Ref. 13. The anode drain increases proportionally with the group repetition frequency and is thus limited by the capacity of the available battery supply. However high repetition frequency is desirable since more pulses can compete with interference which may also trigger the sweep. Also, with more pulses displayed per second, a more intense blip is seen on the screen. The group repetition frequency at the transmitter of 65 groups per second was chosen as the highest permitted by the capacity of the batteries.

### 5.3. *The modulator*

The modulator must provide pulse trains having peak amplitudes of 300-400 volts to the anodes of the triodes. Since only a low voltage supply is used, some form of voltage conversion or transformation is necessary. A special blocking oscillator circuit has been developed for this purpose which generates pulses, forms pulse groups, and steps up the voltage of the pulses as well, in a simple manner. A transistor as an active circuit element is very suitable in this application, since it does not require any filament supply and performs well in switching applications. Since the battery voltage used is 16 volts, the blocking oscillator will generate pulses of approximately this magnitude, and therefore the pulse transformer must have a voltage step-up winding with a secondary-to-primary ratio determined by the required voltage across the secondary, and limited by the maximum peak current of the transistor. The push-pull transmitter draws about 32 mA peak current when a 400-volt pulse is applied to the anode. A voltage drop of approximately 400 volts is observed in the R4-C4 pulse group forming network, which will be referred to later, so that 800 volts are required at the secondary of the pulse transformer. Since the pulse on the primary exceeds slightly the battery supply, the transformer turns ratio was chosen to be 40:1. The feedback winding to the primary winding turns ratio is 1:1. The peak current in the primary is then about 1·3 amperes which can be realized with commercially available transistors. The pulse transformer employs a ferroxcube 3B1 pot core. The operation of the circuit can best be understood with reference to Fig. 6 and the following sequences of operation.

(a) (b) (c)

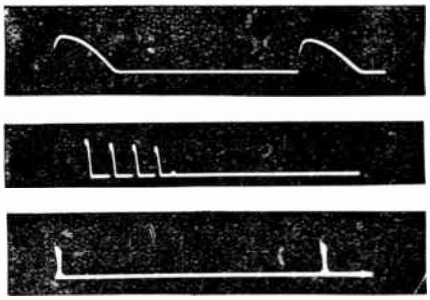


**Fig. 6.** Wave form of the transmitted r.f. signal (a) Pulse waveform (b) Four pulses in a train forming one group (c) Group waveform.

(1) When the capacitor C3 is discharged to the point at which the base reaches the potential of the emitter, collector current begins to flow. During the period of collector current, both the collector and base assume a positive potential slightly lower than the battery voltage and capacitor C3 partially charges up. The secondary voltage is 180 deg out of phase with the primary voltage, so that a negative voltage is applied to the anodes of the triodes, which at that time present a very high impedance.

(2) When the transformer core reaches saturation, the voltage across the secondary breaks down. The energy stored in the magnetic field of the transformer is transferred to the capacitor C4 and the load

presented by the triodes. This period is characterized by a voltage swing in the opposite direction, so that a positive voltage appears on the anodes of the valves and a negative voltage across the primary of the transformer. Capacitor C3 discharges only very slightly because of the large time-constant, mainly determined by the product $C_3.R_3$. As a result of overshoot, supported by the discharge of C4, the voltage at the base reaches the potential of C3 and overshoots below it until the base reaches the potential of the emitter, at which time collector current begins to flow again.

(3) When the collector current begins to flow again, step (1) is repeated and the charge on C3 is further increased.

(4) Step (2) is repeated.

(5) The same sequence of events repeats until C3 charges up to a positive potential which can not be overcome by the negative swing at the base, and oscillation stops.

(6) The capacitor C3 then discharges through the associated resistances determined mainly by R3, until the base reaches the potential of the emitter where the steps (1) to (6) are repeated again. The group repetition frequency is mainly determined by the time constant $R_3C_3$.

The width of the positive pulse in the primary is determined mainly by the primary inductance of the pulse transformer. The capacitor C4 assists in the formation of the overshoot across the secondary when it discharges. The combination of the capacitor C4 and resistance R4 also provides a frequency dependent load, so that the high frequency components of the positive secondary pulse are loaded by the series reactance of C4 and input impedance of the oscillator, whereas the low frequency components are loaded by the series resistance of R4 and the input impedance of the oscillator. As a result, the positive current pulse in the secondary is made narrower and more peaked than the primary pulse.

The capacitor C3, which determines the length of the time for the base potential to reach the emitter potential as a result of the negative voltage swing, and the resistive choke L1, which modifies the charging time constant, determine the number of pulses in the group. This capacitor also determines directly, as mentioned above, the group repetition frequency.

The transistor employed in the blocking oscillator section is a germanium p-n-p alloyed junction power type which can deliver a current of up to three amperes, and can withstand a very high impact shock.

### 6. Filament Switching and Circuitry

In addition to pulse modulation of the anode of the transmitter, a further economy in battery supply can be achieved by periodically switching on and off the valve filaments[12], since the filament supply constitutes two-thirds of the total power drain. Certain limitations are, however, posed on the on- and off-periods of switching as these are restricted by performance and operational requirements. The minimum on-period can not be less than about 0·3 sec for a filamentary-type cathode, which is the time required to reach the operational temperature. The off-period depends not only on the properties of the filament, but also on conditions at the search aircraft. The speed and altitude of the aircraft, and the sensitivity of the receiver will influence the period during which the signal is received. Also, because the "Sarah" receiver is being swept $\pm 1{\cdot}5$ Mc/s every 10 seconds, only a small fraction of this time is available to receive signals in the fringe areas. Therefore to ensure that a filament-switched beacon has a chance to be detected in each frequency sweep of the receiver, the switching period of the filament should be smaller than the period the receiver tuning crosses the proximity of the beacon frequency. Although a large ratio of the off- to on-period is desirable for maximum saving in battery power, the optimum ratio must be determined experimentally and may differ for each speed and altitude of the search aircraft.

The time available for reception of the beacon signal when the receiver is automatically tuned back and forth over a range of frequencies depends on the rate of change of tuning and on the width of the receiver selectivity curve. If this selectivity curve were rectangular, the time available would not depend on signal strength. In general, however, the sides of the curve are slanted so that weak signals are detectable over a narrow band of frequencies, whereas strong signals can penetrate the receiver over a much wider band. Measurements made on the "Sarah" search equipment show that the time during which the aircraft is in the reception area of the beacon rises to several seconds as the distance from the beacon decreases and the signal strength rises above the threshold of recognizability.

Three characteristic modes of valve operation can be distinguished in filament switching depending on the length of the on- and off-period. A long on- and off-period allows the filament to reach its full operating temperature and then to cool off completely. In this case, the minimum on-period should at least equal the full value of 0·3 sec required for the directly heated filament to reach its full operating temperature. As the on-period is reduced, there may be insufficient time for the filament to reach its full operating temperature. However, if the switching frequency is increased by also decreasing the off-time, the filament may not cool completely and will heat to a higher temperature on each subsequent cycle, until it eventually creeps up to the full operating temperature. If the on-period is further reduced, a point will be found beyond which the full temperature will never be reached. This is a result of the heating and cooling time constants and filament resistance, which at lower temperatures exhibit different values and make the temperature creeping impossible.

Filament switching can be considered a practical method of reducing the filament drain only if the saving in the filament power supply is not counteracted by a reduction in the r.f. output. The relationship between the r.f. output power and the switching frequency for three values of on-periods, is shown in Fig. 7. It is seen that for the filament on-period equal to 0·3 sec or more, maximum peak r.f. output is realized and is not influenced by the value of the switching frequency and therefore by the length of the off-period. As the on-period is reduced, the power output is reduced at low switching frequencies, but approaches the full value at high switching frequencies. The latter case is a result of the reduced off-period which permits the temperature creeping action to take place.

An additional characteristic element of identification, is provided by switching the filament. Due to the thermal inertia of the filament, the signal increases to a maximum and then decreases to zero during a period of time which can be perceived by an observer. The display on the screen consists, therefore, of pulses with slowly varying amplitude, which adds the feature of well-defined movement against the background of random noise.

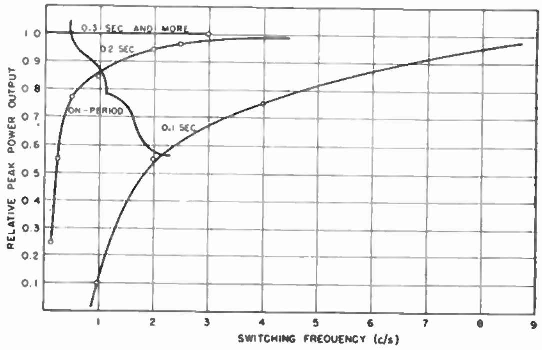



**Fig. 7.** Relative peak power output as a function of the filament switching frequency. On-period as a parameter.

Switching of the filament can be accomplished by means of a transistor operated through a grounded collector stage from a transistorized multivibrator. The multivibrator is of a conventional design[13] and is shown in Fig. 5. The on- and off-periods are proportional to the products of $R_5C_5$ and $R_6C_6$, and have been adjusted for 0·8 second and 1·2 seconds respectively, since this ratio has been found to result in favourable performance. The value of the resistors R7 and R8 are such as to satisfy the bottoming condition of the transistors, expressed by (7).

$$\frac{V}{R_6} = \frac{1}{\alpha} \cdot \frac{V}{R_7} \text{ and } \frac{V}{R_5} = \frac{1}{\alpha} \cdot \frac{V}{R_8} \quad \ldots\ldots(7)$$

where $V$ = battery voltage,
$\alpha$ = current gain factor of the transistor.

The total power consumption of the filament switching unit is about 5-10 mW, which is a small fraction of the total filament power.

In general, switching of the filament reduces the life of a valve. A large number of tests indicate that the CK 5971 triodes used in the transmitter circuit shown in Fig. 5 operate satisfactorily for at least 300 to 500 hours, which is 3 to 5 times the required period of operation.

### 7. The Power Supply

The power supply for the radio beacon has to satisfy a number of requirements. As stated previously, the total weight of the batteries should not exceed four pounds, and yet should provide adequate energy to power the radio beacon for 100 hours. Therefore in the choice of suitable batteries, the ratio of watt-hours per pound is very significant. Consideration must also be given to the temperature characteristic of the batteries, because almost full capacity is required at $-40^\circ$ C. Since the C.P.I. beacon may be required to operate after having been installed for many years on operational or non-operational aircraft, the batteries used should have a very good shelf life, be simple in charging or trickle-charging, and withstand considerable abuse and overcharging. Also, a very rugged construction is required in order that the batteries can withstand considerable shock when the unit is released at high speed and lands on hard terrain.

Although silver zinc storage batteries have a very high watt-hour per pound ratio (about 20-40, depending on size), their capacity decreases to a small fraction at $-40^\circ$ C, and they require considerable care in charging. The solid state and nuclear batteries have excellent shelf life, temperature characteristics and shock resistance, but they deliver very small currents at very high voltages and the overall ratio of watt-hour per pound is not favourable. Nickel-cadmium batteries present a very good compromise for the above-mentioned requirements. The watt-hour per pound ratio is about 10 to 12, with only a 15 per cent. to 30 per cent. capacity decrease at $-40^\circ$ C. These batteries can be discharged in any position, are very ruggedly built, and can be left for very long periods of time in any state of charge or discharge. Moreover, maintenance of Ni-Cd batteries is very simple since they cannot be damaged by limited overcharging.

The design of the tumbling beacon was based on trickle charged Saft nickel-cadmium batteries, and requires a 1·3-volt filament supply

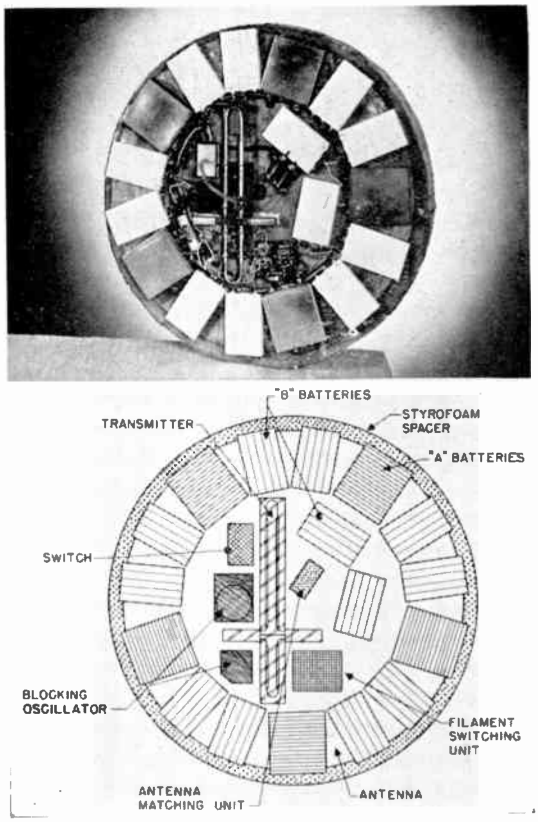



**Fig. 8.** Low drain distress beacon for a Crash Position Indicator (a) top view (b) layout.

with 160 mA current, and a 16-volt supply with an average drain of about 7 mA. Five 4-ampere-hour VO4 Saft Ni-Cd batteries provide the 1·3-volt source with a total capacity of 20 ampere-hours at room temperature and 17 ampere-hours at $-40^\circ$ C, and will last 125 and 106 hours respectively. Twelve 0·8-ampere-hours VO8 Saft Ni-Cd batteries in series provide the 16-volt supply with a total capacity of 0·8 ampere-hours at room temperature and 0·68 ampere-hours at $-40^\circ$ C. These will also last 125 and 106 hours at their respective temperatures by adjusting the current drain to 6·5 mA by suitable choice of group repetition frequency. The weight of the five VO4 cells is two pounds, and of the twelve VO8 cells is 1·3 pounds, resulting in a total of 3·3 pounds.

The above figure for the battery drain assumes continuous operation of the filament.

With filament switching in use and the values of 0·8 sec and 1·2 seconds for the on- and off-periods, the length of operation of the beacon can be more than doubled or, leaving the length of operation unchanged, less than 1·65 pounds of batteries are required with the present beacon design.

### 8. The Layout and Construction

The present design of the complete unit is shown in Fig. 8 and the circuit diagram is shown in Fig. 6. All components are evenly spaced for good weight distribution and balance and cemented on the upper antenna plate. The twelve 1·3 volt batteries making up the 16 volts are shown in white and the five 1·3 volt batteries are shown in grey. They are distributed in the outer circle on top of the upper antenna plate. The parallel line push-pull transmitter is seen in the centre, with the two CK 5971 triodes tightly enclosed by a metal foil which makes contact with the upper antenna plate. Thus the heat of the valves is evenly distributed to the batteries, which is of some value at very low ambient temperatures. Also, the heat is dissipated away from the foam and eliminates the chance of foam shrinkage. The parallel lines are spaced by about ½ in. from the upper antenna plate to reduce the effect of its proximity. The modulator, filament switching circuitry, and the on-off switch are placed in the centre and their relative positions can be found with the help of Fig. 8.

Connections between the low frequency current conducting components as well as between the batteries, have been coiled in order to provide flexibility if the components should dislocate when subjected to severe impact shock. The complete unit is then potted in shock-absorbing foam which is transparent to radio waves.

### 9. Experimental Results

The C.P.I. radio beacon, potted in the tumbling aerofoil as shown in Fig. 1, has undergone several tests designed to simulate conditions encountered in an actual aircraft crash and during a subsequent search.

The majority of tests were performed on the beacon with continuous filament operation, the development of which is now considered completed. The tests on the filament-switched beacon are continuing. In particular, more information is required with regard to the optimum ratio of the on-off periods for given altitudes and speeds of the search aircraft.

Experiments have been carried out in two cases involving Beechcraft "Expeditor" aircraft to prove that normal aircraft operation in flight is not disturbed by the presence of the aerofoil on the tail.

Aircraft crashes were simulated by a rocket sled speeding into a cliff at a known velocity. The C.P.I., suitably mounted on the sled, was designed to be released when the nose of the rocket hit the obstacle. In the two tests performed the C.P.I. successfully survived crashes in which the rocket hit the cliff at 120 miles/hr. and 230 miles/hr. In both cases the C.P.I., upon hitting the airstream, was lifted high in an arc and landed safely away from the point of impact.[5]

Laboratory shock tests were performed on a testing installation consisting of a spring-mounted test platform which could be shocked about three different axes by means of a large hammer or drop weight. The unit tested survived successfully a total of 18 tests, ranging from 170 to 1100*g*, with no change in performance. It is estimated that the batteries and electronic components received a shock of at least 700*g*.

A total of 49 range test flights were carried out in a Beechcraft flying at altitudes of about 9,000 ft. using "Sarah" search equipment with nose or wing tip antenna installation. The purpose of these tests was to evaluate the range of the C.P.I. under different conditions of terrain. The range of the C.P.I. when located on a hilltop or flat terrain was found to be 20 to 35 miles, and in a narrow valley surrounded by hills rising to 700 ft. and buried in snow, 5 to 12 miles. Several flights were carried out using a filament-switched C.P.I. with on-periods of 0·8 sec and off-periods of 1·2 seconds, with comparable ranges obtained.

Several actual search flights were performed with a C.P.I. placed in various locations unknown to the crew of the search aircraft. The area searched was about 8,000 square miles, and the beacon was precisely located in the majority of cases within half an hour, and at no time did the search exceed 2½ hours.

The beacon with continuous filament operation works from $-40°$ C to $+50°$ C with a 2 to 3 db decrease in r.f. output at the lower temperature. Although the batteries last only slightly more than 100 hours, a series of life tests on the circuitry show that the C.P.I. operates satisfactorily for periods well in excess of that time. A slight decrease in r.f. output was observed after 500 hours of operation, probably due to ageing of the valves. On testing the filament-switched beacon, usually one of the valves was found to fail after 300 to 500 hours of operation.

## 10. Conclusions

The radio beacon for a crash position indicator described in this paper is believed to have a high probability of surviving the majority of crashes involving low and medium speed commercial and military aircraft.

Modification in the design and further development will be required to make the beacon survive crashes of transonic and supersonic planes.

## 11. Acknowledgments

Appreciation is expressed to the colleagues in the Royal Canadian Air Force, the Defence Research Board, Canadian Army Signals Engineering Establishment, and the divisions of Applied Chemistry, Mechanical Engineering and Radio and Electrical Engineering of the National Research Council of Canada for their co-operation and assistance. In particular, the authors wish to thank Mr. H. T. Stevinson of the Flight Research Section of the National Research Council, who was in charge of the mechanical and aerodynamical development of this project, Mr. W. A. Cumming of the Microwave Section of the National Research Council, who designed the antenna. Thanks are also due to Mr. D. Tiffin for help in the preparation of the manuscript.

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# OBITUARY

Many members will learn with regret of the death of Captain John Danvers Crossman, C.B.E., Royal Navy (Member), who died suddenly on the 4th December, 1958 at his home in Oxford at the age of 56.

He joined the Royal Navy in 1916 and during his long and distinguished career had command of H.M.S. *Ariel* and H.M.S. *Collingwood*. In 1954 he was appointed a Commander of the Most Excellent Order of the British Empire and soon after was appointed an aide-de-camp to Her Majesty The Queen.

Captain Crossman retired from the Royal Navy in 1956 and entered industry, joining Cottage Laboratories. In 1958 he decided to retire to a new home in Oxford; it is indeed sad that he was destined to enjoy it for such a short time.

All those who have served with him will remember him with respect and affection and extend their sympathy to his widow and two sons.

G.C.T.

* * *

I first met Walter Charles Gee on board a torpedo boat destroyer at Scapa Flow in 1916. He was a young Royal Naval Wireless Telegraphist. In fact the day we met history was made as far as we two were concerned. We were listening on the ship's radio receiver, on headphones, and heard someone speak. Imagine year after year listening to morse signals then suddenly hearing a real live voice. This first telephony heard by Gee and myself was afterwards found to be originating in one of the battleships three miles away where some officers were experimenting with telephony.

Walter Gee left the Royal Navy in the early 1920's and eventually joined the Colonial Service. He was elected a Member of the Institution in 1930. He was then in charge of Posts and Telegraph Department, Kuala Lumpur, F.M.S., and held this post until he left just before the Japanese occupation. In fact he was one of the fortunate last few to get away from Malaya. I saw him in London later, he had come home via the Gold Coast where he worked for a short time. In London he was engaged on work which would assist a return to Malaya and he returned there in 1945 as a Major attached to the Telecommunications Headquarters of the British Military Administration.

I knew he had set his heart on retiring to Tasmania or New Zealand and he gave me glowing accounts of these countries. In 1947 he set up as Radio Consultant in Hobart, Tasmania, but the following year saw him off to take up a post with the Australian Post Office as Transmission Engineer.

Two years later he was appointed Divisional Engineer, Posts and Telegraph Department, for the territories of Papua and New Guinea, stationed at Port Moresby, a post which he held until his death.

Walter Gee took a keen interest in the work of the Institution and he strongly advocated the extension of its activities within the Commonwealth.

C.E.B.

* * *

Advice has only just been received of the death on the 8th August 1957 of Ronald James Sullivan. Mr. Sullivan, who was elected an Associate Member of the Institution in 1948, died after a minor operation at the age of 41.

Mr. Sullivan served in the Royal Air Force during the War as a Signals Officer. In 1946 he joined British Overseas Airways Corporation as Superintendent of Signals Operations, and in 1947 was transferred to the International Civil Aviation Organization H.Q. in Montreal as deputy chief of the Communications Section.

In 1953 Mr. Sullivan became Director of the Ground School at the Training Centre of the I.C.A.O. Technical Assistance Mission in Mexico; from 1955 until his death he represented Decca Radar Ltd. in Mexico and Central and South America.

* * *

The death took place on 31st October 1958 of Captain Harbans Singh Oberai of the Indian Army Signal Corps. Captain Oberai, who was 36 years of age, was an Instructor with the Air Formation Signals Staff at I.A.F. Training Centre, Bangalore. He registered as a Student of the Institution in July 1957, and had already passed part of the Graduateship Examination.

# Cold-cathode Voltage-transfer Circuits†

*by*

J. H. BEESLEY, B.SC.‡

*A paper read before the Institution in London on 21st May 1958.*
*In the Chair: Dr. G. L. Hamburger (Member)*

**Summary:** The paper describes a new method of operation of cold-cathode triode switching tubes, which has some distinct advantages compared with the standard "pulse + bias" technique. A number of differences occur in the way in which tubes can be interconnected and as a result the logical design of switching equipment employing these circuits has some unusual features. These differences are most apparent in counters, some of which are described in detail.

## 1. Introduction

In recent announcements by the Post Office describing some of the engineering features of the subscriber trunk dialling system which is being provided in this country, mention has been made of an electronic version of GRACE, Group Routing and Charging Equipment, which employs cold-cathode voltage-transfer circuits[1]. In the last few years, cold cathode tubes, mostly of the trigger triode type, have become favourite devices for experimental low speed electronic switching applications in telephony, primarily because of their promise of very long and trouble-free lives[2]. Most of the experimental equipments have employed the cold-cathode tubes in circuits of a type which is known as "pulse plus bias." These basic circuits together with a number of variations which have been employed to improve their performance have been amply described in a number of papers which have been published recently[3, 4, 5]. This paper describes the rather different technique which has been employed in the first full scale application of cold-cathode tubes in the British telephone system.

## 2. The Two Methods of Operation

In the pulse + bias technique a tube is struck by superimposing the differentiated output from one tube on the steady output from another, as illustrated in Fig. 1. The h.t. and the circuit components are chosen so that the voltage appearing at the cathode of a tube when it is conducting is about two-thirds of the striking voltage of the tube. Thus, if T2 is struck when T1 is not conducting, the output at the cathode of T2 is differentiated by the CR network, and the voltage appearing at the trigger of T3 is insufficient to strike the tube. This is illustrated by the dotted waveform in Fig. 1.

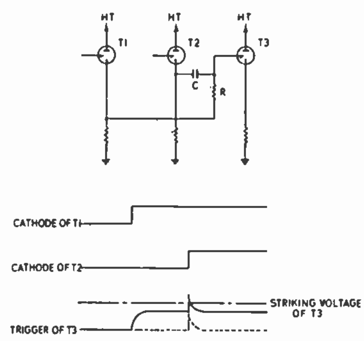


**Fig. 1.** Illustrating the pulse-plus-bias method of triggering.

Alternatively, if T1 is struck the output from its cathode is integrated and applied to the trigger of T3, which again does not strike. However, if T2 is struck when T1 is conducting, its differentiated output is superimposed on the output from T1, and T3 strikes. Pulse + bias circuitry is rarely used in as simple a form as described here, since it is normally necessary to

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‡ Formerly General Electric Co. Ltd., Telephone Works, Coventry; now with Computer Developments Ltd., Kenton, Middlesex.

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stabilize the amplitude of the striking signal, in order to ensure reliable performance.

In the voltage-transfer method, voltage addition and the use of differentiated signals is avoided by arranging that the steady output from the first tube has sufficient amplitude to strike the third tube directly, and the presence or absence of a signal from the second tube is used to control the passage of the output signal from the first tube to the trigger of the third.

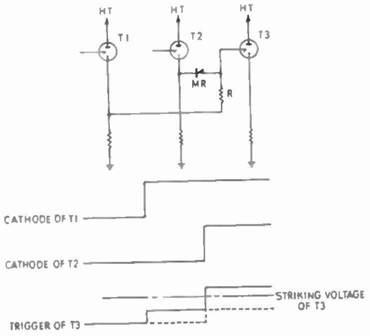



**Fig. 2.** Illustrating the voltage-transfer method of triggering.

This is illustrated in Fig. 2 where the capacitor between T2 and R has been replaced by a rectifier connected so that it conducts in the low-resistance direction when current flows from T1 through R towards T2. The value of R is chosen to lie between the forward and reverse resistances of the rectifier, so that when either T1 or T2 is conducting, the voltage at the trigger of T3 is small compared with the output from the cathode of the tube conducting. However, when both T1 and T2 are conducting, the full output voltage of T1 appears at the trigger of T3. The h.t. and the circuit components are chosen so that this output voltage is about four-thirds of the voltage required to strike T3.

Although there are only two points of difference between these basic circuits, considerable differences arise in the methods employed for their logical interconnection. Two causes of this are immediately apparent. In the voltage transfer system T3 will strike whenever T1 and T2 are both conducting irrespective of the order in which they were operated, but in the pulse + bias system T3 can only be triggered if tube T2 is operated when T1 is already conducting. Further, if after all three have been struck T3 is extinguished by a momentary reduction of the h.t., then in the voltage transfer system it will immediately restrike, but in the pulse + bias system this will not occur.

The simple circuit of Fig. 2 has been developed into a range of standard circuit elements, which may be logically assembled in a very flexible manner. The cold-cathode tube employed, the CCT6, has been specially developed to have suitable characteristics for voltage transfer operation, and the rectifiers used are small selenium Q-type "unistors."

## 3. The Cold-cathode Tube Circuits

### 3.1. *The characteristics of the CCT6*

The chief characteristics of the CCT6 are as follows:—

Main gap breakdown voltage (with trigger between 0 and 50V)—greater than 250V.

Main gap maintaining voltage (anode current 1 mA-40 mA)—65-80V.

Normal anode current range—1-5 mA.

Maximum anode current (intermittent operation)—40 mA.

Anode-cathode voltage before triggering—190V minimum.

Trigger-cathode breakdown voltage—70-90V.

Trigger-cathode maintaining voltage (pre-transfer; for current of 30 μamps)—80V maximum.

Trigger current to cause transfer (anode voltage 190V minimum)—30 μA.

These figures have been chosen, after exhaustive life testing, to ensure that the CCT6 will have a very long life in voltage transfer circuitry.

### 3.2. *The characteristics of the CCT6 circuits*

The application of the characteristics of the CCT6 to a typical voltage-transfer tube circuit will be illustrated by considering the circuit of Fig. 3 in which two tubes are arranged to be mutually extinguishing.

In all voltage-transfer circuits the h.t. supply is chosen to be within the range 225V to 250V (240V nominal). The minimum trigger-cathode voltage necessary to guarantee that a tube strikes is given as 90V, but since, as will be shown later, a small current from external circuits can flow through the cathode resistor RC when the corresponding tube is not conducting, an allowance of 5V is made for the drop between cathode and earth. Hence the minimum voltage which must be applied to the trigger of a tube to guarantee striking is 95V. A drop of up to 25V also occurs in the gating circuits between the cathode of one tube and the trigger of another, and as a result the output voltage at the cathode of a tube which is conducting must never be less than 120V. Since the minimum voltage of the h.t. is 225V and the maximum main gap maintaining voltage of the CCT6 is 80V, the difference, 145V, is therefore the minimum voltage dropped across the anode and the cathode resistors. The relative values of these components are therefore determined by the fact that, under extreme conditions of component tolerances and loading of the cathode output of the circuit, the cathode voltage must not fall below 120V. The actual values are determined by the magnitude of the output current required, by the fact that the minimum anode current permissible is about 1 mA and by certain extinction conditions which are mentioned later. Common values for the anode and cathode resistors are 5·6k ohms and 120k ohms respectively; with the nominal h.t. voltage and an average tube the output voltage at the cathode is approximately 150V.

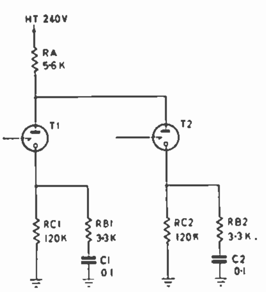



**Fig. 3.** Typical circuit in which the tubes are mutually extinguishing.

In Fig. 3, a common anode resistor RA is used for all the tubes which are required to be mutually extinguishing, and a capacitor C and series resistor RB are placed in parallel with the cathode resistor RC. RB is arranged to be small compared with RC. If we suppose that tube T1 is conducting, then the voltage at its cathode is of the order of 150V, while the cathode of T2 is at earth potential. If T2 is now struck, current flows through RA, T2 and RB2 to charge C2. The voltage at the cathode of T2 rises immediately about 50V due to current flowing in RB2 and continues to rise slowly as C2 charges, approaching a steady value of about 150V after a few hundred microseconds. The anode voltage, which was previously steady at about 225V, falls to about 125V when T2 strikes and then rises in the same form as the voltage at the cathode of T2. Due to the presence of C1 the voltage at the cathode of T1 cannot follow the depression of the anode voltage and as a result the tube is extinguished. The voltage at its cathode now falls as C1 discharges via RC1.

The values of the components in the circuit are dependent on the following requirements as well as those already discussed:—

(1) The minimum value of C is determined by the minimum value of RC, including any external load, because when the tube is being extinguished the voltage at the cathode must not fall too fast, or the tube may restrike.

(2) The maximum value of C is determined by the maximum value of RC since under steady conditions slight oscillations occur in the maintaining voltage of the tube. Extinction of the tube may result if the voltage at the cathode is not able to follow these fluctuations.

(3) The minimum values of RA and RB are determined by the value of C as the rate of charging of this capacitor must not be so fast as to prevent effective extinction of the previously conducting tube.

(4) The relative values of RA and RB are determined by the need for preventing too great a depression of the anode voltage when a tube strikes, since it is necessary to ensure that tubes are not able to conduct in the reverse direction on being extinguished, as a result of the cathode voltage being much greater than the anode voltage. If this were allowed to occur, damage to the tube would result.

All these conditions have to be taken into account while bearing in mind that the primary requirement is to obtain a useful output from a conducting tube, and that it is highly desirable that some variation in the amount of this output should be possible without the need for adjustment of the values of the circuit components. This has been met very satisfactorily with this type of circuit and only two sets of values of components are used to cope with all the output requirements that have been found necessary. One set of values is shown in Fig. 3, and with this circuit up to two output OR gates may be connected as well as a number of AND gate resistor inputs. The use of these gates is described in Section 4. Twice this load may be connected if the component values are changed to:—

RA 2·7kΩ, RB 1·5kΩ, RC 56kΩ, C 0·22μF.

3.3. *Storage circuits*

Different and more simple arrangements of anode and cathode circuits are used when extinction of the tubes is not required to be controlled by other tubes, but rather by switching off the h.t. supply. In the most simple of these arrangements the anode is connected directly to h.t. and the cathode is connected to earth via a resistor as shown in Fig. 4(a). A low value resistor is sometimes included in the anode circuit as shown in Fig. 4(b). If this is done the value must be chosen so that the output voltage at the cathode of the tube has a minimum value of 120V.

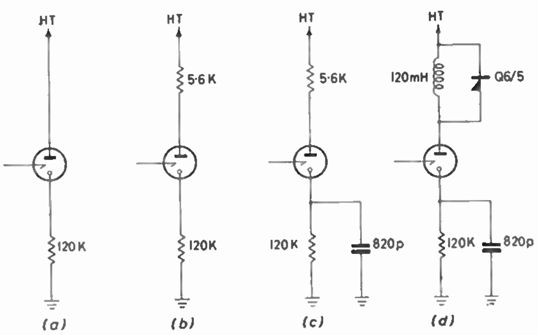
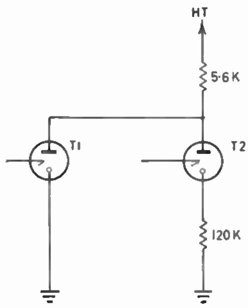



**Fig. 4.** Typical storage circuits.

Another form of circuit is shown in Fig. 4(c). Here a small cathode capacitor (820 pF) is placed in parallel with the cathode load to absorb pulses which may be fed back through the capacitance of the rectifiers of output OR gates. When this capacitor is provided an impedance is included in series with the tube to prevent it arcing on being struck. When fairly low currents are drawn from the tube by the output circuits attached to the cathode this impedance is provided by a resistor in the anode circuit, but when output currents of 10-40 mA are required (when the tube is only operated for very short periods of time) the anode resistor would have to be extremely small to maintain an 120V output signal. Consequently, the arrangement shown in Fig. 4(d) is used. An inductor of 120 mH and resistance of less than 100 ohms provides the series impedance and a rectifier ensures that any oscillations that might occur are damped out. This arrangement is also extremely useful when the output of the tube is fed to a long length of cable which may have a very appreciable capacitance.

**Fig. 5.** Illustrating control of the storage circuit output.




It is sometimes necessary to prevent an output being obtained from a storage circuit, or to be able to remove an output already existing. This may be achieved by means of the arrangement shown in Fig. 5. Here tube T1 has its anode connected to the anode resistor of the storage unit and its cathode connected directly to earth. When T1 is not operated T2 behaves as normal, but when T1 is conducting the potential at its anode is too low to allow an output to be obtained from T2. The anode resistor has to be small, both to allow T2 to provide at least 120V output when T1 is off, and to ensure that T1 may have sufficient anode voltage to transfer when T2 is already conducting. This of course means that T1 draws a very heavy current when it is operated, and therefore the use of this circuit arrangement is avoided if the tube T1 has to remain conducting for a long period of time.

## 4. The Voltage-transfer Gating Circuits

The basic arrangement of the rectifier gates used to transfer signals between tubes is shown in Fig. 6, and typical values of the components are given. Three types of gates are involved, the output OR gate G1, the AND gate G2 which appeared in Fig. 2, and the input OR gate G3.

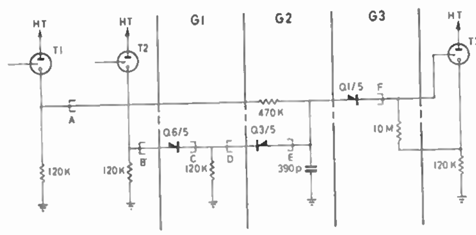



**Fig. 6.** Basic gating circuits.

The rectifiers used are S.T.C. Q type Selenium rectifiers Q1/5, Q3/5, Q6/5 and Q8/5. Conservative forward current ratings are used to ensure good life. The reverse resistances allowed for are also conservative, and although the reverse voltage applied across a rectifier is often somewhat in excess of the normal d.c. value of 20V per plate, no trouble has arisen due to this. The chief parameters of the rectifiers, as used in the circuit design, are given in the Table below

4.1. *The output* OR *gate*

This gate allows the output signals from a number of tubes to be combined as shown by the common C in order to control the operation of AND gates. Output signals from any given tube may be fed to a number of these OR gates as shown by the common B. Since the output OR gate is of relatively low impedance the rectifiers used are Q6/5 or Q8/5. The value of the resistor is determined by the maximum current that is fed back from an AND gate when a signal is applied to its resistor input, and is arranged to be such that the voltage at the output of G1 is never greater than 50V when T2 is not operated. Several varieties of these gates are required to allow for an output OR gate being connected to different numbers of AND gates at the common D. As well as permitting the combination of different signals, the rectifiers in the OR gate serve to prevent back feeds from AND gates from appearing at the cathodes of unoperated tubes. This is an important function since any voltage present at the cathode when a tube is about to be triggered, reduces the available triggering voltage by that amount, and for this reason output OR gates having only one input lead often appear in voltage-transfer circuitry. For certain functions an OR gate is employed as the input circuit to the resistor input of G2, and in these circumstances the impedance level of the gate can be higher.

4.2. *The* AND *gate*

The AND gate permits the combination of output signals from a number of tubes applied either directly or via output OR gates, in such a manner that an output is obtained from the gate only if signals are applied to all its inputs simultaneously. One of these signals is applied to the resistor input of the gate, and all the others are applied to different rectifier inputs as indicated by the common E. The value of the resistor is arranged to be about four times the value of that required in an output OR gate that is dealing with one back feed, and the rectifier, which may be of a smaller plate area than the one employed in the OR gate, is type Q3/5. As a result the voltage at the output of the AND gate never exceeds 60V, which is insufficient to allow a tube to strike, except when all the input signals are present. An exception to this would occur for periods of some microseconds when a sharply rising signal is applied to a rectifier in-

**Table 1**

| | Q1/5 | Q3/5 | Q6/5 | Q8/5 | |
|---|---|---|---|---|---|
| Maximum forward current | 100 μA | 500 μA | 4 mA | 15 mA | (pulse) |
| Maximum voltage drop across the rectifier when passing Maximum forward current | 15V | 10V | 10V | 15V | |
| Minimum reverse resistance with 100V applied across the rectifier | 100 MΩ | 25 MΩ | 6 MΩ | 1·5 MΩ | |
| Capacitance at Zero Volts | 4 pF | 13 pF | 100 pF | 200 pF | |

put, since the rectifiers have an appreciable capacitance. To avoid this spurious signal, which could result in false operation of the succeeding tube, a small capacitor is connected between the output of the AND gate and earth, its value being chosen so that it is about 30 times the effective capacitance of the rectifier. The capacitor potentiometer thus formed prevents the transient from rising more than about five volts above the normal value of the output signal in the non-operated condition. If it is possible for sharply rising signals to be applied to several of the rectifier inputs simultaneously, the value of the capacitor is chosen to be the appropriate multiple of the unit value. If all the rectifier inputs and to an AND gate are from counter circuits the capacitor is not required since the outputs from these circuits have a minimum rise time of several hundred microseconds. A sharply rising signal may be applied to the resistor input of the gate without any spurious signals occurring. When a capacitor is present in the gate it causes a lag in the appearance of a signal at its output, but this rarely exceeds about 200 microseconds, which is not important in voltage transfer circuitry.

For testing purposes it is often desirable to prevent the operation of a gate in order that a sequence of operations may be slowed down sufficiently for it is to be observed in detail. This is particularly simple with voltage transfer circuits, as all that is necessary to inhibit an AND gate is to earth its output. This has no adverse effect on any of the circuits connected to the inputs of the gate, and on the disconnection of the earth the gate will immediately function as usual. In addition to its use for fault location this facility is often made use of in detecting disconnections of electro-mechanical relay contacts.

### 4.3. *Timing circuits*

A re-arrangement of the AND gate is shown in Fig. 7. The input resistor is connected direct to h.t. and is increased in value by about 14 times. The size of the capacitor is also increased while the rectifier is changed to a high impedance type similar to that used in the input OR gate. Owing to the high value of the input resistor compared with that of the OR gate, the voltage at the output is low as long as any one OR gate associated with it is not operated, but when all the OR units are operated, each of the input rectifiers is cut off and the capacitor slowly charges at a rate determined by the values of the resistor, the capacitor and the h.t. until it has risen to the striking voltage of the tube associated with the output of the timing circuit. This circuit therefore provides a delay device, which proves very useful where exact timing is not important.[6] (Similar circuits have been described previously for use in interval timers, but these employ special cold-cathode tubes having highly stable striking conditions.[7] General purpose cold-cathode triodes are not suitable for such applications.)

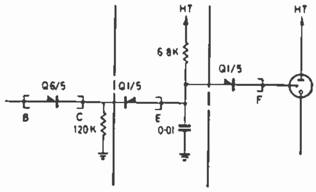



**Fig. 7.** Simple timing circuit.

(*Note.*—The 6·8 K resistor should read 6·8 M).

### 4.4. *The input* OR *gate*

The output signal from an AND gate is fed to the trigger of a cold-cathode tube by means of an input OR gate, which permits the operation of the tube from any one of a number of AND gates as shown by the common F in Fig. 6. The impedance level of the input OR gate is made high compared with that of the AND gate to prevent mutual interference with their operation. The gate is employed even when there is only one input to a tube, since it also serves to prevent the trigger drawing a large amount of current when the tube is conducting. This feature is important for two reasons, firstly because damage can be caused to a cold-cathode tube if the trigger draws more than a few microamperes, due to the contamination of the cathode surface by material sputtered on to it from the trigger, and secondly because the passage of a high current from the trigger via the AND gate to an output OR gate might cause the operation of other AND gates connected to it.[8] The purpose of the resistor is to limit the impedance at the trigger to a finite and known value and also to ensure that the capacitance of the input rectifiers is discharged when the tube is extinguished.

Three varieties of input circuits to tubes are shown in Fig. 8. Type (a), which is of the form

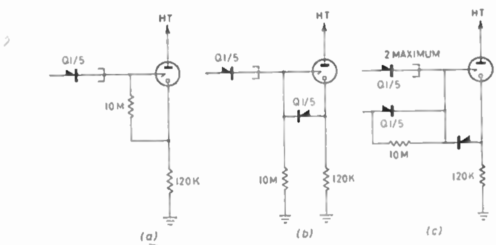



**Fig. 8.** Various cold-cathode tube input circuits.

shown previously, has the resistor of the input OR gate connected between the trigger and the cathode of the tube. If the capacitance at the trigger of the tube is small, this circuit ensures that in normal circumstances the trigger will not go appreciably negative with respect to the cathode, and also allows for the rapid discharge of the trigger capacitance when the tube is extinguished, but it is only suitable for use when a small number of AND gates are connected, since the input rectifiers largely determine the magnitude of the capacitance. If the trigger goes negative with respect to the cathode it may cause false operation of the tube, while if the capacitance at the trigger is not discharged quickly enough a tube may restrike after it has been extinguished.

When large numbers of AND gates act as input circuits to a tube, neither of these conditions would be met by circuit of Fig. 8(a) since the large total capacitance of the rectifiers would prevent the trigger voltage from responding quickly to changes in the cathode voltage. In these conditions the circuit shown in Fig. 8(b) is used in which the trigger resistor is returned to earth and a high impedance rectifier is connected between the cathode and trigger. This ensures that the discharge of the trigger capacitance can take place at the same time as the discharge of any capacitance at the cathode, rather than after it as in the circuit of Fig. 8(a), and also guarantees that any positive voltage fed back to the cathode appears also at the trigger.

The arrangement of Fig. 8(c) is a variation of the previous circuit in which the resistor is connected to one of the inputs rather than to earth. This is used when the tube is operated from a timing circuit as it is then necessary to prevent leakage from the capacitor while the timing process is occurring. By arranging that the only leakage paths are via the reverse impedance of rectifiers, and by limiting the maximum number of alternative inputs to two this leakage is kept sufficiently low to prevent the timed period from being too indeterminate.

Because of the necessity of using this arrangement, only one timing circuit is ever used as an input to any particular tube.

### 4.5. *Striking conditions*

To operate a tube two conditions are necessary; first, prior to striking a voltage must be applied to the trigger in excess of the breakdown voltage, and second, after this has caused the breakdown of the trigger-cathode gap, sufficient current must flow in this gap to ensure that the discharge can transfer to the anode-cathode gap.

The pre-breakdown conditions are shown in Fig. 9. As mentioned in Section 3, up to 5V may appear across the cathode resistor due to back feeds from output OR gates, and therefore 95V must be applied to the trigger. The current $i$ may be up to 20 microamperes and with this current the 25 volts allowed for is dropped across the resistor and rectifier.

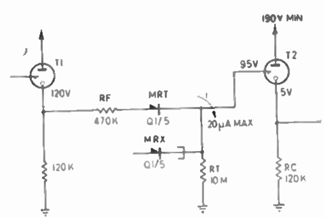



**Fig. 9.** Circuit conditions—before striking.

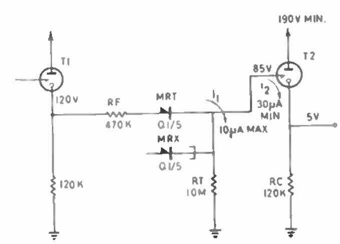



**Fig. 10.** Circuit conditions—after striking.

Once breakdown of the trigger-cathode gap has occurred the conditions are altered to those shown on Fig. 10. A current now flows through the tube while the voltage across the trigger-cathode gap falls to about 80V. To allow satisfactory transfer of the discharge to the main gap, the tube current $i_2$ has to be at least 30 μA, but $i_1$ falls to about 10 μA maximum as a result of the reduction of the voltage at the trigger. The resistor and rectifier now drop 35 volts in providing the 40 μA current which is required.

It is important to note that in the timing circuits the resistor is of much too high a value to allow the current flowing through it to cause transfer, and the transfer current must therefore come from discharge of the capacitor. This requirement imposes a lower limit on the value of the capacitor of 0·01 μF, which gives a delay time of about 25 msec.

## 5. Basic Counter Logic

### 5.1. *The simple counter circuit*

The complete circuit of a simple ring connected counter is shown in Fig. 11.[9] This is re-drawn in Fig. 12 using functional symbols to represent the circuit units. Each of the squares represents a cold-cathode tube together with its cathode and trigger circuit including the input OR gates. A common anode circuit serves each of the units and this is indicated by drawing all stages of a counter in a row, different counters being shown on different rows. The input to each of the AND gates which is drawn opposite the output, represents the resistor input to that gate.

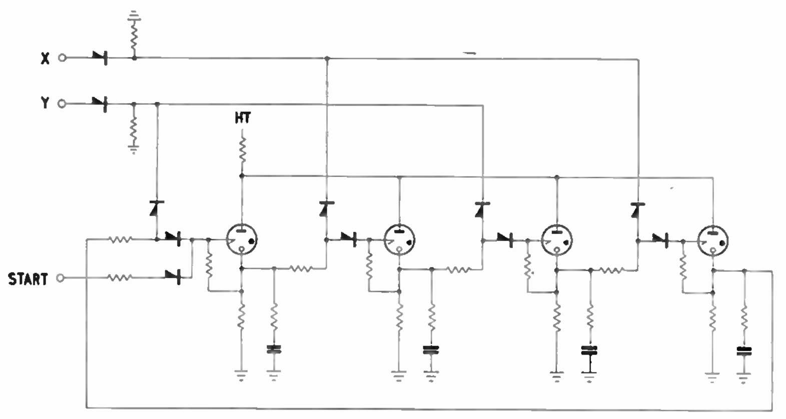



**Fig. 11.** Circuit diagram of elementary ring counter.

The use of voltage-transfer circuitry which employs relatively slow changing long duration striking signals, results in two features that greatly affect the logical construction of counter circuits.

(1) A minimum of two stepping leads, such as X and Y in Fig. 12 are necessary for each counter.

(2) The output from a tube in the counter may be connected directly to one of the stepping leads of another counter.

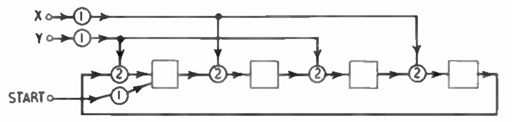



**Fig. 12.** Diagram of elementary ring counter using functional symbols.

The operation of the counter is as follows. Suppose that each tube in the counter is unoperated, and that any voltages on leads X, Y and START are less than 50V; if the potential of the START lead is now raised to at least 120 volts, the first tube triggers and remains operated after this start signal has been disconnected. An output from the first tube is connected to the AND gate between the first and second tubes, but a triggering voltage is not applied to the second tube until a signal of at least 120 volts is present on lead X. When this signal is connected the second tube operates and the first is extinguished and the output from the first stage of the counter falls to zero. The second tube now remains operated after the 120V signal on the X lead is removed, but if a 120V signal is now applied to the Y lead the count will transfer from the second to the third tube. Removal of the signal on the Y lead followed by the re-application of a 120V signal on the X lead transfers the count from the third to the fourth tube. Clearly this process can be operated through many more stages than are shown in the diagram, until finally the last stage is operated and an increase in the Y-lead voltage to 120 volts restores the counter to its initial condition.

If at any time during this process both the X and Y leads have voltages in excess of 50 volts applied to them simultaneously there is a possibility that a multiple count will register due to an immediate transfer through several stages of the chain. Alternatively, two stages of the chain might remain operated simultaneously. Since it is most important that neither of these conditions should occur, the rule that signals in excess of 50 volts must not be allowed on both the X and Y leads simultaneously has to be followed without exception.

If the signals applied to the stepping leads are derived from tubes of another counter, this rule defines the upper operating frequency of the counter, since the output from such tubes decays slowly due to the presence of a capacitor in the cathode circuit. However, when the X and Y leads are fed from other sources, which allow higher speed operation, the feature that determines the maximum frequency at which the counter can be driven is the time constant in the cathode circuits of the tubes in the counter itself. The limiting condition is that the output signal from any stage must have decreased to less than 50 volts before the next triggering signal is applied to that lead on which the previous signal caused the stage concerned to be switched off.

This rule can be explained most simply by again referring to Fig. 12. Suppose that stage 1 of the counter is operated and a signal is applied to lead X. Stage 2 will operate and the voltage at the output of stage 1 will decay slowly. If the pulse on the X lead is followed quickly by a pulse on the Y lead, the third stage of the counter will be operated while there is still a voltage in excess of 50 volts at the output of stage 1. In these circumstances, a further signal applied to lead X will produce a striking signal at the output of the AND gate following stage 1, as well as from that following stage 3 and this could result in false operation of the counter.

A further factor that reduces the frequency limit when the counter is a very short ring, such as that shown in Fig. 12, is the necessity for the output signal from any stage in the ring to have dropped to 5 volts before the stage is required to be switched on again. The maximum speed of operation of these types of counter circuit is between 50 and 200 steps per second, depending on which of the rules introduces the restriction.

*5.2. Operation of ring counters in cascade*

In the design of equipment employing cold-cathode tubes a counter is often required to take one step for each revolution of another counter. With the type of circuit just described a signal cannot be taken from a counter each time it reaches a particular stage, and used to cause another counter to take one step, because two stepping leads are necessary. This means that two connections from the first counter are needed and, because of the rules discussed previously, certain limitations have to be applied. As both leads must not have signals in excess of 50 volts applied to them simultaneously, the two stepping leads cannot be connected to adjacent stages of the previous chain. If the leads are connected to the chain so that there are at least two stages between those feeding the leads, no additional restrictions apply. However, if the leads are connected so that there is only one intermediate stage in the counter, then this counter must be operated at a sufficiently low speed to ensure that the output from the stage connected to one lead has decayed to below 50 volts before the stage connected to the other lead is operated. (It should be noted that the particular limitations described here do not necessarily apply if the AND gates in the chain are controlled by other signals as well as those of the stepping leads, but the basic rules always apply.)

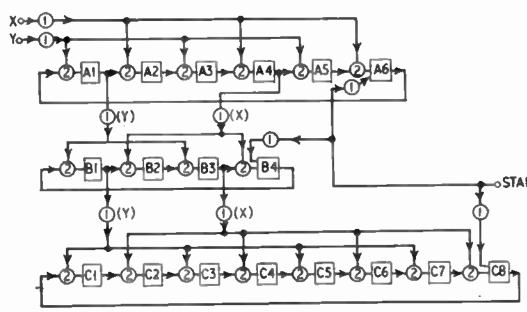



**Fig. 13.** Ring counters connected in sequence.

Figure 13 shows a suitable method of operating a counter having eight stages (C1-C8) so that it takes one step for each revolution of a six stage counter (A1-A6). The stepping leads X and Y of the counter A are supplied with signals as previously described. Twice during each revolution of counter A, on the operation of stages A1 and A4, counter B takes one step, and on every alternate step of counter B, at the operation of stages B1 and B3 counter C makes a step. Counter B is therefore acting merely as a device for distributing the output signals from stage 1 of counter A so that they are applied alternately to the X and Y leads of counter C. It will be seen that lead X of counter B could have been connected to stage A3 or A5, instead of A4, without affecting the operation of the circuit.

### 5.3. *Input circuits*

Very frequently it is necessary to operate cold-cathode tube ring-counter circuits from external electro-mechanical contacts, and a number of different techniques are available using the voltage-transfer method of operation.

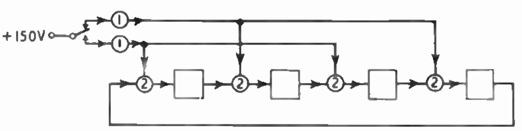



**Fig. 14.** Changeover contact input circuit.

The simplest method, which may be used when the counter is to be operated by a changeover contact, is shown in Fig. 14. A low impedance source of about 150 volts amplitude is applied to the common spring of the contact, and the other springs are connected to the inputs of the OR gates on the stepping leads. Since the application and removal of the signal to the stepping lead is sudden, AND gates including capacitors are necessary between the stages of the counter.

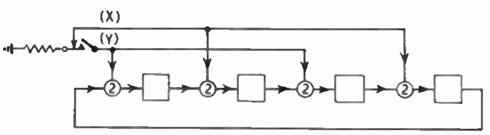



**Fig. 15.** Make-before-break contact input circuit.

An alternative method suitable for use with a make-before-break contact, is shown in Fig. 15. Here the common spring is connected to earth via a 120 kΩ resistor, and the other springs are connected to the stepping leads with the OR gates omitted. Suppose that the contact is in the position shown, then the gates in the chain connected to the X lead are earthed through the same impedance as is normally used in the OR gate, and none of them are able to operate. The gates connected to the Y lead are disconnected, and so act as if the X lead does not exist. If stage 1 is on, and the contact is operated, both sets of gates will be earthed momentarily while the contacts bunch; then, while the Y lead remains earthed, the X lead will be disconnected. The gates connected to the X lead will now act as if the Y lead did not exist and so the counter will step from stage 1 to stage 2. On the return of the contact the gates attached to the Y lead are able to operate and the count advances to stage 3. This action is repeated through each stage of the counter until finally the count steps from the last stage to the first. Capacitor type AND gates are again used in this type of counter to prevent possible false operation if slight contact bounce occurs during the bunching period.

Another form of circuit, which is very useful if only a make or a break contact is available, and it can be predicted that this contact will not remain operated for more than a certain proportion of the minimum interval between operations, is shown in Fig. 16.

Suppose that stage 1 is operated and that the contact is normal. If the contact is now made, the count is transferred to stage 2 and the output from this stage allows the timing circuit to charge slowly. After a time, which is arranged to be greater than the maximum period that the contact is made, the timing circuit triggers the next stage of the counter. On the next operation of the contact stage 4 comes on, followed by the second timing circuit, which operates after a delay and restores the chain to its original condition. If the contact to be used is a break instead of a make the input circuit to the counter is modified to the form employed in Fig. 15.

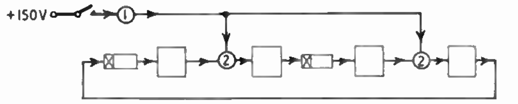



**Fig. 16.** Make contact input circuit using timing units.

## 6. More Complex Counter Circuits

### 6.1. *Counting from a preset position*

The four-stage chain acting as a "divide by two" element is a circuit that is frequently used when a counter is required to take one step for each operation of an external device, such as a relay. In its simple form the four-stage chain is suitable only if the count is pre-arranged to commence from either an even or an odd stage of the counter. In Fig. 13, for example, the start signal ensures that the count commences from an even stage. If, however, the start lead had been connected to C7, then the first stepping signal would be required on lead X instead of lead Y and the connections of these leads to the chain would have had to be reversed. In certain circuits it is necessary to be able to pre-operate any given stage in the counter in order to register a particular count that is required, and then to step the counter down to a zero position. Since in these circuits, the count registered may be odd or even, the simple circuit of Fig. 13 is not suitable and the modified arrangement of Fig. 17 is used.[10]

In this circuit the principle of Fig. 13, in which the B chain is set to conform with the conditions of counter C at the commencement of the count only, is altered to one in which B is set prior to each step of the counter, and two of the connections between adjacent stages of B are removed. Suppose a start signal is applied to C2. A signal therefore appears at the output of the "evens" OR gate, and on the application of a pulse to lead Y stage B3 operates. The following X pulse causes B4 to operate, which in turn steps the count from C2 to C3. Before

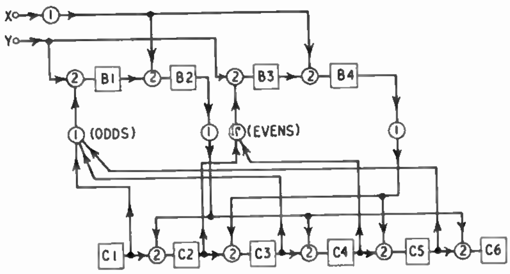



**Fig. 17.** Connections for counting from a preset position.

the next Y pulse occurs the output of C2 has been removed and in its place the output from C3 appears at the input of the "odds" OR gate so that the Y pulse causes B1 to operate. Then B2, operating to the next X pulse, causes the counter to make a further step to C4. The count then proceeds down the chain with each stage in turn selecting the pair of stages in the B counter that is needed to cause transfer of the count.

### 6.2. *Counting an odd number*

It is apparent that, because of the necessity of having at least two input leads, the counting of an odd number is not possible with the circuits described up to now. Numbers that are divisible by three or five can be counted by providing the B chain with six or ten stages respec-

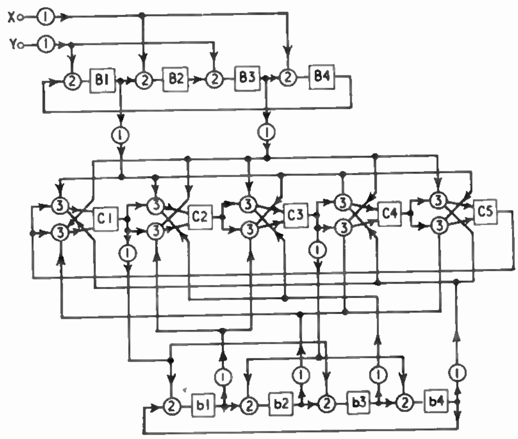



**Fig. 18.** Arrangement for counting an odd number.

tively, and the counter with three or five stepping leads, each connected to alternate stages of the B chain. However, any extension beyond six stages of the B chain becomes rather uneconomical, and in any event the method is not applicable to prime numbers. In the solution of this problem the four stage B chain is again used. Figure 18 shows the circuit configuration employed.[11] A normal B chain acting as a divide by two unit drives a five-stage C chain, which itself operates a further B-type chain b. If the C chain had had twice as many stages no problem would have occurred in the operation since the number of stages would have been even. The method of approach of this solution is to treat the counter as if it had twice as many stages as it has in fact, and then to operate it in the normal way.

Suppose the first stage of each of the counters is operated. An output signal appears from B1 and is applied to the upper AND gate input to C2, but this cannot operate since the other input lead to this gate is connected to b3 which is not operated. When the B chain has made two steps an output appears from B3 and this, together with the existing outputs from C1 and b1, causes the lower AND gate to pass a triggering signal to C2, and so the C counter makes one step. When the first stage of the B chain operates again the combination C2 + B1 + b1 at the lower AND gate following C2 causes another step to take place. Following this, C3 causes b2 to operate in place of b1, so that the next step results from the combination at the next lower gate of C3 + B3 + b2. Then we have C4 + B1 + b2 = C5, and C5 + B3 + b2 = C1. Now C1 causes one more step of chain b so that the next operation is C1 + B1 + b3 = C2 via the upper AND gate. This is followed by:

C2 + B3 + b3 = C3
C3 + b3 = b4
C3 + B1 + b4 = C4
C4 + B3 + b4 = C5
C5 + B1 + b4 = C1, all via the upper AND gates, and then C1 + b4 = b1, so that after two revolutions of the chain C the circuit is restored to the original conditions.

If the chain C is to be followed by another counter making one step for each revolution of C, the b chain also serves the purpose of the "divide-by-two" input to this next counter, but if no further division is required a more economic arrangement can be obtained by a modification of the circuit used for counting from a preset position.

### 6.3. *Preset odd-number counters*

In Fig. 19 the counter B is of the same form as in Fig. 13 except that now it has three pairs of stages. If C1 is operated, the first pair of B stages responds to the Y and X pulses and causes the counter to step to C2, the second pair control the step from C2 to C3, and the third pair from C3 to C4, the first pair from C4 to C5 and the third pair from C5 to C1, so completing the cycle.

## 7. Special Features of the Voltage-Transfer Method

### 7.1. *Circuit features*

In assembling cold-cathode tube "bricks" the voltage-transfer method has a number of advantages over other methods.

(1) Only one power supply is necessary as bias stabilizing voltages are not required.

(2) Signals can be transferred from tube to tube without any re-shaping stages being required. Complete low-speed electronic switching equipments can easily be assembled using only the standard circuit elements.

(3) As relatively slowly changing signals are used for striking the cold-cathode tubes, the circuits are not highly sensitive to external interference.

(4) Any special "clock-pulses" that may be required can normally be generated by cold-cathode circuits.

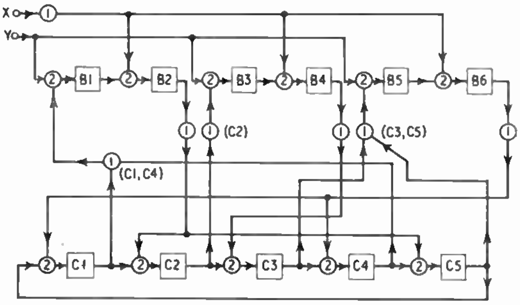



**Fig. 19.** Alternative arrangement for counting an odd number.

### 7.2. *Tube features*

The development of the CCT6[12] and the voltage-transfer circuitry proceeded side by side, and the two are complementary. The CCT6 has two special features, firstly a thick coating of cathode material which gives it a long life compared with normal thinly coated tubes. Secondly a sufficiently wide range of anode current is permissible to allow the tube to be used for all the functions required in electronic switching equipment, instead of several types of tubes with different current ranges being required as has been common with pulse + bias circuits

The thick cathode coating and the fact that the h.t. is rather higher than is required normally with cold cathode circuits, combine to make the triggering sensitivity of the tube rather lower than would be required for pulse + bias operation, but of course this is unimportant when the voltage-transfer method is employed.

### 7.3. *Testing, training and fault finding*

Voltage-transfer circuits are particularly simple to check since the operation of the circuits is not dependent on transient signals. At very little expense it is possible to arrange slow speed testing of all or a part of an equipment at any time, so that the intricacies of its operation may readily be mastered. Fault finding is aided by this and two other features. One which has been mentioned previously is that any AND gate may be inhibited temporarily by earthing its output. The other feature is that the presence of a signal at any gate in the circuits may be detected by means of a "test lamp" consisting of a miniature neon indicator diode with a 1 megohm resistor in series. The use of the "test lamp" does not interfere with the normal operation of the equipment.

## 8. Acknowledgments

The success of the development described in this paper is due to the close co-operation of teams at the G.E.C. Telephone Works, Coventry, and the G.E.C. Research Laboratories, Wembley. The author is particularly indebted to Dr. T. R. Neill and Mr. J. S. Miller who were responsible for the development of the CCT6 and to Mr. E. A. R. Peddle who gave much assistance in the circuit aspects. He also wishes to thank the Directors of The General Electric Company Ltd., for permission to publish the paper.

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11. British Patent 775,134.
12. British Patents 761,882 and 769,419.

# DISCUSSION

**J. R. Hughes** (Member): Mr. Beesley has given us a survey of new techniques which are interesting for two reasons. In the first place there is the circuit aspect of this subject which is particularly topical at the present time because of GRACE and similar developments; in the second place it is of interest because of the attention devoted to the cold-cathode tube as such. It happens that I have a particular interest in cold-cathode tubes and will therefore leave comment on the circuit aspects to Mr. Beesley's paper to other speakers.

The cold-cathode tube is not a particularly new device and both in its diode and its triode form has been known and available for many years. Yet it is only relatively recently that its peculiar merits in electronic circuitry have been realized. It is interesting to speculate upon the reasons for this delay in its general acceptance. Certainly one reason has been that in those branches of engineering where it can be of greatest use, such as telephone engineering, a previous long dependence upon electro-mechanical methods has produced an attitude of mind more favourable to electro-mechanical solutions than to electronic ones. Certainly it is clear from Mr. Beesley's paper that he has thought without difficulty in electronic terms.

A further factor which has delayed the wider acceptance of the cold-cathode tube was undoubtedly the coming of the transistor. For a time it was widely believed that the transistor once it became available at competitive prices would replace the cold-cathode tube amongst other things. Further reflection has very much modified this original viewpoint and Mr. Beesley's paper has further strengthened that later view. It is of course true that for high-speed switching functions (for example in some types of computer) the transistor is the logical successor to the hard valves which have been widely used so far.

On the other hand in low-speed computing circuits and in low-speed switching circuits for telephone purposes, the cold-cathode tube has a number of advantages which may well enable it to maintain its position in competition with the transistor even when the latter becomes available at a competitive cost. Amongst its advantages is a point which for a time was regarded as almost frivolous but which later experience has shown that on the contrary may be the most significant of all. Mr. Beesley has mentioned the merit of cold-cathode tubes being self-indicating and this opinion is supported by a great deal of experience elsewhere. Traditionally the telephone engineer has analysed faults and serviced his equipment by looking at relays and sometimes pushing up a relay here or there to see what happens. It may well be that the fact that the cold-cathode tube is self-indicating will turn out to be its decisive advantage as compared with the transistor in all types of counting, calculating and switching circuits where its speed of operation is adequate.

Mr. Beesley indicated that the life of a cold-cathode tube used under pulsed conditions was a function of the integrated operating time. In fact it is much better than that and not only does the life not diminish with the number of operations of the tube, but it actually increases. Thus in that respect a cold-cathode tube behaves in the opposite way to electro-mechanical devices such as relays and switches. It would be interesting to know whether Mr. Beesley's experience confirms this opinion.

A further point of interest arising from Mr. Beesley's paper is his reference to the fact that in the circuitry which he was describing the cold-cathode tube was being used for controlling purposes only, whilst the speech path switching was being done with metallic contacts. He mentioned in his paper that one of the features of the cold-cathode tubes he was describing was that the maintaining voltage varied from instant to instant and of course this phenomenon would give rise to noise in a speech circuit. Cold-cathode tubes of special types however have been designed which are sufficiently silent to act as speech switches. Perhaps Mr. Beesley could tell us whether he considers it likely in the future that cold-cathode tubes will be used for this function in practical telephone applications, and thus whether exchange systems completely dependent upon cold-cathode tubes will emerge.

**Dr. T. B. Tomlinson** (Associate Member): There is one comment which I should like to make with reference to this philosophy of extra long life for the equipment. Mr. Beesley has several times referred to a life of thirty years. Gas-filled devices are already in competition with semi-conductor devices and with the present day rate of progress in electronics technique, it is my opinion that 30 years is far too long. I would much prefer to see equipment designed to be as reliable as possible for, say, ten years after which time it fails in so many departments that it has to be scrapped and replaced by a more modern design. Perhaps Mr. Beesley would give us his views, including a definition of "useful life."

On a technical matter—it has been explained how the current flowing in the newly-struck gas triode extinguishes the other tubes because of the increased volts-drop across a common anode resistor. How many tubes can be extinguished by the one tube, newly struck, and is it ever necessary to extinguish more than one?

**A. Hann** (Associate Member): Has the author experienced any deterioration in the selenium-type rectifiers used, when subjected to long periods of operation in the biased-off condition, such that the circuits discussed become unreliable in operation. If so, would it not be preferable to design circuits so that they operate in the biased-on condition for the greater part of their life wherever this was possible.

**D. L. Benson:** Tonight we have had described to us circuits that will be used in the register-translators for the first installation of Subscriber Trunk Dialling in this country.† This installation at Bristol will also be the first large-scale use of electronic switching equipment in this country and electronics engineers working in the telephone field are greatly interested. Those

† See, for instance, "Subscriber trunk dialling in the British Post Office," *J. Brit.I.R.E.*, **19**, pp. 45-46, January 1959.

who are responsible for the successful development of this equipment are to be congratulated on their achievement.

The circuit technique described is essentially a very simple arrangement and the virtue of this simplicity may well be realized in equipments that are not very complicated, but in equipment as complicated as the register-translators for Subscriber Trunk Dialling much of its value is lost. We have seen in Mr. Beesley's paper how, as the circuits grow, the complexity builds up. In fact the main adverse comment about the register-translator equipment is its lack of simplicity.

It must be emphasized that the voltage-transfer circuit technique and the high-voltage cold-cathode tube go together. It would be difficult to say which came first, the circuit or the tube, probably, if the truth be known, they were developed together. In comparing this combination of voltage-transfer circuitry and the high-voltage tube with the alternative combination of bias-plus-pulse circuitry and the more common medium-voltage tube, the following observations may be made.

The high-voltage tube is less sensitive and slower to strike than the medium-voltage tube. To overcome this a higher striking potential must be used in voltage-transfer circuits and this detracts from the wider margins. In order to obtain a high output potential, anode resistance is kept to a minimum. The potential drop across this anode resistor acts as a buffer against h.t. supply surges and since only a low potential drop is permitted the circuit is much more susceptible to h.t. surges. This reflects on the h.t. supply which has to be more carefully controlled. H.t. supply becomes quite a problem when it is appreciated that current consumption is several times greater than that required by bias-plus-pulse circuits and the h.t. potential is appreciably greater.

Despite these comments it must be emphasized that the register-translator model in our laboratory is giving a good account of itself. After eliminating some circuit design errors the equipment has been subjected to continuous artificial traffic. It has now been running for over a fortnight without interruption, during which time it has dealt with about 100,000 calls without failure.

**J. H. Beesley** (in reply): Mr. Hughes has raised several very interesting points concerning cold-cathode tubes and circuitry; however, a number of them are the subject of considerable controversy at this time. In particular his views on the merits of cold-cathode tubes compared with solid state devices are now being supported by relatively few people. The progress made in the last few years in the development of these devices has been so great that I now feel compelled, with some regret, to differ from Mr. Hughes' opinion. As a result of this opinion I think it most unlikely that completely cold-cathode-tube telephone exchanges will be installed.

The life of a cold-cathode tube is a very mysterious quantity which is difficult, though not impossible, to predict by means of accelerated life tests. The behaviour Mr. Hughes mentions certainly occurs in some tubes, but only slightly, if at all, with the CCT6. This is not a disadvantage; rather, it means that the shelf life of the CCT6 is good.

Dr. Tomlinson has struck a blow at conventional accounting methods and I feel it would be presumptuous for me to make any comment. However, from the engineering point of view I have yet to meet a range of very reliable, but short life, devices. The answer to his technical question is that it is bad practice, though not impossible, to arrange that one tube extinguishes two or more other tubes.

In answer to Mr. Hann, we have found no evidence of the type of failure he has described. The main trouble we have experienced is that some years ago $1\frac{1}{2}$ per cent. of the rectifiers went completely open circuit within 200 hours. This was due to damage in transit; 2 per cent. of the rectifiers arrived cracked or broken. I believe that this trouble has been cured completely by improved packing methods.

Mr. Benson has raised a number of points about which we have had friendly arguments over several years. To attempt to counter all his points would take far too much time, and in any case nearly all of them are matters of opinion. A long-term answer will be provided by a comparison of the reliability of voltage-transfer and pulse + bias circuits in equipment actually in service and maintained by normal maintenance staff.

# APPLICANTS FOR ELECTION AND TRANSFER

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

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

### Direct Election to Full Member

WELSBY, Vernon Gearon, Ph.D., B.Sc.(Eng.). *Solihull.*

### Transfer from Associate Member to Member

McCULLAGH, John Charles. *London, W.4.*
MILLER, Charles Walter, D.Sc., M.Sc., B.Sc. *Ashton-on-Mersey.*
WARDEN, Charles Alexander. *Chalfont St. Peter.*

### Direct Election to Associate Member

BUTTERWORTH, Lawrence. *Lowestoft.*
CHAMBERS, Lieut.-Com. Alfred George, R.N. (Retd.). *Richmond, Surrey.**
CONSTANCE, Patrick Henry. *Wallington.*
DENTON, Sqdn. Ldr. Colin Arthur Frank, R.A.F. *Bury St. Edmunds.*
DUNN, William Joseph. *Teanech, New Jersey.*
GORDON, Douglas Stuart, Ph.D., B.Sc. *Glasgow, W.2.*
GOULT, Ian Frederick Howard. *Enfield.*
MASUD, Col. Khwaja Mohd. B.Sc. *Pakistan E.M.E., Chaklala.*
RUDDOCK, Com. Henry Ernest, R.N., B.Sc.(Eng.). *Chippenham.*
WOOD, John Malcolm Lester, B.Sc. *London, E.18.*
WRIGHT, Donald Richard. *St. Albans.*

### Transfer from Associate to Associate Member

ANDREW, John. *Manchester.*

### Transfer from Graduate to Associate Member

BREADNER, Sqdn. Ldr. John Harold, R.A.F. *Aldergrove.*
DIX, Dennis Lee. *Ruislip.*
HICKS, Ronald Arthur, B.Sc. *Weymouth.*
HOLE, Bernard Gerard. *Thornton Heath.*
MAHAPATRA, Subrata, M.Sc. *Bombay.*
STREET, Derek Ewart. *Surbiton.*
SZKUTNICKI, Zbigniew Ryszard. *London, S.W.12.*

### Transfer from Student to Associate Member

BRUNNER, Amos. *Tel-Aviv.*
SPARKE, William Geoffrey. *Reading.*

### Direct Election to Associate

BRADLEY, Raymond Henry. *Cardiff.*
BURTON, John Lawrence. *Sidcup.*
CLAXTON, Lieut. Stephen Frederick, R.N. *Gosport.*
FOX, Charles Reginald. *Aldershot.*
HEWITT, John Patrick. *New Malden.*
HEWSON, Ronald Thomas. *London, S.E.18.*
MACLEOD, William Alexander. *Norwich.*
VACHHA, Russi Pirozshaw. *Bombay.*

### Transfer from Student to Associate

ROBINSON, Kenneth Robert. *Cambridge.*

### Direct Election to Graduate

ACKUN, Jacob Kobina. *London, S.E.3.*
BARHAM, Clifford Stanley, B.Sc. *Ipswich.*
BARRS, Ronald Albert. *Crawley.*
BOSE, Arun Kumar, B.E.E. *Calcutta.*
BRADBURY, Bryce Thomas. *Montreal.*
CHAUDHURI, Capt. Suhas Chandra, B.Sc.(Hons.), Indian Corps of Signals. *Mhow.*
CLARK, David Welsh. *Grangemouth.*
DAVIES, Bryan. *Market Drayton.*
DAWE, Geoffrey Huntley. *Johannesburg.*
DIBBEN, Leslie Charles. *London, N.W.10.*
DIGBY, Peter William. *London, N.W.9.*
GEORGE, Royston Arthur. *London, S.E.9.*
HUELIN, Arthur John. *London, S.E.12.*
JAQUES, James Brian, B.Sc. *Evesham.*
JEFFS, Ernest David. *Harrow.*
JENNINGS, William John. *Pinner.*
LUCK, John Edward. *London, N.22.*
MAIDENS, Michael Joseph. *Liverpool.*
NETHER, Ronald Egmont. *Pinner.*
PARKINSON, Peter, B.Sc. *Cheltenham.*
ROGERS, James Arthur. *St. Albans.*
SMITH, Clifford Robert. *Wokingham.*
TAYLOR, Albert Henry. *Liverpool.*
WAGGETT, Arthur Michael. *Leicester.*
WEISBLOOM, Norman. *Ruislip.*
WILSON, Francis Cyril. *Bromley.*

### Transfer from Student to Graduate

ARMSTRONG, Dennis Howard, B.Sc. *Tipton.*
BEALE, Stanley George. *Stevenage.*
CORBETT, John Richard Galliers. *Cheltenham.*
ELLIS, Victor Eric Henry. *Newcastle-on-Tyne.*
HO CHUN FAI. *Birmingham.*
HORE, John Reginald. *Evesham.*
MARATHE, Yashvant. *Akola.*
POOLE, Lloyd William. *Edgware.*
WARBY, Gordon Stanley. *High Wycombe.*

# STUDENTSHIP REGISTRATIONS

The following 29 Students were registered at the January meeting; the names of the 33 Students registered at the February meeting will be published later.

APOSTOLIDIS, George. *Athens.*
ASHCROFT, Lawrence Victor. *Farnborough, Hants.*
BATES, Gordon Harry. *Long Crendon.*
BRUNN, Clement William Arthur. *Birmingham.*
CAMP, William Ernest David. *Taunton.*
CASEY, Samuel. *Jamalpur.*
CONROY, Richard Peter. *Montreal.**
DAVEY, Peter Henstone Lionel. *Bristol.*
FOOKES, Reginald Arthur. *Caringbah, New South Wales.*
GOLDSMITH, Geoffrey Grant. *Bromley, Kent.*
HARVEY, Giles Covington Wingate. *Langport.*
HINDLEY, Peter John. *Hayes, Middlesex.*
JOG, Vidyadhar Mahadeorao. *Nagpur.*
LIDGETT, Ronald Arthur, B.Sc. *Llangollen.*
MALLALIEU, John Gaston Hugh. *Trinidad.*
MORTEMORE, Eric Arthur. *Negri Sembilan.*
MUKHERJEE, Jnanada Nanda, M.Sc. *West Bengal.*
OBIOHA, Raphael Francis. *Enfield.*
RAMPAL, Raj Kumar. *London, W.14.*
RATHORE, Jagdish Singh. *Barrackpore.**
RAY, Oswin. *Manchester.*
ROUSE, David George. *Bracknell.*
SANDERCOCK, Desmond Gilbert. *Truro.*
SITSKY, Robert. *Bondi, New South Wales.*
STASINOPOULOS, Demetrios. *Athens.*
STYMPHALIADIS, A. B. *Athens.*
TIMMS, Anthony Francis. *Knowle.*
UNNIKRISHNAN Kartha, B., B.Sc. *Kalady.*
WILSON, James Albert. *Newcastle-upon-Tyne.*

* Reinstatement.

# A Vidicon Camera for Industrial Colour Television†

*by*

I. J. P. JAMES, B.SC.‡

*A paper read before the Institution in London on 17th December 1958.*

*In the chair: Mr. L. H. Bedford, C.B.E., M.A., B.Sc. (Past President)*

**Summary:** The choice of systems, i.e. field-sequential or simultaneous, is discussed, and the conclusion is reached that it would be expedient to exploit the simultaneous colour camera using three vidicons. The main features of the camera and its associated control equipment are described. The novel optical system employed allows for maximum light efficiency, and reduces vidicon lag to a minimum; there is a combined focus-and-turret control. The signal amplifiers and line and field scanning circuits are discussed. It is emphasized that negative feedback forms an essential feature of reliable colour equipment, especially for continuous operation by relatively unskilled personnel. Particular attention has been given to monitoring facilities for checking the amplifier operation. All of the electrical registration controls are situated at the camera control unit instead of in the camera itself, thus considerably simplifying the problem of remote control of the camera. The picture quality obtainable is adequate for 625-line broadcast standards and the equipment is of universal application for general industrial use.

## 1. Introduction

Monochrome industrial television has advanced considerably in the last few years, particularly with the advent of the vidicon pick-up tube. With colour, progress has been much slower, largely because of the complexity of the available colour cameras and the price of suitable pick-up tubes for them.

It is noticeable that with monochrome industrial television there are increasing requests for better definition. The author believes that the addition of the extra dimension of colour will satisfy this demand rather than the provision of more bandwidth and a greater number of lines. The requirements of colour television for industrial use can only be met in general if the picture definition and colour rendition are excellent and at least equal to good broadcast quality standards, and for this reason the specification of the camera channel to be described is such that it can satisfy broadcast requirements for the 625-line standards.

† Manuscript received 28th January 1959. (Paper No. 493.)

‡ Electric and Musical Industries Ltd., Research Laboratories, Hayes, Middlesex.

U.D.C. No. 621.397.222:621.397.132

This camera channel has been developed to reduce the difficulties associated with earlier equipment and it is believed that appreciable progress has been achieved in producing a reliable camera which is relatively simple to adjust and to operate. In addition, such features as efficiency of the optical system, stability of colour balance and registration, and provision of a good signal/noise ratio have been given particular attention.

This paper will be concerned with a description of the equipment and not with applications, but for completeness mention will be made of a few. The medical use of colour television for operative surgery and for pathological purposes is well known. Equally of interest are those applications where it is necessary to observe machining operations and dangerous chemical processes remotely, and for assisting in process control. Merchandising, in its many forms, is another obvious use, especially in locations where a number of people are held static for periods, e.g. in airport lounges, hairdressing salons, and restaurants of departmental stores, and also for overflow meetings. Another important use of a colour television camera in conjunction with a large-screen projector is as a magnifying device to assist a lecturer in illustrating a lecture, and for allowing the audience in the rear seats of an auditorium to see an enlarged view of a stage performer.

Undoubtedly one of the most important uses of colour television in the future will be for educational purposes, and it is believed we shall see a renaissance in pictorial art equalling that which sound radio has achieved with music.

## 2. General Considerations

### 2.1. *Choice of system*

In designing a colour television camera the first decision that has to be made concerns the system[1, 2] to be adopted, that is, whether it should be (a) field-sequential, or (b) simultaneous.

There is no doubt that the field-sequential camera is the simplest type to design and manufacture—only a single pick-up tube is employed associated with a simple optical system—and operation is only slightly more difficult than with a monochrome camera. There are, however, three important factors which detract from it. Firstly, the size of display by the simplest receivers using a rotating disc in association with a white phosphor cathode-ray tube is limited to about 12-inch picture width. For large-screen projection, the Eidophor provides an excellent picture, but there are attendant difficulties, such as the requirements of continuous evacuation of the Eidophor, which at the moment prevent its general use. Tricolour tubes and trinoscope projectors can be used, but they need considerable modification to cope with the high video-bandwidths (15-18 Mc/s) and scanning frequencies. Secondly, the wide bandwidths make relaying to any appreciable distance difficult, not so much technically but because of the fact that most available radio and cable links are limited to monochrome bandwidths. The third factor is colour fringing on rapid movement, which although it is not normally important does prove troublesome with some applications.

The simultaneous camera is certainly more complicated than the field-sequential type since there are three pick-up tubes and their associated scanning and focus coils, three channel amplifiers, etc., and the camera is greater in size and weight. Against these disadvantages must be weighed the considerations, (a) that a number of display systems are, or will be, available from the normal broadcast market at a lower price than field-sequential displays, and (b) relaying to a distance is possible on the standard monochrome bandwidths if coding by, say, the N.T.S.C. system is adopted.

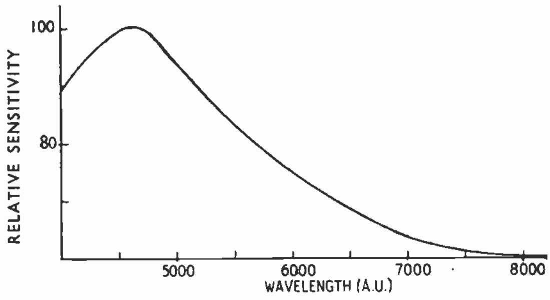


**Fig. 1.** Spectral characteristics of vidicon type 10667S.

Before reaching a decision it is worth while considering the choice of pick-up tube for a field-sequential camera. The two main types of interest are the image-orthicon and the vidicon. A number of manufacturers have demonstrated colour television with image-orthicons in the field-sequential system and there is no difficulty in obtaining excellent pictures. As far as using a vidicon in the field-sequential camera is concerned, it was known that there might be difficulty because of the "hangover" effect. To settle this problem a series of tests was carried out in 1956 on early samples of the vidicon. In essence a vidicon tube was exposed to the light from a lamp by means of a revolving shutter so that only one field in six was illuminated (field period = 1/150th sec.). The signals on the six successive fields were then measured on a waveform monitor. In general the results were such that with 1,000 ft. candles illumination with the lens at $f/2$, the hangover was about 30 per cent. for the second field, 15 per cent. for the third and 10 per cent. after six fields. A very desaturated picture was expected in view of these results and subsequent tests with a breadboard field-sequential camera confirmed this prediction. It therefore is concluded that the vidicon is of no practical value in a field-sequential system.

As a result of considering the above and other factors it was decided to proceed with the design of a simultaneous three-tube camera.

2.2. *Choice of pick-up tube*

The choice of pick-up tube for a simultaneous camera lies between the image-orthicon and the vidicon. Such factors as signal/noise ratio, sensitivity, true black-level, spurious signals, burn-on, ease of operation, size of camera, weight of lenses, price (an image-orthicon costs about five times as much as a vidicon) and "lag" with movement (see Section 5.2.) need assessing. Space does not permit a discussion of these considerations suffice to say that a decision to proceed with the vidicon seemed expedient. The colour response (see Fig. 1), low-lag and low dark-current of the E.M.I. type 10667S vidicon are points in favour of using this particular make.

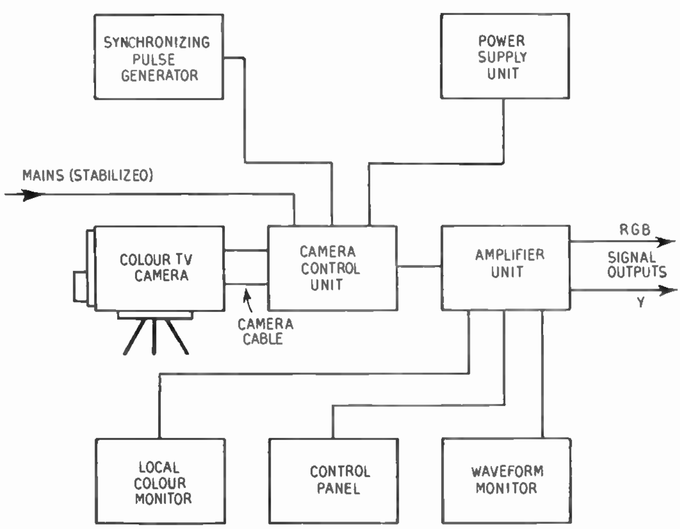


**Fig. 2.** Block diagram of colour television camera channel.

### 3. General Description of Channel

The camera channel (see Fig. 2) consists of the camera connected by two cables to the camera control unit; the amplifier unit; the control panel; the synchronizing-pulse generator; the power-supply unit and a waveform monitor. These units, with a colour-monitor, provide a complete channel for closed-circuit operation. Since the equipment is designed to be used not only for broadcast studio use, but also for outside broadcasts and industrial applications, it has been constructed to be readily portable in the form of suitcase units. The units, other than the camera, the waveform monitor and the control panel, are of such a size (24 in. long × 18 in. high × 8½ in. wide) that two units can be mounted side-by-side to fit conveniently into standard 19-inch cubicles (or consoles). Alternatively the units can be clipped together to form a self-supporting structure. The front and rear panels including the chassis are mounted on runners so as to give easy access to the internal assemblies for servicing purposes.

In order to cater for the international market the equipment is suitable for 625 lines 50 fields/sec, 525 lines 60 fields, or 405 lines 50 fields/sec interlaced 2:1, or for special closed-circuit applications with 300 lines sequential 50 pictures/sec (non-interlaced). Relatively simple modifications to the units are required when changing standards, other than obtaining the correct timing-pulses from the synchronizing-pulse generator.

Design considerations of importance besides those already indicated are (a) desirability for the camera to be capable of being remotely controlled as far as is practical, and (b) reliability—with a short warm-up time and long-term stability and operation by relatively unskilled personnel.

Reliability is obtained by the adequate use of negative feedback in the signal amplifier circuits and scanning circuits, and in the d.c. power supplies.

### 4. Electrical Features

4.1. *Inputs*

The equipment is designed to operate from a single-phase stabilized mains supply at 50 or 60 cycles/second with nominal voltages between 90 and 140 or 205 and 255 volts r.m.s. The voltage stability of the input supply should be ±2 per cent. and the power consumption for a single channel is approximately 2 kVA.

Four different input pulses are required of amplitude 2 or 4 volts negative, namely

(a) mixed line-and-field-frequency synchronizing pulses,
(b) mixed line- and field-frequency blanking (or suppression) pulses,
(c) line-drive pulses, and
(d) field-drive pulses.

These pulses are normally provided by the synchronizing-pulse generator, but for large installations, the pulses would be obtained from the master pulse sources.

All pulse inputs are high impedance.

### 4.2. *Outputs*

Four unbalanced outputs at 75 ohms impedance are provided, two for colour signals and two for monochrome signals.

One output (relay controlled by the censor/transmit switch) gives separate red, green and blue non-composite signals at standard level (0·7 volt peak-to-peak picture).

One output gives separate R, G and B non-composite signals at standard level for a local colour monitor.

One composite output (relay-controlled by the censor/transmit switch) supplies luminance signals at standard level (0·7 volt peak-to-peak picture 0·3 volt sync.).

One composite output (luminance signal) at standard level is provided for a local monochrome-monitor.

In addition, there are two outputs for mixed line- and field-frequency synchronizing pulses for synchronizing colour-monitors at 4 volts negative level.

## 5. Camera

The main items in the camera, other than the optical system, are shown in the block diagram (Fig. 3). These include the three alignment, focus and scanning coil assemblies for the three vidicon tubes and the three head amplifiers. A focus-current stabilizer-circuit for passing a constant current through the three focus coils is also located in the camera. The vidicon blackout-circuit provides pulses for suppressing the beam current during line and field scan return-periods. For reasons outlined later the line-scan output circuit is also situated in the camera. Other facilities included are the audio talk-back circuits and miscellaneous switching circuits.

The viewfinder, which is of the electronic form, may be removed in certain applications where remote operation only is required. The space vacated is then available for servo-mechanisms to actuate the optical focus, turret-change, iris, etc., as required.

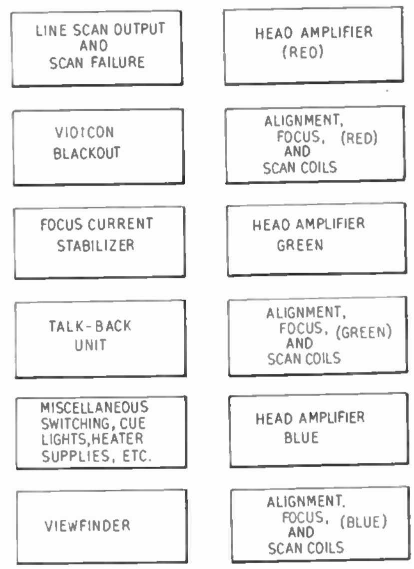


**Fig. 3.** Block schematic of camera.

The dimensions of the camera are 15 in. wide, $15\frac{1}{2}$ in. high and 31 in. long, including turret lenses, and the total weight is 135 lb. (See Fig. 15).

### 5.1. *Optical system*

An investigation of beam-splitting optical systems using relay lenses indicate that they are inefficient and suffer from a number of defects, such as astigmatism. A new approach has been made in this camera to improve the light efficiency, and to this end each pick-up tube is provided with its own objective lens. Located in front of these lenses (see Fig. 4) are the dichroic mirrors necessary for splitting the light entering the aperture in the front of the camera into its colour components, and two front-surface mirrors for reflecting the blue and red beams into their respective tubes, which are mounted parallel to the central tube generating the green signal. The three vidicon focus- and scanning-coil assemblies are mounted on a carefully designed carriage, arranged to move relatively to the three objective lenses by means of the optical focus-control. Mechanical precision has to be of a high order, since the width of a picture element on the photoconductive surface of the vidicon is only about one-thousandth of an inch.

The objective lenses are chosen to give the relatively narrow horizontal angle of view of 9 deg. (The angle of view ($\alpha$) is given by

$$\cot \tfrac{1}{2}\alpha = 2F/W,$$

where $F$ is the focal length of the lens and $W$ is the width of the image; in this instance, $W = \frac{1}{2}$ in. and $F = 8$ cm.) A narrow angle is preferred because of the changes in spectral characteristics of dichroic mirrors with the angle of incidence, especially for large angles; these changes will cause modifications of the shapes of the camera taking-characteristics resulting in colour errors.

The dichroic mirror surfaces are approximately four inches square and for rigidity are applied to glass plates about one-quarter inch thick. By mounting them in front of the lenses astigmatic errors due to the thickness of the glass are avoided, and the definition obtained is equivalent to that obtained with monochrome cameras using similar Taylor, Taylor & Hobson 8 cm $f/1{\cdot}4$ Vidital lenses. It should be noted that these lenses are especially designed for use with vidicon tubes, since corrections are made for the thickness of the front window of the tube, and the frequency responses of the lenses are such that they suit the sharp cut-off characteristics associated with television as opposed to photographic applications.

However, a camera with only one angle of view is of little value for general usage. One way of altering the angle of view is to change the three objective lenses to another set of a different focal length. This method suffers from a number of disadvantages, such as the increase in angle of incidence of the light on the dichroic mirrors with an attendant increase in size of the dichroic mirrors, and also the mechanical difficulties of replacing the lenses in precisely the correct positions to maintain registration.

The method adopted is shown in the diagram.[3] A lens turret is located in front of the blue-reflecting dichroic mirror; the turret has four positions, one of which consists of a plain hole giving the 9 deg. horizontal angle of view already mentioned. Another turret position substitutes a convex lens in front of the aperture, the combination giving an angle of view of 6 deg. The other two lenses of the turret are concave (negative) lenses and these in combination with the objective lenses produce angles of view of 18 deg. and 29 deg. The focal lengths of the lenses in the turret can be calculated

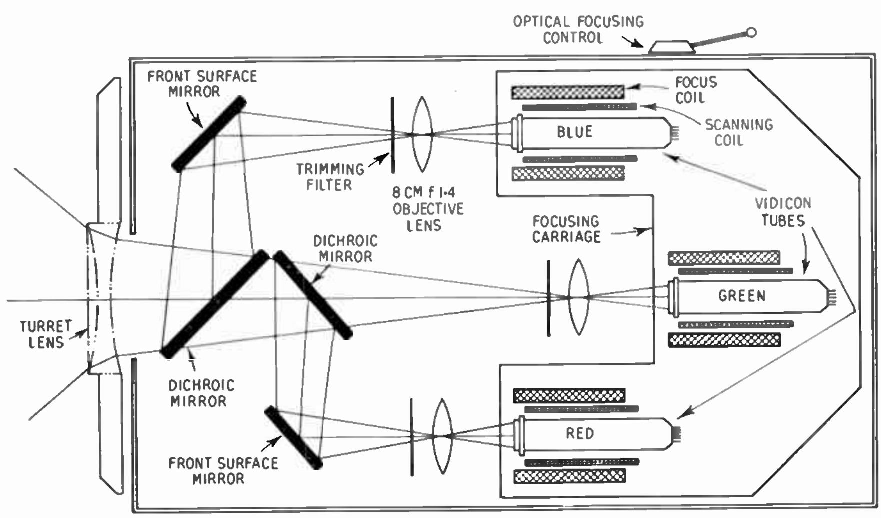


**Fig. 4.** Optical layout of camera.

approximately from the relationship

$$F_1 = \frac{F(F_2 - D)}{F_2 - F},$$

where $F$ is the effective focal length of the combination, $F_1$ is the focal length of the turret lens, $F_2$ is the focal length of the objective lens and $D$ is the distance between the turret lens and the objective lens. The effective focal lengths of the lenses in this camera are 2½ cm, 4 cm, 8 cm and 12 cm. The lenses in the turret are colour-corrected doublets designed and supplied by Messrs. Taylor, Taylor & Hobson for use with the standard Vidital objective lenses, and we are indebted to Mr. G. H. Cook of that Company for his helpful collaboration in this project.

Trimming filters for obtaining the correct camera-taking spectral characteristics are located in front of each objective lens.

There is a slight barrel distortion with the 2½ cm combination and also some curvature of field, but otherwise with apertures of $f/2$ and smaller the aberrations are considered to be negligible.

### 5.2. *Iris control*

In normal cameras, using for example, image-orthicon pick-up tubes, it is usual to control the peak-light input to the pick-up tube by means of an iris diaphragm mounted in the lens assembly, or by means of a variable neutral-density filter. With this camera, however, the iris diaphragm is opened as widely as possible subject to depth of focus requirements. Under average conditions this implies operation at $f/2$. The object of this procedure is to reduce the "lag" (transparency) effect observed with movement. Lag produced by a vidicon tube comprises two main components, one being a function of the beam discharge characteristic and the other being a function of the semi-conductor material employed in the photoconductive layer. The first-mentioned component is normally negligible for signal currents exceeding about 0·1 microamperes (the signal current is usually approximately 0·25 microamperes). The second lag component can be minimized by using the maximum possible amount of light (greater than about 5 ft.-candles effective on the target). In order to cater for different depths of focus the three iris diaphragms in the objective lenses are ganged together by a simple link mechanism so that they can be adjusted in the range $f/1·4$ to $f/5·6$. As will be described in more detail later (Section 7·1), signal-level variations due to changes in scene illumination are controlled by gain-controlled stages in the video amplifiers.

### 5.3. *Focus and turret control*

Present day practice in monochrome cameras is for the focus handle to be mounted on one side of the camera and an additional control for rotating the lens turret to be mounted at the rear of the camera. Following a suggestion[4] by D. G. Perkins and E. W. Taylor, a single-control has been incorporated in this camera to combine both functions and is mounted on the right-hand side. An angular movement of the control arm (about 90°) serves to provide focus adjustment by moving all three vidicons simultaneously relative to the three objective lenses, whilst each complete revolution of the control arm rotates the turret to the next lens position. The advantage of this arrangement is that lenses can be changed in a minimum of time without awkward movements of the hand from one control to another. The actual taking lens is located at the bottom centre position of the turret. An extension of the turret shaft provides an indication on a dial at the rear of the camera of the actual lens being used.

The control mechanism has involved considerable care in design in order to maintain the necessary precision and to reduce noise during turret rotation. For remote operation the focus and turret-change can be servo-controlled by suitable motors mounted inside the camera carcase.

### 5.4. *Vidicon scan and focus assemblies*

The three vidicon tubes are mounted in three specially designed scanning and focus coil assemblies. Great care has been taken in constructing and testing the coils to maintain good raster geometry, and to reduce curvature of field, so that definition is uniformly good over the whole picture area.

The scanning coils can be rotated inside the focus coils for registering the three colour signals and the line and field coils can be adjusted relatively for skew-correction. The line scanning coils are of low impedance to reduce capacitance effects. The focus coils have each 5,000 ohms d.c. resistance and with 22 mA d.c. focus current provide a focusing field of 40 gauss.

5.5. *Focus-current stabilizer*

In order to maintain the stability of electrical focus and of registration by reducing temperature effects the three focus coils are connected in series and are supplied from a constant current source. Since the total d.c. potential drop across the coils is greater than 300 volts, it is necessary to take current from both the +300 volt and − 150 volt supplies and Fig. 5 shows the stabilizing circuit used.

The current passing through the focus coils is also arranged to pass through a resistance connected to the − 150 volt line. The potential drop across this resistance is compared with a d.c. reference potential by means of the differential amplifier on the left. The output from the differential amplifier is fed into the regulator valve, which controls the potential applied to the positive potential end of the coils, thereby fixing the current in the coils at the required value.

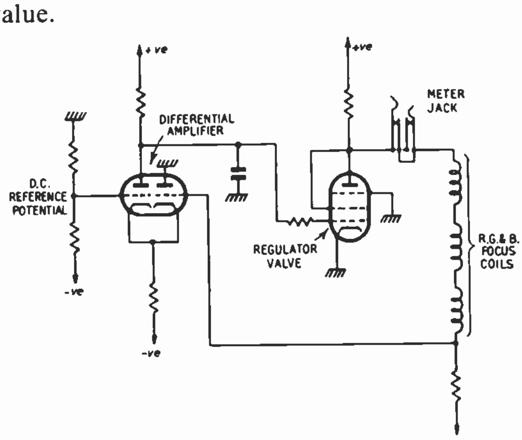


Fig. 5. Focus-current stabilizer-circuit.

5.6. *Miscellaneous facilities*

The head amplifier and line scan circuits are described in Sections 7·2 and 6·3, respectively. A heater transformer for supplying the heaters of the vidicon tubes and the various valves is provided in the camera. A cue light is mounted on top of the camera to indicate to the camera operator and others that the camera is "on the air." Standard talk-back facilities are provided by two jacks at the rear of the camera, for plugging-in the head set for the camera operator and a pair of headphones for the dolly operator to use in broadcast-type applications. Volume controls are mounted near the jacks to adjust the sound level from the camera-control-unit microphone and the producer's microphone. A call button is mounted on the back of the camera for switching on a lamp and buzzer in the camera control unit.

5.7. *Viewfinder*

The electronic viewfinder tube, on which is displayed a monochrome picture which is selected and fed back from the amplifier unit, is a rectangular Mullard Type AW17-20 C.R. tube giving a $3\frac{1}{2}$ in. × $4\frac{1}{2}$ in. picture. The associated circuits are as normally used in a monochrome camera equipment developed by E.M.I. Electronics Ltd. and comprise two printed boards carrying, respectively, the signal amplifier and the line scan and e.h.t. (12 kV) circuits. The field-scan currents are fed to the viewfinder from the camera control unit. At the top left of the front panel of the amplifier unit are mounted four push-buttons (R, G, B and Y). By pressing the appropriate buttons it is possible to select any of the signals R, G, B, $\frac{1}{2}$(R + B), $\frac{1}{2}$(R + G), $\frac{1}{2}$(G + B), $\frac{1}{3}$(R + G + B), or Y for display on the viewfinder tube.

## 6. Camera Control Unit

The block layout of the camera control unit which is shown in Fig. 6 illustrates the main features of this unit and these include the shading generator, the vidicon field-scan generator, the viewfinder field-scan generator, the pulse converter unit and the talk-back circuits. The front panel controls can be divided into four main functions:— (a) shading correction, (b) geometrical registration, (c) tube controls, and (d) miscellaneous controls. The controls associated with amplification such as black-level, gain control, and colour balance are located in the associated amplifier unit.

6.1. *Tube controls*

The tube controls are the normal ones associated with any monochrome vidicon camera. Thus, there is the beam-current control which varies the bias on the modulator of each vidicon, the beam-focus control which varies the potential of the wall anode of the vidicon tube, and

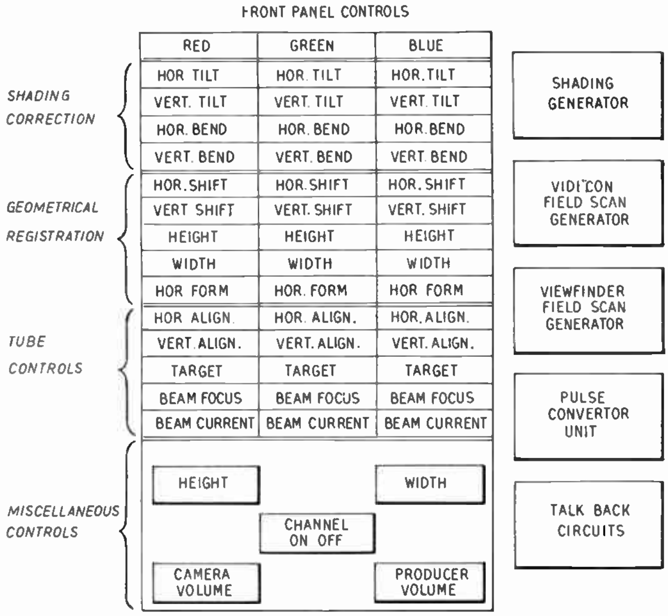


**Fig. 6.** Block schematic of camera control unit.

the target-control which varies the potential of the target electrode and controls the sensitivity of the tube and also affects the amount of dark current. In addition, there are the horizontal alignment and vertical alignment controls, which vary the currents through the alignment coils in order that the electron beam in each vidicon is parallel to its associated focus field. The alignment coils in the camera are orientated in such a way that the alignment controls move the picture either horizontally, or vertically, in a similar manner to the shift, or centring, controls and not at some arbitrary angle.

### 6.2. *Field-scan circuit*

At field-scanning frequencies the impedance of the scanning coils is largely resistive with only a relatively small amount of inductive reactance. If the scanning coils were wired in parallel and if the temperature of the coils varied differentially, then the resistance of the coils would also vary in a similar manner and the scanning currents would subsequently drift causing mis-registration. It is preferable, therefore, that the scanning coils should be wired in series and fed by a constant-current negative-feedback circuit. This arrangement has, therefore, been adopted in the present equipment.

A simplified schematic of the field-scan circuit as shown in Fig. 7. The output valve is transformer-coupled to the three series-connected field scanning coils, and one end of the transformer is connected in series with a feedback resistance from which negative feedback is taken to the input stage of the output amplifier. Sufficient negative feedback is applied to linearize the scanning waveform within $\pm 1$ per cent. In order to adjust the individual red, green and blue field-scan amplitudes each scanning coil is shunted by a high resistance in series with an inductance and a variable resistor. The impedance of the two resistances is about 10 times that of the resistance of each coil, so that the variable resistor can be adjusted to effect approximately $\pm 5$ per cent. variation in scan amplitude. Since it had been decided to locate all the electrical-registration controls at the camera control unit instead of in the camera itself, it was arranged that the field-scan generator and the three differential-amplitude controls should be mounted in the camera control unit, and connected by a quad cable to the three scanning coils located in the camera itself. The inductance connected in series with the differential-amplitude control is arranged so that the $L/R$ ratio of the differential control is the same as the $L/R$ ratio of the scanning coil and hence the scanning linearity is not affected by the amplitude control. In order to obtain centring, or shift, of the individual scanning waveforms, it is arranged that an additional shift coil is wound over each field coil and each shift coil is supplied with its own individually-adjusted shift current. By this means the difficulty is avoided of providing three separate supplies, which would normally be required if the shift currents were passed into the series-connected scanning coils.

### 6.3. *Line-scan circuit*

At line scanning frequencies the impedance of the scanning coils is mainly inductive, since the resistive component is negligible. Because of the shunting effect of the stray capacitances in the circuit it is preferable to connect the line-

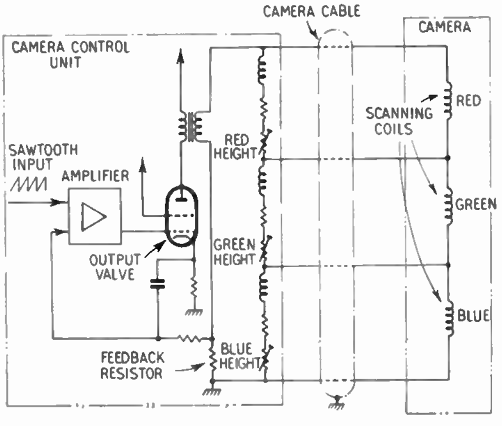


Fig. 7. Simplified field-scan circuit.

scan coils in shunt and not in series as has been adopted with the field-scanning circuit. Voltage negative feedback is then used to linearize the scanning waveforms. Since the voltage applied to the three scanning coils in parallel is the same, the simplest way of obtaining differential-amplitude control for the scanning currents for the three tubes is to connect a pre-set inductance in series with each scanning coil. The value of this pre-set inductance is about 10 per cent. of the scanning coil inductance. This is sufficient to allow for the amount of differential scanning adjustment necessary in practice. Since altering the inductance in each separate scan circuit effects the $L/R$ ratio of each circuit it is obvious that the linearity of scanning is also affected and for this reason a pre-set resistance is also connected in series with each scanning coil for the purpose of maintaining the $L/R$ ratio constant in each scanning coil circuit. This pre-set resistance is known as the "horizontal-form" control. In previous simultaneous colour cameras it has been the practice to locate the differential scanning inductance and the form control in the camera close to the scanning coils; however, since in this particular camera it was considered necessary to locate all the electrical registration controls in the camera control unit, considerable attention was given to methods of achieving this requirement.

The circuit finally adopted[5] is shown in Fig. 8. It will be observed that the scanning output valve and its associated output transformer for impedance matching to the line scan coils are located in the camera itself. This was done in order to avoid capacitance effects lowering the resonant frequency of the scanning circuit and thereby lengthening the return time. The pre-set differential inductance and its associated form control are located in the camera control unit and are connected by means of a quad cable to the camera where the cable is then impedance-matched to the scanning circuit by means of a matching transformer. This transformer has a turns ratio of approximately 10:1 so that the impedance of the form and amplitude controls is reduced about 100 times at the camera end. By this means the inductance and the resistance of the quad cable can be ignored in comparison with the impedance of the adjustable controls and, therefore, is unaffected by the length of camera cable which is used. Each scanning coil is a.c.-coupled through a capacitor to the output transformer, and by this means it is possible to feed the centring, or shift, current into the scanning coil via the iron-cored hold-off inductance shown in the figure. This inductance is used to hold-off the impedance of the shift supply from the scanning coils and therefore stops the scanning currents being short-circuited by the shift supply impedance. Damping resistances (not shown in the diagram) are also included in the circuit and these are used to reduce subsidiary resonances. By the use of this circuit a scanning linearity of better than

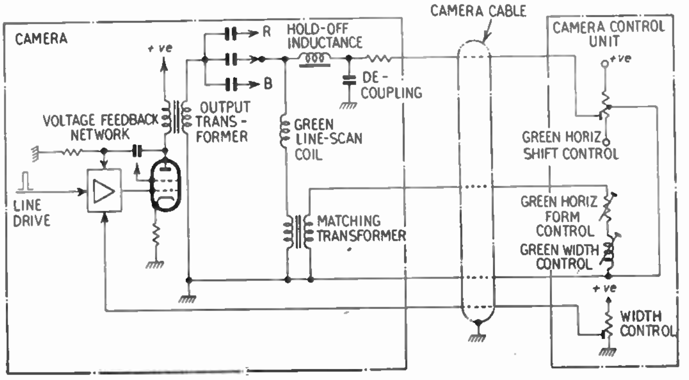


Fig. 8. Simplified line-scan circuit.

1 per cent. overall is obtained and is maintained under operating conditions.

### 6.4. *Shading correction*

In a colour channel there are three colour-component signals and if a uniform background is to be obtained then the sensitivity of each pick-up tube should be the same over the whole picture area. Even if they are not quite uniform they should have at least similar errors. Differential errors greater than about 2 per cent. produce noticeable changes of hue and saturation and should be avoided.

To avoid the necessity of matching vidicon tubes precisely a small amount (2-3 db) of shading correction has been incorporated in this equipment.

The correction waveforms are identical with those used in older forms of monochrome equipment, namely, line-frequency and field-frequency sawtooth and parabolic waveforms ("tilt" and "bend"). The circuits used for the generation of these waveforms are quite straightforward, since it is only necessary to generate sawtooth waveforms in the normal manner and to integrate them to form the requisite parabolic waveforms. The four waveforms are fed in push-pull to potentiometers, having earthed centre-taps, the sliders giving positive or negative outputs of controllable amplitudes. Each vidicon has its own set of controls.

The waveforms are, however, used differently from the normal tilt-and-bend waveforms which are *added* to the picture signals. In this instance, the signals are applied via cathode-followers to the cathodes of the respective vidicons, where they serve to *modulate* the sensitivity of the tubes, since the output signal is a function of the target potential to cathode potential. As the signal from the vidicon in the absence of light is zero, then no modulation of the black-level is obtained by this procedure. The extremely small dark-current obtained with the Type 10667S vidicon makes this method of sensitivity correction feasible. However, too much correction should not be attempted otherwise registration difficulties become apparent.

### 6.5. *Pulse converter*

The pulse converter is fed with standard line- and field-drive pulses from the synchronizing pulse generator and converts them into (a) camera line-drive pulses, (b) camera field-drive pulses, (c) mixed blackout pulses for the camera tubes, (d) line-clamp drive-pulses, (e) a.g.c. pulses and (f) field-clamp drive-pulses. The latter three sets of pulses are required in the amplifier unit.

## 7. Amplifier Unit

A block layout of the amplifier unit is shown in Fig. 9. The main units are the red, green, and blue signal amplifiers giving standard level non-composite outputs into 75 ohms; the luminance output circuits giving standard level composite outputs in 75 ohms and the mixed synchronizing pulse distribution circuits. A field-switch is provided to facilitate the display of the three signals on the waveform monitor.

### 7.1. *Amplifier chains*

In a colour camera channel it is not only necessary to register the geometry of the three picture components, but also to match the contrast characteristics of the three signals. These are basically the black-levels, the peak-levels and the gamma characteristics. Other factors affecting contrast registration are spurious sig-

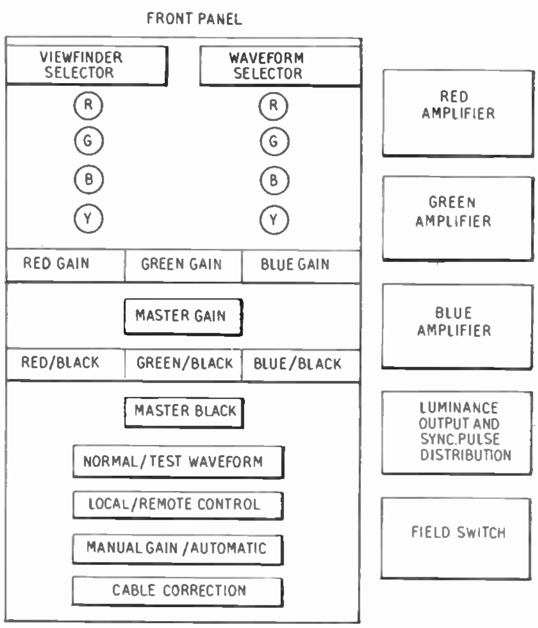


Fig. 9. Block diagram of amplifier unit.

nals generated in the pick-up tube, such as dark-current shading, variations of tube sensitivity over the area of the photo-surface, and miscellaneous distortions, such as mains ripple, streaking and non-linear amplifier distortions.

For accurate colour balance it is essential that the gains of the three-channel amplifiers be maintained relatively constant within 2 per cent. of each other. In its simplest form the problem can be solved by providing each stage (or group of stages) with sufficient negative feedback to stabilize the total gain of each channel within the specified tolerances.

However, the requirement of having to control the gains of the amplifiers in order to take up variations of signal output from the pick-up tubes because of light changes (see Section 5.2) complicates the design. Alteration of output levels by varying the target potentials is not thought to be satisfactory in a three-tube camera because of the variations in dark-current that this produces.

The most basic form of multiple gain-control is a three-ganged potentiometer, say of 75 ohms impedance. This low impedance will allow the controls to be independent of frequency over the 6 Mc/s required for a 625-line system.

This arrangement is not so convenient for remote operation, unless a constant-impedance form of attenuator is used, and these attenuators are quite expensive. Measurements of a three-gang wire wound potentiometer of normal manufacture costing approximately £3, show that its tracking characteristics are not adequate. For remote operation it would be possible to use the three-ganged potentiometer with a servo-controlled motor drive. This again is inconvenient because of expense, size, and possibly most important of all, because of the slowness of operation.

An alternative form of gain-control is a valve arrangement in which a variable bias is applied to one of the electrodes of a valve to alter its effective mutual conductance. Whilst such a circuit is quite adequate for controlling the gain of a monochrome amplifier, it is of little use in colour channels, because of the difficulty of tracking the gains of the three amplifiers.

Because of these difficulties a different approach to the problem has been adopted in the present equipment. The block-schematic in Fig. 10 shows the arrangement.[6] The red, green and blue signals from the head amplifiers, which are located in the camera, are passed via the camera cable into the three low-impedance potentiometers (labelled R, G and B gain) which are adjusted to obtain the correct colour balance for a white object placed in front of the camera; that is, the R, G and B signals are made equal

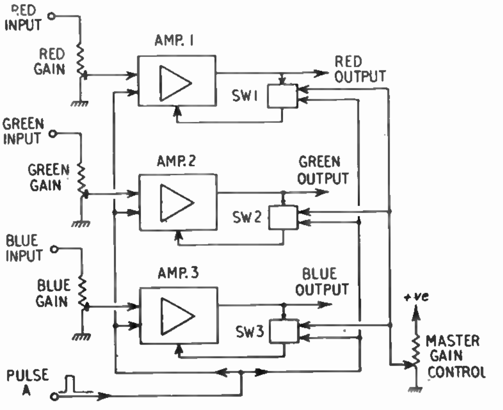


**Fig. 10.** Block schematic of a.g.c. circuit.

in value. The signals are subsequently amplified in the amplifiers 1, 2 and 3. Also fed into the inputs of the three amplifiers is a pulse A which is generated during the line-return period, and this pulse is amplified by each of the amplifiers to the same extent as the individual signals are amplified. At the output of each amplifier is a four-diode switch and storage capacitor (SW 1, 2 and 3) and these switches are pulsed by the pulse A, so that the charges in the capacitors are not affected by the picture signals. The stored potentials are compared with a d.c. potential obtained from a potentiometer, which acts as the master-gain control, and the amplified outputs are applied to gain-controlled amplifier valves in each of the channels. If the gain of each feedback loop is adequate, then, as the potentiometer is varied, the gain of each channel varies in unison independently of the characteristics of the gain-controlled valves in each amplifier.

Of course, all the stages prior to, and subsequent to, amplifiers 1, 2 and 3 are stabilized by negative feedback. A detailed description of the amplifiers follows. Although the head amplifiers are situated in the camera they are described at this point to preserve continuity of description.

### 7.2. *Head amplifiers*

Each head amplifier, a circuit schematic of which is shown in Fig. 11, is designed to have a good signal/noise ratio. It employs a low-noise triode in the first stage, which is connected in a cascode arrangement[7], that is, it has another valve connected in series with its anode circuit, and this reduces the Miller effect in the input circuit, thereby simplifying equalization. The cascode stage is followed by two direct-coupled amplifier stages which feed into a cathode-follower valve. The grid-leak resistance for the first valve is connected between the grid of this valve and the cathode-follower valve output, the phase of the feedback being such that the effective value of the input impedance is reduced, thereby equalizing the overall frequency response[8] up to 6 Mc/s. To avoid hum and microphonic effects the grid-leak is made approximately 1·5 megohms in value.

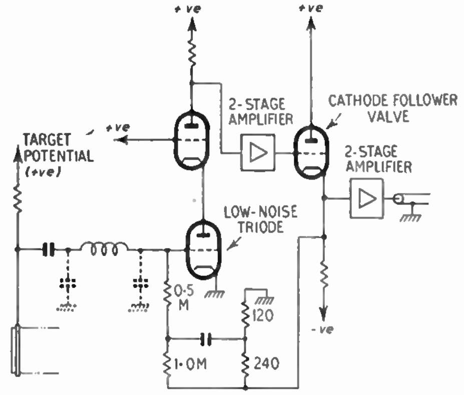


**Fig. 11.** Simplified circuit of head amplifier.

However, at high video-frequencies the stray capacitance across this resistance introduces feedback problems, and to eliminate these the resistance is divided into two parts in the ratio of 2:1 and the junction is connected via a relatively small capacitor to a low impedance point in the cathode follower load.[9] The gain of the amplifier is approximately 1,000 and since the whole of the output signal is fed back negatively into the input the gain stability is excellent and the output voltage is precisely equal to the vidicon output current times the grid-leak resistance, i.e. for a signal current of 0·25 microamperes and a grid-leak of 1·5 megohms the output voltage at the cathode follower is 0·375 volts.

In order to reduce the noise at high frequencies due to the input valve the input circuit is provided with an inductance to split the capacitance of the pick-up tube from that of the input of the amplifier.[7] This inductance has the effect of producing a "dip" or "hole" in the noise characteristic, which is normally of a "peaked" or triangular shape. This reduction in noise near the top end of the video band is advantageous if the camera is used in conjunction with an N.T.S.C. transmission system, since the dip can be made to occur at the same frequency as the sub-carrier and its chrominance side-bands.[10]

The output from the cathode-follower valve is fed into a two-stage negative feedback 75-ohms output amplifier for feeding the signals through the coaxial cable in the camera cable to the camera control unit, whence the signals are conveyed by relatively short cables to the amplifier unit. Two feedback-stages are required since the normal cathode-follower circuit employed in monochrome channels does not have sufficient stability of gain.

### 7.3. *Main amplifier*

The camera cable is terminated in the amplifier unit by a low-impedance potentiometer, which is used as a colour balance control. (See Fig. 12.) The picture signal is of positive polarity at this point and is fed, in addition to an a.g.c. pulse, into a gain-controlled stage followed by feedback-stabilized amplifiers (shown as a block). The output of these amplifiers, at about 10 volts level, is d.c. clamped by a fast-acting two-diode switch at the grid of a cathode-follower valve. The high level of signal is used to improve clamping stability. The a.g.c. pulse at the cathode is observed by the four-diode switch in conjunction with the storage capacitor. The potential of the capacitor is compared by the long-tailed differential-amplifier with the d.c. potential set by the master gain-control potentiometer. The amplified output from the differential amplifier is used to control the gain of the chain. As outlined previously, since the master-gain potential is common to all three amplifiers and the loop gain is adequate, all three amplifiers amplify equally.

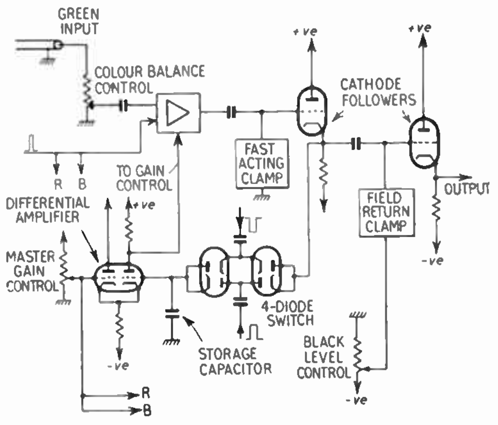


**Fig. 12.** Simplified circuit of main amplifier.

The cathode-follower valve output is fed into an additional cathode-follower valve, at the grid of which a field-return clamp operates to re-insert the d.c. level during the line periods occurring during the field-blackout periods. The advantage of this arrangement[11] is that the d.c. potential is referenced relative to the field-return true black-level from the vidicon tube and is not subject to errors due to spurious pick-up (which varies with scan amplitude, etc.) occurring during the line-flyback periods as is the previous clamp stage. The d.c. level at this point is controlled to set the black-level for the particular colour signal (e.g. green-black, red-black, etc.). By a combination of resistances all three black-levels can be controlled simultaneously by a further control labelled "master black-level" (usually called "lift" or "sit-up" in monochrome practice).

### 7.4. *Blanking mixer and distribution amplifier*

Figure 13 shows the circuit succeeding the field-clamp cathode follower for inserting the blanking (or suppression) pulses. The current through the resistance to the positive h.t. potential maintains the two diodes conducting during the picture periods; during the blanking periods, the mixed blanking pulses drive the anodes of the two diodes negative to earth, thereby cutting off the signals at earth potential.

The advantage of this circuit is that it "clips-off" signals which are negative to earth during the picture periods, thus preventing them affecting the synchronization of the monitors and it also acts as a "peak-signal" clipper to prevent subsequent amplifiers overloading.

The output from the diode load resistance is fed into a three-stage negative feedback distribution amplifier.[12] This form of circuit is used in three-stage and two-stage varieties of amplifiers throughout this equipment. The overall frequency response of each channel is flat within 1 db from low-frequencies to 6 Mc/s, and is therefore adequate for the 625-line standard.

### 7.5. *Luminance output and pulse distribution*

The purpose of the luminance output amplifier is to supply picture signals, including mixed line- and field-synchronizing pulses, at the standard level for distribution to monochrome monitors to cater for those requirements (cueing, overflow, etc.) where a colour monitor is unnecessarily cumbersome, or expensive. Another use is for compatible colour broadcasts, where it is imperative that the monochrome director should keep a watchful eye on the transmission quality. The luminance signal is formed by passing the red, green and blue signals into a resistive matrix, the output of which is then fed into a triple-stage feedback distribu-

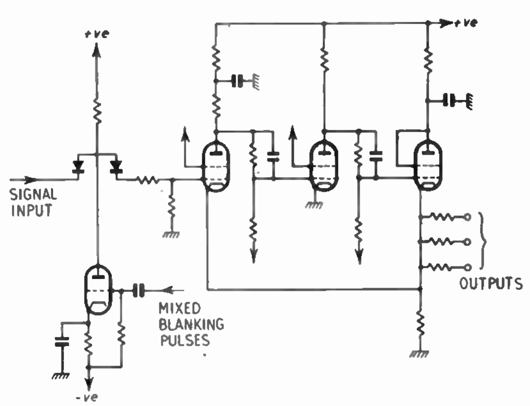


**Fig. 13.** Simplified circuit of blanking mixer and distribution amplifier.

tion amplifier, which is capable of supplying two 75-ohm terminated loads with a bandwidth of 6 Mc/s. The distribution amplifier is used in addition as a synchronizing pulse mixer since it is fed with synchronizing pulses of constant amplitude.

An output amplifier is provided for distributing mixed line- and field-synchronizing pulses of negative polarity and 4 volts amplitude to the colour monitors.

Additional pulse distribution valves are situated in the amplifier unit for supplying the three amplifiers with line-return clamp pulses, line-return a.g.c. pulses and field-return clamp pulses. The latter pulses are arranged to switch the clamp valves on during the periods between line-suppression pulses occurring during the field-blackout periods. These circuits consist of double-triode "long-tailed pair" valves, which are employed to "clean-up" the incoming pulses and to supply push-pull output pulses for feeding the various two- or four-diode switches.

### 7.6. *Field-switch*

The purpose of the field switch is to take the outputs from the simultaneous red, green and blue channels and to convey them in sequence to the waveform monitor. If the monitor time base is operating at one-third of the field frequency then the three signals, red, green and blue are displayed sequentially on the cathode-ray tube screen. If, however, the scanning circuit of the waveform monitor is synchronized at field-frequency then all three signals appear superimposed and differences in black level, gamma and peak level, etc., can be readily observed and compared.

The circuit, which is due to D. G. Perkins[13], is basically a scale-of-three ring counter (see Fig. 14) triggered by field-frequency pulses to form the $\frac{1}{3}$ field-frequency pulse sequence, the same valves also operating as cathode followers feeding a common output load.

In essence, the ring counter is designed so that only one triode valve is conducting during a field-period, the other two valves being switched off. When a field-pulse arrives it triggers on the next valve in the sequence and switches off the valve that was previously conducting.

In this particular circuit a resistance is connected in the common cathode lead to the three valves, thus each valve in turn acts as a cathode follower for the colour signal applied to its grid via the diode isolating circuit. A trigger pulse is derived from the anode of one of the triodes for triggering the waveform monitor at $\frac{1}{3}$ field-frequency. A test switch is provided to check the operation of this circuit by connecting the red and blue inputs to the green input.

### 7.7. *Monitoring facilities*

In order to simplify the setting up of the equipment and to check its operation, a number of facilities have been provided including the addition of a switch on the amplifier unit which is labelled "Normal/Test Waveform Switch."

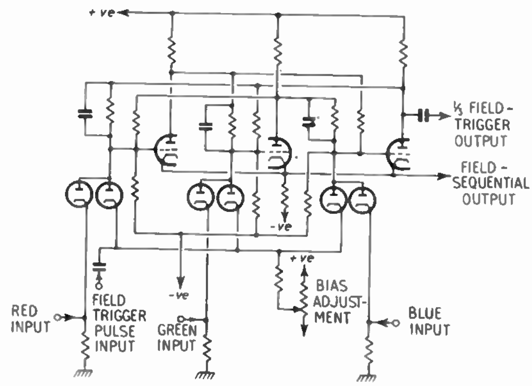


**Fig. 14.** Circuit of field-switch.

This switch serves to energize a relay located in the camera and the contacts of the relay feed a calibrated ramp waveform of line frequency into the inputs of all three head amplifiers. The amplitude of the waveform is such that it produces a current in the input of each head amplifier equivalent to a given signal current; for example, it might be equivalent to 0·25 microamperes of signal current. By observing the ramp waveform on the waveform monitor and comparing it with the picture signal it is possible to estimate the signal current from each pick-up tube and to check whether it is of the correct magnitude. In addition, it is a simple matter to compare the gains of the three channels and to check whether the amplification has changed by noting the gain settings for matching all three ramp outputs on the waveform monitor. The ramp test waveform is extremely useful for setting the three black-levels, for checking the linearity and gamma tracking on the three channels and also for checking whether the three peak-levels occur at the same output voltage level. Another use of the test waveform is for checking that the gains of the three amplifiers track equally as the master gain control is operated.

In order to assist the operation of registering the three signals a phase-reversing amplifier can be switched into the green channel so that it is possible to display R-G, or B-G, signals. The use of subtractive signals for this purpose gives a more sensitive indication than additive signals.

7.8. *Miscellaneous facilities*

The channel is designed to operate with a camera cable of maximum length of 300 ft. With this length of cable in circuit the frequency response is such that a loss of approximately three decibels occurs at 6 Mc/s. In order to correct for this loss a cable-length correction switch is incorporated in the amplifier unit for adjusting the equalization necessary. Phase-compensated aperture-correction is also included to correct for the loss at high frequencies due to the vidicon modulation characteristic and this means that a high-frequency boost of approximately six decibels at 5 Mc/s is required for adequate compensation. It has been found with the E.M.I. vidicon Type 10667S that the gamma tracking of these tubes is excellent, and that for most applications no further gamma correction is necessary.

A local-remote switch allows the master gain-control and master black-control to be operated from the separate control panel.

## 8. Control Panel

This unit contains the programme controls necessary for the remote operation of the channel. These are: (a) "master gain" (this accommodates normal variations of studio lighting in place of the usual iris control). (b) "master black-level" which is common to all three chains, and allows the "lift" to be adjusted, and (c) "censor/transmit" switch. As has been mentioned previously, these controls are also available in the amplifier unit. Talk-back facilities are available at this point including "camera volume" and "producer volume" controls for the plug-in head-set.

## 9. Waveform Monitor

This unit, which has been designed by the Broadcast Equipment Division of E.M.I. Electronics Ltd., is a completely self-contained monitor specifically designed to facilitate the observation of television waveforms of 405, 525, and 625-line standards. It is 24 in. deep, by $6\frac{5}{8}$ in. high and $17\frac{1}{2}$ in. wide, and is arranged to be mounted across the camera control and amplifier units. Waveforms are displayed on the 5 in. diameter screen of the cathode ray tube, which has an illuminated cursor showing peak level, blanking level and sync.-tip level to enable accurate setting up of waveform amplitudes to be accomplished. The a.c. coupled input signal has its black-level d.c. clamped and then it is amplified by a long-tailed pair differential amplifier having a pre-set gain and variable shift before being d.c. coupled to a wide-band push-pull amplifier to give symmetrical Y-plate deflection. The black-level clamp may be switched out of circuit to permit observation of hum, or other distortion on the incoming waveform. A variable gain push-pull amplifier, also with variable shift, provides a symmetrical X-plate deflection. The time-base frequencies of line, half-line, field or $\frac{1}{3}$ field are selected by a four-positioned switch to enable one or two lines, or one field or three-field scans to be displayed.

The h.t. supply from the self-contained power unit is stabilized by a series regulator, the operation of which may be checked by the test meter provided, to ensure stability of the X- and Y-plate sensitivities. The e.h.t. potential of 2·5 kV for the cathode-ray tube is derived from a screened high-frequency oscillator. The wide-band amplifier response is substantially flat from zero to 3 Mc/s.

## 10. Power Supplies

The channel requires a power supply unit, which is of conventional design. It supplies power at +300 volts d.c. at 1200 mA, and −150 volts d.c. at 400 mA, and employs series-connected stabilizer valves referenced from neon reference stabilizers. In addition there are 24 volt supplies for miscellaneous facilities and for shift and alignment supplies.

The a.c. input voltage to the channel requires to be stabilized to within ±2 per cent. of the nominal voltage, and any standard type of mains voltage stabilizer of sufficient power should be suitable for use with the equipment.

## 11. Synchronizing Pulse Generator

A synchronizing pulse generator of standard type designed by E.M.I. Electronics Ltd. is normally used with this equipment and can be operated (by minor modifications) on any of the usual standards i.e. 405, 525 and 625-lines. This unit supplies the pulses specified in Section 4.1.

## 12. Colour Displays

This equipment is suitable for supplying signals to any of the normal simultaneous colour-display devices. At the moment, there are three main types of display available. These are: (a) Trinoscopes, in which three separate cathode-ray tubes are arranged to have their pictures superimposed by means of mirrors; these monitors give good-quality pictures but only allow of viewing by two or three people at a time because of the restricted front-apertures. (b) 21-inch shadow-mask cathode-ray tubes, as used for broadcast television reception in the U.S.A.; these are capable of showing good pictures to a number of people. (c) Large-screen projectors giving good pictures up to 8 ft. × 6 ft., and consisting of three cathode-ray tubes operating in conjunction with Schmidt mirror-systems; these allowing several hundred people to view the pictures.

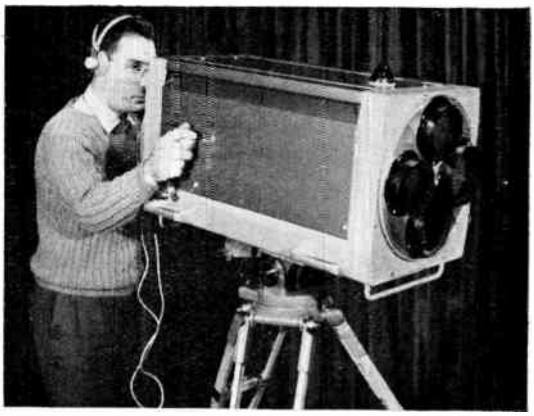

**Fig. 15.** The E.M.I. colour camera as demonstrated before the Institution on 17th December 1958.

## 13. Acknowledgments

A project of this nature depends on the work of a team of people and the author is fortunate in having a very good team. He wishes to mention in particular Mr. D. G. Perkins, who has been responsible for the mechanical design of the camera, and Mr. G. R. Watson, who has been responsible for the general design and progressing of the equipment. He is also indebted to Mr. G. C. Newton and his Section for their collaboration in regard to optical problems, for providing the original optical assembly, and for supplying the dichroic and front-surface mirrors. Thanks are due to Dr. H. G. Lubszynski for the provision of the excellent vidicon tubes and for helpful discussions, and to Mr. R. Puleston's Section for measurements of vidicon spectral-characteristics. In addition, the author acknowledges discussions on the camera channel specification with Messrs. F. R. Trott and J. Kingsbury of the Broadcast Equipment Division of E.M.I. Electronics Ltd.

Finally, acknowledgments are due to the management of the Research Laboratories of E.M.I. for permission to publish this paper.

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## DISCUSSION

**L. W. Germany:** There are three questions which I would like to ask Mr. James regarding his excellent paper and demonstrations. Firstly, does he find that secondary images, reflected from the rear surface of the dichroic mirrors to be troublesome? Secondly, when the camera is used for industrial purposes, is it envisaged that the three colour signals would be encoded, and would the aperture correction be applied to each individual colour, or to the luminance signal? Thirdly, what degree of geometric registration error is achieved with this equipment?

**I. J. P. James** (in reply): The secondary images caused by reflections from the rear surfaces of the dichroic mirrors are rarely troublesome under normal conditions. They only become noticeable with lights that are considerably greater in brightness than the normal peak level of the scene.

For simple industrial systems the three colour signals would not be encoded. Coding would only be employed when transmitting the signals over very long distances, or when a large number of receivers would make it more economic to do so. In this equipment phase compensated aperture correction is applied in each individual colour channel.

It is difficult to specify geometric registration errors—small errors can probably be described best in terms of the percentage modulation of the matrixed signals for high-frequency test patterns, whilst larger errors can be measured in terms of the number of lines displacement. There is an additional difficulty introduced because of the differences between individual pick-up tubes. In general with this equipment and with suitable tubes the errors in the central 80 per cent. of the picture area are negligible and overall the maximum errors are about 2 lines.

**D. W. Heightman** (Member): Could Mr. James give us an indication of the lag time of the vidicon tubes used in the camera? It was observable, during the demonstration, that blurring of the images occurred unless the camera was "panned" very slowly, or if the subject moved with only moderate speed. Admittedly, the effect was not disturbing to the viewer, but it might place limitations on the use of the camera. I would be interested to have some information on the spectral characteristics of the vidicon tubes—i.e. without filters, etc.

With the high intensity illumination in the "studio," the reproduced picture showed some *red* emphasis; for example, the model's hair appeared reddish, whereas, in fact, it was blonde. On the other hand, when using low intensity illumination on the colour chart, the reproduced hues were virtually accurate, i.e. the red was not excessive. Did this mean that the gamma correction was optimum for the lower intensity illumination?

**I. J. P. James** (in reply): It is difficult to give a quantitative reply to the question on lag—so much depends on the scene, the movement involved, the shape of the vidicon lag curve, etc. This camera is limited in regard to lag in the same manner as monochrome equipment using vidicons and as these pickup tubes improve with further research so will the range of applications. With good present-day tubes it is considered that the camera is adequate for presentation purposes with 300 foot-candles incident illumination at $f/2$. By making the trimming filters wider it is of course possible to reduce lag at the expense of true colour rendition. The spectral characteristics of the vidicon Type 10667S are shown in Fig. 1. The recommended peak signal current is about 0·25 microampere and the dark current can be reduced to less than 10 millimicroamperes by the use of a suitable target potential.

It is always difficult to diagnose precisely what is at fault during a hurriedly arranged demonstration and it is suggested that the effects noted were due to the differences in colour temperatures of the two separate illuminants rather than to differences of gamma.

**Dr. H. G. Lubszynski:** The shading signals in the old Emitron were dark shading, i.e. variations of the black level in the picture, which, moreover, depended on the intensity and distribution of light in the picture. The shading correction in Mr. James's colour camera is done in order to correct for variations in actual light sensitivity over the target area from tube to tube. The absolute sensitivity of our vidicon tubes is so high that for the illumination used here we need only dark currents of about 5 milli-microamperes. Under these conditions dark shading is non-existent.

**G. B. Townsend:** It is usual broadcast practice to normalize the red, green and blue camera outputs on the studio white before gamma correction is carried out. In this three-vidicon camera, where the transfer characteristics of the pick-up tube itself provides all the gamma correction, the red, green and blue camera outputs are normalized on studio white after the gamma correction has taken place. If the colour signal is now encoded N.T.S.C. and received on a standard receiver (normalized on Illuminant C), does the reproduced picture differ from that due to a standard transmission because the signal has been normalized after non-linear operation has been introduced?

**I. J. P. James** (in reply): There should be no differences in the amplitudes of the outgoing signals if they are normalized before, or after, gamma correction. The advantage of using a vidicon with a gamma of about 0·5 compared with a linear tube ($\gamma = 1$) is that the signal/noise ratio of the former is greater since no increase in noise in the near-blacks is produced. Similar improvements also apply to lag.

**R. C. Whitehead:** Would the author please tell us a little more about his system for stabilizing the gains of the three amplifiers, using pulses and an automatic-gain-control system, and explain the advantages over a conventional negative feedback system.

**I. J. P. James** (in reply): The advantage of the gain-stabilized system over the conventional system is that the gain is controlled by a single d.c. potential and as mentioned in the paper this readily permits remote operation of the gain level in a pre-set manner. A further property of this technique is that it lends itself to the application of automatic light-level control, whereby the peak-signal is maintained at a relatively constant level independently of changes in the scene brightness. This is important in unattended industrial equipment and also in telecine applications to allow for films of varying density. The automatic level control functions quite rapidly in only a few field periods and a motor-operated system would generally be much slower.

**W. R. Daniels:** No gamma compensation is made in each colour channel in the particular camera. As the gamma of a vidicon with $Sb_2S_3$ layer is only between 0·5 to 0·6, and as the spectral response of such a layer favours the red part of the spectrum, this could lead to a colour distortion under varying levels of illumination, especially if the original setting up of the camera for a white signal was imperfect.

**D. V. Ridgeway:** I should like to ask Mr. James how long it takes, from switching on the equipment, for the camera registration to "settle down" and for the errors to decrease to an acceptable value. When this state has been reached, can the camera be used for long periods before re-adjustment of the registration controls becomes necessary?

I should also like to ask a question in connection with the trimming filters. Is the division of the spectrum, for analysis purposes, performed primarily by the dichroic mirrors or the trimming filters? In other words are the trimming filters used just to perform a light balancing function or are they narrow-band filters?

**M. F. Osmaston:** Mr. James has mentioned that the gamma of the vidicons employed in this colour camera is between 0·5 and 0·6. It would be interesting to know whether these tubes exhibit different gamma to different colours in a manner analogous to that observed in many photographic emulsions.

**I. J. P. James** (in reply): The pickup tubes used do not appear to have different gammas for different colours and this is confirmed by the good gray scale response. Some samples of tubes have rather different input—output curves, but we normally select tubes which have similar gamma characteristics. The equipment takes only about 5 minutes to settle down to an acceptable condition, and the long-term stability is excellent. It was considered to be an essential requirement of industrial colour equipment that it had "built-in" stability of a high order.

The dichroic mirrors have broadband characteristics and the trimming filters are essentially narrow-band. This helps to reduce secondary images produced by the dichroic mirrors.

# Signal/Noise Ratio in Pulse-Code Modulation Systems - Use of the "Ideal Observer" Criterion †

*by*

J. W. R. GRIFFITHS, PH.D., B.SC., ASSOCIATE MEMBER‡

**Summary:** In order to determine the relation between the output and input signal/noise ratios of a p.c.m. system, it is necessary to determine the probability of error in selecting a single pulse in a background of noise. This reduces to a problem in statistics which requires the use of a criterion for deciding as to which of two possible probability distributions a particular sample belongs. The "ideal observer" criterion is applied in this paper and the results are compared with those obtained by Flood.[1] Considering the difference in initial assumptions and method of solution, there is a surprising similarity between the results predicted by the two methods.

## 1. Introduction

In a pulse-code modulated (p.c.m.) system, the signal to be transmitted is sampled at regular intervals and the information from each sample is conveyed to the receiver in the form of a group of coded pulses. The usual code is the binary code since this has the advantage that the devices used need only have two states, i.e. "on" or "off." The number of pulses required per sample depends on how many different amplitude levels are required to be transmitted. If the number of levels is $m$, then the number of pulses required will be log $m$.

At the receiver the incoming waveform, after rectification, is applied to a slicing circuit to produce regenerated pulses, provided of course that the amplitude of the incoming voltage is sufficient. Malfunctioning of the receiver can be caused by the incoming waveform being perturbed by random noise. It is assumed that synchronization is achieved and the purpose of the receiver is to decide, at a particular instant, whether or not there is a pulse present.

Flood[1] has considered this problem but his analysis has three implicit assumptions which do not appear to be necessary:—

(a) he considers the noise as being added after rectification of the modulated carrier.

(b) he arbitrarily fixes the slicing level at half the peak signal amplitude.

(c) his analysis only applies for large signal/noise ratios.

None of these assumptions is necessary, since Rice[2] has determined the probability distributions for the output of a "linear detector" when noise alone or noise plus a sinusoid is applied to the input, and the optimum slicing level can be determined by the ideal observer theory outlined below.

Knowing the probability distribution at the output of the linear detector reduces the problem to one quite common in statistics—first, to determine to which of two possible probability distributions a particular sample belongs, and second, having made a choice, to calculate what is the average error introduced. A statistical criterion developed by Neyman and Pearson was applied to problems of the detection of pulse signals in noise by Siegert[3] and he developed what is known as the Ideal Observer theory. This method minimizes the total error and seems most suitable for application to the problem of the signal/noise ratio in p.c.m. systems.

† Manuscript received 13th August 1958. (Paper No. 494.)

‡ Electrical Engineering Department, The University of Birmingham.

U.D.C. No. 621.376.56

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3 J. L. Lawson and G. E. Uhlenbeck, "Threshold Signals," p. 167, (McGraw-Hill, New York, 1950).

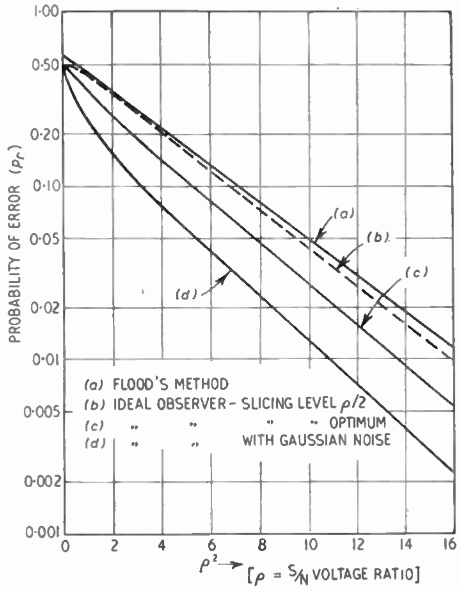


**Fig. 1.** Probability of determining the presence or absence of a signal in a background of noise when the *a priori* probability is 0·5.

In most practical systems the receiver bandwidth (in c/s) is of the order of the reciprocal of the pulse duration (in seconds) and hence little or no information is lost by sampling at one point only in each pulse.

## 2. Signal/Noise Ratio in P.C.M.

### 2.1. *Flood's method*

The dependence of the signal/noise power ratio at the output of a pulse code modulation system on the probability of error $p_r$ in determining the presence or absence of a single pulse, is derived in reference 1 but is repeated here for convenience.

If a binary code group has $\mu$ pulses, the contributions which the pulses make to the decoded output voltage are

$$A,\ 2A,\ 2^2A,\ \ldots\ 2^{r-1}A,\ \ldots\ 2^{\mu-1}A.$$

where $A$ is the height of the quantizing step in volts. If the probability of an error in the $r$th pulse of the group is $p_r$ the mean-square noise voltage produces at the output is

$$V_n^2 = A^2 \sum_{r=1}^{\mu} p_r\, 2^{2(r-1)}$$

If $p_r$ is the same for each pulse then

$$V_n^2 = \tfrac{1}{3} A^2 p_r (2^{2\mu} - 1)$$

The output signal obviously depends on the depth to which the original signal was modulated at the transmitter, and so in order to have a standard we shall consider the case where the signal is modulated to the maximum depth. This corresponds for a sine wave to a maximum amplitude of $\frac{1}{2}A\ (2^\mu - 1)$. Thus the mean square output signal is given by

$$V_s^2 = \tfrac{1}{8} A^2 (2^\mu - 1)^2$$

Hence the output signal noise ratio under these conditions is

$$\left(\frac{V_s}{V_n}\right)^2 = \frac{3\,(2^\mu - 1)}{8\,(2^\mu + 1)}\,\frac{1}{p_r}$$

Further, making the assumptions given in the introduction, Flood shows that

$$p_r = \frac{B\,T}{\sqrt{3}}\exp\left(\frac{-V^2}{2\sigma^2}\right)$$

where $B$ = cut-off frequency of an ideal low-pass filter.
$T$ = pulse duration.
$2V$ = peak signal.
$\sigma$ = r.m.s. noise voltage.

Now defining $\rho$ as the r.m.s. input signal/noise voltage ratio ($2V/\sigma\sqrt{2}$), and letting $BT$ be equal to 1, (this is only an approximation, since $B$ is the low-pass bandwidth and not the receiver bandwidth):

$$p_r = \frac{1}{\sqrt{3}}\exp\left(-\frac{\rho^2}{4}\right)$$

a curve of which is plotted in Fig. 1 (curve a).

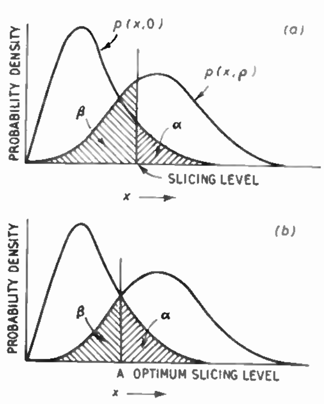


**Fig. 2.** Curves showing the probability distribution of the envelope of noise alone and noise plus a sine wave.

### 2.2. *Alternative method using the Ideal Observer theory*

If we consider the noise to be introduced before rectification then the probability distribution of the rectifier output depends on the signal/noise ratio in the input. Figure 2(a) shows the distribution when noise alone is present: $p(x, 0)$; and a typical distribution when a signal is present: $p(x, \rho)$.

In making a decision about the presence or absence of the signal there are two types of error that we can make:

(a) we can say there is a signal when in fact there is not;
(b) we can say there is no signal when in fact there is one.

If we fix our slicing level $A$ then the area under $p(x, 0)$ to the right of this level, gives the proportion of errors of the first type (let this be $\alpha$). The area under $p(x, \rho)$ to the left of this level gives the proportion of errors of the second type (let this be $\beta$).

The total proportion of errors $= p\alpha + q\beta$.

where $q$ = *a priori* probability of there being a signal.

and $p$ = *a priori* probability of these being noise alone.

In our problem $p = q = \frac{1}{2}$

Therefore, Total error $= \frac{1}{2}(\alpha + \beta)$

Siegert[3] has shown in another connection that an ideal observer will minimize these errors if the slicing level $A$ is chosen so that

$$\frac{p(A, \rho)}{p(A, 0)} = \frac{p}{q} = 1$$

i.e. at the intersection of the two curves of Fig. 2(b). Rice[2] has shown that the probability distribution for a sine wave plus random noise is given by

$$p(x, \rho) = 2x\, I_0(2x\rho) \exp(-x^2 - \rho^2)$$

where $x$ is the amplitude expressed as a ratio of $\sqrt{2}$ times the r.m.s. noise level,

i.e. $x = \text{amplitude}/\sigma\sqrt{2}$.

$I_0(z)$ is the modified Bessel function of argument $z$, and is tabulated, e.g. in Janke and Emde's "Tables of Functions": $I_0(0) = 1$.

Hence $A$ is defined by the equation

$$\exp(-\rho^2)\, I_0(2A\rho) = 1$$

An explicit solution cannot be found for $A$ but the value can be determined using tables; for high values of $\rho$ an iterative method terminates very rapidly—see Appendix 1.

The values of $\alpha$ and $\beta$ can now be found by suitable integration but unfortunately tables have to be used since the integral of $p(x, \rho)$ over a finite limit is not soluble (other than for $\rho = 0$).

Thus

$$\alpha = \int_0^A 2x \exp(-x^2)\, dx = \exp(-A^2)$$

$$\beta = \int_A^\infty 2x \exp(-x^2 - \rho^2)\, I_0(2\rho x)\, dx$$

A curve of $\frac{1}{2}(\alpha + \beta)$ when the slicing level is set at the optimum is shown in Fig. 1(c).

Flood's slicing level is set at $V$, i.e. half the peak signal voltage. Normalizing this gives

$$A = V/\sigma\sqrt{2} = \tfrac{1}{2}\rho$$

This brings out an important difference between the two analyses: the ideal slicing level is not in general when $A = \frac{1}{2}\rho$ and only tends to this value for high values of $\rho$. However, the difference in total error due to having the slicing level at $\frac{1}{2}\rho$ instead of $A$ is not very large and a curve of the total error under this condition is shown for comparison in Fig. 1, curve (b).

### 2.3. *Approximate method using the Gaussian distribution*

It is implicit in Flood's work that the noise has a Gaussian distribution and that the presence of the signal does not alter the distribution but displaces it by an amount equal to

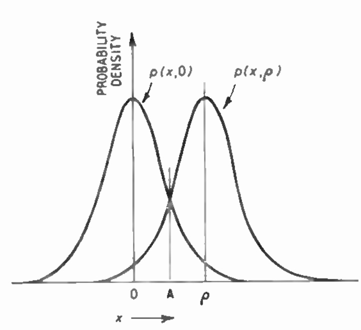


**Fig. 3.** Showing the distribution for noise alone and noise plus signal when the signal is a "d.c." pulse in a background of Gaussian noise.

the amplitude of the signal (see Fig. 3). On a normalized scale the amplitude of the signal is equal to the signal/noise ratio $\rho$. Applying the ideal observer theory it is obvious, because of the symmetrical nature of the curves, that the slicing level should be half the peak signal and that the two types of error will be equal (i.e. $\alpha = \beta$). Thus the total error is given by

$$\frac{1}{\sqrt{\pi}}\int_A^\infty \exp(-x^2)\,dx = \tfrac{1}{2}\{1 - \text{erf}(A)\}$$

$$= \tfrac{1}{2}(1 - \text{erf}(\tfrac{1}{2}\rho))$$

$$\left[\text{erf}(A) = \frac{2}{\sqrt{\pi}}\int_0^A \exp(-x^2)\,dx\right]$$

Curve (d), Fig. 1, compares this result with those of the other methods and it can be seen to give a substantially lower error. Moreover, as is shown in the Appendix, when $\rho$ is large, the gap between the results widens since the error falls at a greater rate than the others.

### 3. Discussion and Conclusions

In view of the difference in assumptions and method of solution there is a rather surprising similarity between the errors predicted by the two methods (2.1 and 2.2). The two curves (a) and (c), in Fig. 1, are of the same order of magnitude over a large range of $\rho$ and, as is shown in the Appendix, it is only for high signal/noise ratios that the ideal observer predicts substantially lower error. The error predicted by Flood's method curve (a) is proportional to $\exp(-\frac{1}{4}\rho^2)$ whereas the ideal observer curve (c) gives an error proportional to $\exp(-A^2)$. Although the optimum slicing level $A$ tends to a value $\frac{1}{2}\rho$ it converges slowly enough to produce a marked difference in the two results at high values of $\rho$.

It is interesting to note that if the slicing level of the ideal observer is fixed at $\frac{1}{2}\rho$ and not at the optimum, see curve (b) in Fig. 1, there is very good agreement between the predicted errors and curve (a). This, to some extent, is rather fortuitous since in order to compare the two methods, we made the assumption that $BT = 1$. In fact this will not be exactly true and hence the results obtained by Flood would have to be modified accordingly.

### 5. Appendix: Approximations for large values of $\rho$

When $z \gg 1$ $I_0(z) = \dfrac{\exp(z)}{\sqrt{2\pi z}}$

Hence $\quad I_0(2A\rho) = \dfrac{\exp(2A\rho)}{\sqrt{4\pi A\rho}}$ for large $\rho$

Thus the equation defining $A$ may be written

$$\exp(2A\rho - \rho^2) = \sqrt{2\pi}\,.\,\sqrt{2A\rho} \qquad \ldots\ldots\ldots(1)$$

This enables $A$ to be found very rapidly by an iterative method since the left-hand side of the equation varies very rapidly with $A$ whereas the right-hand side varies quite slowly.

Two factors emerge from the calculations of $A$ and $\beta$:

1. $\beta \to \exp(-A^2)$ and hence

$\frac{1}{2}(\alpha + \beta) \to \exp(-A^2)$.

2. $A \to \frac{1}{2}\rho$ but is sufficiently different to give no justification for the approximation:

total error $= \exp(-\frac{1}{4}\rho^2)$

Therefore, let $A = \frac{1}{2}\rho + \delta$

Error $= \exp(-A^2)$

$$= \exp - (\tfrac{1}{2}\rho + \delta)^2 \cong \exp - (\tfrac{1}{4}\rho^2 + \delta\rho)$$

Using equation (1) we find

$$\exp(\delta\rho) = (4\pi A\rho)^{\frac{1}{2}}$$

$$\cong (2\pi)^{\frac{1}{2}}\rho^{\frac{1}{2}}$$

Therefore, Error $\cong \dfrac{\exp(-\frac{1}{4}\rho^2)}{(2\pi)^{\frac{1}{2}}\sqrt{\rho}}$

We can also approximate in the method described in 2.3.

Error $= \frac{1}{2}(1 - \text{erf}\,\frac{1}{2}\rho) \cong \dfrac{\exp(-\frac{1}{4}\rho^2)}{\rho\sqrt{\pi}}$

when $\rho$ is large.

Comparing the three cases we get the main factor $\exp(-\frac{1}{4}\rho^2)$ in each case but the multiplier is different.

Flood's method: Error $= \dfrac{1}{\sqrt{3}}\exp(-\frac{1}{4}\rho^2)$

Ideal Observer: Error $= \dfrac{1}{(2\pi)^{\frac{1}{2}}(\rho)^{\frac{1}{2}}}\exp(-\frac{1}{4}\rho^2)$

Gaussian Approximation:

Error $= \dfrac{1}{\rho\sqrt{\pi}}\exp(-\frac{1}{4}\rho^2)$

# News from the Sections . . .

## NORTH WESTERN SECTION

Under the title of "Recent Astronomical Research using Radio Waves" Dr. H. P. Palmer of the Jodrell Bank Experimental Station read a very comprehensive paper at the February meeting in Manchester.

To introduce his subject he described the Jodrell Bank Radio Telescope in some detail, and showed several colour slides of its construction and use. The weight supported by the rail track of the telescope is approximately 2,000 tons, of which the bowl structure and the welded steel reflecting sheet comprise 800 tons. The telescope can be moved in azimuth and elevation by eight variable-speed electric motors, each of 50 h.p. An electro-mechanical computer controls the positioning of the instrument, so that it can follow selected objects across the sky, or execute scanning motions in alt-azimuth, celestial or galactic co-ordinates.

The telescope is used for observations in the range 30 metres to 21 cm. A primary feed appropriate for the waveband in use can easily be fitted when the telescope is in the inverted position, and such changes take only about four hours. For observations at the shorter wavelengths pre-amplifiers are fitted with the primary feed, while for work at the lower frequencies much of the apparatus is housed in the swinging laboratory, just below the bowl structure.

Dr. Palmer pointed out that radio waves from extra-terrestrial sources can only be studied at the frequencies for which the atmosphere and ionosphere is transparent, a range of wavelengths from about 1 cm to between 10 and 30 m. Much of this radio noise comes from our own galaxy, and is concentrated into a band along the Milky Way. The broad features of this emission probably originated in the interstellar gas of the galaxy, and the discovery of the spectral line emission of neutral hydrogen at 1421 Mc/s has provided a very powerful tool for investigating the galactic structure. There are also localized concentrations of emission called discrete radio sources, about 3,000 of which have now been detected. They show no correlation at all with the stars visible to the naked eye, and in the fifty or so cases where the optical object has been identified, it is always faint, and usually peculiar.

Most of the identified galactic sources observed at metre wavelengths seem to be associated with the remnants of stars which have suffered a super-nova explosion, the radio emission being generated by the expanding gas cloud which remains.

A rather larger number of sources have been identified with extra-galactic objects. Normal external galaxies have been detected, but their emission is weak, and the intense extra-galactic sources are associated with excited or interacting galaxies. The source Cygnus A is the most intense galactic interaction of this type. Although it is 700 million light-years distant, and only just detectable optically, it is the second most intense radio source. There is evidence that similar radio sources have been studied which are of the order of ten times further away. The majority of the unidentified sources may be of this type, and their study may give important cosmological information.

Radio echo techniques have also been used for studies within the Solar system. The echoes from the trails of shooting stars or meteors give information about the orbits and distribution of the dust particles of interplanetary space. The trails are formed about 80 km above the earth's surface, and can also be used to study the winds and air pressures and temperatures at these heights. Long pulse radars have been used to obtain echoes from the Moon, and incidentally, from Earth satellites. These echoes suffer Faraday rotation in the ionosphere and above, and this work has yielded data on the interplanetary electron content. In his concluding remarks, Dr. Palmer referred to experiments now in preparation for obtaining radar signals from Venus. This planet is always more than 160 times as distant as the Moon, and the problem of obtaining echoes was at least ten million times as difficult.

The discussion following the paper was extremely lively, and dealt at some length on the problems of radio interference from man-made sources which often severely hamper the work of the radio astronomer. F.J.G.P.

## SOUTH WESTERN SECTION

"A Six-channel H.F. Telemetry System" was the title of the paper read by Mr. R. Fowler, B.Sc., of the Bristol Aircraft Company on February 25th last. Mr. Fowler pointed out that the idea of a multi-channel, continuous telemetry system arose from the need to investigate vibrations and waveforms occurring at frequencies far beyond that possible using the twenty-four channel, sampling system. A f.m.-f.m. system was envisaged but, unfortunately, the design and power limitations of the only transmitter available dictated an a.m.-f.m. system and limited the number of channels to six.

In designing the sub-carrier generators, the centre frequency for each channel and the deviation of $\pm 6$ kc/s were chosen to avoid harmonic relationships and give adequate channel separation. The transitron oscillator, with its inherent stability and simplicity, was an obvious choice.

The design of the various units was based on a small "pin board" which carries all components and valves. No attempt is made to introduce special screening or protection for the units. The six sub-carrier generators slide on runners into a single metal case which carries, on its side, all the necessary decoupling components.

In the ground equipment it is probably the filters which are most worthy of note. They are unusual in design and, by careful control of the damping, will reproduce complex waveforms with very high accuracy. Recording is carried out by high-speed photography of the channel outputs which are displayed on separate cathode-ray tubes.

Dealing with the question of valve selection in the ensuing discussion, Mr. Fowler stated that the valves were wired into a simple circuit and then tapped with a rubber grommet attached to the end of a pencil, the valve output being displayed on a cathode-ray tube. This somewhat crude device had proved very reliable. He then produced figures to show the very high reliability achieved during the course of over one hundred practical flights.

The latest type units are being encapsulated and this fact caused some discussion. Mr. Fowler stated that although the new product was undoubtedly neater, he did not think that it would be any more reliable. E.G.D.

## SOUTH MIDLANDS SECTION

Members of the Section had an introduction to some of the material which will be discussed in the 1959 Convention when Mr. B. V. Somes-Charlton presented a paper on "Industrial and Underwater Television" on January 28th.

In his paper, which was supported by a demonstration of an industrial television system, Mr. Somes-Charlton reviewed the development of closed circuit television, illustrating with slides and films the nature of the considerable diversity of applications which have taken place in the industrial, underwater, scientific, medical and educational fields. Methods of using remote observation by means of closed-circuit television to meet the special problems likely to be encountered in the increasing use of industrial automation were also described. Further prospects for the television medium in the new space travel and earth satellite era were discussed, including proposals for an orbitting astronomical telescope and the use of television scanning devices for interplanetary probes.

R.D.

## MERSEYSIDE SECTION

The Vice-Chairman of the Section, Mr. C. R. Bates (Associate Member) presented a paper at the February meeting entitled "High Speed Electronic Welding Control," in which he described the development of sequence controls for resistance welding. The first type of equipment described used relay operation and the latest models employed fully electronic sequencing. The use of hypersil welding transformers had led to certain difficulties and he explained the method by which these were overcome. Finally, the ultimate ideal of a universal controller, and the way in which it had been achieved, was discussed.

## CONFERENCE OF LOCAL SECTION CHAIRMEN

The Chairman and Honorary Secretaries of the Sections in Great Britain will meet in London at the Institution's offices on April 23rd to discuss mutual problems and complete arrangements for the 1959-60 Session's programme.

# PRACTICAL EXAMINATIONS FOR THE TECHNICIAN AND MECHANIC†

The main feature of the work of the Radio Trades Examination Board has been the inclusion of a practical test in its examinations. For the past fifteen years such examinations have been based on actual radio and television receivers. In 1959 the Radio Servicing examination will incorporate a test based on a "Trainer-Tester" which has already been used experimentally for training of radio and electronics tradesmen in the Services.

These notes describe the "trainer-tester" method of examining mechanics and technicians on their ability to diagnose faults—in this instance of a radio receiver. The receiver is presented in the form of a circuit diagram and chassis layout.

## 1. Introduction

The work on which a mechanic or technician is employed necessitates practical ability in diagnosis or fault finding as well as ability to remedy faults and ensure that the equipment is in working order. For this reason, any examinations designed to afford proof of efficiency *must* incorporate a practical test.

From the inception of the Radio Trades Examination Board, practical tests have been an integral part of the examination, so that notwithstanding the candidate's proved ability in theory and written papers, his success has finally depended upon his ability to negotiate successfully fault finding and repair. Since 1944 over seven thousand candidates have been examined by the Radio Trades Examination Board; the number of candidates entering the examinations has, however, presented many difficulties.

## 2. The Problem

First and foremost, the conduct of the practical examinations has depended upon the ability to procure from manufacturers a sufficient number of chassis. In recent years as many as 1,000 and more have been needed. To ensure a fair examination a variety of differing types of receivers of modern design has been required, and a wide variety of faults inserted. The faulting and re-faulting of a large number of receivers has involved not only many hours of work by the Board's examiners, but also considerable cost to those companies who have supplied the receivers.

It has thus become increasingly evident that an alternative form of practical examination should be arranged. Such an alternative is the "Trainer-Tester" devised by Van Valkenburg, Nooger and Neville Inc., New York.

## 3. The "Trainer-Tester" Scheme

This scheme of examination enables the candidate to be tested on his fault-finding ability and logical diagnosis without the use of the actual equipment but employing identical techniques to those he would use in practice.

The radio receiver is presented as (a) a pictorial layout of the equipment showing the physical arrangement of all the components suitably annotated with a reference number; (b) the circuit diagram showing the wiring and component values and (c) a series of specially developed fault sheets from which the student can apply his diagnostic skill.

The components on the circuit diagram are annotated with the conventional C, R, L and V references with the values of the capacitors and resistors printed beside the components concerned; valve types are indicated and the transformer windings bear the identifying code at their terminations. Other test points are provided, for example on the h.t. line and the a.g.c. return. The fault sheet which constitutes a given fault condition, provides the candidate with test point data at all the test points which are likely to be required. This is irrespective of whether or not the fault actually affects the measurement at any test point. The test data at each of these points is given in three ways—the voltage, the signal condition and the resistance to earth. In addition the sheet provides the resistance across

† Report No. 16. Prepared by the Secretariat.
U.D.C. No. 621.396.62:371.33

individual components when taken out of circuit. The heading of the sheet gives the fault symptoms and the conditions under which the tests are assumed to be made.

The test points are referred to by a reference number and in order to identify them the candidate has to relate the reference number on the chassis layout to the component reference on the circuit diagram. This means that in order to identify a particular component he would have to trace the connections in exactly the same way as he would on an actual chassis.

When presented with the "Trainer-Tester" the candidate will be unable to see the test point data on the fault sheet since this is masked by an ink layer which can be removed by a normal ink eraser.

By making the conventional tests which would normally be required in an actual receiver the candidate can by logical diagnosis trace the fault and eventually cure it by replacing a particular component.

The operation of the test can best be understood by considering a typical example.

## 4. The Form of the Examination

In the examination to be used in 1959 the Board will provide each candidate with (a) a sheet showing the equipment configuration components and wiring, suitably annotated so that cross reference may be made with the fault diagnosing sheet (Fig. 1); (b) a circuit diagram in which the components are given their correct reference numbers and the values stated (Fig. 2); (c) a number of fault diagnosing sheets, each setting forth a different fault situation (Fig. 3); and (d) a step-by-step instruction sheet which explains to the student the procedure which may be followed in locating the first fault. This is intended to enable the candidate to familiarize himself with the working of the "Trainer-Tester" and with the circuit diagram and receiver with which he is working.

Three specimen sheets are illustrated in Figs. 1, 2 and 3 and it will be seen that the fault sheet has several columns showing check points and remedial action which can be taken following such checks. Against each point or action is printed the data response (answer) which one would find when applying the appropriate test instrument or renewing a component. These data responses are, however obscured by an over-printing of a specially developed erasable ink which can quite simply be removed by the use of a normal ink or typewriter eraser—thus exposing the answer. The student performs his testing of the equipment and takes his remedial actions as he would in an actual situation and as each step is taken it is numbered consecutively in the appropriate column opposite each erasure. Once the special ink has been removed it is impossible to disguise this fact, and, therefore, a permanent record remains of the "thought process" of the participant's mind.

## 5. Procedure

On fault Sheet No. 1 the fault symptoms are given as follows:—"There is no output from the receiver except for a very low hum. Inspection reveals that all the valves are warm and that there is no obvious physical damage." The student is asked to investigate and remedy the cause of the fault.

*Mental Analysis*

As the symptoms state that all the valves are warm, a brief inspection of the Circuit Diagram Sheet should tell the participant that the input mains supply, the main fuses, the main switch and the primary and heater windings of the power transformer are not at fault. It might therefore be advisable first of all to check the h.t. supply.

*First Check*

From the Circuit Diagram it appears that the most suitable point at which the h.t. voltage can be measured in this receiver is the bleeder resistor R 15, which is test point D. Turning to "Test Results" on the Fault Diagnosing Sheet, we find test point D listed in the "Test Point Data" section. Three possible data responses are given for test point D—voltage, resistance and output signal. We are interested at the moment in voltage, so by erasing the special ink obscuring this result and recording a figure 1 opposite the erasure (to indicate that this is the first step), we find that the answer uncovered is "+210." We now have to make the same decision as when we read "+210" on the voltmeter—good or bad, right or wrong, within or outside the permitted tolerance. If we have understood correctly our course of instruction or if we "know" receivers of this type, we would come to the decision that the h.t. response is normal. We would not go inside the h.t. supply, make more tests and start replacing the transformer, capacitors, resistances, etc.

*Second Check*

Three principal methods of signal injection and tracing are used in fault finding: in this example the student will use one of these methods, namely, to inject a signal into each stage, starting from the output stage. The student may assume that the results quoted are those which are obtained when a signal of proper amplitude and frequency is injected at any chosen point. He is, however, required to indicate opposite his erasures what type of signal he would inject.

As there is a hum from the loud-speaker he can assume (or should) that it is serviceable and the first point at which to inject a signal is, therefore the grid of V4. Since all components are referred to on the Fault Diagnosing Sheet by arbitrary numbers, the student must identify this valve on the Photographic View Sheet (locate the point in the receiver), where these numbers also appear. As V4 is the output amplifier, it may be best to look first for the loud-speaker and work backwards from that. The loud-speaker cannot be seen on the Photographic View Sheet, but a pair of sockets at the lower edge of the chassis is connected to a transformer which could well be the output transformer. Inspection shows that the other two leads to the transformer connect to pins 3 and 4 of a valveholder and that a capacitor is connected across them. This corresponds exactly with the anode and screen connections of V4 (the screen being connected directly to h.t.), so the student may be sure that he has found the correct valve. The number shown on the Photographic View Sheet opposite this valve is 29, and the number of the pin connected to the grid is 5. Knowing this, the student can immediately consult the "Test Point Data" on the Fault Diagnosing Sheet, when following an erasure in the signal column against 29-5 (and writing in a figure 2, followed by a.f.), he will find that the answer is "normal." This means that a signal injected at this point reaches the speaker and the student must therefore continue towards the input stage.

*Third Check*

The control grid of V3 should now receive attention. From the Circuit Diagram it can be seen that the anode of V3 (pin 6) is coupled via a capacitor to the control grid (pin 5) of V4. From the underside of the chassis (Photographic View Sheet) the student already knows the position of V4, and he can easily find a capacitor connected between pin 5 of V4 and pin 6 of another valve which must be V3; the number opposite this is 25. An erasure here (No. 3 a.f.) against 25-2 reveals the answer "none," and the student has thus reached (or should recognize) the stage where more detailed checks are needed.

*Fourth Check*

It will be seen that V3 is acting both as a detector and an amplifier, but as the student has already established that it is the amplifier section which is faulty, there is no need to check the detector circuits. If a replacement valve is to hand it would be a good idea to try a substitution, otherwise it would be better to continue with voltage and resistance checks. Assuming that the student has a valve and decides to make the exchange, he must next refer to the "Part Replacement" list on the Fault Diagnosing Sheet. He already knows that the number of V3 is 25, so by making an erasure (No. 4) against 25 he finds that the answer is "SR," meaning that the fault symptom remains. Thus he knows that V3 is not faulty.

*Fifth Check*

Having discovered that the amplifier stage of V3 is at fault, but that the valve is not faulty, he must make voltage and resistance checks in the stage to locate the fault.

Several checks are possible, but it is a good idea first to checks the anode voltage. Under "Test Point Data" an erasure (No. 5) in the voltage column against 25-6 shows that the answer is "0," thus it would appear that there is an open circuit between V3 anode and the h.t. line.

*Sixth Check*

To ensure that this assumption is correct the student can take a resistance reading between the anode and chassis and the answer he might expect would be the value of R11 (270k), plus

Contd. on page 194

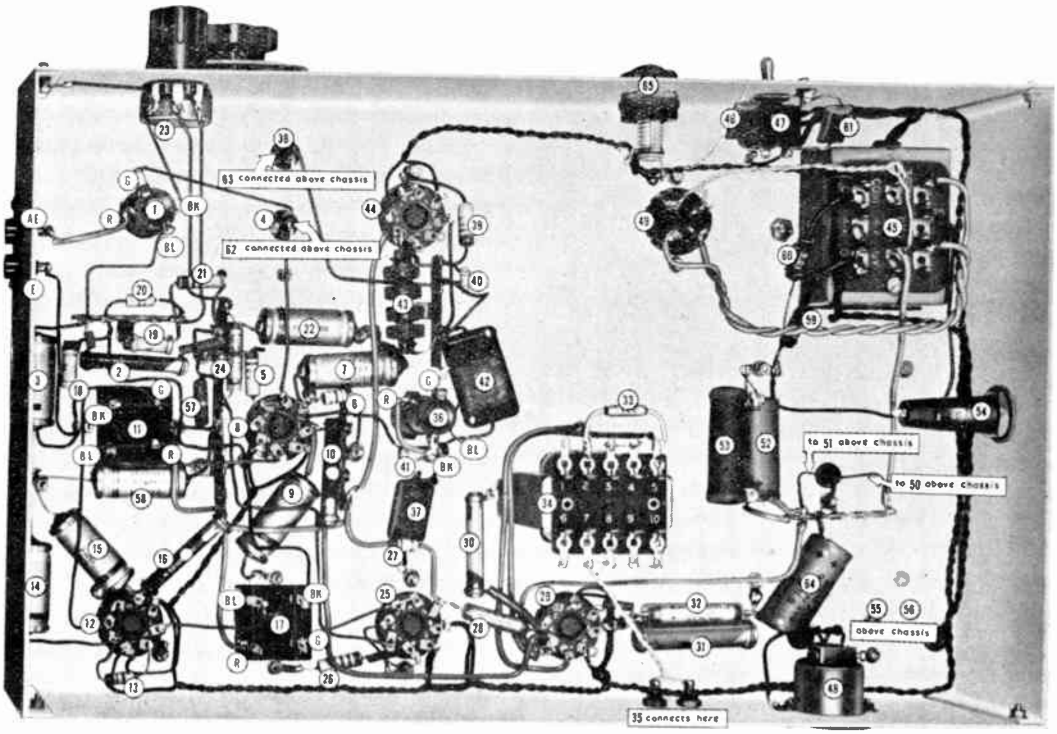


Fig. 1. Component layout and wiring of the test receiver.

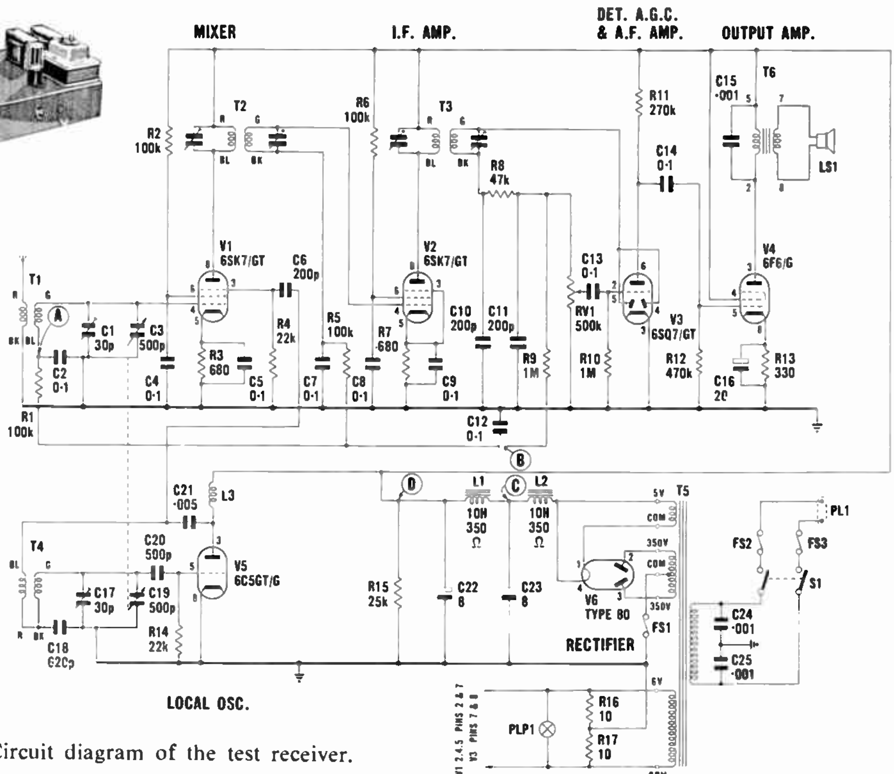


Fig. 2. Circuit diagram of the test receiver.

## READ THIS BEFORE DIAGNOSING THE FAULT

The measurements given on this sheet were made with the proper instruments, correctly used and interpreted. Measurements were made between the test point and chassis, and voltages are d.c., except where otherwise stated.

Answers shown in signal columns indicate whether or not a signal is reproduced by the speaker when injected at the point indicated.

Resistances across individual parts were measured with the parts completely disconnected; where such a resistance is obvious from a measurement made at a test point, it has not been given. Resistance across a capacitor shows only leakage or short circuit; an open circuit capacitor can be found only by replacement or signal checks.

Each erasure revealing a test result must be numbered as it is made. If the erasure is in a signal column, write down the type of signal you would inject (i.e.: r.f., i.f., a.f., or local oscillator).

### FAULT SYMPTOMS

**There is no output from the receiver except for a very low hum. Inspection reveals that all the valves are warm and that there is no obvious physical damage.**

***Investigate and remedy the cause of the fault.***

### TEST POINT DATA

| Test Point | Voltage | Step No. | Resistance (ohms) | Step No. | Output Signal | Step No. |
|---|---|---|---|---|---|---|
| 1-R | [redacted] | | [redacted] | | [redacted] | |
| 8-1 | [redacted] | | [redacted] | | [redacted] | |
| 8-2 | [redacted] | | [redacted] | | [redacted] | |
| 8-3 | [redacted] | | [redacted] | | [redacted] | |
| 8-4 | [redacted] | | [redacted] | | [redacted] | |
| 8-5 | [redacted] | | [redacted] | | [redacted] | |
| 8-6 | [redacted] | | [redacted] | | [redacted] | |
| 8-7 | [redacted] | | [redacted] | | [redacted] | |
| 8-8 | [redacted] | | [redacted] | | [redacted] | |
| 12-1 | [redacted] | | [redacted] | | [redacted] | |
| 12-2 | [redacted] | | [redacted] | | [redacted] | |
| 12-3 | [redacted] | | [redacted] | | [redacted] | |
| 12-4 | [redacted] | | [redacted] | | [redacted] | |
| 12-5 | [redacted] | | [redacted] | | [redacted] | |
| 12-6 | [redacted] | | [redacted] | | [redacted] | |
| 12-7 | [redacted] | | [redacted] | | [redacted] | |
| 12-8 | [redacted] | | [redacted] | | [redacted] | |
| 25-1 | [redacted] | | [redacted] | | [redacted] | |
| 25-2 | [redacted] | | [redacted] | | none | 3 AF |
| 25-3 | [redacted] | | [redacted] | | [redacted] | |
| 25-4 | [redacted] | | [redacted] | | [redacted] | |
| 25-5 | [redacted] | | [redacted] | | [redacted] | |
| 25-6 | [redacted] | | [redacted] | | [redacted] | |
| 25-7 | [redacted] | | [redacted] | | [redacted] | |
| 25-8 | [redacted] | | [redacted] | | [redacted] | |
| 29-1 | [redacted] | | [redacted] | | [redacted] | |
| 29-2 | [redacted] | | [redacted] | | [redacted] | |
| 29-3 | [redacted] | | [redacted] | | [redacted] | |
| 29-4 | [redacted] | | [redacted] | | [redacted] | |
| 29-5 | [redacted] | | [redacted] | | normal | 2 AF |
| 29-6 | [redacted] | | [redacted] | | [redacted] | |
| 29-7 | [redacted] | | [redacted] | | [redacted] | |
| 29-8 | [redacted] | | [redacted] | | [redacted] | |
| 34-7 to 8 | [redacted] | | [redacted] | | [redacted] | |

* = with V6 inserted.

| Test Point | Voltage | Step No. | Resistance (ohms) | Step No. | Output Signal | Step No. |
|---|---|---|---|---|---|---|
| 44-1 | [redacted] | | [redacted] | | [redacted] | |
| 44-2 | [redacted] | | [redacted] | | [redacted] | |
| 44-3 | [redacted] | | [redacted] | | [redacted] | |
| 44-4 | [redacted] | | [redacted] | | [redacted] | |
| 44-5 | [redacted] | | [redacted] | | [redacted] | |
| 44-6 | [redacted] | | [redacted] | | [redacted] | |
| 44-7 | [redacted] | | [redacted] | | [redacted] | |
| 44-8 | [redacted] | | [redacted] | | [redacted] | |
| 45-5 to Com. | [redacted] | | [redacted] | | [redacted] | |
| 45-350 to Com. | [redacted] | | [redacted] | | [redacted] | |
| 45-Com to 350 | [redacted] | | [redacted] | | [redacted] | |
| 45-6 to chassis | [redacted] | | [redacted] | | [redacted] | |
| 45-6 to Com. | [redacted] | | [redacted] | | [redacted] | |
| 45-Primary | [redacted] | | [redacted] | | [redacted] | |
| 45-5 to chassis (*with 5 and Com disconnected from circuit*) | | | [redacted] | | [redacted] | |
| 45-350 to chassis (*with 350, Com and 350 disconnected from circuit*) | | | [redacted] | | [redacted] | |
| 45-6 to chassis (*with 6, Com and R16-R17 junct. disconnected from circuit*) | | | [redacted] | | [redacted] | |
| 45-Primary to chassis (*with primary disconnected from circuit*) | | | [redacted] | | [redacted] | |
| 45-Primary to chassis (*with primary connected to circuit*) | | | [redacted] | | [redacted] | |
| 49-1 | [redacted] | | [redacted] | | [redacted] | |
| 49-2 | [redacted] | | [redacted] | | [redacted] | |
| 49-3 | [redacted] | | [redacted] | | [redacted] | |
| 49-4 | [redacted] | | [redacted] | | [redacted] | |
| A | [redacted] | | [redacted] | | [redacted] | |
| B | [redacted] | | [redacted] | | [redacted] | |
| C | [redacted] | | [redacted] | | [redacted] | |
| D | +210 | 1 | [redacted] | | [redacted] | |

† = with V6 removed.

### RESISTANCE ACROSS INDIVIDUAL PARTS

| Part | Resistance (ohms) | Step No. | Part | Resistance (ohms) | Step No. |
|---|---|---|---|---|---|
| 1-R to BK | [redacted] | | 34-2 to chassis | [redacted] | |
| 1-R to chassis | [redacted] | | 34-2 to 7 | [redacted] | |
| 1-R to G | [redacted] | | 34-7 to 8 | [redacted] | |
| 1-G to BL | [redacted] | | 34-7 to chassis | [redacted] | |
| 1-G to chassis | [redacted] | | 35-coil | [redacted] | |
| 2 | [redacted] | | 36-BL to R | [redacted] | |
| 3 | [redacted] | | 36-BL to chassis | [redacted] | |
| 4 | [redacted] | | 36-BL to G | [redacted] | |
| 10 | [redacted] | | 36-G to BK | [redacted] | |
| 11-BL to R | [redacted] | | 36-G to chassis | [redacted] | |
| 11-BL to chassis | [redacted] | | 37 | [redacted] | |
| 11-BL to G | [redacted] | | 38 | [redacted] | |
| 11-G to BK | [redacted] | | 40 | [redacted] | |
| 11-G to chassis | [redacted] | | 41 | [redacted] | |
| 16 | [redacted] | | 42 | [redacted] | |
| 17-BL to R | [redacted] | | 46 | [redacted] | |
| 17-BL to chassis | [redacted] | | 47(ON) | [redacted] | |
| 17-BL to G | [redacted] | | 47(OFF) | [redacted] | |
| 17-G to BK | [redacted] | | 52 | [redacted] | |
| 17-G to chassis | [redacted] | | 53 | [redacted] | |
| 18 | [redacted] | | 54 | [redacted] | |
| 19 | [redacted] | | 55 | [redacted] | |
| 20 | [redacted] | | 56 | [redacted] | |
| 21 | [redacted] | | 57 | [redacted] | |
| 22 | [redacted] | | 58 | [redacted] | |
| 23 | [redacted] | | 59 | [redacted] | |
| 24 | [redacted] | | 60 | [redacted] | |
| 27 | [redacted] | | 61 | [redacted] | |
| 28 | [redacted] | | 62 | [redacted] | |
| 33 | [redacted] | | 63 | [redacted] | |
| 34-2 to 5 | [redacted] | | 64 | [redacted] | |

### RESULT OF PART REPLACEMENT

| Part | Result | Step No. | Part | Result | Step No. |
|---|---|---|---|---|---|
| 1 | [redacted] | | 38 | [redacted] | |
| 2 | [redacted] | | 39 | [redacted] | |
| 3 | [redacted] | | 40 | [redacted] | |
| 4 | [redacted] | | 41 | [redacted] | |
| 5 | [redacted] | | 42 | [redacted] | |
| 6 | [redacted] | | 43 | [redacted] | |
| 7 | [redacted] | | 44 | [redacted] | |
| 8 | [redacted] | | 45 | [redacted] | |
| 9 | [redacted] | | 46 | [redacted] | |
| 10 | [redacted] | | 47 | [redacted] | |
| 11 | [redacted] | | 48 | [redacted] | |
| 12 | [redacted] | | 49 | [redacted] | |
| 13 | [redacted] | | 50 | [redacted] | |
| 14 | [redacted] | | 51 | [redacted] | |
| 15 | [redacted] | | 52 | [redacted] | |
| 16 | [redacted] | | 53 | [redacted] | |
| 17 | [redacted] | | 54 | [redacted] | |
| 18 | [redacted] | | 55 | [redacted] | |
| 19 | [redacted] | | 56 | [redacted] | |
| 20 | [redacted] | | 57 | [redacted] | |
| 21 | [redacted] | | 58 | [redacted] | |
| 22 | [redacted] | | 59 | [redacted] | |
| 23 | [redacted] | | 60 | [redacted] | |
| 24 | [redacted] | | 61 | [redacted] | |
| 25 | SR | 4 | 62 | [redacted] | |
| 26 | [redacted] | | 63 | [redacted] | |
| 27 | [redacted] | | 64 | [redacted] | |
| 28 | [redacted] | | 65 | [redacted] | |
| 29 | [redacted] | | | | |
| 30 | [redacted] | | | | |
| 31 | [redacted] | | | | |
| 32 | [redacted] | | | | |
| 33 | [redacted] | | | | |
| 34 | [redacted] | | | | |
| 35 | [redacted] | | | | |
| 36 | [redacted] | | | | |
| 37 | [redacted] | | | | |

### RESULT OF PART ADJUSTMENT

| Part | Result | Step No. |
|---|---|---|
| 11 | [redacted] | |
| 17 | [redacted] | |
| 62 | [redacted] | |
| 63 | [redacted] | |

SR = *Symptoms remain* FC = *Fault cured*

**Fig. 3.** Fault diagnosis chart—partly completed.

the source impedance of the power supply—which, from the value of R 15, he would assume to be about 25kΩ—a total of 295kΩ. The erasure (No. 6) at 25-6 in the "Resistance" column reveals the answer "inf.", so it is now certain that there *is* an open circuit.

*Seventh Check*

The circuit diagram shows only one resistor (R 11) in the anode circuit and it is therefore evident that this is the faulty component, but the student must, however, check that this is so before changing the component. To do this he turns to the "Resistance Across Individual Parts" section and makes an erasure opposite the appropriate component number. Reference to the Photographic View Sheet shows that the resistor connected to pin 6 of component 25 (V3) is numbered 27; an erasure (No. 7) beside this number shows that the resistance is infinity, and he can now proceed to change the resistor.

*Eighth Check*

Turning once again to the "Result of Part Replacement" section, he makes an erasure (No. 8) opposite part No. 27 and finds that the result recorded is "FC," indicating that the fault is cured.

## 6. Assessment

One of the great advantages of the "Trainer-Tester" system is that it enables the examiner to follow precisely the candidate's procedure in tracing a fault. The assessor will thus be able to follow the candidate's reasoning and give credit for even partially correct work.

Possibly, however, the greatest value will be the establishment of a uniform standard. Previously candidates were confronted with a wide selection of different makes and types of receiver and this led of necessity to considerable differences in the difficulty and complexity of the tests to be performed. It will also ensure that uniform standard of assessment is possible, whereas previously a great deal of responsibility rested with local assessors.

The principal disadvantage would seem to be the lack of contact with the actual equipment but the candidate is required to provide satisfactory evidence of practical experience and is therefore expected to have completed a suitable course, involving practical training on receivers.

## 7. Soldering and Wiring Test

The Radio Servicing practical examination has always included a compulsory soldering test. It is regarded as an important part of the practical test and candidates who have failed the soldering test have been failed in the whole of the practical examination.

With the introduction of the "Trainer-Tester" scheme a more elaborate soldering and wiring test has also been introduced. Candidates will be supplied with all the components required for a single valve stage, and will be required to assemble the sub-unit in accordance with a circuit diagram.

In the assessment of the test the examiners will be looking particularly for neatness and accuracy, layout, any overheating of components and dry joints.

Candidates will for this test be required to bring to the examination a small soldering iron, solder and small tools.

## 8. Conclusion

The "Trainer-Tester" examination provides what is undoubtedly the next best test to that on an actual receiver. In fact it has many advantages over the use of the actual equipment. It obviates the need for the training and testing of a large number of candidates on very costly equipment which is not available in large quantities for examination purposes. It has applications in more complex circuits than are available on domestic radio receivers, and the Board might well be able to use it in the Television Servicing Examination.

It has already been announced that the Radio Trades Examination Board is preparing syllabuses and curricula for the examination of technicians employed in the operation and maintenance of more complicated electronic equipment. The use of a "Trainer-Tester" type of examination may also be invaluable in assessing the practical ability of the candidates taking such a course.

This will be the first occasion that this type of examination has been used in the United Kingdom, and the success of this method will be watched with interest by many in the field of education and training.

# Radio Engineering Overseas . . .

*The following abstracts are taken from European and Commonwealth journals received in the Library of the Institution. Members who wish to borrow any of these journals should apply to the Librarian, stating full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the Journal unless otherwise stated. The Institution regrets that translations cannot be supplied.*

### AUTOMATIC CONTROL

In a recent French paper the problem of automatic regulation to a given fixed specification value is considered, introducing the notion of symbolic impedance for the apparatus. The author develops this in terms of symptoms with exponential response, with or without delay. He next defines the role of a regulator and control functions currently used; proportional, integral and differential action. Then the criterion of stability is developed in terms of the location of the roots, and even though it is based on Nyquist's classical criterion, appears to be very convenient in the treatment of the stability of regulating circuits. The criterion is applied to the case of control with proportional and differential action, and the means to obtain optimum control are given. The introduction of the third type of action, namely integral, is then discussed. Finally, two examples are considered; one with small delay, the other with large delay compared with the effects of time constants. It is claimed that the method makes it possible to study not only of systems involving an appreciable propagation time, but even those introducing a continuous transmission effect by heat flow or diffusion.

"Stability of equipment arranged for automatic control," P.-L. Dubois-Violette. *L'Onde Electrique*, **38**, pp. 819-829, December 1958.

### DIELECTRIC HEATING BY MICROWAVES

The production of high-power c.w. magnetrons permits the application of microwave energy to dielectric heating processes. The methods differ from the inductive and capacitive heating methods in the medium-wave and short-wave range where the magnetic and electric energy spaces are separated. A German paper shows that microwave generators must meet several conditions simultaneously, such as a homogeneous heating in substances of varying geometric dimensions and dielectric loss figures; they should also meet the condition imposed by the valve, which requires that the reflections from loads due to load variations in the operating space be kept within permissible limits with regard to the phase relationship between the reflected wave and the wave coupled out of the magnetron. For this reason, industrial c.w. magnetrons must be capable of stable operation even during great changes in the load impedance.

"The application of microwave energy in industry." W. Schmidt. *Nachrichtentechnische Zeitschrift*, **12**, pp. 79-84, February 1959.

### TRANSISTOR CIRCUITS

The problem of stabilizing the d.c. operating point of transistors may be compared with the corresponding problem in valve practice. However the operating point of a transistor may shift considerably when the ambient temperature changes. A graphical method has been presented in a Dutch paper whereby this phenomenon can be accurately analysed for a type of circuit to which many circuits in common use can be reduced. The design of a circuit guaranteeing a certain prescribed degree of stabilization of the operating point is also discussed, and illustrated with a practical example. The design in question also allows for the spread in properties exhibited by individual transistors. Advantages may be gained using a thermistor in the circuit.

"The junction transistor as a network element at low frequencies: III. Stabilization of the operating point, in particular with regard to temperature changes." J. P. Beijersbergen, M. Beun and J. te Winkel. *Philips Technical Review*, **20**, No. 5, pp. 122-134, November 1958. (In English.)

### TRANSISTOR AMPLIFIERS

A Czechoslovakian paper considers two types of neutralization for low-frequency amplifiers, series-parallel and parallel-series. Formulae are given for the design of neutralization networks for any transistor circuit and the most important formulae for design of neutralized amplifiers. These are verified by measurements on a common-emitter amplifier.

"Neutralization of transistor low-frequency amplifiers," Jan Mikula. *Slaboproudy Obzor*, **20**, pp. 31-37, January 1959.

### OSCILLATORS

A paper from the Institute für Elektrotechnik of Mainz University shows that by considering the characteristic impedances it can be decided whether a bridge-type oscillator is suitable as a current source or as a voltage source when operated under the conditions for optimum frequency stability.

"Frequency stable oscillators as current or voltage sources," W. Herzog. *Nachrichtentechnische Zeitschrift*, **11**, pp. 550-556, November 1958.

## SCATTER PROPAGATION

The nature of the propagation of v.h.f. and u.h.f. signals beyond the horizon is quite different for the tropospheric, stratospheric, and ionospheric cases. Several different theories exist, attempting to explain the phenomena of over-the-horizon propagation, and although complete agreement on the contribution of the various factors has not been achieved, the expected signal at the distant receiver can now be calculated with a fair degree of accuracy. An Australian paper explains that this signal is affected by fading to a greater extent than that of a short line-of-sight link but fading can be reduced by employing frequency and space diversity techniques. Other interesting characteristics of tropospheric scatter propagation such as the gain which can be realized from large aperture reflectors and the useful bandwidth of an over-the-horizon system are also discussed. Equipment which is used for over-the-horizon television links is outlined and details of installations in the United States of America and Europe are given. Finally a description is given by propagation measurements over a tropospheric scatter path of 112 miles, from Goulburn to Kings Cross in New South Wales, using an average output power of 20 watts (+43 dbm) at 900 Mc/s.

"Tropospheric scatter propagation and equipment." J. Fieguth. *Proceedings of the Institution of Radio Engineers, Australia,* **20**, pp. 12-19, January 1959.

## ELECTRO-ACOUSTICS

In view of the complexity of operation of the human ear it is difficult to establish quantitative measurement of the sensation of a noise by normal sound-level meters. A very small portable sound spectrum-analyser is described, which analyses the sound spectrum in nine octave pass-bands so that more detailed information is obtained. Particulars are given for calculating loudness level, loudness and speech-interference level. The possibilities of hearing loss from noise exposure is discussed with a tentative no-damage-risk-level for octave bands. Charts are given for estimating the reaction of people to noise in a residential area and for recommended noise criteria for rooms.

"A small portable noise-level analyser for the measurement of sound spectra," Chr. Peekel. *Tidschrift van het Nederlands Radiogenootschap,* **23**, No. 6, pp. 287-302, 1958.

## ELECTRONIC TELEGRAPH EQUIPMENT

An electronic signal regenerator, which has been described in a German paper, operates without vacuum or gas-filled valves and is equipped only with transistors. Its low power consumption permits an extremely compact construction. The circuit employs a counting method which makes the regenerator suitable also for higher information rates.

"Teleprinter signal regenerator equipped with transistors," F. Obst and F. Ohmann. *Nachrichtentechnische Zeitschrift,* **11**, pp. 610-613, December 1958.

## TELECONTROL

A remote control equipment has been described where the controlling pulses are transmitted either as 50 c/s pulses over two-wire lines without repeaters or as voice-frequency (2900 c/s) pulses over low-frequency lines, carrier-frequency channels or microwave link order-wire channels when equipped with repeaters. V.h.f. radio equipment can be used also as transmission means. Order-wire channel equipments, provided also with selective calling means for the various stations, have been designed to carry additional speech channels on such circuits. The transmission links and the station equipment for remote control are supervised either by means of a continuous 50 c/s signal or by means of pilot tone equipment operating automatically with 2700 c/s. The equipment can be adapted to various operational conditions without additional expenditure (signal regeneration at repeaters, branching circuits).

"Remote control equipment for telecommunication systems, the transmission of the signals and supervision," G. Pietzik. *Nachrichtentechnische Zeitschrift,* **11**, pp. 614-618, December 1958.

## HUMAN ENGINEERING

Some general conclusions relating to human information processing can be drawn from observations of the human behaviour, according to a German engineer. In all processes investigated in detail so far, the speed of human information processing has been below approximately 50 bits/sec. Controlling actions are very important and mostly comprise a large number of interlaced control circuits. Internal and external control circuits can be found in connection with deliberate movements and the delay in these circuits can be estimated. The nerve cell is the basic element in this information processing. An equivalent electric circuit of a nerve cell on the basis of existing knowledge shows that this is not a simple switching mechanism. In certain regions, a nerve cell can carry out simple additions or simple differentiations of incident irritations. However, in the most general case, it is a time or space evaluation of exciting and impeding effects. The statistical uncertainty of operation in a nerve cell requires a multiple parallel processing of signals as proved by anatomy.

"Human information processing." K. Küpfmuller. *Nachrichtentechnische Zeitschrift,* **12**, pp. 68-74, February 1959.