ELECTRONIC ENGINEERING

VOL. 28 No. 344

OCTOBER 1956

Commentary

THE Royal Military College of Science, which recently published its annual report, is not, perhaps, very well known outside of military circles. It is, nevertheless, a science-teaching organization of the highest class. The college no longer confines itself to gunnery pure and simple but teaches science in its widest meaning and includes among other courses, the preparation of students for London University degrees in mathematics, physics and the main branches of engineering.

Although the college has only been known by its present title for a comparatively short time it has been in existence in one form or another for a considerable period and has much excellent tradition behind it.

The foundations of the college were laid in 1772 when two young officers founded the Military Society of Woolwich for the scientific study of gunnery. This was followed in 1840 by the establishment at Woolwich of the R.A. Institution, the purpose of which was the study of science and modern languages.

The first Director of Artillery Studies was appointed in 1850 and from that year lectures were given from time to time on various suitable subjects; opportunity was thus afforded to Artillery officers to extend their knowledge. This indefinite arrangement was clearly only a beginning which led, in 1864, to the establishment of the 'Advanced Class', a course which provided two years of organized instruction. This was continued until 1940, and those passing out successfully received a qualification which was recognized throughout the army.

Instruction of the 'Class' took place in the R.A. Institution until 1885 in which year the Artillery College was set up, also at Woolwich. In 1889 it became the Ordnance College. After the 1914-18 war, considerable extensions were made to the accommodation and it was renamed the Artillery College. It was not until 1927 that it became known as the Military College of Science. It was honoured by Her Majesty with the appellation 'Royal' in 1953.

The College dispersed from Woolwich in 1939 and was re-established in converted barrack buildings on a country estate at Shrivenham in 1946. As a result of developments made during the war, particularly in the use of predictors and radar, a great broadening of the scope of the studies then took place and extensive new laboratories were planned and equipped. The 'Advanced Class' which had catered predominantly for gunnery was replaced by the Technical Staff Course which provides for officers from all arms of the home and Commonwealth land forces.

In addition, in 1946, degree courses were set up and the College was approved by the University of London for its external degrees. The degree students number about 200, the majority being young officers, mostly from Sandhurst, the remainder being civilians holding Ministry of Supply Studentships. The students may be prepared for the B.Sc. special or general degrees in mathematics, physics or chemistry and for the B.Sc. (Engineering) degree in civil, mechanical or electrical engineering.

As in any other academic institution research by both staff and students is encouraged and, in addition to the contributions made by many distinguished serving officers, the College has been fortunate from the beginning in attracting men of distinction to its academic staff, most of whom are, of course, civilians. It is seldom appreciated today how numerous and important the contributions of army officers to science have been and it is worth recalling that between 1780 and 1890 at least forty officers became Fellows of the Royal Society, while one of them, General Sir E. Sabine, became the President. The present well staffed and generously equipped college can hardly fail to add lustre to the tradition that has been laid for it.

As would be expected in a college devoted to science for military uses, electronic engineering in all its aspects, including radar, computers, servomechanisms and guided weapon control is well to the fore. Nuclear physics and atomic energy are also catered for.

It may, indeed, be a sad reflection on our state of civilization that a military college in any form is necessary but, if the need be granted, there is no doubt that the Royal Military College of Science as now constituted is performing its task well and is making a significant contribution to the country's scientific manpower.

The Design of Cold-Cathode Valve Circuits

(Part 1)

By J. E. Flood*, Ph.D., A.M.I.E.E. and J. B. Warman*, A.M.I.E.E.

Cold-cathode gas-filled valves have many applications in switching circuits where reliability is required if the speed of operation need not be very high. The characteristics of diodes and triodes are described and the limitations which these place on circuit design are discussed. Basic methods of operating and extinguishing cold-cathode valves are explained and circuit elements are described for performing logical operations, counting, information storage, etc. The effects of tolerances on circuit operation are examined and methods are described for obtaining adequate circuit margins. Multi-cathode valve circuits are discussed briefly and the uses of cold-cathode valves in practical equipment are reviewed.

MANY digital data handling circuits use large numbers of valves. It is desirable to avoid the use of thermionic valves, where possible, both from the point of view of reliability and of power consumption. Two alternatives to the thermionic valve are the cold-cathode gas-filled valve and the transistor. Both eliminate the need for heated cathodes and so offer reduced power consumption and long life. The transistor offers great future potentialities but the amount of experience so far gained in its use in digital circuits is limited and transistor circuits are still expensive. The cold-cathode valve is limited to low speed circuits but there are many applications for these in telephony and elsewhere.

Cold-cathode gas-filled valves do not have the current-carrying capacity of hot-cathode thyratrons, but their currents are ample for operating telephone relays. They can also control saturable reactors or magnetic amplifiers, which may in turn operate other devices. However, many of the applications of cold-cathode valves lie in circuits for performing logical operations rather than producing power; these circuits only need produce enough power to operate other cold-cathode valves for indicating that they have performed certain discriminating functions. It is with such circuits as these that this article will chiefly deal.

Considerable experience has been gained in the use of cold-cathode valve circuits in telephone and other applications, but the design techniques evolved are little known except to those engaged in the art. It is hoped that this article may help others to appreciate the capabilities and limitations of cold-cathode valves and to design reliable circuits using them. Some typical cold-cathode valves used in switching circuits are shown in Fig. 1. Table 1 lists the characteristics of the valves.

The Cold-Cathode Diode

The simplest form of cold-cathode valve is a diode consisting of a pair of electrodes enclosed in a glass envelope filled with an inert gas at low pressure. The usual fillings are neon and argon. A typical voltage-current characteristic for such a diode is shown in Fig. 2: the voltage scale is linear, but the current scale is logarithmic. The curve is shown divided into several regions[3] which are also reasonably well defined in practice. At low anode voltages (region 1) a small residual current flows because of ionization due to cosmic rays or radioactivity or photo-electric emission from the cathode. (Without these external processes no current would flow). As the voltage is raised, the current is increased quite rapidly by secondary emission but is still only of the order of 10^{-10}A. If the p.d. across the valve is increased further a rapid increase of current follows, until in range 2 a self-maintained (or Townsend) discharge is established. The voltage at which this increase of current occurs is called the breakdown or striking voltage (V_s). In this region (2), each electron from the cathode is accelerated sufficiently to be able to produce positive

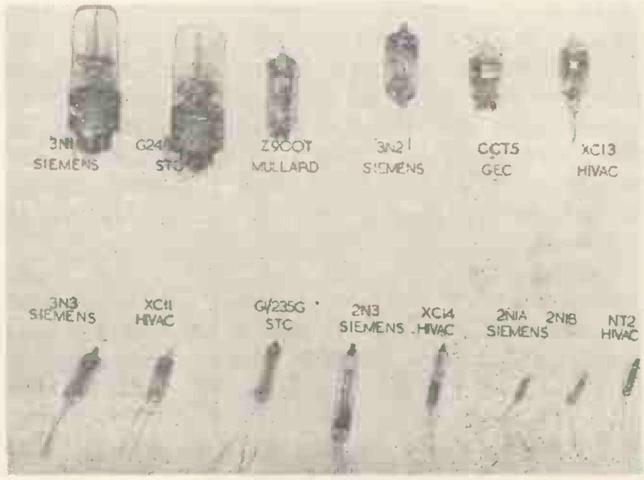


Fig. 1. Some typical cold-cathode valves

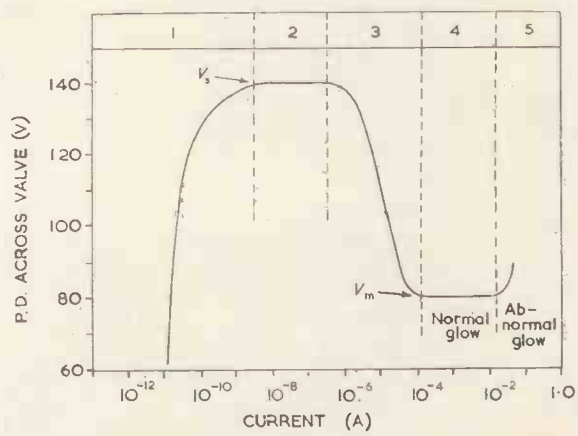


Fig. 2. Characteristic of cold-cathode diode

ions in the gas and these each arrive back at the cathode to release by bombardment, on the average, a further electron: hence the discharge is self-sustaining. The glow discharge starts in this region.

So far, the characteristic has been discussed in terms of voltage as the independent variable. However, the voltage

* *Siemens Brothers & Co. Ltd.*

now begins to fall with increasing current (region 3) so it is more convenient to consider current as the independent variable. Indeed, the valve can only be controlled by regulating the current through it by means of external resistance. In this region, a space charge of positive ions develops near the cathode producing a large voltage gradient which accelerates electrons. By the beginning of region 4, most of the potential drop appears across this layer which forms the cathode dark space. Electrons accelerated through this layer produce the cathode glow immediately beyond it. In region 4, as the cathode current increases the voltage remains at an almost constant value, known as the maintaining voltage (V_m). The cathode current density remains almost constant, so the glow spreads over a larger area of the cathode when the total current increases. This region is usually called the normal glow region.

When the glow entirely covers the cathode, a further increase in current causes the cathode current density to increase and electrons are accelerated still more. The voltage now increases with increasing current (region 5). This region is known as the abnormal glow region. The conditions here may not be associated with equilibrium (as distinct from regions 1 and 4) since temperature rises may now occur in the cathode which take the discharge into the entirely different category of an arc.

The use of cold-cathode diodes as voltage stabilizers is well known[4] and will not be discussed here. In switching circuits, a diode is normally operated in region 1, where the valve acts as an insulator and is said to be "off", and region 4, where the valve acts as a conductor and is "on". The important parameters for the circuit designer are the striking voltage V_s and maintaining voltage V_m. In order to turn the valve on, a voltage V_a (greater than V_s) is applied across it via a series resistance (R). The valve then breaks down and the voltage across it falls to V_m, the current flowing in the valve being $(V_a - V_m)/R$. The value of R must thus be chosen to give a current in the working range of the valve (region 4). In order to turn the valve off again, the current must be interrupted or the

LIST OF SYMBOLS

C_c = Coupling capacitance
C_k = cathode capacitance
I_t = transfer current
R = total resistance in series with valve
R_a = anode resistance
R_b = bias resistance
R_k = cathode resistance
R_t = trigger resistance
T_d = deionization time
T_i = ionization time
v_a = anode potential
v_k = cathode potential
v_t = trigger potential
V_a = anode h.t. supply voltage
V_k = cathode steady-state potential when valve is on
V_m = maintain voltage
V_{am} = maintain voltage between anode and cathode
V_{tm} = maintain voltage between trigger and cathode
V_s = striking voltage
V_{as} = striking voltage between anode and cathode
V_{ts} = striking voltage between trigger and cathode

TABLE 1

Some Typical Cold-Cathode Valves

TYPE NO.	MANUFACTURER	D.C. RATING (mA)	ANODE STRIKING VOLTAGE (v)	ANODE MAINTAINING VOLTAGE (v)	TRIGGER STRIKING VOLTAGE (v)	TRANSFER CURRENT* (μA)	IONIZATION TIME* (μsec)	DEIONIZATION TIME* (m sec)
G240/2D (CV2174)	S.T.C.	30	230 min	110 max	65–90	15 max	—	—
G150/2D (CV413)	S.T.C.	30	150 min	60–77	60–80	10 max	—	—
3N1	Siemens	30	230 min	90–110	65–90	15 max	50	6
Z900T	Mullard	25	200 min	62 nom.	73–105	160	20 nom.	0·5 nom.
3N2	Siemens	10	230 min	80 max	60–80	15 max	50 max	1 max
XC13	Hivac	7·5	200 min	55 nom.	75 nom.	—	—	—
CCT6	G.E.C.	5	250 min	65–80	70 90	2	100 max	0·5
GK3	Ferranti	5	150 min	70 nom.	79–85	4	—	1·5
G1/235G	S.T.C.	1·5	235 min	70 nom.	85 max	3	100 max	0·4
XC11 (CV2257)	Hivac	1	190 min	70–85	60–85	20 max	50 max	0.7 max
3N3	Siemens	1	230 min	80 max	60–80	15 max	50 max	0·5
NT2 (CV2213)	Hivac	1	85 max	52–65	Diodes		50	0·15
2N1	Siemens	1	85	52–65	Diodes		50	0·15
G50/1G (CV2208)	S.T.C.	0·5	90V max	62V max	Diodes		50	0·15
XC14	Hivac	0·75	145–170	75 max	Diodes		50	0·15
2N3	Siemens	0·75	180–200	80 max	Diodes		50	0·15

* *These figures depend on the conditions under which they are measured (see manufacturers' data sheets). The conditions specified by various manufacturers differ, so direct comparison between different valves on a basis of information given above is inadvisable.*

applied voltage (V_a) reduced below the maintaining voltage (V_m) to extinguish the glow discharge.

The Cold-Cathode Triode

The cold-cathode triode consists of a diode with a third electrode, known as the trigger, inserted in the gap between the anode and cathode. By applying different potentials to the electrodes it is possible to make the valve break down

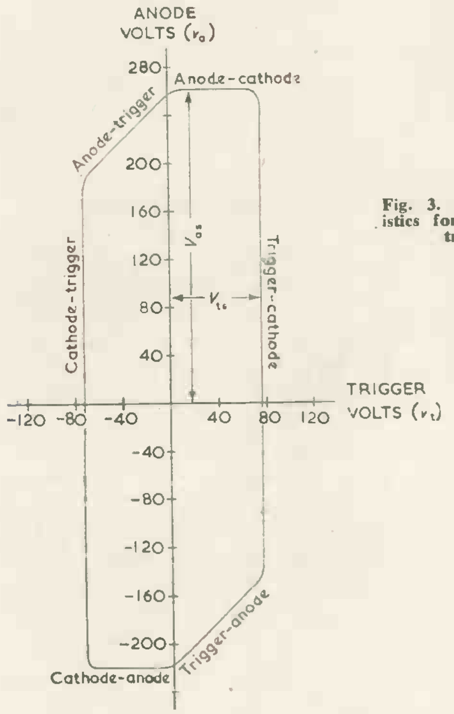


Fig. 3. Breakdown characteristics for typical cold-cathode triode type 3N3

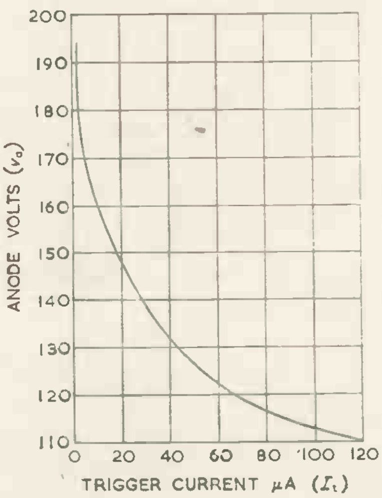


Fig. 4. Trigger control characteristic for cold-cathode triode type 3N3

between anode and cathode, between trigger and cathode or between trigger and anode. The voltages at which breakdown occurs between the different electrodes of a typical cold-cathode triode are shown in Fig. 3. When the anode-cathode voltage (v_a) and trigger-cathode voltage (v_t) are represented by a point inside this "target diagram" the valve will not break down, but if the point is outside, the valve will fire. For example, if $v_a = +200V$, $v_t = +40V$ the valve will not fire; if $v_a = +300V$, $v_t = +40V$ breakdown occurs between anode and cathode; if $v_a = +220V$, $v_t = -40V$ breakdown occurs between anode and trigger.

The triode is usually employed with both anode and trigger positive, but with the voltage on the anode less than the value (V_{as}) required to cause breakdown. If the voltage applied to the trigger is raised above its firing voltage (V_{ts}) the valve breaks down between trigger and cathode. The current flowing between trigger and cathode causes ionization in the gap between anode and cathode. If the ionization is sufficient, then breakdown occurs between anode and cathode, thus transferring the glow discharge from the trigger gap to the main gap. The current which must flow in the trigger to cause this breakdown of the main gap is called the transfer current. The variation of transfer current (I_t) with anode voltage (v_a) for a typical triode valve is shown in Fig. 4. The value of I_t decreases as v_a is increased

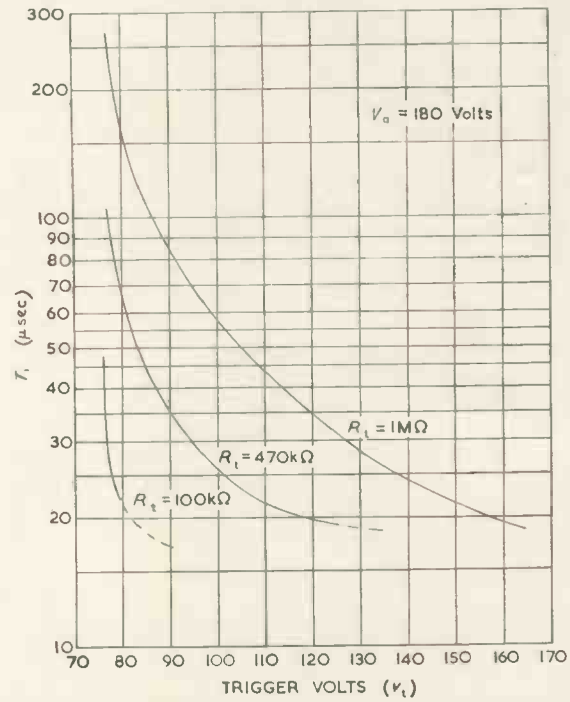


Fig. 5. Ionization time characteristic for cold-cathode triode type 3N3

until, obviously, $I_t = 0$ at $v_a = V_{as}$. It is normally very much smaller than the current which flows in the anode after transfer, so the valve acts as a power amplifier. Because the current required in the trigger is only a few microamps, the value of the resistance (R_T) in series with it can usually be several hundred thousand ohms.

When a voltage is applied to the trigger gap, it does not break down instantaneously because the gap takes a finite time to ionize. A further time interval elapses before the discharge transfers to the main gap. The sum of these two times is commonly called the ionization time of the valve. The ionization time T_i decreases when the trigger voltage is increased, as shown in Fig. 5; usually it varies inversely as the amount by which the applied trigger voltage exceeds the striking voltage V_{ts}.

Although a triode can be turned on by means of its trigger, it can only be turned off by removing its anode voltage. After the valve has thus been turned off, the gas takes a finite time to deionize. If the anode voltage is reapplied before this deionization time has elapsed, the valve breaks down again between anode and cathode, although no voltage is applied to the trigger.

The deionization time (T_d) increases both with the anode current and applied anode voltage. Values of the order of 500μsec to 5msec are common (see Table 1).

The considerations outlined above determine the conditions which have to be satisfied by a circuit using a cold-cathode triode. The circuit must satisfy the following conditions:

(a) The h.t. supply voltage V_a connected to the anode must be less than V_{as} (to prevent direct anode-cathode breakdown).

(b) When the valve is required to be "off", the voltage applied to the trigger must be less than V_{ts}.

(c) When the valve is required to be turned on, the trigger voltage v_t must be raised above V_{ts} and the current $(v_t - V_{tm})/R_T$ which then flows in the trigger circuit must exceed I_t.

(d) The time for which the operating voltage is applied to the trigger must exceed the ionization time (T_i) of the valve.

(e) When the valve is on, the current flowing through it, $(V_a - V_{am})/R$, must come within the rating of the valve (i.e. the normal glow region).

(f) When the valve is extinguished by removing its anode supply potential, the time which elapses before this is restored must exceed the deionization time T_d.

In practical circuit design, the values assumed for the above valve parameters must allow for an adequate tolerance and a margin for ageing. For example, the value of V_{ts} used in condition (b) must be the minimum allowed by the specification of the valve and in condition (c) the maximum value of V_{ts} must be used.

In order to make the striking and maintaining potentials as low as possible, the cathodes of cold-cathode valves are usually "activated", i.e. coated with a material having a low work function[1]. Cathodes are commonly nickel or iron coated with barium oxide which is reduced to a barium-barium oxide mixture by heating during manufacture. Such coatings usually emit electrons freely on illumination by visible light.

Intense illumination of the cathode may produce currents of the same order of magnitude as the transfer current and this has the effect of reducing the anode breakdown voltage. Some light is needed to produce preliminary ionization, but this need only cause photo-electric emission in the range of 10^{-12} to 10^{-9}A. It is thus inadvisable to operate cold-cathode valves either with direct sunshine falling on them or in complete darkness. Under all ordinary conditions of room illumination satisfactory operation can be obtained.

Unlike thermionic valves, cold-cathode valves consume no power when not taking anode current. Also, no deterioration takes place while waiting to operate, whereas a hot-cathode valve will eventually suffer from heater failure or loss of emission even if it never conducts. When a cold-cathode valve is conducting, its cathode coating is being continually sputtered away by positive ion bombardment. The life depends on the current and can often be predicted fairly accurately[5]. The life can be increased by reducing the current, but if the current is made too small, the valve operates in region 3 of its characteristic (see Fig. 2) and the value of its maintaining voltage becomes uncertain. Even when the current in a valve is very high, its life in equipment may still be long, because of the low duty cycle with which valves usually operate in digital circuits. Thus, a conducting life of only a few hundred hours may correspond to an expectancy of life in telephone equipment of over 40 years.

Methods of Extinguishing Cold-Cathode Valves

Once a cold-cathode triode has been turned on by means of its trigger, it can only be turned off by interrupting the anode current. This fact limits the usefulness of the valve and the practical difficulties involved in various circuit techniques are bound up with the methods adopted for extinguishing the valves.

The obvious way of interrupting the valve current is by means of a mechanical contact, as shown in Fig. 6. If the valve is used to operate a relay, a contact on the relay can be used to interrupt the anode circuit, another contact being used to provide a holding circuit for the relay coil. If a particular valve is not used for relay operation it can sometimes be extinguished by a relay operated by another valve, provided that extinguishing the first valve can await the firing of the second. In some circuits it can be arranged for each valve when fired to remain "on" until the end of the circuit action when all the valves are extinguished by the operation of a "reset" key or relay.

An alternative to interrupting the current is reducing the anode voltage below the maintaining value. If the anode voltage supplied to the valve contains an alternating component, the valve will extinguish each time the anode voltage goes below V_{am}; if a steady firing voltage is applied to the trigger the anode will fire again each time it goes positive. Thus, a pulsating current will flow in the cathode load for as long as a positive signal is present on the trigger. This technique has been widely used in simple circuits where high speeds are not required and the a.c. mains can be used to provide the anode waveform[6,8,12].

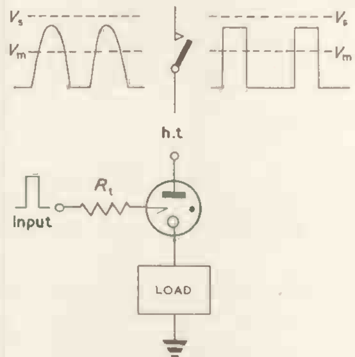


Fig. 6. Extinguishing cold-cathode triode by switching anode supply voltage

In more complicated circuits operating at higher speeds, it is often possible to arrange for the h.t. supply to take the form of a train of periodic pulses. If the signal applied to the trigger is a short pulse which coincides with one of the anode pulses, a single pulse of current will be delivered to the cathode load. If the trigger has a steady firing voltage applied, the load will receive a train of pulses for as long as the trigger signal is present. In a complicated circuit, the pulse generator used to supply the anode pulses will be common to a large number of valves and it may even be desirable to use several generators supplying pulses in different phases to facilitate organization of the circuit action. The circuits used for supplying the pulses can be thermionic valve stabilizer circuits with a controlling voltage waveform applied to the grid of the stabilizer valve. If the stabilizer valve is in series, it is convenient for the output to consist of short positive pulses, during any of which a cold-cathode valve can fire. If the stabilizer valve is in shunt, it is convenient for the output to consist of a d.c. voltage interrupted by short negative pulses, during any of which a cold-cathode valve can deionize. The design of pulse supplies is discussed in the Appendix.

Another method of extinguishing a valve is shown in Fig. 7. The anode is connected to a positive d.c. supply through a high resistor R_a (e.g. 10MΩ) which limits the anode current to a value too small to sustain a self-maintaining discharge in the valve. When a short positive pulse is applied to the trigger, the valve fires and current flows. Initially the anode is at the h.t. potential V_a because the capacitor is fully charged. The p.d. across the cathode load therefore rises immediately to $(V_a - V_{am})$. However, the valve current begins to discharge the capacitor, the anode potential falls exponentially and the cathode potential falls with it. Consequently, the current in the valve decays towards the small value determined by R_a and when it is too small to sustain the discharge the valve extinguishes. The capacitor then recharges through R_a until the anode is again at the h.t. potential. Thus, each time a short pulse is applied to the trigger a positive pulse is generated at the cathode, provided that the interval between input pulses is sufficiently long for the anode capacitor to recharge. Used in this way, the valve forms a very useful buffer stage since the trigger presents a high input impedance and the cathode gives a low output impedance. Moreover, whatever signal is applied to the input is reshaped by the circuit action. Alternatively, if a steady firing potential is applied to the trigger, pulses will appear at the cathode for as long as this

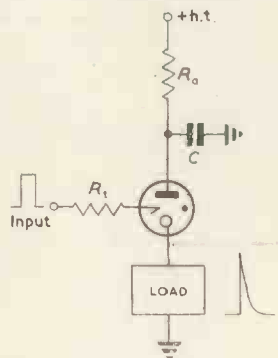


Fig. 7. Self-extinguishing R.C circuit for cold-cathode triode

is present: used in this way the circuit forms a switched relaxation oscillator.

Another method of extinguishing a valve is to fire another valve with which it shares a common anode resistor, as shown in Fig. 8. If the second valve (V_2) has a lower maintaining voltage than the first, or if its cathode is connected to a negative potential, then firing V_2 makes the p.d. across V_1 less than its maintaining voltage and the valve is extinguished. However, the use of valves with different values of V_{am} and the use of different cathode supply potentials are both undesirable. The disadvantages of these techniques are obvious when a circuit is considered in which a number of valves are fired in turn, each extinguishing the preceding one. This requires either a number of different types of valve with successively lower values of V_{am} or a number of different cathode potentials. Furthermore, once valve V_1 has been extinguished by firing V_2, it is impossible to fire V_1 again. This disadvantage can be overcome by replacing V_2 with a thermionic valve turned on by a short pulse applied to its grid. This is usually undesirable unless the thermionic valve can be made common to a large number of cold-cathode valves. The method is then equivalent to the use of a common pulse supply as described earlier.

A method of using the common anode resistor which avoids the disadvantages mentioned above is shown in Fig. 9. If, initially, valve V_1 is "on" and V_2 is "off" the cathode of V_1 is at a positive potential V_k and the cathode of V_2 is at earth potential. Consequently capacitor C_{k1} is charged and C_{k2} is uncharged. The p.d. across valve V_1 is V_{am} so both anodes are at potential $V_k + V_{am}$. If a positive pulse is applied to the trigger of V_2, this valve fires and takes anode current. The capacitor C_{k2} prevents the cathode of V_2 from rising instantaneously so the anode potential immediately falls to V_{am}. The capacitor C_{k1} prevents the cathode potential of V_1 falling instantaneously, so the p.d. across V_1 is immediately reduced to $(V_{am} - V_k)$ and the valve is extinguished. The cathode potential of V_2 now rises exponentially to V_k as its cathode current charges C_{k2}. Meanwhile the cathode of V_1 falls exponentially to earth as C_{k1} discharges through R_{k1} and the p.d. across V_1 thus rises exponentially to $(V_k + V_{am})$. The time-constant of this rise must be sufficiently large for V_1 to have deionized before its anode voltage has restored, so that the valve remains off. The circuit thus reaches a state of equilibrium with V_1 off and V_2 on as a result of the pulse applied to the trigger of V_2. If, subsequently, a firing pulse is applied to the trigger of V_1 the circuit changes back to the state with V_1 on and V_2 off. The circuit of

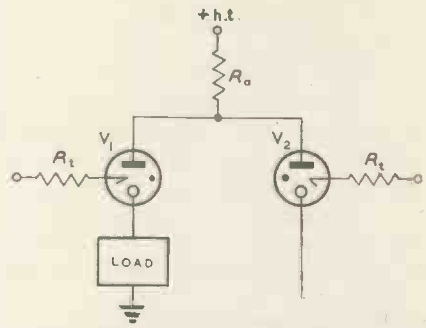


Fig. 8. Extinguishing cold-cathode triode by firing another valve with common anode load

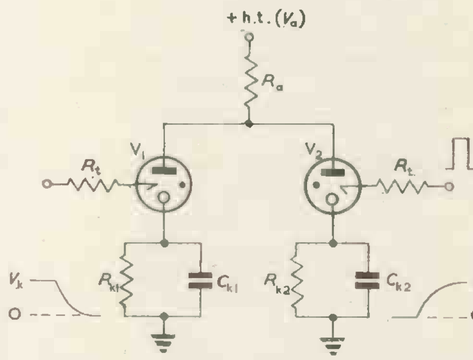


Fig. 9. Use of cathode capacitors for valve extinguishing

Fig. 9 can be extended to contain several more valves sharing the common anode resistor each with its cathode load shunted by a capacitor. Firing any one valve in the circuit then extinguishes any other valve.

The circuit of Fig. 9 and variations of it are very widely used and provide the basis of many practical circuit designs. The circuit depends for reliable operation on the cathode capacitors providing a sufficiently long time-constant to ensure that the valve which is to be extinguished cannot restrike. A design procedure which ensures this is outlined below.

First the h.t. voltage V_a is chosen to be as high as is possible without any possibility of direct anode-cathode breakdown under adverse circumstances (i.e. low V_{as}). The anode resistor (R_a) is then chosen so that the permissible current (I_{max}) through the valve is not exceeded when the valve is first struck and the cathode capacitor is uncharged.

$$R_a = (V_a - V_{am})/I_{max} \qquad (1)$$

The cathode resistor is then chosen to give the required cathode output voltage V_k.

$$R_k = R_a V_k/(V_a - V_{am} - V_k) \qquad (2)$$

The value of V_k which is attainable is limited, because if

R_k is made too large the current through the valve becomes too small (i.e. the working point on the characteristic shown in Fig. 2 is moved from region 4 to region 3). In practice, R_a and R_k are often about equal.

It remains to determine the value of the cathode capacitance C_k from the deionization time (T_d) of the valve. The voltage conditions existing during deionization are shown in Fig. 10. If valve V_1 is being extinguished, its instantaneous cathode potential is:

$$V_{k1} = V_k e^{-\alpha t} \quad \ldots\ldots\ldots\ldots\ldots \ (3)$$

where $\alpha = 1/R_k C_k$.

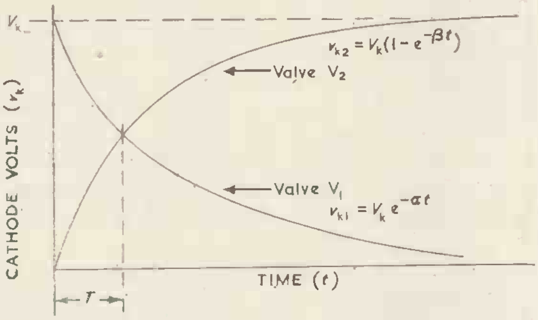


Fig. 10. Cathode voltage waveforms for circuit of Fig 9

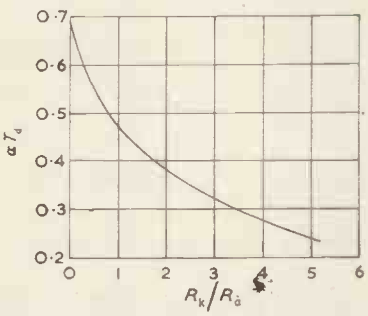


Fig. 11. Design curve for circuit of Fig. 9

The instantaneous cathode potential of V_2 is:

$$V_{k2} = V_k(1 - e^{-\beta t}) \quad \ldots\ldots\ldots\ldots\ldots \ (4)$$

where $\beta = (R_a + R_k)/R_a R_k C_k$.

At the time (T) when $v_{k1} = v_{k2}$, the p.d. across each valve is the same. But V_2 is on, so the p.d. across each valve is V_{am}. The p.d. across V_1 is thus less than V_{am} when $t < T$. If $T \geqslant T_d$ the valve will have deionized before the p.d. across it exceeds V_{am} and so it cannot restrike.

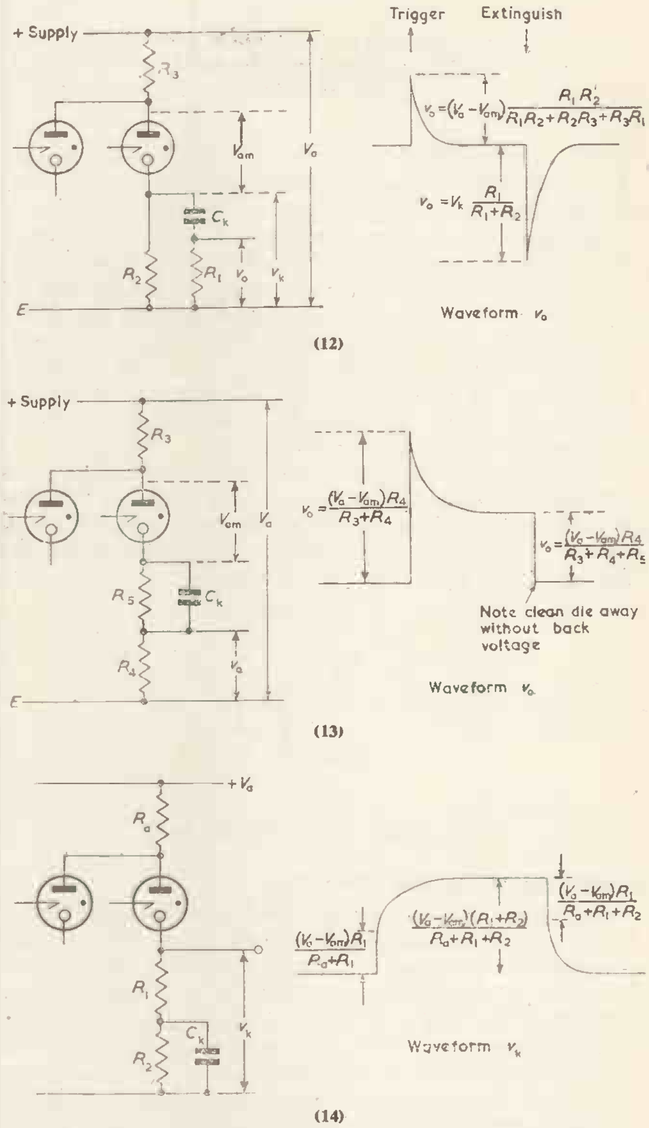
Now, from equations (3) and (4) when $t = T$:

$$e^{-\alpha T} = 1 - e^{-\beta T} \quad \ldots\ldots\ldots\ldots\ldots \ (5)$$

This equation can readily be solved for α by graphical means and the solutions obtained are plotted in Fig. 11. Thus when R_a, R_k and T_d are known, α can be obtained from Fig. 11 and $C_k = 1/\alpha R_k$.

The method described above usually results in a conservative circuit design because it assumes the p.d. across the valve must be less than V_{am} until the time exceeds T_d. The value of T_d usually given in valve data, however, is that measured for some higher re-applied anode voltage.

The basic circuit shown in Fig. 9 produces an exponentially rising output waveform, which is a disadvantage in some applications where a sharply rising output signal is required. However, a fast rise in output voltage can be obtained without preventing deionization of the valve by including an additional resistor in the circuit. The circuits which result and the output waveforms obtained are shown in Figs. 12, 13 and 14. The design procedure described above is easily adapted to cater for these modified circuits. The circuit in Fig. 14 is probably the most useful, for reasons which are explained in Part 2.



Figs. 12, 13, 14. Alternative cathode circuits for valve extinction

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(*To be continued*)

Polar Co-ordinate Oscilloscopes

By G. F. Craven*

The generation of a circular time-base by various methods is described, together with circuits used for radial modulation. Examples of the use of polar co-ordinates are given, with special reference to the employment of a Magslip transmitter as the time-base generator.

THE cathode-ray tube is becoming increasingly important in modern engineering and is continually finding new applications. One important use is in investigations of the performance of rotating machinery and it is in this sphere that the polar co-ordinate oscilloscope is especially desirable. Among the advantages of this type of instrument, the absence of flyback, the ability to synchronize the rotating spot to the equipment under investigation and the length of the trace are especially noteworthy. In addition, a trace in polar co-ordinates is often more readily understood by personnel unused to interpretation of linear time-base traces.

Oscilloscopes employing circular time-base displays are not readily obtainable in this country and the purpose of this article is to describe such an instrument in detail, together with the various methods of producing circular time-bases and obtaining radial deflexions.

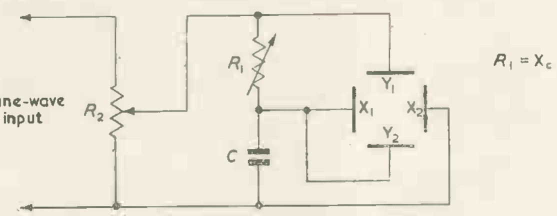

Fig. 1. Simple circular time-base circuit

Generation of Circular Time-Base

A circular or elliptical time-base may be readily produced by applying sinusoidal voltages which differ by 90° in phase to the two sets of deflexion plates of the cathode-ray tube. If the deflexion sensitivity of both sets of plates is the same the trace will be circular, but if, as is common in most cathode-ray tubes, the two sets of plates are not of equal sensitivity, an elliptical trace is produced. The ellipse may be transformed into a circle by adjusting the voltage to one set of plates in order to make the deflexion of both sets equal. For fixed frequency working simple circuits such as that of Fig. 1 may be used. Adjustment of R_1 controls the phase shift of the circuit and hence the degree of circularity of the trace and R_2 controls the amplitude of the output voltages and the diameter of the circle. Simple circuits such as this have several disadvantages. Single-ended deflexion, with consequent defocusing and distortion of the spot results and the circuit may only be used over a relatively narrow band of frequencies without changing the capacitor value.

If the voltage applied to the phase shifting circuit contains an appreciable harmonic content it becomes impossible to obtain a circle. Fig. 1 may be modified by replacing R_1 by a parallel LC circuit tuned to the frequency of the supply[1]. The parallel LC circuit then becomes equivalent to a pure resistance and the impedance is capacitive for harmonics in the supply, with the result that the harmonic content in the output voltages is substantially reduced.

In the above discussion, the circuits are suitable only for fixed frequency working. This is not often practicable when the oscilloscope is to be used in conjunction with rotating machinery as the speed may be continually changing, or may not be related to, say, the 50c/s mains. To provide perfect synchronization an alternator driven by the machine under investigation may be used. A small two-phase machine is the most desirable type to employ, but such an instrument is not readily available. Single-phase alternators require phase shifting circuits which again are suitable at one frequency only. The writer has found a Magslip generator to give the most satisfactory results.

In its most common form a Magslip generator consists of a three-phase stator and a single-phase rotor energized via slip rings. If the rotor is energized from a low-voltage d.c. supply a three-phase a.c. output is obtained across the stator windings. The three-phase output may be used directly if a magnetically deflected tube is available and a deflexion coil assembly with windings spaced at 120° is used. As the majority of users will employ conventional electrostatic tubes, the three-phase output must be converted to two-phase. This may be done by the circuit in Fig. 2 which has the advantages of cheapness and simplicity. The operation of the circuit is shown in Fig. 3. E_1, E_2 and E_3 are the three voltages produced at the rotor terminals of the Magslip. Point by point addition of E_1 to a fraction of $-E_3$ produces the curve EA. Similar addition of E_2 and $-E_3$ produces EB. The maximum amplitude points of E_1 and E_2 are 120° apart and the effect of adding the fraction of $-E_3$ is to bring the maximum amplitude points of EA and EB closer together. By correctly adjusting the tap on the potentiometer R_3 the maxima may be shifted to make EA and EB exactly 90° apart. The above system provides a two-phase output which maintains the correct phase relationship from very low frequencies up to several thousand cycles per second.

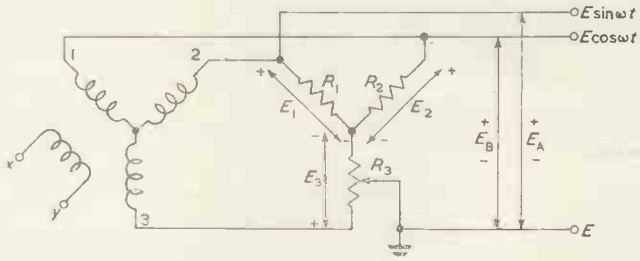

Fig. 2. Conversion of three-phase Magslip output to two-phase

Modulation of the Trace

So far only the production of a circular time-base has been considered and no means of modulation of the trace has been discussed. There are, however, several methods of modulating the trace, each having its own advantages and disadvantages.

The simplest type of modulation is a signal injected at the grid or cathode of the tube. This produces modulation of the brilliance only and gives no indication as to the

* *Craven Electronics Ltd.*

shape of the input waveform. There are several important uses of brilliance modulation such as the injection of time or position markers, but these are normally used in conjunction with radial deflexions of the time-base.

Injecting the modulating waveform in series with one of the time-base voltages results in a trace which is not radial and is generally of little use[2]. True radial deflexion may be achieved by several means. The final anode voltage of the tube may have the modulating voltage injected in series with it. This results in the sensitivity of the tube varying with the modulating signal and, therefore, the radius of the circular time-base. Quite a large modulating voltage is required for this method and arrangements must be made to modulate the anode used to focus the spot if the resulting trace is to remain undistorted.

A method due to Moss[2] offers a simple method of modulation, again providing a sufficiently large signal is available. In this method the signal is applied to a conducting area of graphite or similar material, painted on the centre of the tube screen in the form of a circle. An alternative is to use a tube with a post-deflexion acceleration electrode and apply the signal to this, which again requires a large voltage swing. Special tubes[3,4] have been

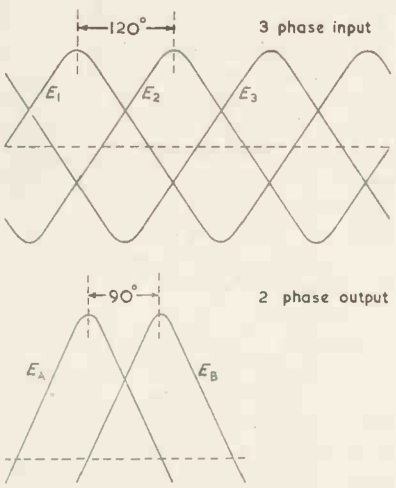

Fig. 3. Voltage relationships of Fig. 2

made with electrodes through the centre of the screen specially for use with radially modulated circular time-bases, but they do not appear to be readily available.

All the modulation systems described so far are independent of the time-base circuit producing the circular trace. The circuit about to be described has the disadvantage of complexity, but has the advantage of providing balanced push-pull signals to the deflexion plates and also radial modulation of the time-base. Fig. 4 is a simplified circuit from which the operation may be explained. The push-pull pentode amplifiers $V_1V_2V_3V_4$ are fed with 4 voltages 90° out of phase derived from a two-phase input via the two-phase splitter circuits. Each pentode has its screen grid connected to a common line terminating at the anode of a fifth pentode, V_5. The operating conditions of V_5 are chosen so that the quiescent anode voltage is correct for the screen grids of $V_1V_2V_3V_4$. An input signal at the grid of V_5 will cause the screen grid voltage of $V_1V_2V_3V_4$ to change by the appropriate amount and the change in screen voltage causes the gain of the amplifiers to change also. In this way the amplitude of the time-base deflexion voltages change accordingly and the electron beam deviates from its circular path. Radial modulation is thus obtained without using special cathode-ray tubes.

Complete Circuit

Fig. 5 is the circuit of a complete circular time-base with radial modulation designed on the simple circuit given in Fig. 4. The time-base input voltages are derived from a Magslip generator type AP10547. A simple transformer-rectifier unit is incorporated to provide rotor energization at about 2V d.c. Conversion of the three-phase output to two-phase is carried out as previously described and the correct displacement of the resultant two-phase output is adjusted by the potentiometer VR_4. V_2 and V_5 are phase-splitters which provide push-pull signals for the amplifier pentodes $V_{1\text{-}3\text{-}4\text{-}6}$. Although a.c. couplings are used in the time-base amplifiers, the output pentodes are d.c. coupled to the deflexion plates of the cathode-ray tube.

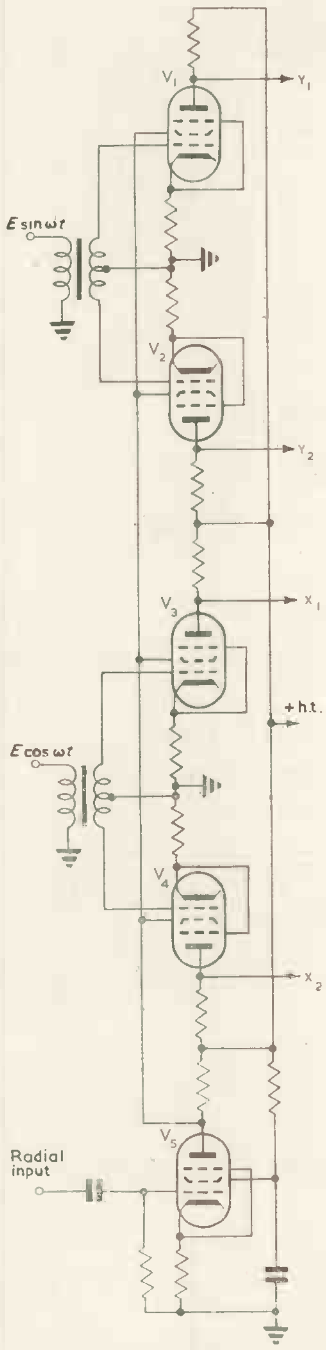

Fig. 4. Simplified radial modulator and circular time-base

Each output pentode has its screen grid connected via a variable resistor $VR_{1\text{-}2\text{-}6\text{-}7}$ to a common line which is taken to the modulating amplifier. The purpose of the variable resistors is to adjust the screen current of each pentode to the same value in order to provide perfect balance.

The modulation amplifier uses two double triodes V_7 and V_8. V_{7a} is a cathode-follower which drives V_{7b}. This in turn provides an amplified signal at the grid of V_{8a} which further amplifies and provides the driving signal for the cathode-follower, V_{8b}. The quiescent cathode voltage of V_{8b} is about 75V, sufficient to ensure that the pentodes are working in a linear manner even though their screen grid voltage may be swung through several volts about this point. As the radial modulation amplifier is d.c. connected and the time-base pentodes are also d.c. connected to the tube deflexion plates, slowly varying input voltages may be examined.

One disadvantage of using an alternator as the time-base supply voltage source is the fact that the output voltage decreases with the speed. This effect is overcome in this circuit by using a simple integrating network in the input to the phase-splitters. Using the values of resistors and capacitors shown, the circular amplitude of the trace will remain constant down to speeds of a few revolutions per minute. Adjustment of the circular amplitude is made by VR_3, the distortion being adjusted to zero by VR_8, which equalizes the effect of dissimilar deflexion sensitivities of the X and Y plates.

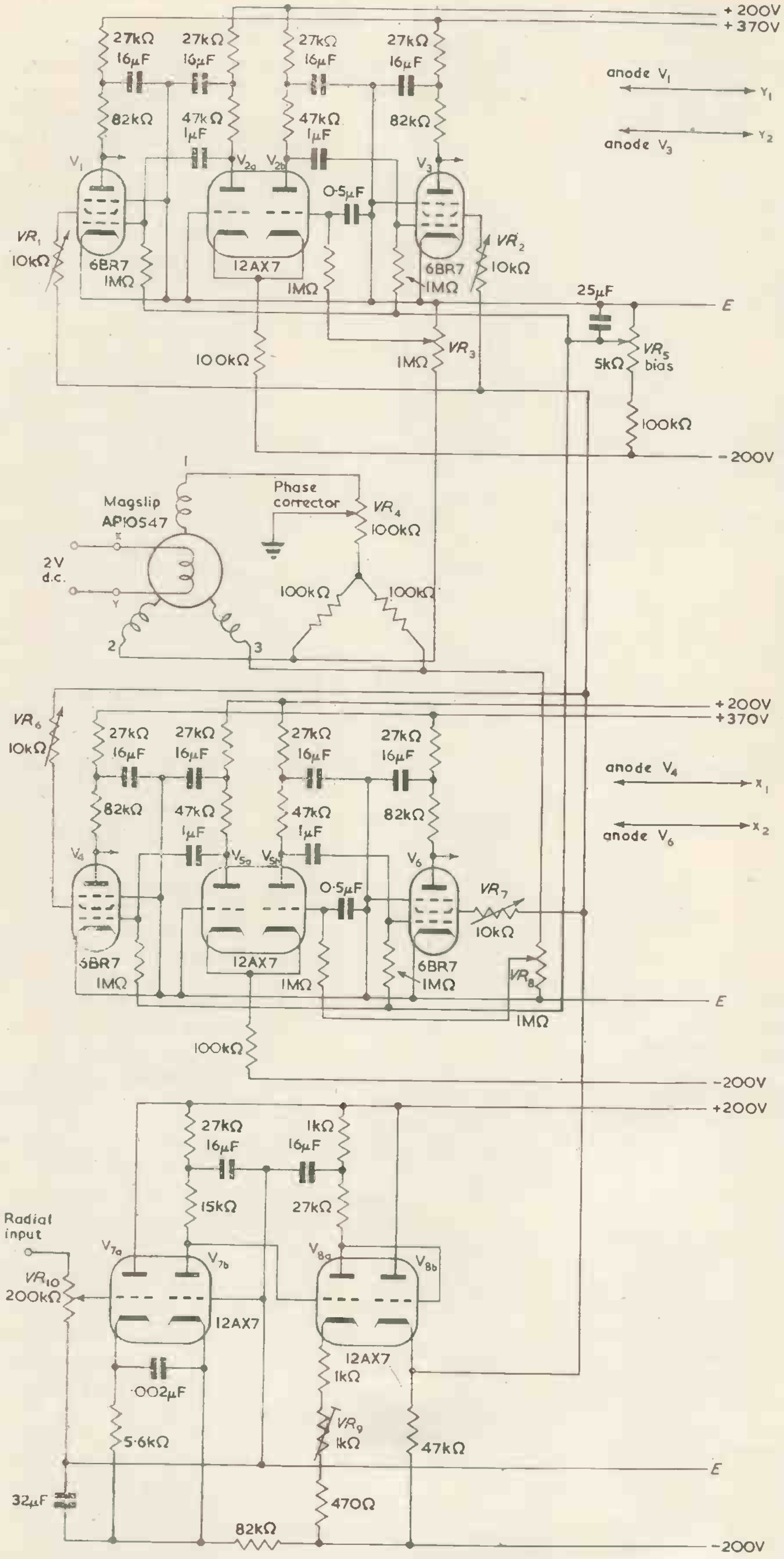

Fig. 5. Complete circular time-base and radial modulator

Uses of the Polar Co-ordinate Oscilloscope in Engineering

The chief attraction of the polar co-ordinate display is in the investigation of the performance of any type of rotating machinery. Pressure, displacement, angular position, etc., may be converted to electrical signals by suitable transducers. Among these are strain gauges, differential transformers, Magslips, commutators, variable capacitance and inductance transducers, etc. Auxiliary equipment such as pre-amplifiers, f.m. oscillators and frequency modulation detectors are often required as the signals received from the various transducers are often too small for direct use.

Machinery using cams for timing purposes, notably internal combustion engines, are readily adjusted if each timing cam is made to provide modulation of the circular trace. The cathode-ray tube screen may be divided into 360° and the alternator stator adjusted so that the spot tracing out the circle is in correct angular alignment with the machine under investigation. Deviations from correct adjustment are then readily observed by noting the angular position of the modulation signals on the trace produced by the operation cf the cams.

Pressure measurements under dynamic conditions are also readily made, the slope of the time-pressure curve as well as amplitude being simultaneously displayed. Several types of pick-up are available, the most usual being the strain gauge type, variable capacitance, variable inductance transducers and in some cases piezo-electric crystals. All suffer from various disadvantages, low level signals from the strain gauge requiring amplifiers with a gain of up to 10^5, temperature effects with the capacitance and inductance types and the extremely high output impedance of the crystal renders it very prone to picking up spurious signals from mains supplies, etc. Against these disadvantages, the strain gauge may be made to be very stable and the remaining three transducers are capable of delivering large output signals when used with suitable auxiliaries. Attree[5] has described an f.m. oscillator-amplifier which is especially useful with capacitance type transducers as its frequency response is linear from d.c. up to several thousand cycles per second and means are provided for eliminating the effect of the coaxial cable used to connect the transducer to the instrument. The sensitivity is high and very little amplification is required.

One unusual application of the polar co-ordinate oscilloscope with which the writer has been associated is the inspection of large thermo-plastic pre-forms before moulding. The pre-forms are required to be of uniform density throughout, as any variation in density results in a useless product after moulding, which, of course, is not recoverable. Inspection in the pre-moulded form enables incorrect pre-forms to be sent back to the mixing mill and re-made.

The pre-forms, circular in shape, are placed on a rotating table. Also driven from the table are a Magslip to provide the time-base supply and a lead screw arranged to carry a simple capacitor plate across the table. The lead screw has a potentiometer attached to one end via a gear train, so that the excursion of the capacitor plate from the centre of the table to the edge causes the potentiometer slider to travel from one end to the other of the track.

Initially, the capacitor plate is over the centre of the pre-form and the potentiometer at zero. This causes the circle on the cathode-ray tube to appear merely as a spot as the potentiometer controls the circular amplitude. As the table rotates the spot traces out a spiral path which actually appears to be an expanding continuous circle. The capacitor plate detects changes in density due to variations in the amount of the dielectric immediately below it and the resultant capacitance changes are converted to voltage changes in a circuit similar to that in ref. 5.

Fig. 6. Pattern on cathode-ray tube screen, showing effect of faulty pre-form

The circular time-base is brilliance modulated by injecting into the grid of the tube and a typical pattern on the long persistance screen is shown in Fig. 6. A good pre-form gives no bright or dark patches and faulty ones may easily be detected and salvaged.

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VIAC

A Variable Interval Automation Controller

By M. L. Klein*, H. C. Morgan*, and J. R. Wood*

The utilization of high speed oscillographs as recording media requiring time durations of up to two minutes requires that some means of paper conservation be employed. This is due to the paper capacity of the instrument and the necessity of obtaining high frequency information at different periods during the record duration.

To fulfil this requirement the Variable Interval Automation Controller was designed and fabricated. The unit allows four discrete time intervals to be preset to obtain a sequential operation. Three of the intervals can be set in steps of one second increments up to a total of sixteen seconds per interval. The third interval is set in increments of four seconds to a total of sixty-four seconds. Automatic indexing from the second and third interval to the fourth interval is provided. The unit can be operated remotely by a 24V actuating signal or locally by a switch on the front panel.

THE investigation of high frequency transient phenomena requires the application of a system whose bandwidth is large compared to the fundamental frequency involved. In this application a high speed cathode-ray recording oscillograph is used that has a magazine paper capacity of approximately 300ft. Since record durations of upwards of one minute were experienced it became necessary to devise an automatic sequential system to control the actual running time of the recording system so that only those times of particular interest would be recorded, thereby conserving paper and still obtaining all vital information.

With this requirement in mind the VIAC was developed

* *North American Aviation, Inc.*

Fig. 1. Programme

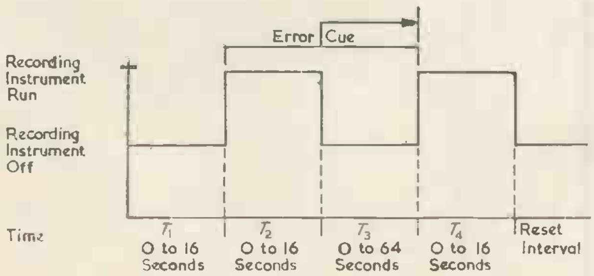
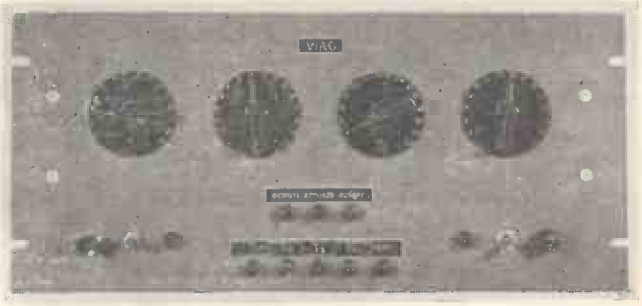


Fig. 2. Front panel of VIAC



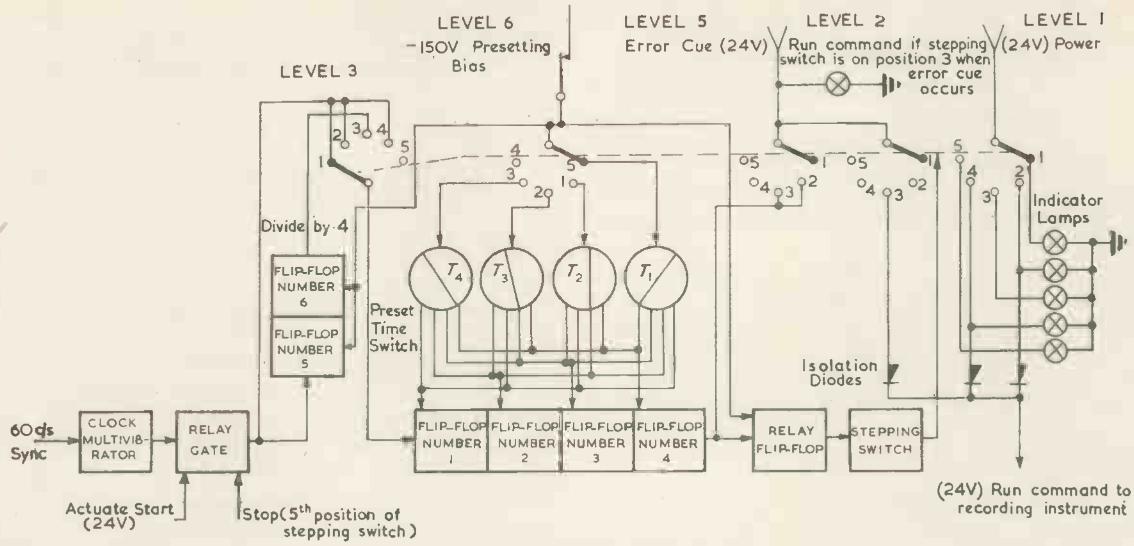
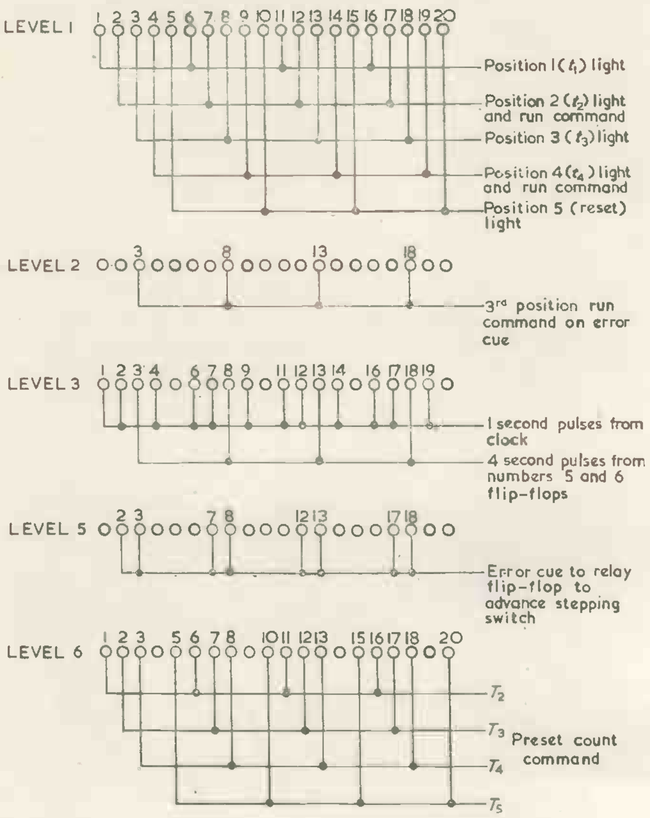


Fig. 3. Block form of operation

with the basic control sequence as depicted in Fig. 1. The programme consists of four discrete periods, T_1 being a delay period with one second settings from zero to sixteen seconds. At the end of period T_1 the VIAC indexes to period T_2 and starts the recording system at a preset speed and continues this operation for the time set into T_2 whose range is zero to sixteen seconds in steps of one second. Upon the completion of T_2 indexing is accomplished to T_3 which is a non-recording period adjustable in four-second steps from zero to sixty-four seconds. At the end of T_3 indexing again occurs and period T_4 is begun which returns the recording system to an operating condition at the same speed that occurred in period T_2. T_4 is continued for a preset period set up in one second steps from zero to sixteen seconds. After T_4 has completed its period indexing is accomplished to the reset interval. When the programme has completed its sequence and rests in the reset period it cannot be initiated again until the VIAC has been manually reset.

To ensure that all pertinent information is recorded an error or cut-off signal is incorporated in the unit such that, if cut-off occurs during period T_2, automatic indexing occurs which transposes the sequence to T_4 causing the recording to continue for the period of T_4. If cut-off occurs in period T_3, which is a non-recording period, automatic

Fig. 4. Wiring of stepping switch levels



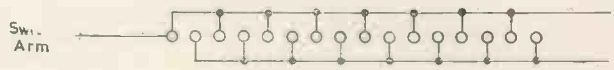
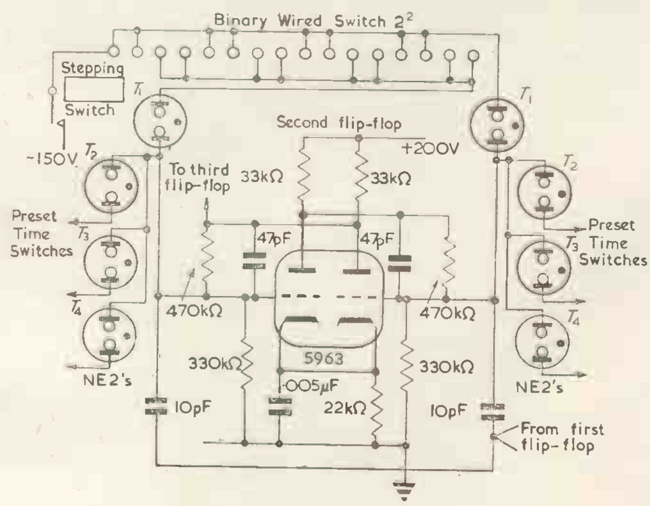


Fig. 5. A binary wired switch

Fig. 6. Preset circuit, second flip-flop



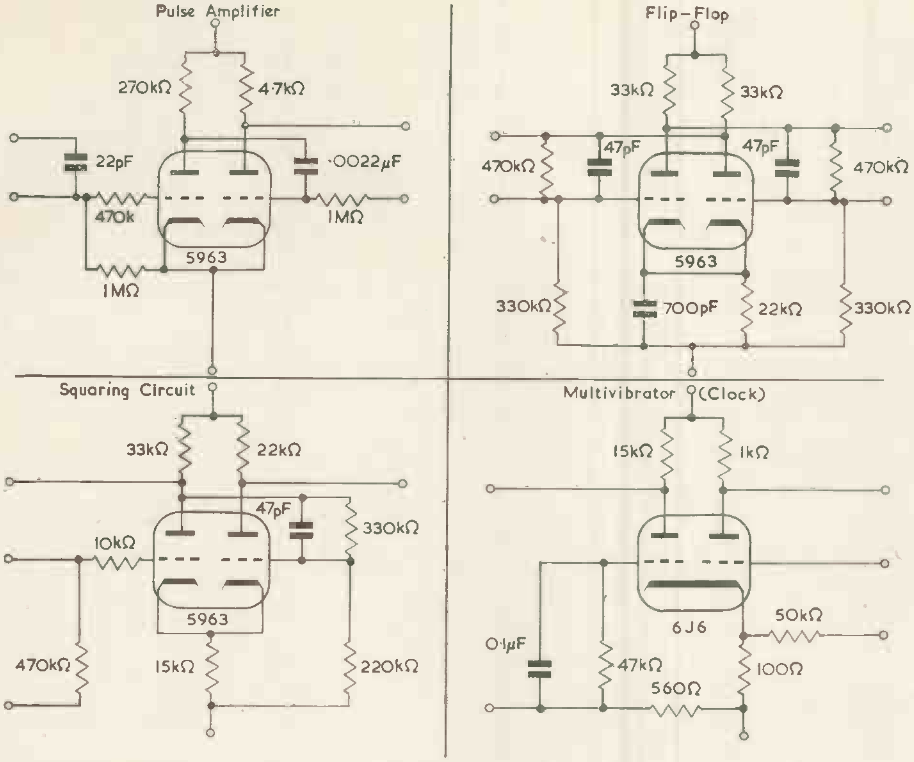


Fig. 7. Plug-in circuits

Fig. 8. Component parts of plug-in unit

indexing again occurs to period T_4. Operation is instigated by an external 28V step function which electrically locks the system in such a way that any other signal or a re-occurance of the step function will have no further effect on the sequence. The error or cut-off signal is another external signal consisting of a 28V step function. A manual switch on the front panel is provided to allow the programme to be initiated manually.

The instrument has been constructed for standard rack mounting with all controls located on the front panel. VIAC is illustrated in Fig. 2 which shows the four selector switches on which the various selected time intervals are preset. Indicator lights on the front panel show the progress of the programme and the initiation of the actuate remote, cut-off and reset pulses.

Fig. 3 shows in block form the operation of the unit. A synchronized free-running multivibrator clock emits one second pulses which drive the logical circuits. These pulses are fed through a relay gate and a mechanical stepping switch to the flip-flop counting circuits. The preset count on the indicating switches are placed into the counting circuits in complement. When the required number of pulses has been fed into the flip-flops from the clock a pulse is emitted which is fed to a monostable flip-flop that contains a pilot relay in its anode circuit. This relay actuates the stepping switch, indexing to the next timing period, resetting the flip-flops and placing the complement of the next period into the counting circuit. A cueing signal is wired through the second and third intervals of the stepping switch to allow indexing of the stepping switch to the fourth interval on an error or cut-off signal. Another level of the stepping switch supplies current to the output when the error signal comes in the second period to ensure continued operation of the recorder during bridging of the third period T_3. The wiring of the stepping switch levels is shown in Fig. 4.

For ease of operation and setting the preset count is set in binary wired, decimally numbered switches, using one switch level for each bit. Typical wiring of such a switch is shown in Fig. 5, and the resetting of the flip-flop counters to a preset number is indicated in Fig. 6.

Since the third interval has four second increments it is necessary to transfer the clock pulses to a divide by four circuit which then feeds the flip-flop counter at the rate of one pulse each four seconds. This transfer is accomplished by appropriate wiring on one level of the stepping switch.

It should be noted that the stepping switch can be replaced by appropriate "and" circuits to institute memory so that an all electronic device is obtained to allow high clock rates. The existing electro-mechanical unit will operate at clock rates of up to 10p/s which reduces the timed periods proportionately.

The inherent accuracy of the VIAC is plus or minus one second which occurs in the first T_1, plus the stability of the

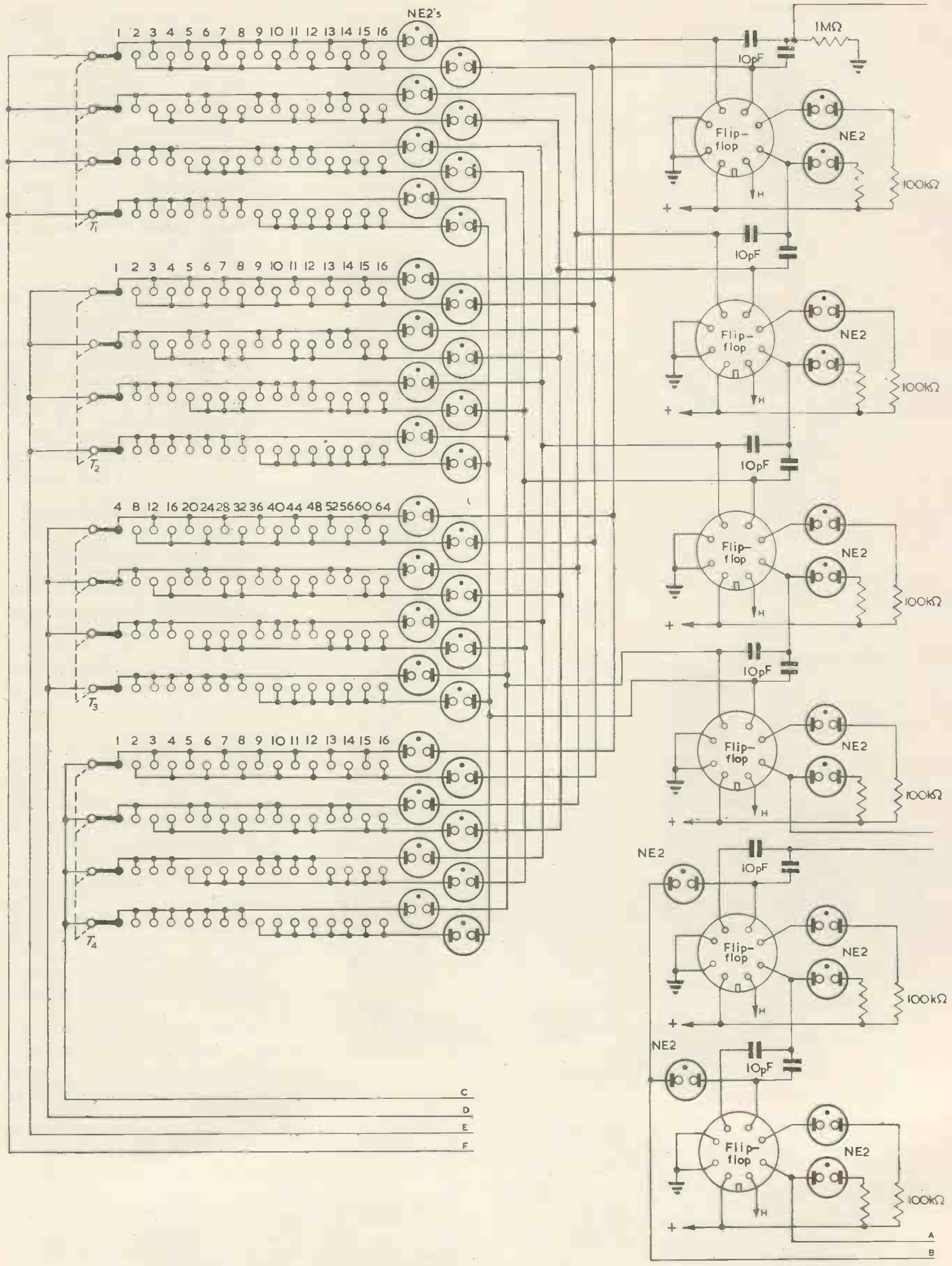


Fig. 9(a). Binary wired switches

(*Continued on Fig. 9(b)*)

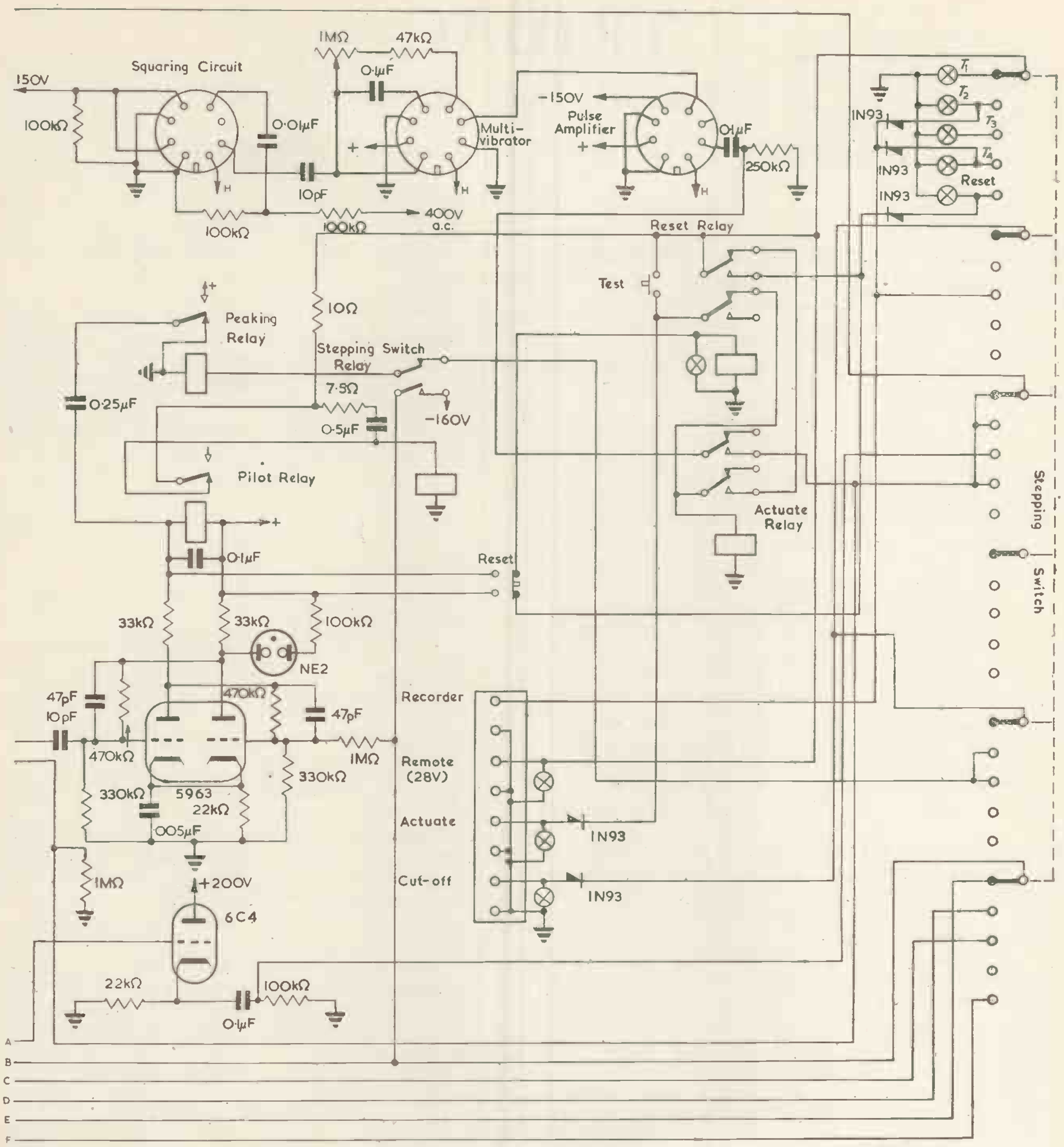


Fig. 9(b). Binary wired switches

(*Continued from Fig. 9(a)*)

clock. It is quite apparent that, since the actuate pulse appears at a random time compared to the clock pulses, a maximum error of one second is possible.

The physical set-up procedure and operation is as follows: determine the time periods desired, T_1, T_2, T_3 and T_4 and set these periods into the VIAC with the unit setting in the reset condition. Depress reset button which prepares circuit to await actuate pulse. Upon receipt of the actuate pulse the unit will begin its sequence and furnish no output voltage in period T_1, 24V output in T_2, no voltage in T_3, 24V in T_4, and shut off completely in reset. If error signals are present in either period T_2 or T_3, indexing to T_4 will occur.

Plug-in Construction

In VIAC plug-in construction has been used wherever possible. Fig. 7 shows some typical plug-in circuits, while Fig. 8 shows the construction of one unit. These are assembled separately, the elements sprayed with suitable protective coating and mechanically contained in a die cast aluminium housing. The advantages of such construction allowing rapid building of experimental as well as production equipment are evident although the circuits possess a somewhat higher stray capacitance than the same circuits in an optimal layout. Fig. 9 is a schematic drawing of the circuit.

TRIDAC

A Research Flight Simulator

By J. J. Gait*, M.A., B.Sc., A.M.I.E.E., A.Inst.P., and J. C. Nutter†, M.A.

(Part 2)

The Introduction of Variable Derivatives and Parameters

The variation of the aerodynamic derivatives with incidence or with the component velocities u, v, w is covered as in the following example. If in the force component $(\partial Y/\partial v) \, . \, v$ the derivative $\partial Y/\partial v$ is not a constant, but a function of, say u and v, for a given altitude, then one may write:

$$(\partial Y/\partial v) \, . \, v = Y_{vo} \, . \, v(1 + a_1 u + a_2 u^2 + \ldots) \times (1 + b_1 v + b_2 v^2 + \ldots)$$

where in practice a sufficient approximation to the non-linearity is obtained by using only the first few terms in the power series expressions. Such power series corrections to $Y_{vo} \, . \, v$ may be obtained by passing the analogue voltage for $Y_{vo} \, . \, v$ though arrays of linear potentiometers carried on shafts which are servo-driven to follow u and v.

The variation of the aerodynamic derivatives with altitude is covered by first computing the forces and moments as though the missile were at sea-level and then correcting for altitude by multiplying them by p/p_o, where p is the atmospheric pressure at the altitude considered and p_o is the atmospheric pressure at sea level. This is achieved using an array of linear potentiometers driven via a cam cut to represent the variation of p/p_o with altitude and servo-driven from an input signal representing altitude. Further, under conditions of varying altitude the variables u, v, w, p, q, r are replaced by u'', v'', w'', p'', q'', r'' where $u'' = u \, . \, (a_o/a)$ etc. and a_o/a is the ratio of sound velocity at sea level to that at height. Again the factor a_o/a is introduced by an array of potentiometers driven via a cam cut to represent the variation of a_o/a with altitude and servo-driven from an input signal representing altitude.

It will be noted that u, v, w can vary rapidly with incidence, whereas p/p_o and a_o/a can only vary slowly with altitude. Consequently the u, v, w arrays of potentiometers require fast hydraulically powered servo systems whereas the p/p_o and a_o/a arrays of potentiometers require only relatively slow electrically powered servo systems.

If the missile is powered, and is not simply a coasting dart, then its mass changes during flight as fuel is consumed. Associated with this change of mass there are changes in the moments of inertia and in the position of the missile centre of gravity. The rate of consumption of fuel may usually be regarded as a predetermined function of time so that parameters such as thrust (T), mass (m), moments of inertia (A, B, C) and the centre of gravity position may all in turn be regarded as predetermined functions of time and their variations may, therefore, be fed into the simulator in this way.

Axis Transformation

There are three approaches to the problem of axis transformation, which may for present purposes be described as the "direction-cosine system", the "gimbal or flight table system" and the "synthetic gimbal system". These are considered in turn and compared in order that the method used on TRIDAC may be seen in its correct perspective.

(a) The Direction-Cosine System

The relevant direction-cosines are defined as the projections of unit vectors lying along a set of axes (x_e, y_e, z_e) fixed in the earth on to the principal axes (x, y, z) of the missile. We thus have for x_e, y_e and z_e the direction-cosines (l_1, m_1, n_1), (l_2, m_2, n_2) and (l_3, m_3, n_3) which at any instant

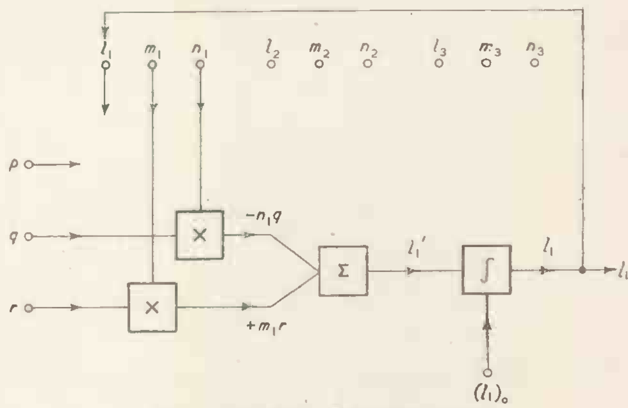


Fig. 10. Derivation of direction cosines

may be determined, from known initial values of the direction-cosines $(l_1)_o$ etc., and the missile's angular rates p, q, r about its own axes, using the following expressions for the rates of change of the direction cosines:

$$l_1' = m_1 r - n_1 q \qquad l_2' = m_2 r - n_2 q \qquad l_3' = m_3 r - n_3 q$$
$$m_1' = n_1 p - l_1 r \qquad m_2' = n_2 p - l_2 r \qquad m_3' = n_3 p - l_3 r$$
$$n_1' = l_1 q - m_1 p \qquad n_2' = l_2 q - m_2 p \qquad n_3' = l_3 q - m_3 p$$

Fig. 10 shows how the direction-cosines may be derived in an analogue computer. Once the direction-cosines are available transformations between missile and earth axes may be made as in equations:

$$x_e = l_1 x + m_1 y + n_1 z \qquad x = l_1 x_e + l_2 y_e + l_3 z_e$$
$$y_e = l_2 x + m_2 y + n_2 z \quad \text{or} \quad y = m_1 x_e + m_2 y_e + m_3 z_e$$
$$z_e = l_3 x + m_3 y + n_3 z \qquad z = n_1 x_e + n_2 y_e + n_3 z_e \qquad \ldots\ldots\ldots\ldots\ldots (4)$$

Fig. 11 shows in schematic form how a transformation of this sort would appear in a simulator.

(b) The Gimbal or Flight Table System

An alternative method of defining the missile attitude and of achieving the necessary axis transformations is to consider the missile as mounted in a set of orthogonal gimbals such as those of Fig. 12. The missile attitude is uniquely defined in terms of the various angles of the gimbal frames. Ideally, only three gimbals are required, but in order to avoid mathematical singularities, corresponding to a condition of "gimbal lock", a fourth gimbal, referred to as the "redundant gimbal" is used to carry the other three and it is orientated in such a way that this difficulty of singularity or lock can be avoided. (The phenomenon of "lock" also occurs in gyroscopes and a free or datum gyro will "topple" when the gimbals holding it take up the attitude

* Royal Aircraft Establishment
† Elliott Bros. (London) Ltd.

in which the spin axis of the rotor coincides with one of the gimbal axes.)

If the gimbals and their angles relative to their mountings are denoted as follows (from outermost to innermost): redundant yaw Z_r, pitch Y_g, true yaw Z_g and roll X_g; then the attitude of the missile relative to the earth (i.e. the values of Z_r, Y_g, Z_g, X_g) is determined by the initial attitude (i.e. the initial values of the gimbal angles, say Z_{ro}, Y_{go},

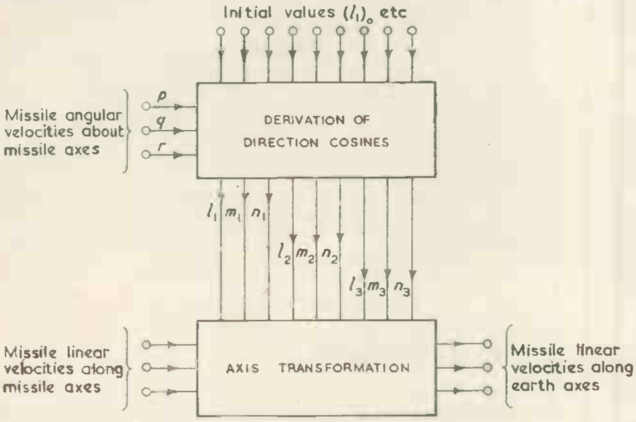


Fig. 11. Direction cosine system simulation

Fig. 12. Gimbal system

Z_{go}, X_{go}) and the subsequent angular motion as given by the missile angular rates p, q, r. The necessary rates of angular movement of the gimbals, for the above order of gimbals, may be expressed as follows:

$$X_g' = p + \cos Z_g \sin Y_g \,.\, Z_r' - \sin Z_g \,.\, Y_g'$$
$$Y_g' = (q \cos X_g - r \sin X_g - \sin Y_g \sin Z_g \,.\, Z_r') \sec Z_g$$
$$Z_g' = q \sin X_g + r \cos X_g - \cos Y_g \,.\, Z_r' \qquad \ldots\ldots\ldots\ldots\ldots (5)$$

where the redundant gimbal (Z_r) is moved in some predetermined fashion simply to avoid locking of the other gimbals.

The transformations between earth axes and missiles axes are again as in equations (4), but the direction cosines l_1, m_1, etc. are now known as functions of the gimbal angles X_g, Y_g, Z_g and Z_r. Thus, for example, n_1 for the stated order of gimbals, is given by:

$$n_1 = \sin X_g \cos Z_g \sin X_r + (\cos X_g \sin Y_g + \sin X_g \sin Z_g \cos Y_g) \cos Z_r \qquad \ldots\ldots\ldots (6)$$

with similar expressions for the other direction cosines.

Missile attitude representation may, therefore, be achieved by the actual construction of a set of gimbals, each gimbal being servo-driven relative to its outer neighbour, from a known initial position, according to the relationships of equations (5). Axis transformations may then be achieved using sine and cosine resolvers mounted on the gimbal shafts to fabricate the direction-cosines, as typified in equation (6). Fig. 13 shows the appropriate schematic. Such a device has the advantage that it can be made into more than a computing element by arranging that the innermost gimbal carries a platform or table. This table will always assume the attitude relative to the earth that a corresponding table rigidly mounted in the missile would assume. If, therefore, the simulation is carried out on a 1 : 1 time scale, instruments can be mounted on the gimbal table, or flight table, and they will then be subjected to the same angular motions as would occur in actual flight.

The order of gimbals used in the above discussions is only one of 12 practical gimbal arrangements, and this particular order has been selected on the grounds that the outermost gimbals, which have to carry the inertia of the innermost gimbals, should be those for which the lowest rate of response is required.

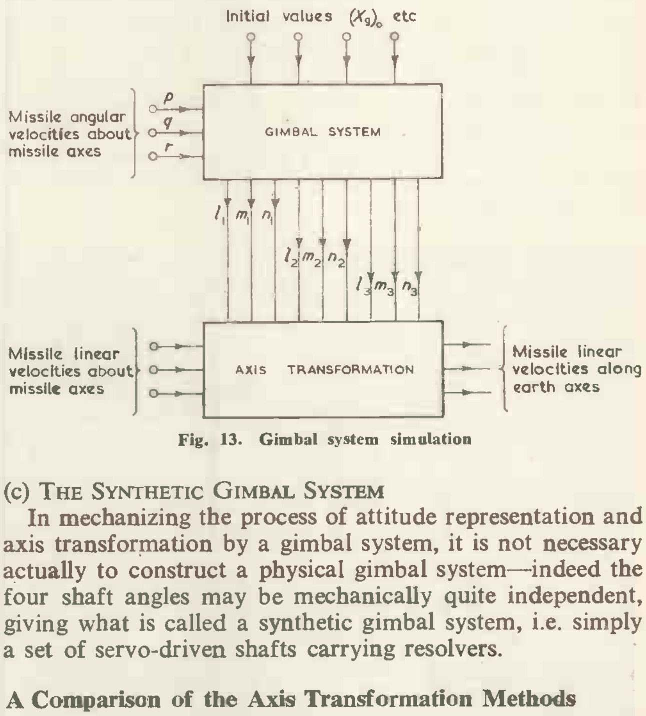


Fig. 13. Gimbal system simulation

(c) The Synthetic Gimbal System

In mechanizing the process of attitude representation and axis transformation by a gimbal system, it is not necessary actually to construct a physical gimbal system—indeed the four shaft angles may be mechanically quite independent, giving what is called a synthetic gimbal system, i.e. simply a set of servo-driven shafts carrying resolvers.

A Comparison of the Axis Transformation Methods

The direction-cosine system (a) has the merit of mathematical simplicity. The direction-cosines themselves, however, have no physical significance in the real system, so that this method offers nothing other than the transformation itself.

The flight-table system (b), in addition to providing the means of axis transformation, also provides a platform on which missile instruments may be mounted and incorporated in the simulator. Further, the actual angles of the gimbals carrying the table can have close analogies with the missile system. Thus, if under certain conditions the order of the simulator gimbals is the inverse order of the gimbals of a missile-borne gyro, then the simulator gimbal angles correspond to the gimbal angles of the real gyro. The construction of such a flight table with a useful load carrying capacity for guided missile work is, however, a major engineering undertaking, in view of (1) the very high response rates required to simulate the missile motion in real time, (2) the high accuracy of simulation required in the axis transformations and (3) the rigidity required of the gimbal frames. The physical size of the outer gimbal would have to be about 6ft diameter in order that the inner gimbals together with their servo drives and the volume of the "table" could be accommodated inside.

With the synthetic gimbal system (c) no flight table can be attached, but the problem of making the servos operate fast enough for real time scale simulation is greatly eased, since each shaft may be directly driven from a rigid stationary base and the only load to be carried is that of the resolvers themselves. The valuable analogy of the gimbal angles to missile borne gyro angles is retained, with the added advantage that the order of the gimbals may be readily changed to suit the simulation of the angles of the gimbals of various gyro configurations.

It will be noted that, with all three systems, a limited number of variables (the direction-cosines or the sine/cosine of the gimbal angles) are used again and again to give products with a wider class of variables (the quantities to be transformed from one set of axes to another). Analogue multiplication, under such circumstances, is most readily carried out if servo-driven shafts are used to represent the limited number of variables and the necessary products with the wider class of variables is obtained by means of arrays of potentiometers, linear or of the sine/cosine variety, carried by these shafts. If this technique is applied to the direction-cosine method, then nine servo-driven shafts are required, corresponding to the nine direction-cosines. If, on the other hand, a gimbal method is employed only four servo-driven shafts are required, corresponding to the four gimbal angles.

Fig. 16. Sine/cosine unit

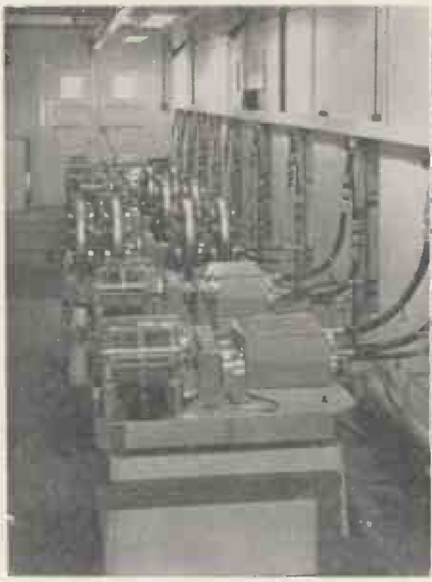


Fig. 14. Hydraulic servos

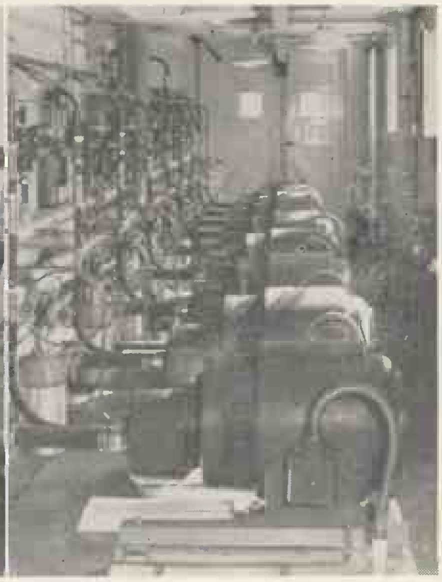


Fig. 15. Hydraulic pumps

There is, therefore, much to commend a synthetic gimbal method and this is the system which is used on TRIDAC. Should a flight table ever be necessary, then this could act simply as a slave which follows the synthetic system so that the danger of the table performance jeopardizing the major computations is avoided, no resolvers need be carried and there is a general easing of the flight table design problem.

The TRIDAC synthetic gimbal system consists of a set of four hydraulically powered servos, each of which drives via a "swash-plate" sine/cosine linkage two sets of 12 wipers, each with a travel of 2in along linear potentiometer elements. Fig. 14 shows the TRIDAC servos—four for the synthetic gimbal system and one for each of the velocities *u*, *v*, *w*, and two general purpose resolving servos. Fig. 15 shows the set of nine high pressure oil pumps used to drive the servos, Fig. 16 the swash-plate mechanism.

TRIDAC Monitoring Systems

Power Supplies

All the main electrical power supplies for the machine, totalling some 600kVA, are generated locally in a room set aside for this purpose and thence distributed throughout the machine. To protect the generating machinery, main fuses are installed at the distribution points. It is possible, however, for power faults to occur in the equipment which, while not producing sufficient overload current to destroy a main fuse, may nevertheless cause substantial damage to individual units. As an alternative to the use of many hundreds of small fuses a system of power protection has been employed which operates individually on ten groups of four cabinets each. Such groups are referred to as "rafts" because of the mechanical form of construction. Each incoming supply is monitored continuously in voltage or current or both by magnetic amplifier and relay circuits and, in the event of undue changes occurring, relays operate causing the affected supplies, or if necessary the whole of the supplies, to that raft to be switched off at source. To facilitate subsequent rectification of the fault, a system of indicator lamps is incorporated which shows the type and approximate location of any fault causing automatic shut-down.

The high-tension supplies to the computing bricks are derived from numerous small stabilizer units situated in each raft and driven by "raw" d.c. supplies from the generator room. Each high-tension stabilizer works with reference to a central master voltage reference cell and gives an output current sufficient to operate, on the average, four computing units. The voltage levels and ripple contents of the outputs of the stabilizers may be monitored by circuits employing uniselectors to scan successively all the stabilizers in each raft. Should the voltage level of any stabilizer be outside a preset tolerance or the ripple in excess of a preset amount then warning lamps are energized which indicate the type of fault and the precise location of the stabilizer at fault.

(a) Functional Monitoring

Should a computing element in an electronic analogue machine fail to function correctly then in many cases the only evidence of this failure lies in the fact that an incorrect solution to the problem under simulation is obtained. With a very large machine, such as TRIDAC, the danger that a computing fault may pass unnoticed is a very real problem. Test problems, with known solutions, can be employed from time to time to check the machine or parts of it. This, however, is not an efficient method of locating the faults and an incorrect test solution throws doubt on all the solutions obtained since the previous correct test solution. Automatic fault location in the computing elements, that is functional monitoring, is therefore desirable, but if carried too far would lead to a situation in which the monitoring equipment would be more complicated and more prone to faults than the computing equipment it is supposed to monitor. For TRIDAC, an automatic functional monitoring system has been developed which will detect all but the more improbable types of faults in the high-gain, drift-stabilized, directly-coupled amplifier circuits.

Drift Monitoring

When working normally, the computing amplifiers have a potential of only a few millivolts at the input grid of the first stage. Among other faults, failure of the drift stabilization system leads to a greater voltage at this critical point. By monitoring this point in each amplifier, faults can be detected, as a voltage in excess of say 5mV, and a system of warning lights brought into action. The warning system is such that the location of faulty units is permanently displayed. In order to minimize the bulk and fault liability of the monitoring system this consists, as in the case of the stabilizer monitoring, of circuits employing uniselectors which can scan through all the amplifiers in about 90 seconds and register all the faults found.

(b) Overload Monitoring

Despite the fact that all units are working normally, an incorrect solution will be obtained if any computing amplifier is driven beyond its working range of ±30V output by the inadvertent application of an excessive input signal. As it is not always possible to assess in advance the signal levels throughout the machine, an automatic monitoring device is necessary. To meet this need the output from each computing amplifier is continuously compared with stable +30V and −30V references and, in the event of the output exceeding these limits, a relay is operated which gives warning of the occurrence. The warning system indicates the polarity of the over-loading signal and the location of the amplifier in which it has occurred. It is then usually necessary, by rescaling or otherwise, to reduce the signal levels in this part of the computer.

Note

A possible source of trouble in the main monitoring systems described above could be a failure of the many warning and fault locating lamps. Should any of these fail then faults detected by the monitoring system would not be displayed and confidence in the system would be lost. To cover this point the lamps are all so wired that, by the throw of a single switch on each raft, all the warning lamps on that raft can be simultaneously energized and hence checked.

Subsidiary Monitoring

In addition to the three main systems a variety of monitoring devices is used to ensure the correct operation and safety of the electro-mechanical and hydraulic equipment. Thus warnings are given, and in certain cases equipment is immobilized, if oil temperatures or pressures exceed certain limits or if adjustable gear ratios in various parts of the machine are not all set to compatible values. The automatic resetting and zeroing equipment of the mechanical servos is monitored to ensure that, at the start of each solution, the servos do start from the correct initial conditions.

Future Developments

Simulators are rarely static in their design and as the needs of the problems change so modifications and extensions to the appropriate simulators are made. In the immediate future TRIDAC will probably undergo such modifications and extensions, but in looking to the future it is of more general interest to speculate on the form that the large simulators of the next decade may take.

Electronic analogue machines now seem to be developed to the stage where the speed of operation is adequate for a real time scale simulation of most problems, but where any further improvement in accuracy is going to be rapidly more difficult. Individual units for addition, integration, etc., can now be easily made such that the errors are always less than 1 per cent of full scale; with considerable attention to detail and with rather more elaborate designs these errors can be reduced to 0·1 per cent of full scale as in TRIDAC. At this level the accuracy is limited by the absolute accuracy and stability of electronic components and the task of obtaining and maintaining large numbers of components to a higher order of accuracy and stability is unattractive. As against this accuracy barrier the analogue machine has the virtue of operating in accordance with a very simple set of rules or logic. Thus a given problem can be set up by simply inter-connecting units for each of the basic mathematical operations, such as addition, integration, etc., in the appropriate sequences. Having once formulated his problem the physicist or engineer can immediately set it up on an analogue machine, without the services of any intermediary specialist, and he can then use the machine as a working model of the system he is studying.

On the other hand, the digital type of machine, being independent of the absolute values and stability of electronic components, can already achieve an accuracy several orders greater than the analogue machine. The present-day digital machines are, however, unsuitable for the simulation of many problems for the following reasons:

(1) The serial form of operation leads to excessively long solution times.

(2) They require that each problem for solution be "programmed", i.e. reduced to a series of very simple numerical operations. This is a task for a specialist and the programming process destroys the valuable model aspect of a simulator.

(3) The inclusion of real parts of the system under study into the machine is not possible in the absence of fast and accurate analogue/digital convertors.

The authors' views are that the ideal simulator should attempt to combine the simple logic of the analogue type of machine with the high accuracy of the digital type of machine. This might be achieved by very fast acting digital units designed to carry out the basic mathematical operations of addition, integration, etc., and arranged such that they could be inter-connected according to the logic of the analogue type of machine. With continuing development the digital machines are becoming faster in operation and various analogue/digital convertors are under development so that it is feasible that the large simulators of the next decade might be of this mixed analogue-digital type.

Acknowledgments

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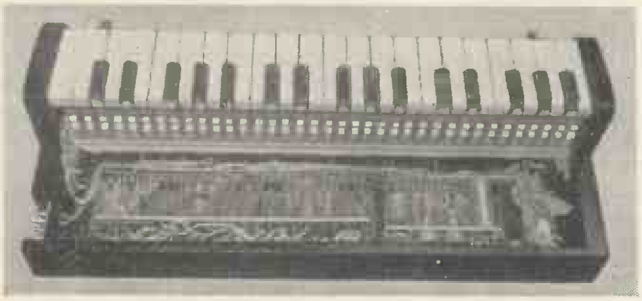
The Univox

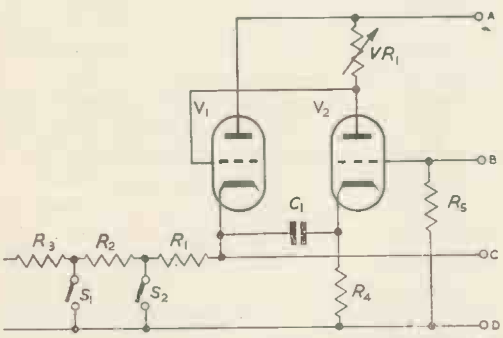
By Alan Douglas, M.I.R.E.

The demand for small melodic instruments capable of producing tones imitative of their orchestral counterparts continues unabated. This circuit has many unusual features and exceptional constancy of tuning.

WHEN the Hammond Solovox[1] was introduced prior to the war, a new field of musical expression was created. This instrument has remained unchanged except for the introduction of a variable inductor and fixed capacitors[2] in place of the fixed inductor and variable capacitors. This circuit also forms the solo pedal generator of the new Hammond RT2 organs[3]. It is outstandingly stable as regards



Interior of keyboard unit, showing layout of circuit components and valves.



(a)

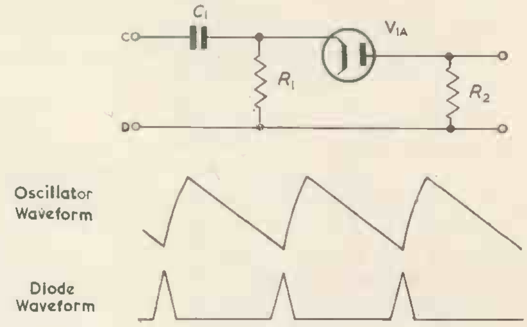
Fig. 1(a). Oscillator circuit

tuning, so much so that there is not even any need for control of the h.t. line voltage.

Shortly after the war, M. Constant Martin produced an unsymmetrical multivibrator[4] which forms the basis of the well-known Clavioline. This has been described in this journal[5] and the latest circuit, with improved frequency dividers due to H. Bode, is given in full elsewhere[2].

While it is true that many very acceptable imitative tones can be synthesized from a pulse or an approximately square wave by a subtractive process, the fact that the harmonic series is irregularly disposed always results in the tones having a somewhat "stringy" nature. This applies more particularly to extremes of the keyboard where the range is almost outside that of the formant circuits.

It has long been known that a sawtooth waveform is superior from the point of true fidelity. In such a wave, the required harmonics are not only all present, but present in their correct proportions. Cost is a most important factor in producing this kind of instrument, and it is not easy to find a simple sawtooth generator in which the required pitch can be covered by manipulating one variable circuit element only. One might, of course, suggest a thyratron, but in spite of the obvious attractions of such an oscillator, the well-known vagaries of this type of gas tube preclude



(b)

Fig. 1(b). Diode shaper circuit

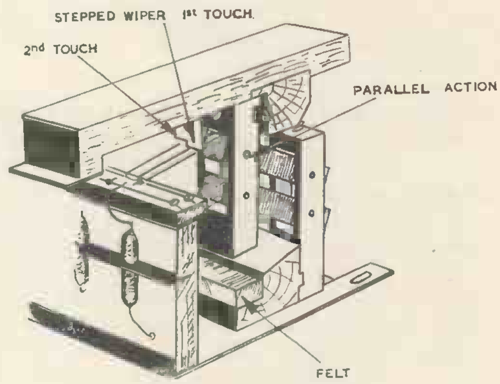


Fig. 2. Key construction

its satisfactory application commercially; there is not a single gas tube generator on the market in any country.

British Patent 722430 discloses a very simple hard valve sawtooth generator, in which the capacitor is charged extremely rapidly and discharged slowly, in contrast to the more usual practice of rapidly discharging the capacitor. Fig. 1(a) shows the elements of the circuit. The double triode valve has a series of cascaded resistors, $R_1R_2R_3$ etc., in the cathode circuit which can be connected at will to discharge the capacitor C_1 via the cathode resistor R_4 of the second half of the triode. For example, by closing contact S_2 resistor R_1 is introduced into the circuit, while if S_2 is closed instead, resistors R_1 and R_2 are placed in series with the first cathode and so the closing of additional contacts to the left of any one closed contact do not affect the resistance connected in this cathode circuit.

The second anode has an adjustable load resistor VR_1 and there is a fixed resistor in the cathode circuit of V_2. The grid of this valve is returned by resistor R_5 to D, thus making this grid negative with respect to the cathode. The grid of V_1 is directly connected to the anode of V_2. Terminal A is +h.t. and terminal D −h.t.

The circuit works in the following manner. At the beginning of each cycle the capacitor is in a discharged condition, and current flows through V_1 to charge it. This charging current flows through the discharge resistor thereby producing a potential difference between the cathode of V_2 and −h.t., such that the cathode is positive with respect to that grid. As the grid of V_2 is electrically connected to −h.t., this has the effect of making this grid negative with respect to its cathode, so reducing its anode current. The result of this is to reduce the voltage drop across the anode resistor, so making the first grid more positive, thus speeding up the charging of the capacitor.

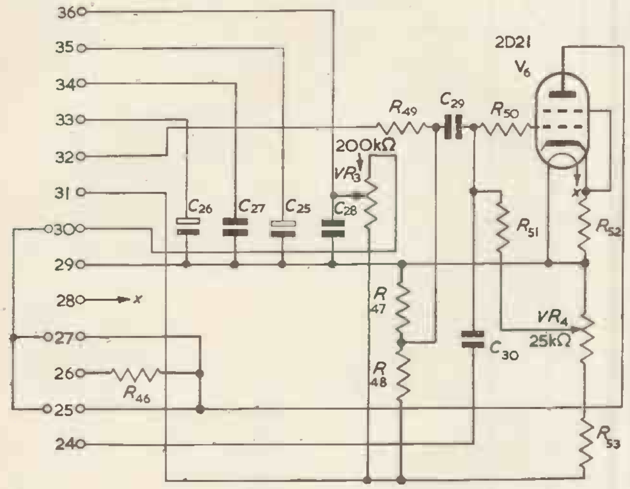


Fig. 3. Thyratron percussion circuit

This increase of voltage across the capacitor continues until the cathode of the first valve rises to a higher positive potential than its grid, so cutting off the anode current of that valve. No further current then flows into the capacitor. This latter now discharges relatively slowly through the discharge resistors, and this reversal of current also flows through the cathode resistor of the second valve. The phase of the discharge is then such as to increase the anode current of this valve, so making the grid of the first valve still more negative, holding off the charging current until the cathode of the first valve drops to such a voltage that it becomes negative with respect to its grid. The capacitor then begins to charge and the cycle starts again.

Since the frequency of oscillation is proportional to $1/(KCR)$ where K is a constant fixed by the valve operating parameters; C = the capacitance of the charging capacitor, and R = the combined value of the discharging resistors, it is evident that the frequency can be readily adjusted by

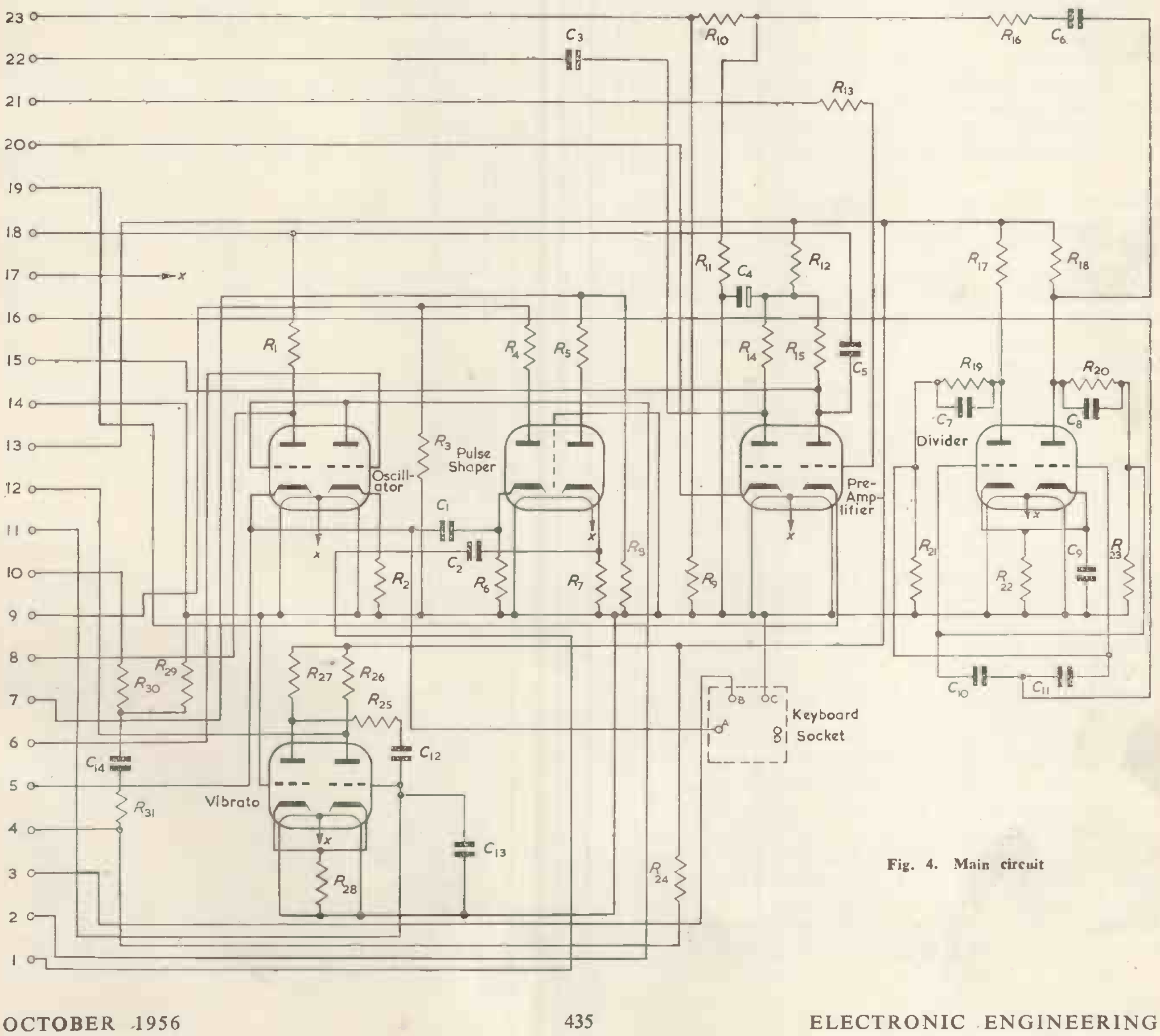


Fig. 4. Main circuit

varying the higher value resistor of the pair of discharge resistors, that is, the one in the cathode circuit of the first valve. The frequency will vary inversely as the value of the capacitor used. This feature is made use of in the Univox to shift the pitch of the keyboard bodily up or down one octave by switching in suitable capacitor values. In practice these are supplemented by small trimmers on account of drift with time, due to ageing of the dielectrics etc.

The value of the anode resistor in the second valve controls the amplitude of oscillation because it sets the "striking" voltage of the first valve, but it performs a more useful function since it can be used to control the oscillation frequency to some extent and is thus a means of exactly tuning the circuit without disturbing the relationship between notes already set up by the cathode series resistors. In the majority of such circuits, the upper (or lowest resistance) part of the series tuning string is made variable in order to adjust the pitch when necessary. It will be appreciated that if the ohmic value of this element is altered, it will mistune all subsequent notes in the ratio of the change in ohmic value of the tuned part to the whole ohmic value of the series string. Admittedly this departure from true pitch may not be serious, but some skill is required to make it unnoticeable and the Univox circuit overcomes this defect.

The waveform from the oscillator is a quite good sawtooth, but the versatility of the generator is increased by providing an auxiliary waveform as a pulse from a diode connected as shown in Fig. 1(b) which also illustrates the available waveforms. The delay circuit in the diode input slows down the build-up of the oscillations and reduces the transients resulting from keying the series resistors.

The grid of the second valve is a convenient place to inject a vibrato signal and in this instrument there is a multivibrator having three frequencies between 4 and 8c/s, any of which can be switched in at will.

In all instruments of this class, the limited compass of three octaves facilitates the application of formant circuits, which will hardly ever cover a compass of five octaves except in circuits of a quite different kind[6]. Even so, there are preferred parts of the keyboard where the best effects are obtainable. This is no particular disadvantage as skill in manipulation is essential to exploit the circuit to the full. For example, the parallel-action plastic keys are fitted with double touch contacts so arranged that a light depression introduces a comparatively slow rate of attack, while further depression produces a more staccato effect. This key construction is shown in Fig. 2. The thyratron circuit shown in Fig. 3 fills a triple purpose: by setting the 25kΩ potentiometer, a very sharp percussive attack is obtained, like a plucked string; by adjusting the 200kΩ potentiometer, a long decay up to two seconds can be given to any note. An ingenious extension of this idea allows the thyratron to be repetitively triggered by the vibrato oscillator, so that reiteration is automatically possible, as in the mandoline, etc.

Extension of the pitch range by frequency division is not only useful to give a total compass of

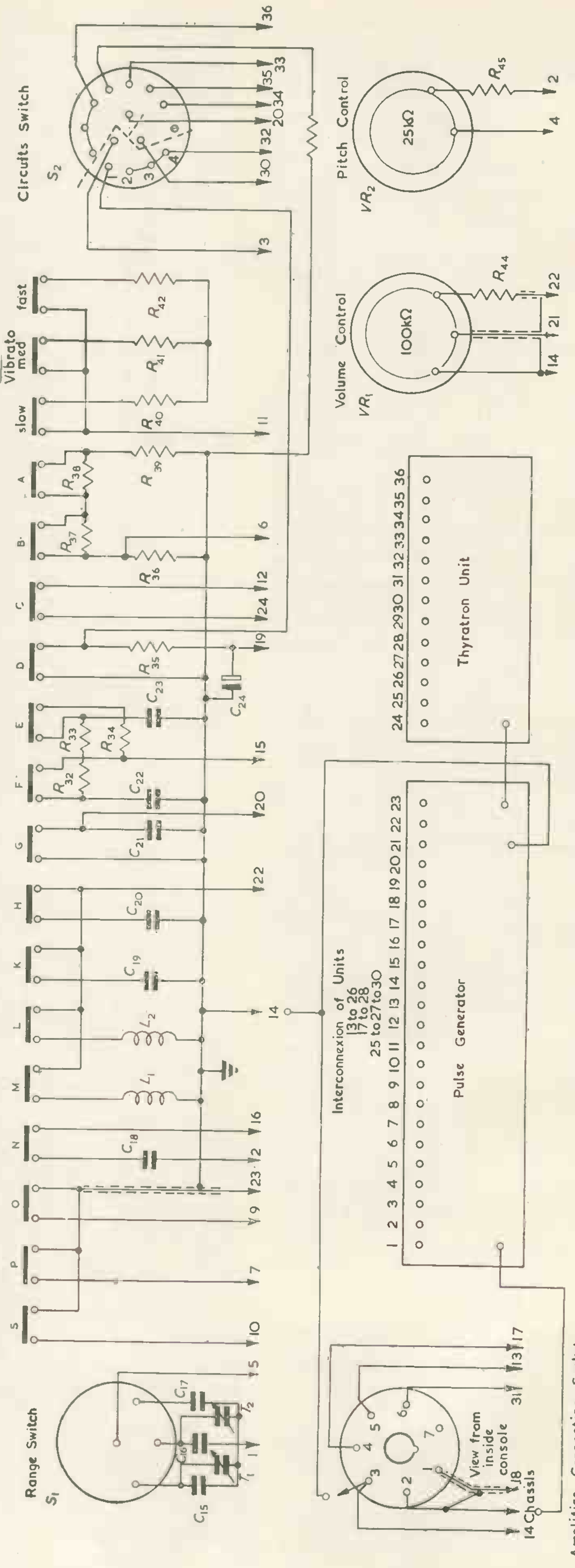


Fig. 5. Layout of tone forming circuits and selector switches

five octaves for single notes, but allows of an added richness and sonority for many tones by sounding two or three octaves simultaneously from one note. The dividers are shown on the main circuit, Fig. 4.

To extend the tonal resources of the Univox to the furthest limits, a series of independent tone forming circuits is available to the performer through the medium of fifteen selector switches, three degrees of vibrato, and the thyratron control switch, Fig. 5. With sufficient skill and the judicious use of the knee-operated volume control, an almost unlimited number of tonal effects can be produced. The realism from string and reed tones is outstanding, such voices as the clarinet and saxophone being particularly good.

The portable amplifier is conventional and has two 6BW6 valves in push-pull driving a wide-range 10in loudspeaker. Maximum power is limited to avoid coarsening the quality of the sound. Many thousands of this ingenious British-designed instrument are in use all over the world, and some of the circuit methods are also used in the polyphonic organs made by the Jennings Organ Company, to whom the author is indebted for permission to disclose the circuit details in this article.

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A NUCLEAR POWER STATION SIMULATOR

The most comprehensive nuclear power station simulator yet built in Great Britain has recently been installed at the G.E.C. Simon-Carves Atomic Energy Group establishment at Erith, Kent.

It is an electronic analogue computer which can simulate the performance of a complete nuclear power station, and is the largest and most advanced of its type in the country to be used exclusively for nuclear power studies.

The computer is one of the major items of equipment now in use at the atomic energy department which combines in one centre all facilities for research, design and test work in the development of commercially-built nuclear power stations.

The main uses of the simulator will initially be in the study of transient phenomena occurring in a nuclear power station following disturbances such as fault conditions, and in the analysis of automatic control systems.

The use of an electrical analogue enables the behaviour of a particular unit or group of units in the plant to be predicted accurately and quickly without the need for long and laborious calculations. A simple example would be the variation in reactor power with movement of the reactor control rods. A series of calculations taking some days to perform would enable graphs to be drawn showing this variation.

By setting the appropriate voltages on one section of the computer, the electrical circuits can be made to simulate the behaviour of the actual equipment and the results obtained in a matter of minutes as graphs on the recording instrument. More complex problems, involving the interdependence of several sections of the plant, can be dealt with equally well, and in these cases the saving of time and effort is even greater.

The flexibility of the computer was carefully considered during the design stages, with the result that it will be equally useful in the investigation of more advanced forms of reactor than the gas-cooled, graphite moderated type now under development.

A unique, and most important feature of the new computer, is that it has been designed to operate either as one large machine or as two completely independent smaller machines. It is thus possible to examine simultaneously two entirely separate problems—a considerable time-saving advantage in cases where neither problem requires the use of the complete machine.

The computer is housed in its own room, the air in which is maintained at slightly above atmospheric pressure by fans above the false ceiling. This precaution ensures that all leaks are outward and tends to eliminate the ingress of dust. A workshop is attached to the main computer room for the storage of instruments and for carrying out routine servicing and testing of computer units. The computer workshop will also be used for the construction and testing of auxiliary circuits for the machine as these become necessary.

In many of the problems encountered the time scale is likely to vary from a fraction of a second to several hours. The computer normally operates in real time, and the performance of any section of the power station can be examined from the traces of two continuous high-speed pen recorders which allow four variables to be recorded simultaneously. Alternative indication of each section is provided by a cathode-ray oscilloscope.

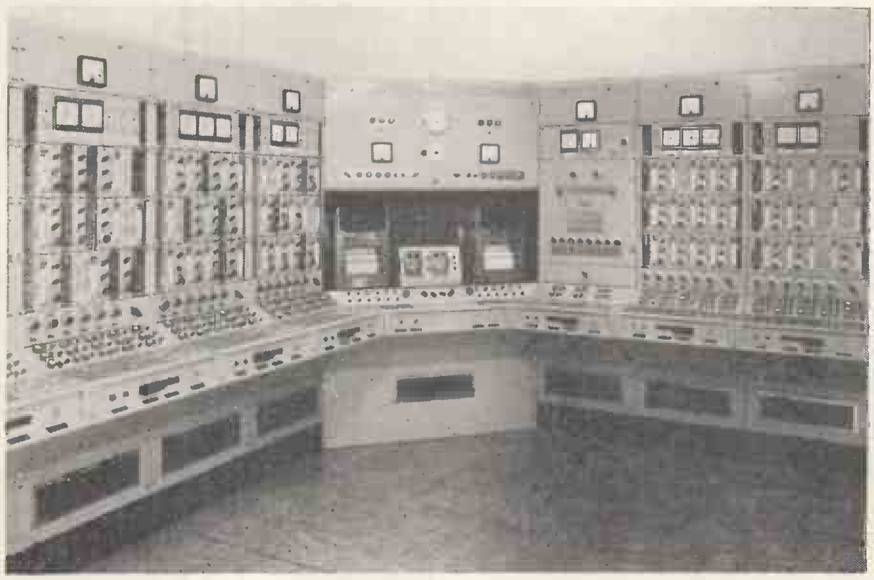
An additional advantage of real time working is that actual units of control systems can be coupled into the simulator circuit and their behaviour analysed. For longer-term problems such as the effects of xenon poisoning of the fuel, the rate of working can be accelerated.

The computer comprises a total of eight cabinets, arranged in "L" formation with the control cabinet at the junction. One special cabinet is permanently connected to simulate the nuclear reactor itself, and the remaining six are identical general purpose cabinets which can be set up to simulate the performance of heat exchangers, control rods, blowers, turbo-alternators or other components of the power station plant. This arrangement allows the equipment to be used with a high degree of flexibility, and will enable a wide variety of problems to be studied.

Provision is made for the incorporation of 100 drift-corrected amplifiers and 20 servo-multiplier units. At present 84 amplifiers are available, any one of which can be used as a summing amplifier, integrator, or servo-amplifier. Two transit time units are provided for the simulation of time delays, the output signal of each unit being the input signal delayed in time.

The simulator was manufactured by the Nuclear Division of Elliott Bros., who collaborated with the G.E.C. in the design of the machine.

The power station simulator.



Data Transmission by Synchros

By F. G. Helps*, B.Sc.Tech., A.M.I.E.E.

Synchros are used for the electrical transmission of the position of a rotating shaft and for computing purposes. The different types of synchros and the factors influencing their accuracy both in their application to transmission problems and in their design and manufacture are considered. Circuits for obtaining the "electrical zero" reference position and for testing synchros are given.

"SYNCHRO" is a term accepted by the British Standards Institution for transducers of the rotary transformer type[1]. The position of a rotating winding relative to a stationary winding determines the voltage induced in one when an alternating voltage is applied to the other, hence providing an electrical indication of their relative positions.

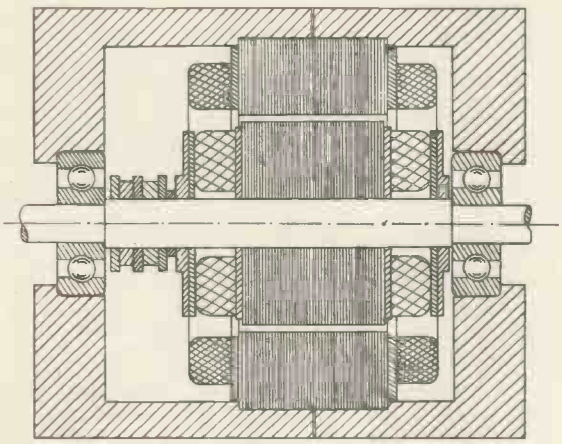


Fig. 1. Cross-section of a synchro with energized rotor windings

A device having three stationary windings and a single rotating winding very similar to present-day synchros is described in a Siemens patent[2] of 1897. Today synchros are manufactured under various trade names such as Asynn, Autosyn, Magslip, Telesyn, etc.

Physically a synchro resembles a small dynamo electrical machine having a wound stator and rotor (Fig. 1).

When the rotor is stationary the voltages induced in the stator windings are all in phase with one another. Hence, "phase" by itself describing the groups of coils in a synchro could cause confusion with the more normal practice in dynamo electric machines where it indicates that the voltages differ in time phase. Synchro windings are, therefore, sometimes described as having a "space-phase" distribution. A group of synchros exists which are excited from a polyphase supply[3]. These are most suited for unidirectional rotation and are employed where larger powers are required than with single phase excitation.

The synchros to be described, however, are all supplied from a single-phase supply.

Synchros can be considered as falling into three categories:

Torque Synchros; Control Synchros; Resolver Synchros.

Torque Synchros

Torque synchros are employed for the transmission of angular position information electrically and for the reproduction of this information by the position of the shaft of the receiver element. Misalignment between the shafts of the transmitter and receiver elements increases with the load on the receiver and for this reason these elements give the highest accuracy when driving balanced indicator pointers of small inertia. The system is not power amplifying and hence any load driven by the receivers is reflected back to the mechanism driving the transmitter.

Both transmitter and receiver have three space-phase stator windings and single phase energizing windings on the rotor.

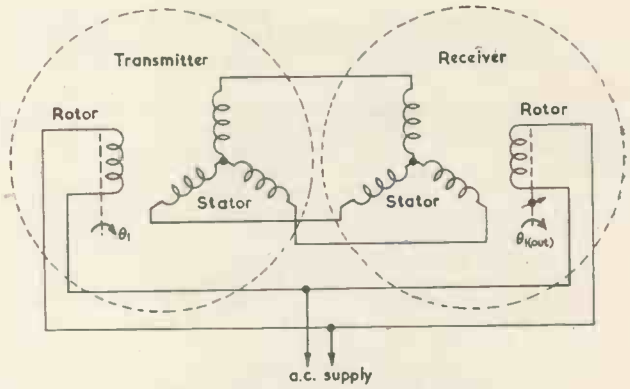


Fig. 2. Principle of torque transmission

PRINCIPLE OF TORQUE TRANSMISSION

The principle of the torque transmission system is as follows. The rotors of both transmitter and receiver are energized from the a.c. supply and produce an alternating flux in their corresponding stators. Should the relative dispositions of rotor to stator in the two elements be different the three voltages created in each of the two stator windings by the alternating fluxes differ, currents flow between them, and a torque is produced in each synchro which is so directed as to eliminate the discrepancy; thus, in effect, to align the two rotors.

Normally the transmitter rotor is held by mechanical means and the receiver rotor is free to turn so that it aligns itself with the transmitter. Thus in Fig. 2 any movement of the transmitter rotor will be repeated synchronously by the movement of the receiver rotor.

MULTIPLE INDICATION

It is possible to have two or more receivers with their stators connected in parallel and connected to one transmitter, but, in general, additional receivers are liable to impair the accuracy of the system unless special precautions are taken. Misalignment due to excessive load on one receiver is reflected back into the system and affects the accuracy of all other receivers. This mutual interference can be reduced by using receivers with higher stator impedances. Similarly, the number of receivers which can be operated also depends on the size of the transmitter.

DIFFERENTIAL TRANSMISSION

If two angles are to be transmitted, the difference or sum

* Sperry Gyroscope Company Limited.

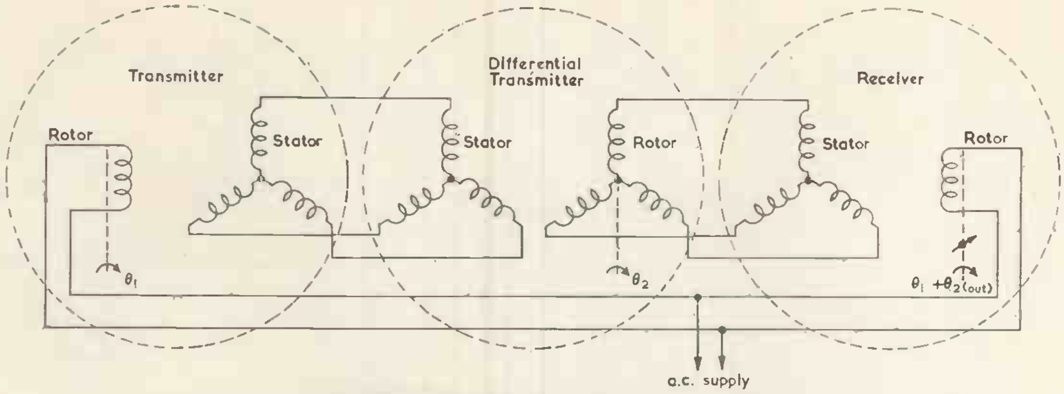


Fig. 3. Differential torque transmission by means of a differential transmitter

of which is to be shown at the receiving end, a Torque Differential Transmitter is inserted in the transmission chain. The differential transmitter has a three space-phase rotor and stator. (Fig. 3).

The angles transmitted may be added or subtracted by reversing two interconnecting stator leads of the transmitter, the resultant angle appearing at the receiver.

An alternative method is to employ only a torque receiver and torque transmitter. If the housing of the transmitter is rotated through one angle and the shaft by another angle, the shaft of the torque receiver will rotate the sum or difference of these angles (Fig. 4).

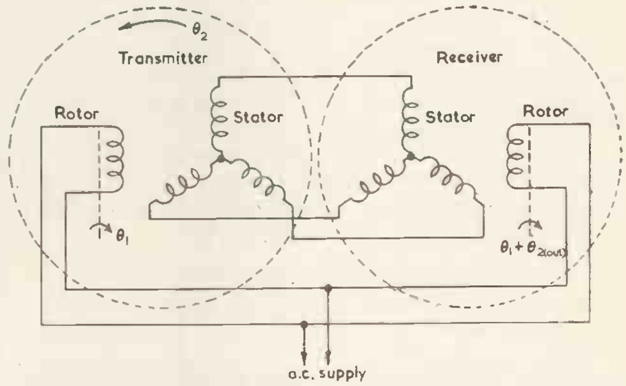


Fig. 4. Differential torque transmission by rotating both the stator and rotor of the transmitter

Control Synchros

Control synchros are employed in a data transmission system where a powered output is required to drive the mechanism which may have large inertia or require a greater torque than can be provided by a torque synchro. This may be a searchlight or directional antenna array on a turntable, or a gear train controlling a sluice valve or any instance where remote control of the position of a mechanism is required.

PRINCIPLE OF CONTROL TRANSMISSION

As in the case of torque transmission the rotor of the control transmitter is energized from the a.c. supply (Fig. 5). The receiving synchro is called a control transformer and the rotor is not energized. Both transmitter and transformer have a single-phase rotor and a three space-phase stator.

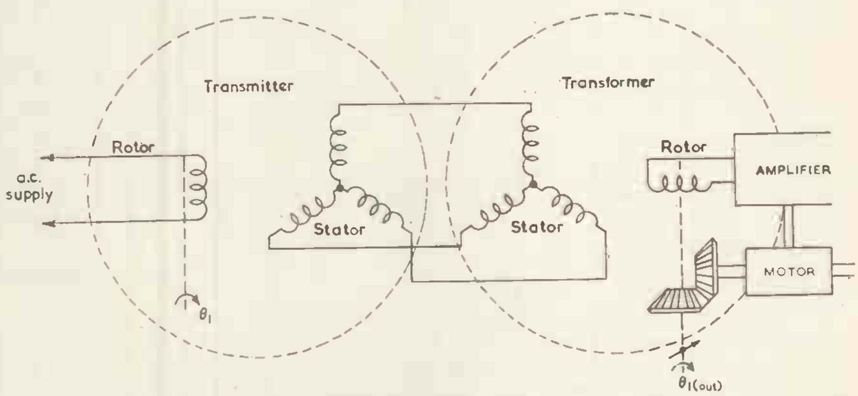


Fig. 5. Principle of control transmission

When the rotor of the transmitter is energized the three line voltages generated in the stator vary with the rotor position. These voltages supplied to the stator of the control transformer reproduce the direction of the alternating transmitter flux and a voltage is induced in the rotor. This voltage is reduced to a minimum value by a servo system which turns the rotor and also drives the mechanism being controlled.

The output power of such a system depends solely upon the power output of the amplifier and servo motor. By means of control synchros, very small units and light controlling forces can operate heavy mechanisms remote from the control point.

DIFFERENTIAL TRANSMISSION

In a similar manner to that described for torque synchros, the sum or difference of two angles may be transmitted by the use of control differential transmitters (Fig. 6).

Resolver Synchros

Resolver synchros are employed to convert voltages representing Cartesian co-ordinates to a shaft position and voltage representing polar co-ordinates, or vice-versa[4].

RESOLUTION: POLAR TO CARTESIAN CO-ORDINATES

If in Fig. 7 an alternating voltage R represents the modulus of a polar co-ordinate and a shaft displacement θ the argument, then the voltages appearing at the stator terminals are $R \cos\theta$ and $R \sin\theta$, i.e. the Cartesian co-ordinates of the polar vector $R\theta$. Accuracy is improved if the unused primary winding is short-circuited as this reduces any cross axis magnetic flux.

RESOLUTION: CARTESIAN TO POLAR CO-ORDINATES

To convert Cartesian to polar co-ordinates a servo nulling device is required. An alternating flux of amplitude and direction dependent upon the voltages V_x and V_y represent-

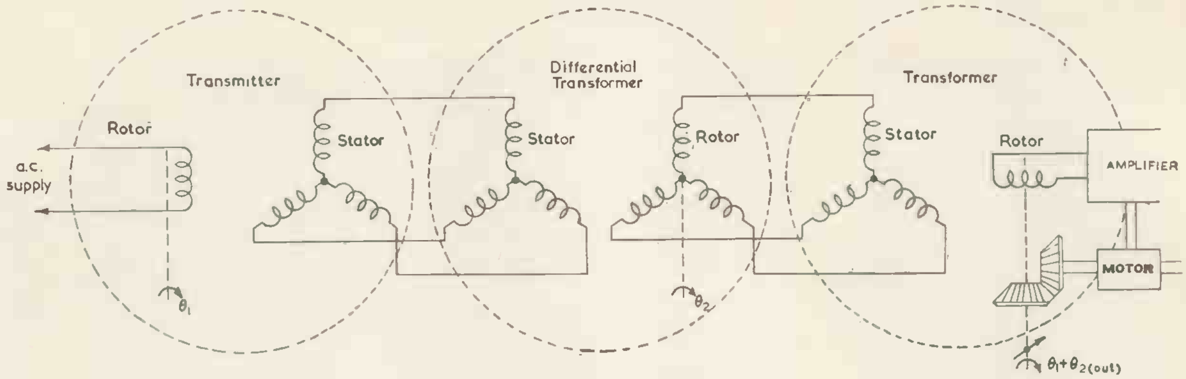


Fig. 6. Differential control transmission

ing the Cartesian co-ordinate is produced when these voltages are applied to the two stator windings (Fig. 8).

One of the rotor windings is connected to an amplifier and servo motor which drives the rotor to a null position. The other rotor winding has induced in it a voltage proportional to the amplitude of the alternating flux, i.e. proportional to $\sqrt{(V_x^2 + V_y^2)}$. This voltage represents the modulus R. The shaft position represents the argument θ of the polar co-ordinates equivalent to the Cartesian co-ordinates V_x and V_y, i.e. $\tan^{-1} V_x/V_y$.

Data Transmission Using Resolvers

In some instances it is more convenient to have positional information transmitted in Cartesian co-ordinates. The information is then readily available for application to the horizontal and vertical plates of an oscilloscope or for modification by other computer elements. Such instances occur, for example, when transmitting the position of a radar scanner (Fig. 9).

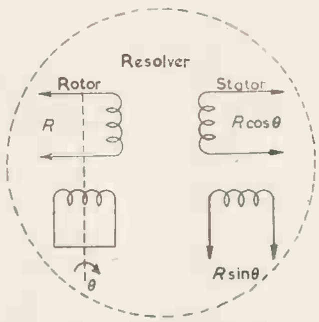


Fig. 7. Resolution. Polar to Cartesian co-ordinates

Resolver as a Phase Shift Device

A resolver can be used as a phase shifting device in conjunction with a resistor in series with a matched capacitor across both stator phases. If the rotor is energized, a voltage can be obtained between the common point of both stator phases and a point between the resistor and capacitor, the phase of which can be varied through 360° by turning the rotor (Fig. 10).

Differential Resolution

It is sometimes necessary to obtain the sine and cosine values of the sum or difference of the two angles. Resolvers may be employed for this purpose, as shown in Fig. 11.

Special Purpose Synchros

In addition to the synchro functions already described, synchros can be designed to perform many special functions[5,6,7]. They can be used, for example, as varying frequency modulators of a carrier signal, as phase computers to indicate the phase of a signal, and also to perform special functions in analogue computers. Some of these applications require that the synchros shall be specially designed for the equipment in which they will operate.

Phase as a Means of Transmitting Position Information

The resolver phase shifter described above produces a signal whose time phase depends upon the position of the rotor. Hence it is possible to transmit angular information in terms of the time phase of an alternating signal with respect to the phase of a reference signal.

Resolver Computing Equations

The voltage transformations of a resolver having two windings on both rotor and stator can be expressed by the following formulæ:

For stator excitation:
$$V_{R1.2} = V_{S1.2}\cos\theta + V_{S3.4}\sin\theta$$
$$V_{R3.4} = V_{S3.4}\cos\theta - V_{S1.2}\sin\theta$$

For rotor excitation:
$$V_{S1.2} = V_{R1.2}\cos\theta - V_{R3.4}\sin\theta$$
$$V_{S3.4} = V_{R3.4}\cos\theta + V_{R1.2}\sin\theta$$

Where $V_{S1.2}$ is the voltage across stator terminals S_1 and S_2 etc., and θ is the rotation of the rotor shaft in a clockwise direction from the position which gives maximum coupling between the windings S_1S_2 and R_1R_2.

Alternatively the curves of Fig. 12 represent the coupling between specific windings.

Fig. 8. Resolution. Cartesian to polar co-ordinates

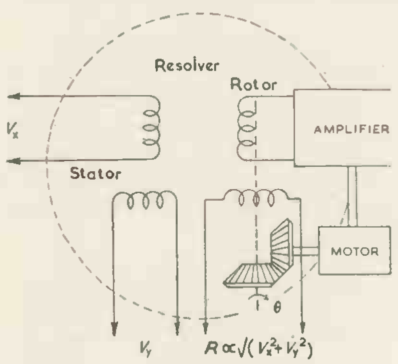
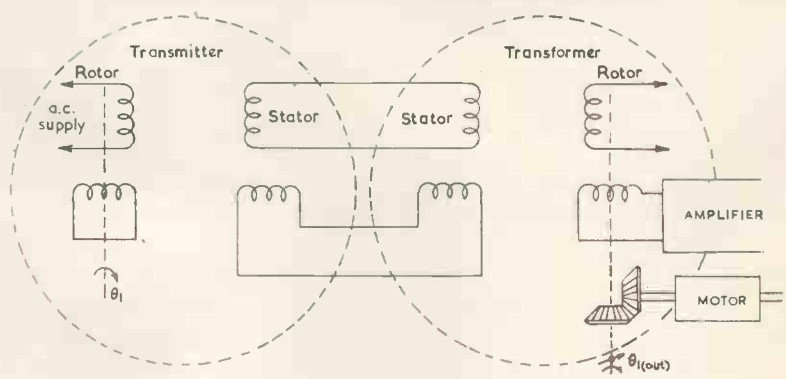


Fig. 9. Control transmission employing resolver synchros



Factors Influencing Accuracy

In recent years the requirements for ever increasing accuracy in synchros, particularly for service application in the field of gun fire control, have resulted in considerable efforts being made to eradicate all sources of error in the units. Positional accuracies of the order of 0·1° are at present being achieved in production synchros.

The accuracy of a synchro is a measure of the manner in which voltages induced in or applied to, the stator windings are related to the rotor shaft position.

To achieve 0·1° maximum positional error, the maximum voltage error which can be tolerated is of the order of 0·2 per cent and, therefore, test equipment of the order of 0·02 per cent accuracy is desirable. It will be appreciated, therefore, that apart from ensuring that design and production are of the highest standards, there remains the problem of testing the finished product.

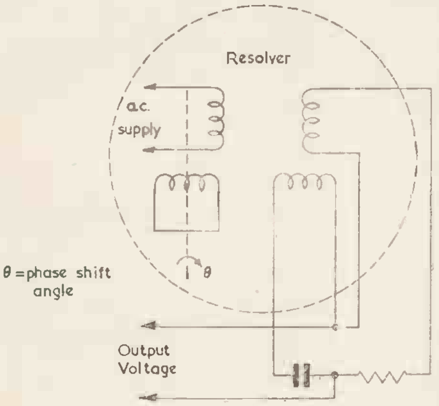


Fig. 10. Phase shifting by resolver synchros

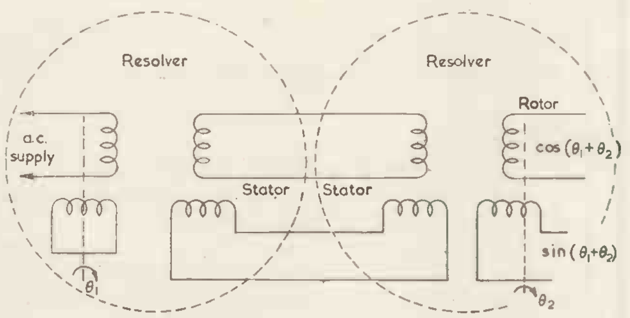


Fig. 11. Differential resolution by resolver synchros

Design

The object of synchro design is to so arrange the windings that the voltages induced vary sinusoidally with shaft position. The closer this object is achieved, the more accurate the synchro. This object is, however, frustrated by the necessity of locating the winding turns in groups, in slots, instead of uniformly spacing them around the periphery of the air-gap. To reduce the discontinuities thus caused in the transformation ratio as the rotor is turned, it is common practice to introduce axial skew of the slots in either or both the rotor and stator lamination stacks.

The selection of the appropriate number of slots for rotor and stator is partly decided by the winding configuration employed and partly by the mathematical analysis of the design. This analysis also determines the number of turns to be located in each slot.

Various methods of analysis are employed[8,9]. One is simply to distribute the windings in the slots according to a sine law. Another solves the problem vectorially and one very comprehensive method analyses the coupling between each coil on the rotor and stator in terms of a Fourier series. The sum of these series represents the total coupling and by selecting suitable coefficients representing the number of turns, it is possible to eliminate all terms except those of fundamental frequency, i.e. shaft rotational frequency, thus obtaining a sine relationship.

It will be found that there are several solutions to each design problem. An examination of existing commercial designs shows that seldom do different manufacturers employ the same winding configuration for a similar design.

The choice of configuration will depend upon a number of factors:

(1) Utilization of existing laminations already available may limit the choice of slot ratios that can be considered.

(2) Utilization of existing automatic machine winding facilities may make it more economic to use one winding pitch in preference to another.

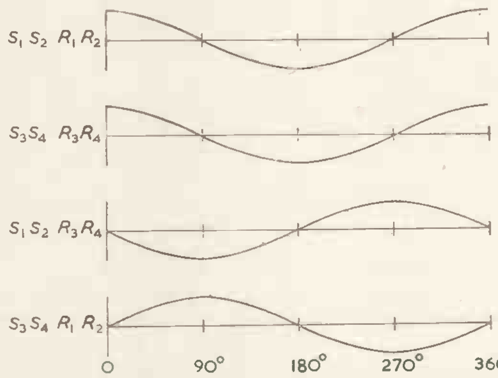


Fig. 12. Coupling between the rotor and stator windings on a resolver synchro

(3) Susceptibility of the design to inevitable manufacturing errors. Some solutions to a design problem will be found, which permit a greater tolerance in the departure of the variables from the ideal conditions, for a given deterioration in performance, than do other solutions to the same problem.

The rotor of a synchro may be cylindrical with many slots, in which case the air-gap is uniform in all directions. Alternatively a salient pole (dumb-bell or H type) rotor is employed; the air-gap is then different on the pole axis from the gap on the axis at right-angles to the pole axis. In addition the radius of the pole face may be less than half the maximum diameter of the rotor, producing a gradually increasing air-gap or " graded gap " towards the pole edges.

The cylindrical rotor is usually employed for receiving or loading elements since the impedance of the windings is independent of rotor position.

The salient pole rotor accommodates more turns and is easier to wind than the cylindrical rotor. The varying air-gaps, however, makes design calculations a little more difficult than in the case of cylindrical rotors.

Once the electrical design has been decided upon it is necessary to translate it into physical realization in the form of lamination designs, assemblies, etc. Magnetic saturation must be avoided and generous iron sections are employed.

In addition to arranging the design so that the highest precision of machined parts is possible, it is necessary to bear in mind that synchros have to function satisfactorily over wide temperature ranges and under adverse climatic and corrosive conditions. Recent designs employ "potting" techniques where the windings are encapsulated in thermosetting resins to assist in this respect.

To ensure uniform high quality production it is necessary to employ a large number of special tools and fixtures. Damage to any synchro component easily causes the assembled unit to fail on test, although similar damage on many other products may have no noticeable effect on performance. For example, any lamination stack dropped should automatically be consigned to scrap. Once assembled, however, the components are sufficiently well protected to withstand considerable mishandling, but faulty units should always be returned to the manufacturer for repair. In fact a synchro should be treated like a good watch.

Testing Units

CONTROL SYNCHROS

The accuracy of a single control synchro is measured in terms of the maximum discrepancy between the shaft position and the information transmitted electrically representing this shaft position. In an ideal control synchro the electrical information would truly represent the shaft position and the error would be zero.

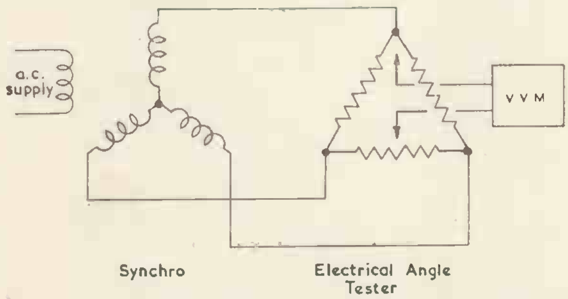


Fig. 13. Resistance network for checking the electrical accuracy of three-phase synchros

In order to test that the electrical signals being transmitted represent the mechanical information supplied to a synchro, it is common practice to employ a specially designed high accuracy resistance network (Fig. 13). This network is connected to the transmission lines and has tappings arranged on the resistors so that between two of them the voltage will be a minimum for certain synchro rotor positions. By having a sufficient number of tappings it is possible to test the synchro accuracy at any desired number of increments, but it is usually considered sufficient to test at 10° intervals.

The minimum voltage is most conveniently determined with a phase conscious frequency selective valve-voltmeter, responding to the in-phase fundamental component of the minimum signal with respect to the excitation supply.

The method of testing is as follows:

(1) Set the synchro to the electrical zero as described below. With the resistance network set on the appropriate tappings the valve-voltmeter will indicate a minimum.

(2) Select the next position on the resistance network and rotate the synchro rotor through the appropriate angle. In order to obtain a voltmeter null reading it will be necessary to turn the rotor a few minutes of arc more or less than this angle. This amount represents the error at that position.

(3) Similar tests are repeated at as many positions as desired.

It will be appreciated that a good dividing head is necessary to read accurately the rotor position and that great care is necessary in the manufacture of the resistance network box to ensure that capacitive and inductive effects are minimized, and that the tappings are accurately positioned.

It is necessary that the null voltage shall be below certain specified limits. The residual voltage will never fall to zero due to the presence of harmonic voltages, which are multiples of the excitation frequency and a fundamental frequency voltage in phase-quadrature with the excitation voltage. These voltages cause loss of sensitivity and can saturate certain stages in associated electronic amplifiers if of too great a magnitude.

These harmonic and quadrature voltages are introduced by the synchro due in part to the non-linearity of the iron in the magnetic circuit. It is important that they should not have added to them harmonics already present in the exciting supply. Both during testing and in service it is advisable to employ a supply having less than 5 per cent total harmonic distortion.

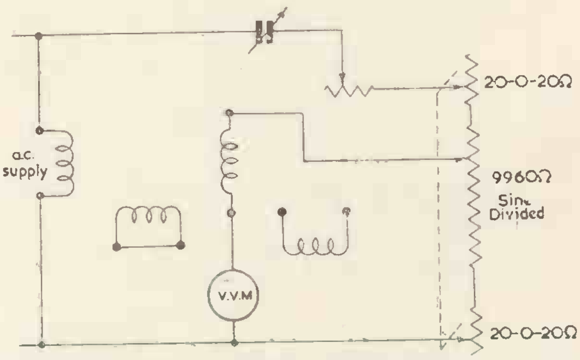


Fig. 14. Resistance network for checking the electrical accuracy of resolver synchros

RESOLVER SYNCHROS

When testing resolver synchros a resistance network of high accuracy is also employed, but this time the tappings are positioned according to a sine law (Fig. 14).

The error in the synchros is not nulled out by turning the rotor since a similar voltage error requires differing shaft movements to cancel it, depending upon the point on the sine curve at which the error occurs. Instead, the point at which the tapping is made is varied until the voltage across the resistance network is equal and opposite in phase to the synchro voltage. This can be detected by connecting the voltages in series with a valve-voltmeter similar to the phase conscious meter described above.

In addition to checking that the output voltage varies sinusoidally with shaft position, it is also necessary that the maximum coupling transformation ratio shall be the same within specified limits and that the windings shall be at right-angles when there is more than one winding on rotor and stator.

Application

The choice of the correct type of synchro from the large range available is no easy matter. It is generally advisable to consult the manufacturer who will suggest the most suitable model. The performance of a synchro depends very much upon the way it is used, and the type of loads and couplings employed. Performance figures quoted by manufacturers generally relate to the operation of the synchro under certain specified conditions.

TORQUE SYNCHRO CHARACTERISTICS

The performance of torque elements is usually quoted for a chain of two synchros, one transmitter and one receiver. The receiver synchro carries no load, or only a light pointer of small inertia. Under these conditions accuracies of the order of $\pm 1°$ are obtained.

The torque available from a chain of torque elements increases sinusoidally with misalignment between transmitter and receiver rotors. The torque is usually quoted in terms of the gradient of this sinusoid close to the aligned, or zero torque position, in gramme-centimetres or pound-inches per degree. Torques of several pound-inches per degree are possible with the larger torque synchros such as are employed in theatre lighting control (Fig. 15).

Damping devices are often built into torque synchros to reduce the overshoot and oscillations of the receiver when the transmitter is displaced[10].

With no added loads the time for the synchro to come to rest after a displacement of 180° is usually less than two seconds.

Most torque synchros are rated for continuous operation. Some models are limited to driving a fixed maximum load, for example a load which is limited so that the unit does not operate continuously with a misalignment greater than, say 20°. Too great a load will, of course, cause the receiving synchro to drop out of synchronism with the transmitter.

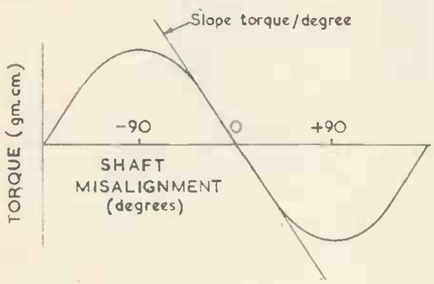


Fig. 15. Variation of torque with shaft misalignment

Control Synchro Characteristics

Accuracies of the order of $\pm\frac{1}{2}$° are quite easily achieved and modern synchros have accuracies as high as $\pm 0{\cdot}1$°. If higher accuracies are required it is necessary to gear the synchros to the drive and output shaft[11]. In this case the errors are reduced by the ratio of the gearing. For example, if a gear ratio of 60:1 is employed the maximum error would be reduced by 1/60 of the synchro error. Unfortunately there would be 60 possible positions of the output shaft for every position of the transmitting synchro, only one of which would be correct. In order to get over this problem of lack of synchronism it is necessary to employ two data channels, one channel geared 1:1 to maintain synchronism, the other channel with a higher gear ratio to position the output accurately when the first channel has approximately positioned the output. Such a system is known as "coarse and fine" transmission. Various methods are employed to change from the coarse to the fine channel[11,12,13,14].

When dealing with high accuracy data transmission systems the limiting factors are often the errors in the gearing and associated mechanical components rather than in the synchros themselves.

The stability and power of a control system depends upon the design of the follow up servo amplifier and not upon the synchro[15] although control synchros do generate a stabilizing voltage when turning.

Resolver Synchro Characteristics

There are many ways of defining synchro resolver performance. The purpose for which the unit is employed decides the most convenient form of expressing the characteristics. The following figures give some idea, however, of the accuracies obtainable.

Angular displacement between two phase windings = 90° ± 4′

Output voltage departs from true sinusoid < 0·1 per cent.

Accuracy obtainable with unit employed as control element = ±6′.

Mounting Synchros

Synchros may be mounted either by bolts through feet on the stator, or flange mounted. In the latter case an accurately machined spigot on the synchro positions the gear on the synchro shaft so that it meshes correctly with the driving mechanism. The mounting bolts and clamps must be strong enough to support the synchro under the most severe vibration conditions that will be encountered. Care should be taken when mounting synchros to use methods which do not distort or stress the stator, since this would impair the accuracy of the unit.

Where space is restricted, control units an inch in diameter and approximately 1¾in long and weighing 3oz are available which are capable of achieving accuracies of ±7 minutes of arc.

In some mechanisms it is not possible to mount conventional synchros, but separate rotors and stators can be more easily built into the structure of the equipment. Such problems as the transmission of gymbal axis position are best treated in this way. These separate elements are called "slab units" and are also useful when coaxial shafts are required or when a number of rotors have to be driven at the same speed. (Figs. 16, 17 and 18).

When mounting the separate rotors and stators of slab units in their housings it should be ensured that:

(a) The location and clamping of the stacks do not distort or stress the laminations.
(b) The stator bore is concentric with the rotor axis.
(c) The rotor and stator are square with the rotor axis.
(d) The rotor run out is within specified limits.

The actual eccentricities etc., which can be tolerated will vary with the unit and the accuracies desired.

The Electrical Zero

In order to use synchros in an equipment, it is necessary to find a unique mechanical reference position. This position is the "electrical zero" and is defined as the position of the rotor windings relative to stator windings which satisfies certain voltage transformation requirements. This position can be found very accurately. A difficulty which is sometimes experienced when assembling equipment containing synchros is fixing pointers or gears to the synchro shaft in the correct position and ensuring that the position is standard in all equipments. This difficulty is overcome if the synchros are first set to the electrical zero position.

In aircraft data transmission systems the electrical zero represents certain aircraft attitudes.

Setting Electrical Zero

To set a synchro to the electrical zero it is necessary to carry out two tests. The first test finds the approximate electrical zero. It is not a very sensitive test, but there is only one position of the rotor which satisfies the requirements. To avoid the necessity of carrying it out it is common practice to indicate on the synchro the approximate electrical zero position with a painted or engraved line on the synchro housing. When the flat or mark on the shaft is aligned with this mark the synchro rotor is set to the approximate electrical zero. In the case of control elements which can be used as either transmitters or transformers, the red mark is the approximate electrical zero position for the transmitter and the yellow that for the transformer.

The approximate electrical zero thus found can only be determined with an accuracy of the order of ±5°.

The second test finds the accurate electrical zero and is capable of setting the datum of a system to approximately one or two minutes of arc.

There are two positions of the rotor 180° apart which satisfy this test, the correct position being the one close to the approximate electrical zero.

The approximate and accurate electrical zero positions are obtained by connecting the synchro as indicated in Table 1 and turning the rotor to obtain a minimum voltmeter reading. It is recommended that for setting the accurate electrical zero position a valve-voltmeter reading to 100mV be used.
The voltages for these tests are indicated on the figures as follows:

V_1 = nominal rotor voltage at nominal frequency

V_2 = nominal stator voltage at nominal frequency

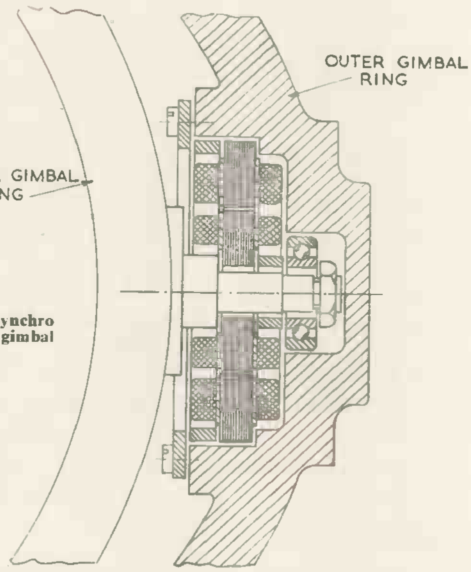


Fig. 16. Slab synchro built into a gimbal system

Shaft Rotation

Positive direction of shaft rotation is defined as anti-clockwise rotation of the shaft when looking at the shaft end of the synchro, or at the side the leads emerge on slab units.

Reversal of Shaft Rotation

It is sometimes necessary to obtain a reversal of the direction of shaft rotation of a synchro. This can be achieved by changing over the leads to two of the stator terminals on one only of the synchros in the chain.

This change should be to the leads connecting to S_1 and S_3.

Differential Synchros

Differential transmitters when connected in the data lines with consistent connexions, i.e. S_1 to S_1 etc., satisfying the following conditions:

The signal produced by a positive rotation of a differential transmitter shall cancel the signal produced by a similar positive rotation of the related control transmitter, i.e., the difference of the two rotations in the transmitted information. The insertion of a differential transmitter shall not reverse the sense of the transmitted information. To obtain the sum instead of the difference of the input angles, reverse the connexions to terminals S_1 and S_2 of the differential synchro.

TABLE 1

TYPE	APPROXIMATE ELECTRICAL ZERO	ACCURATE ELECTRICAL ZERO
Control transmitters / Torque transmitters / Torque receivers ..	Fig. 19	Fig. 20
Control transformers ..	Fig. 21	Fig. 22
Differential transmitters ..	Fig. 23	Fig. 24
Resolvers	Fig. 25	Fig. 26

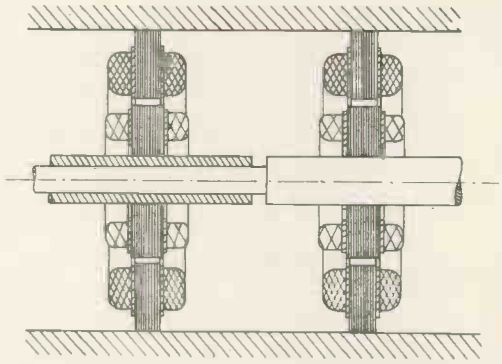


Fig. 17. Slab synchros mounted to provide coaxial shafts for the rotors

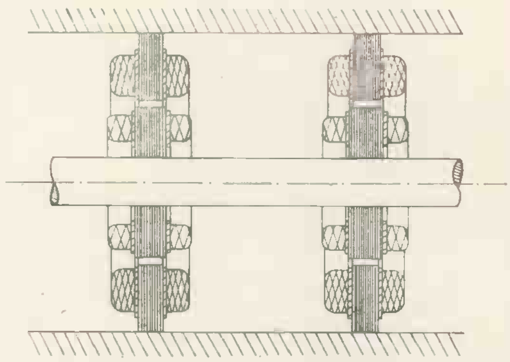


Fig. 18. Rotors of slab units mounted on a common shaft

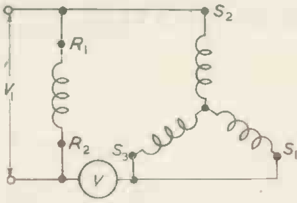
Correcting Synchro System Errors

The accuracy with which information is transmitted depends upon several factors. The accuracy of the gearing driving the synchros, the sensitivity of servo amplifiers, the stability of the system, the load being driven and, of course, errors already present in the synchro elements[3,16,17].

Torque synchro errors can be reduced if light loads of small inertia are driven and if separate transmitters are employed for each repeater. If many torque receivers have to be driven from one transmitter it is possible to employ "buffer" or isolating amplifiers in two of the three stator lines feeding each receiver[18]. To be effective the amplifiers must be stable and have a linear response (Fig. 27).

Errors can be introduced if the lines connecting synchros have differing impedances. These errors and also certain types of error present in synchros can be corrected by loading the lines. Resistors, capacitors and inductors are connected in various combinations in series or parallel with the lines to produce the desired correction[19,20].

A limiting factor to the number of synchros that can be connected to a single transmitter is the heating effect of the magnetizing current flowing through the stator windings. This current can be reduced and hence the load correspondingly increased, if tuning capacitors are connected across the stator line to reduce the current to a minimum (Fig. 28).



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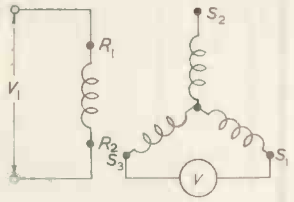

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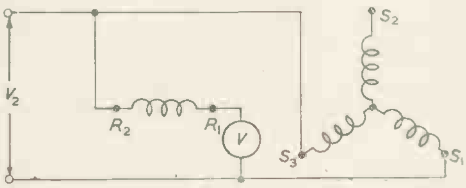

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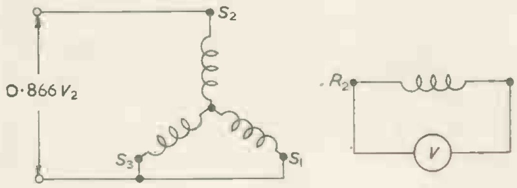

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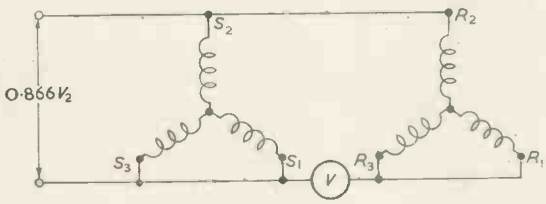

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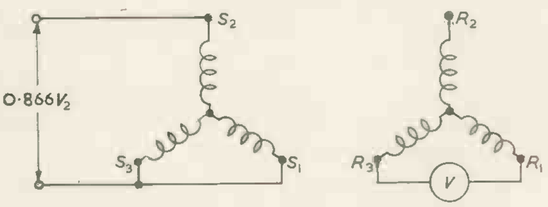

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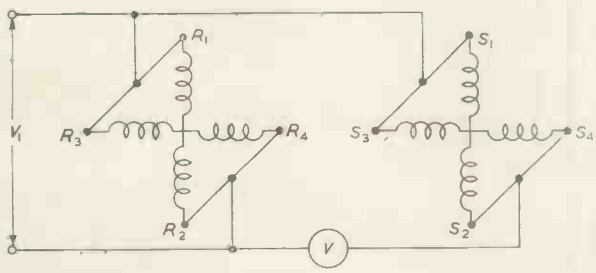

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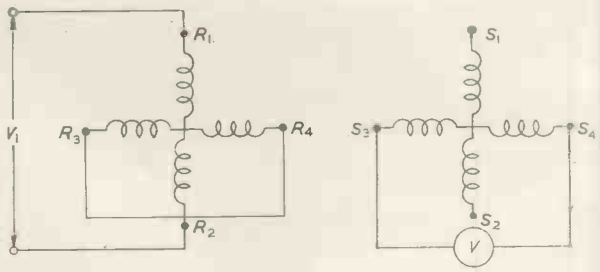

(26)

Figs. 19 to 26. Setting electrical zero

V_1 = nominal rotor voltage. V_2 = nominal stator voltage

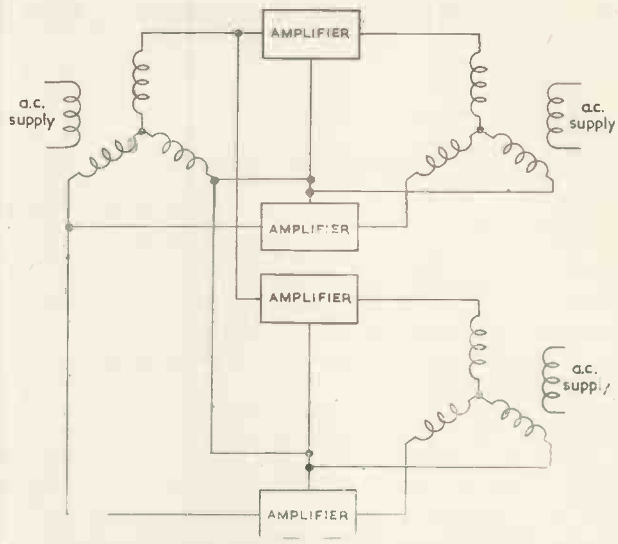

Fig. 27. Buffer amplifiers in a torque synchro system

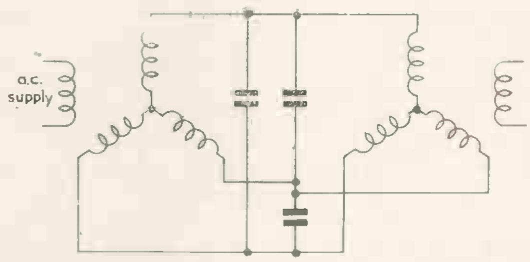

Fig. 28. Capacitors connected across stator lines to reduce load current

Resolver accuracy can be improved by amplifiers and additional windings on the stator which compensate for variations in the transformation ratio of the resolver at different input voltages[21].

In recent years the applications for synchros have increased considerably. As a result, much attention is being paid to the development of small, very accurate, and reliable elements. Each application, however, raises problems of its own and work in this field is by no means at an end.

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A Sensitive Quick Reacting Cardiotachometer

By M. Manzotti*

An instrument that, at every heart beat, gives a signal proportional to the reciprocal of the time interval between that beat and the previous one, is described. The range is 40-200 beats per minute at an approximation of ±2 per cent.

THE subject of recording the heart rate has been approached by several authors. The first mechanical attempts[1,2], too noisy to be of practical use, have been replaced by electronic machines, which are accurate, noiseless, quick and easier to assemble.

Boas's method[3] of counting the heart beats over long periods of time and displaying the total, and the method[4,5,6] of recording on ordinate, a signal proportional to the time interval between two adjacent heart beats and reading the rate on a hyperbolic scale, are only of historical interest. Horton[7] pursuing the idea of recording a rate accurately, adapted a circuit for high frequency measurements to the low frequency of heart rate. Only recently[8,9] has the complete subject of (a) the choice of the most adequate signal synchronous with the heart acitivity, (b) the removal of interference and (c) the computation of the heart rate, been given extensive treatment.

The *R*-wave of the e.c.g. is undoubtedly the most suitable signal for driving the computer and this has been used in the present design. However, a different type of circuit has been preferred to that of Boyd and Eadie[8,9] for the eradication of the muscle interference. The filter has to be of the bandpass type centred on the frequency of 12c/s, but the ringing effect, characteristic of these filters, should be removed as much as possible without damping.

Damping, in fact, decreases the maximum recoverable heart rate.

For this reason a bandpass filter of the normal resistance-capacitance type has been used in conjunction with a diode so that either positive or negative signals, according to the connexion of the diode, are cut off. The overshoot that occurs when a pulse is fed in, is thus eliminated and the ringing effect is considerably reduced without any damping. Of course, this arrangement calls for a pulse shaped signal from the body and for an amplifier of the d.c. type that will not distort the signal. For the same reason mains interference has been erased by using a balanced amplifier to provide degeneration of signals fed in symmetrically on both input leads.

However, the main part of a heart-rate recorder is the computing device. Previously the general tendency has been towards circuits of the integrating type. Though practical, they are not of much use in physiological work[10] because the delay in following the variations of the heart rate increases with accuracy. Reasonable figures are: for an accuracy of ±2 per cent about 30 beats are needed to reach 90 per cent of a variation consisting of a hypothetically sudden jump of the heart rate from 60 to 120 beats/minute.

When other physiological variables, recorded with practically no delay, are to be correlated with the heart rate, it must also be recorded instantaneously, i.e. beat by beat. Therefore a circuit is required that will give at every heart beat a signal proportional to the reciprocal of the time interval between that beat and the previous one.

There are many dividing circuits described in the literature[11], most of them based upon the characteristics—transconductance and anode resistance—of special valves, but they do not satisfy requirements because:

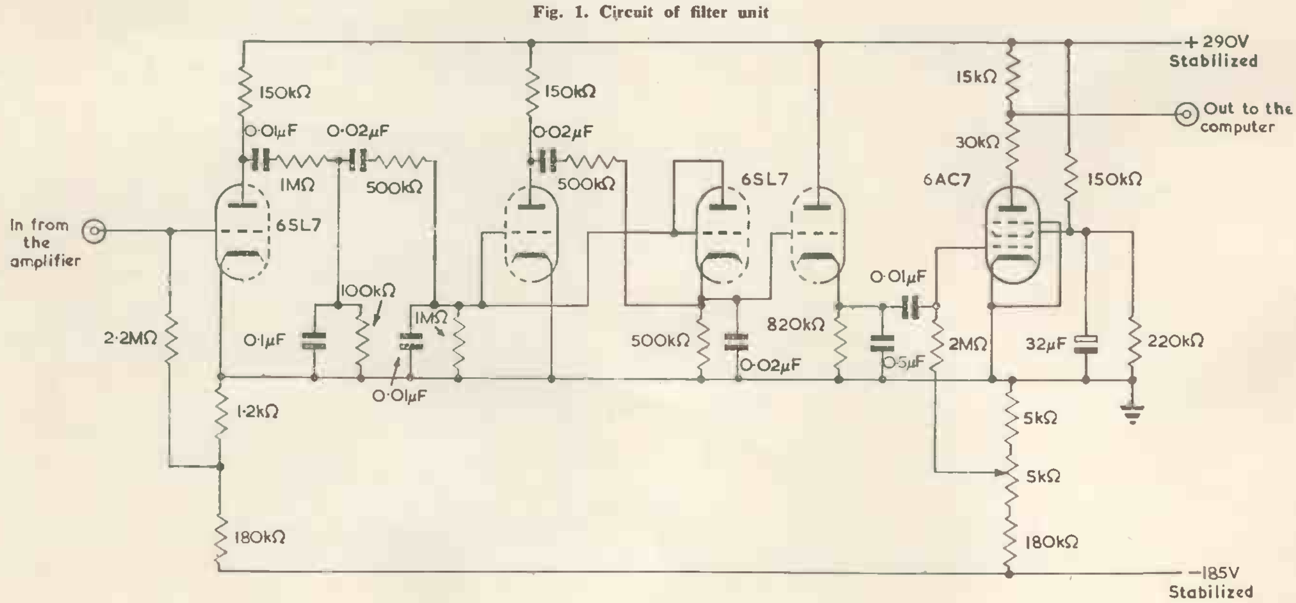
(a) They can handle a range of 50 to 200 beats/minute with a maximum accuracy of ±10 per cent.

(b) The characteristics of the valves are variable with time and consequently the performance of the dividing circuit is not reproducible.

It has been preferred, therefore, to approximate the function $f(t) = 1/t$ by the sum of two exponentials obtained with the discharge of a capacitor through a resistor. By properly choosing the values for capacitors and resistors it

* *University of Birmingham.*

Fig. 1. Circuit of filter unit



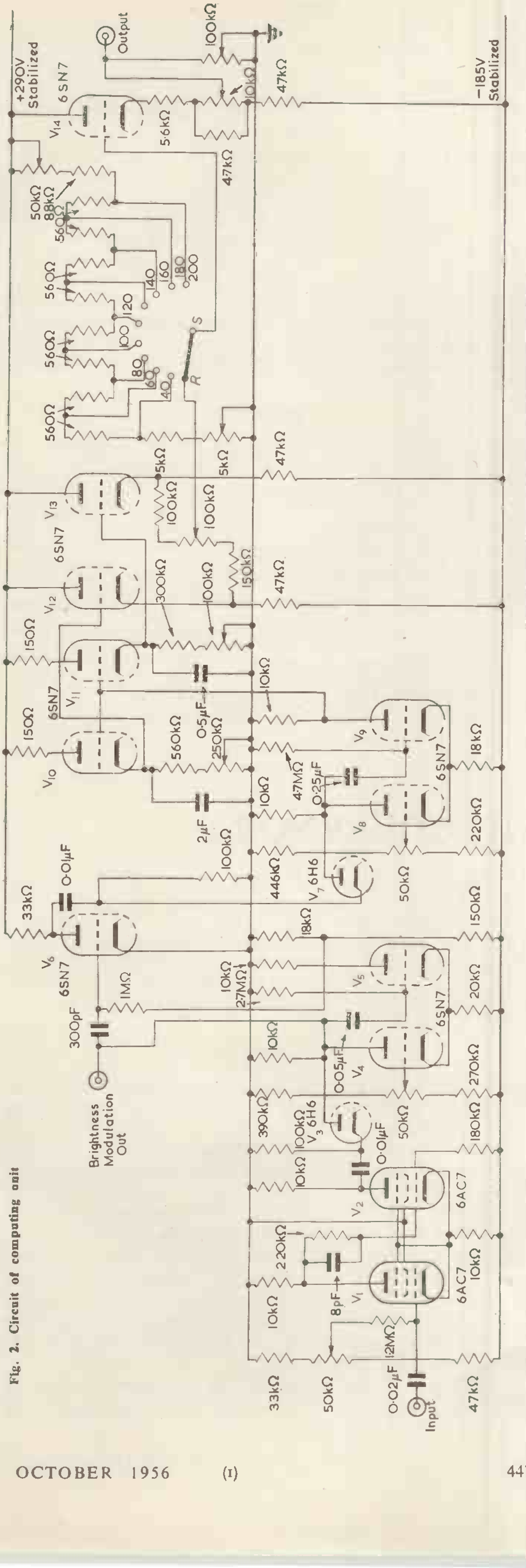


Fig. 2. Circuit of computing unit

is possible to obtain an approximation of ±2 per cent in the range 40 to 200 beats/minute.

The Complete Design

The heart-rate recorder consists of the following units:
(1) A d.c. balanced amplifier of the conventional type *RC*-coupled with the body; input time-constant 0·01sec.
(2) A filter unit for recording the heart rate of subjects doing exercise as well as resting. The circuit diagram is shown in Fig. 1 and does not need any further explanation. It is connected to the amplifier and leads into the computer.
(3) A computing unit. The general operation of this unit is such that for every *R*-wave a constantly delayed signal is

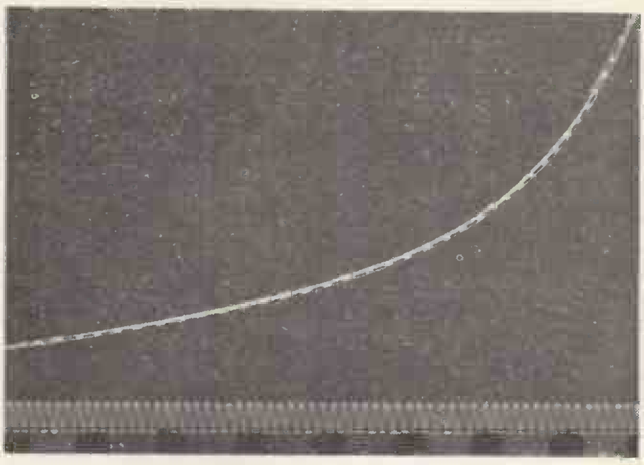
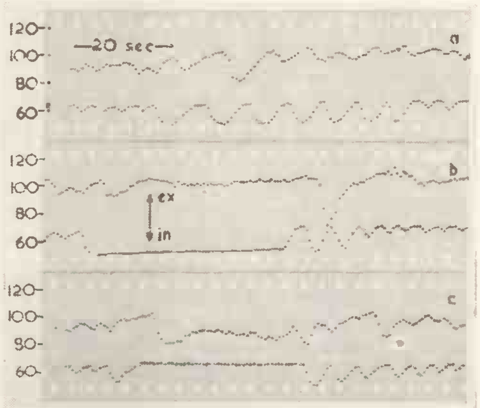


Fig. 3. Output trace of computing circuit

Fig. 4. Recordings of heart rate
(*a*) *Normal and deep breathing*; (*b*) *breathing stopped in deep inspiration*; (*c*) *breathing stopped in deep expiration*.



released. This signal displays on the Y-axis of the cathode-ray tube a potential that decays hyperbolically and therefore is proportional to 1/time.

Because the c.r.t. beam is turned on only for the time between the *R*-wave and its delayed signal, just at the end of an *R-R* interval, the dot that appears on the photographic paper—if the length of the delay has been properly chosen—has an ordinate proportional to the heart rate, as computed on the *R-R* time interval.

This unit, the circuit diagram of which is shown in Fig. 2, is subdivided into the following sub-units:
(1) A Schmitt circuit for voltage discrimination, allowing the computer to be triggered only by pulses of proper amplitude.
(2) A univibrator driven by the Schmitt discriminator for delaying the computer and triggering the beam of the c.r.t. This releases a pulse of a length variable at will between 8 and 40msec.

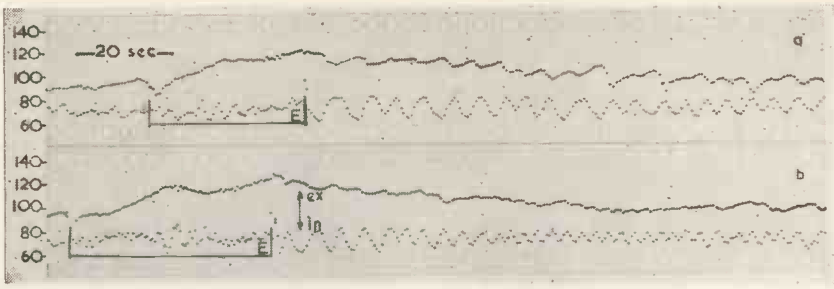


Fig. 5. Variations in heart rate during and after exercise

(a) A weight of 10lb lifted 20 times above the head; (b) the arms vigorously swung backwards and forwards horizontally 30 times.

(3) A second univibrator driven by the trailing edge of the pulse released by the first univibrator, for timing the charge and the beginning of the discharge of the two capacitors. The length of the pulse it releases is 0·2sec.

(4) The computing circuit consisting of two capacitors that charge through valves to the same potential during the pulse released by the second univibrator. Then, the charging valves being cut off, they discharge through resistors so chosen that the two time-constants are 1·2097 and 0·1737sec. The potentials appearing on the two capacitors are added in such a way that 59·85/100 of the output comes from the mesh with time-constant 0·1737sec.

Between 0·3 and 1·5sec from the beginning of the charge, corresponding respectively to 200 and 40 beats/minute, the output follows with the required accuracy the relation $1/t$. This is shown by the black dotted line in Fig. 3 that has been superimposed on the white trace of the c.r.t. beam.

(5) A range unit setting the intervals in which the heart rate, according to the experimental condition, is to be recorded. The maximum sensitivity is 20 beats/minute for full deflexion.

Results

Typical examples of the performance of the heart rate recorder are given in Figs. 4 and 5, in which for timing the events, the respiration record has been included—bottom line of each trace.

The heart rate is in ordinate, in beats/minute. Fig. 4(a) represents the variations of the heart rate during normal and deep breathing; Fig. 4(b) when breathing is stopped in deep inspiration; Fig. 4(c) when breathing is stopped in deep expiration.

In Fig. 5 are reproduced the variation of the heart rate during and after exercise E. In (a) a weight of 10lb is lifted 20 times above the head; in (b) the arms are vigorously swung backwards and forwards on the horizontal plane of the shoulders 30 times.

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AN ELECTRONIC GOVERNOR

By S. C. Hine*

An electronic governor for controlling the speed of a motor is described. The motor is fitted with a tachogenerator and a frequency discriminator provides an output proportional to the speed of the motor, the output being zero when the speed is correct. This output controls the speed of the motor. The advantage is that the motor receives only as much power as is required to drive the load, with the result that no additional noise or vibration is produced, as happens with a mechanical governor.

THE electronic governor described in this article is a device for accurately controlling the speed of a shaded-pole squirrel-cage induction motor. Negative feedback is provided by a tachometer-generator driven by the motor. The output of this generator is fed to a discriminator whose output controls a valve circuit which regulates the power fed to the motor. The device was designed to control the speed of the turntable motor in a gramophone disk recorder, but it obviously has other applications.

The Circuit (Fig. 1)

The tachogenerator consists of a small alternator with a permanent magnet stator. An output of about 2·5V r.m.s. is delivered to the discriminator L_1, C_1, V_1, C_2, C_3, R_1, R_2, whose centre frequency is adjusted to suit the alternator output frequency at the appropriate running speed. The discriminator output signal, in series with a small standing bias, is applied to the grid of V_2.

V_3 and V_4 are a pair of heavy-current tetrodes connected in inverse parallel and in series with the motor across the a.c. mains supply. The capacitor C_4 resonates with the inductive component of the motor impedance and so reduces the voltage required to drive the motor thus compensating for the voltage drop across the valves. The grids of V_3 and V_4 receive alternating voltages from the two secondary windings of the transformer T_1. The connexions are so arranged that these voltages are each out of phase with the voltage between the anode and cathode of the corresponding valve.

When V_2 is non-conducting, the only input to T_1 is the voltage across the P_2 half of the primary winding. The

* *E.M.I. Electronics Ltd.*

magnitude of each secondary voltage is, in this condition, arranged to be such that the grids of V_3 and V_4 are each driven sufficiently negative to cut off anode current, or at least to reduce it to a very low value, during the half-cycles in which the anode goes positive. Thus, when V_2 is non-conducting, the power delivered to the motor is negligibly small, or even zero.

When V_2 conducts, a current at mains frequency flows in the P_1 half of the primary winding of T_1 and this current will oppose that flowing through the P_2 half of the winding. When the mains-frequency current through P_1 balances that through P_2, V_3 and V_4 have zero bias and conduct

amount of improvement was obtained by shunting the secondary windings of T_1 with resistors R_8 and R_9.

(3) By making the capacitance of C_4 about 10 per cent greater than necessary for compensation at the nominal mains frequency, it is possible to correct partially for the power drop due to reduced "slip" if the mains frequency should fall. The frequency of the mains then moves nearer to resonance as the frequency falls, causing an increase in motor current.

(4) The motor may be temporarily switched off by applying a large negative bias to V_2, while leaving the valve heaters switched on.

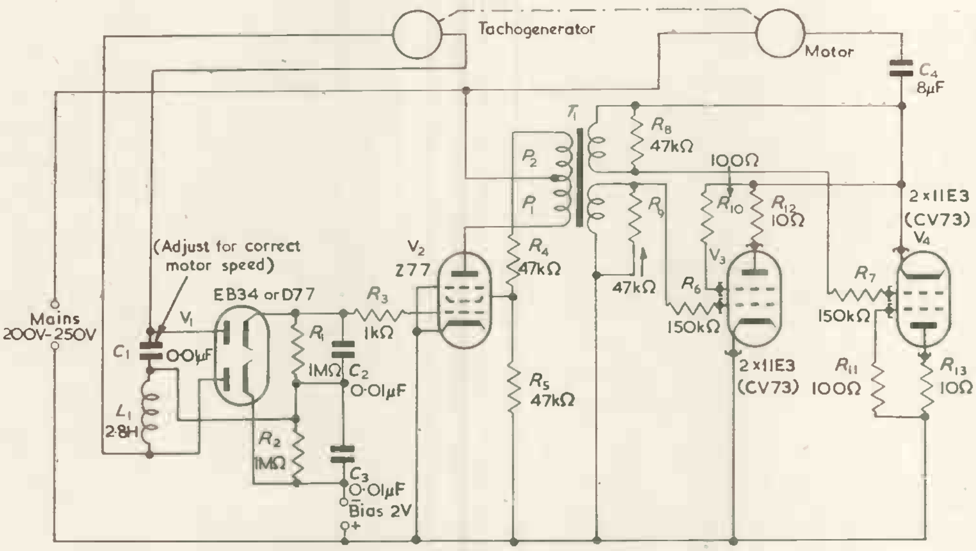


Fig. 1. Diagram of complete circuit

heavily, and the current through the motor is then at its maximum.

The grid stoppers, R_6 and R_7, of comparatively high value, prevent over-heating of the grids of V_3 and V_4 when they are driven positive and so draw current during that part of the cycle when the corresponding anode goes negative.

Operation

The normal operating condition lies between the two extremes described above. If an increase in load causes a reduction in motor speed, a positive d.c. output is obtained from the discriminator and V_2 conducts more heavily. The alternating bias on the grids of V_3 and V_4 is consequently reduced in amplitude, causing the current drawn through the motor to increase, and so tending to restore the motor speed to its former value.

Similarly, an increase in motor speed results in a decrease in motor current with subsequent restoration of the speed to its original value.

Design Details

The following details of the design are worthy of note:

(1) The screen of V_2 is returned to a tap between R_3 and R_4 instead of using a separate bleeder chain; this has the advantage of introducing a small degree of positive feedback which slightly increases the gain of the valve.

(2) The anode current waveform of V_2 is, of course, not sinusoidal. This results in a number of unwanted harmonic components at the output of T_1, so that the bias waveforms of V_3 and V_4 are somewhat distorted. Tuning of T_1 was tried but proved impracticable because of the phase shift involved. However, a certain

The motor and tachogenerator used for the prototype equipment were as follows:

Motor	Hoover type SP303 Speed at maximum efficiency: 1 275 rev/min.
Tachogenerator	Number of teeth: 44 Output frequency at 1 275 rev/min: 935c/s.

Conclusions

An electronic governor, which has the following features has been designed:

(1) Provided the gain of V_2, V_3 and V_4 is high, the motor speed is determined almost entirely by the centre frequency of the discriminator and not by the gain of the valves.

(2) Neither motor nor generator need have slip rings or commutators.

(3) No d.c. supplies are required except for the bias for V_2 and this can be obtained from the mains, noting that, since the circuit operates with 50c/s pulses, it is not necessary to provide much smoothing for the bias supply.

(4) The speed of the motor will be maintained very much more accurately than is possible with a mechanical governor.

(5) Since the motor receives only as much power as is required to drive the load at any instant, it generates no more noise or vibration than without the control. On the other hand, a mechanical governor can add considerably to the amount of noise and vibration.

A Compact Crystal Clock

By D. R. Ollington*, D.F.H.(Hons.)

The article describes a simple crystal clock which may be constructed in a relatively small case. It may be used as a time reference or as a frequency source, the clock face providing a long-term monitor of the accuracy.

CRYSTAL clocks and other accurate sources of frequency usually contain many valves and occupy considerable space. Rack mounting is common practice to accommodate the numerous associated chassis and there appear to be few compact sources available accurate to one part in 10^6 or one part in 10^7. These facts prompted the following design, since a small source was required for laboratory work. It embodies standard components and totals thirteen valves inclusive of power supply. Miniature valves and GT types are used for all but the rectifiers and the output stage (which may be used to drive more than one synchronous motor, if required). The source provides for outputs of 10kc/s, 1kc/s and 100c/s and also a time standard accurate to better than 0·5 second per week.

To simplify the divider chain a 10kc/s crystal is employed. In the design illustrated (Fig. 1.) this is oven controlled at 50°C, the temperature at which the zero temperature coefficient occurs for the particular make chosen, a Marconi type 1652D. A small oven, size 6in by 9in by 5in houses the crystal together with heating elements on five sides, each element being copper sheathed to give uniform heating. A thermostat controlling a cold-cathode tube ensures that the temperature differential is small, not more than a fraction of a degree.

The crystal is connected to the grid of the crystal oscillator, an EF91, in a circuit recommended by the crystal manufacturer. The output from the oscillator is fed to a buffer amplifier (EF91) to prevent frequency pulling of the oscillator stage. The 10kc/s output from the buffer stage is used to synchronize a 10 : 1 divider in the form of a multivibrator running at 1kc/s. This output is similarly used to synchronize another 10 : 1 divider, a second multivibrator, but running at 100c/s. Normally a division ratio of 10 : 1 would be too high for a frequency standard but since the unit was mainly designed for constant temperature use and the clock face provides a constant monitor, it was felt a worthwhile economy. The 100c/s output from the second divider is fed to an *RC* filter network via a cathode-follower to remove the greater proportion of the many harmonics present in the multivibrator waveform. A two-valve amplifier feeds a transformer with a substantially sinusoidal waveform to drive a synchronous clock motor. This is a standard 50c/s type run at twice normal speed. In this condition the motor will not self start since the mass of the rotor is incorrect for the frequency employed. This is not a disadvantage for a crystal clock that is to run for lengthy periods.

A cathode-follower may be switched to the three frequences available, 10kc/s, 1kc/s or 100c/s square wave or 100c/s sine wave.

The power supplies are in every way conventional—neon stabilizers being employed where a steady output voltage

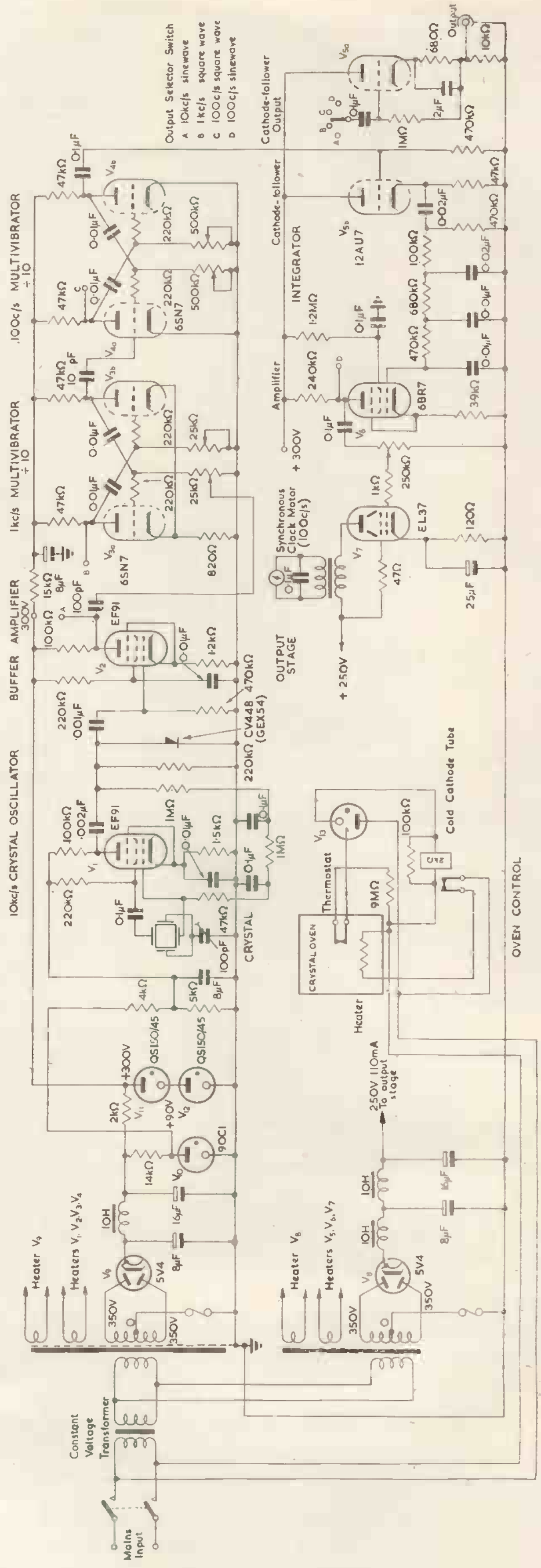


Fig. 1. The complete circuit

* *Venner Electronics Limited.*

is necessary. The output stage is fed from a separate supply to prevent pulling and this has a two-stage filter to reduce the 100c/s component derived from the a.c. mains, an important point, since the output stage is handling a 100c/s signal.

The use of 10:1 divider stages has not caused a great sacrifice of accuracy. After the initial setting up of the crystal by beating the 20th harmonic with the carrier of the Light Programme on 200kc/s by means of the preset trimmer, and later slight adjustments over the following month or so, the clock has been almost continuously functioning, the only interruptions during the last nine months being due to mains supply failures. The average drift per week has been 0·3 sec and the maximum drift during any one week 2·0 sec.

Acknowledgments

The author wishes to thank the Management of Venner Electronics Limited for permission to publish this article and Mr. S. P. Kendon of Venner Limited for originating the design work.

Automatic Component Insertion for Printed Circuits

An automatic in-line machine for the insertion of components into printed circuit boards is now being developed concurrently in this country and the United States under the name of "Dynasert", which is the registered trade mark in the United Kingdom.

The basic "Dynasert" conveyor consists of a straight-line conveyor on which are mounted individual component inserting machines. Up to a maximum of 40 inserting machines can be accommodated on a single conveyor drive motor, while tandem arrangement of two conveyors permits as many as 80 machines in line. At the loading end of the conveyor printed circuit boards are automatically fed in by the board loading machine beneath a ram plate which presses the board into spring clips mounted on a light metal frame or pallet, in which the board is transported by the conveyor belt down the line.

Owing to an inherent tendency in phenolic laminates to dimensional instability, the use of pallets assists accuracy of location, and offers flexibility in the choice of board shape and size. Two or three special location holes are usually punched out at the corners or edges of the board. One of these must be round, the remainder may be drawn to allow for expansion or contraction in the laminate. The spring loaded clips hold the board securely on to location pins in the pallet.

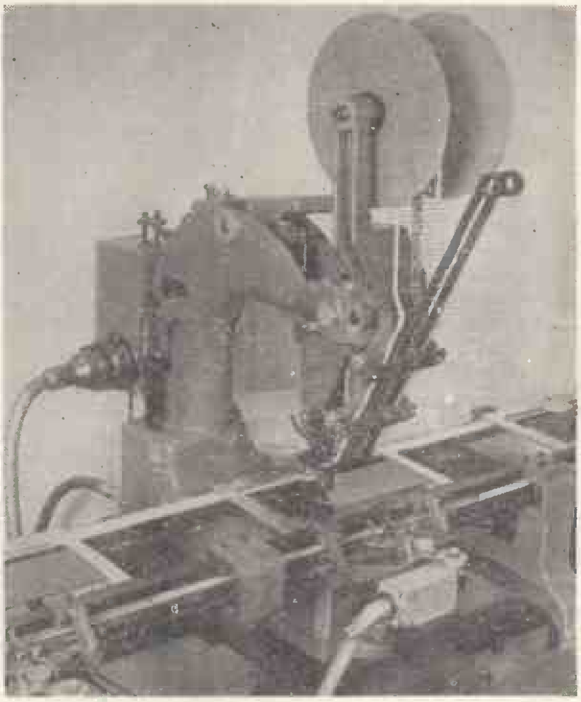
At the other end of the conveyor, a ram plate on the board unloading machines pushes the board off the pallet from underneath, and fingers on the unloader arms raise the board, which slides off down a chute. Empty pallets are then transported by a return conveyor, to the head of the conveyor.

Reciprocating motion of the conveyor is obtained by pneumatic cylinders with their associated lever arms, and rotating motion by electric motor drive, while the overall sequence of operations is controlled electrically. On arrival at an individual inserting head the pallet trips a microswitch, and when and only when the microswitches of all heads have been actuated, will the pallets be raised from the conveyor belts and locked solidly into position. The insertion cycle of every machine is synchronized by electrical timing relays in a master box mounted at the loading end of the conveyor. Various electrical interlock circuits with indicator pilot lights are incorporated to arrest action in the event of a major stoppage. The control box associated with each machine is fitted with appropriate switches which enable the machine to be operated independently, or switched completely out of circuit.

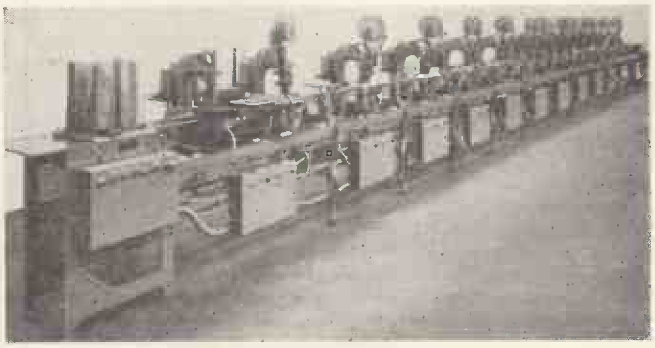
Each head is fixed in position on the conveyor by means of a single clamping screw, which allows it to be removed or re-positioned in a matter of minutes. This permits the inserting head with minor modifications to be used on bench assembly work for small production runs. In order to set an inserting head to place a component in any desired position on the board, the head of the unit is rotated about a vertical axis and the machine is adjusted by the clamping screw on its base plate, the holes in a sample board serving as a set-up-jig.

Components for insertion are the axial lead type which cover the majority of components such as resistors and capacitors, and are supplied in belted form using adhesive tape. A reel of components in belted form is loaded into the head of an individual insertion machine, and in operation the components are drawn down the slide by the tapes into the inserting head. Here their leads are engaged on either side of the component body by accurately spaced grooves round the circumference of two feed wheels. Sufficient length of components is stored in the slide to allow reels to be replaced when expended, without interfering with continuity of production.

The inserting head, which is operated by compressed air, draws down the component and shears cut the component leads to the correct length. The leads are then formed and driven through the punched holes on the printed circuit board, after which operation they are clinched over in the required direction so that the ends of the wires lie along the printed conductors.



A single head



A complete 'Dynasert' conveyor

Other inserting heads are in course of development for placing flat and cylindrical capacitors with radial leads, disk capacitors and printed circuit valve bases.

A single conveyor belt of this type is claimed to have an hourly output of 1 200 boards with a machine insertion reliability of better than 99·8 per cent.

The "Dynasert" insertion machinery is being developed in the United Kingdom through the Geo. Tucker Eyelet Co. Ltd, Birmingham.

This note is based on an article to be published in the Journal of the Institution of Electrical Engineers.

A Time Marker for Electrophysiology

By R. H. Kay*, M.A., D.Phil.

In electrophysiological experiments, sharply peaked pulses are needed at intervals of 100μsec, 1, 10, 100msec and 1sec for marking the time scale on cathode-ray tube displays or for triggering crater lamp discharge tubes to mark moving photographic film similarly. A 10kc/s crystal oscillator will provide a waveform of standard frequency from which the 100μsec marks may be derived.

It has hitherto been usual to follow the primary standard by a series of relaxation oscillator frequency dividers to derive the lower standard frequencies at decade intervals.

This note describes equipment which uses instead four stages of Dekatron cold-cathode tube dividers[1]. Dekatrons have advantages over controlled relaxation oscillators for division at these frequencies, the principal being that they are reliable and that division errors, should they occur, are always gross and easily detected.

The cold-cathode tube decades are followed by pulse shaping circuits and cathode-follower output stages. Here, sharply peaked pulses of c.70V amplitude are available for time marking.

A CENTRAL time marker, serving several rooms in a physiology laboratory is constantly used. The first requirement then, is a high degree of reliability. It is interesting to note here that Florida and Williamson[2] quote a 4 per cent per annum fault rate in thermionic valves in counters and compare this with a ¼ per cent per annum fault rate for cold-cathode tubes in similar applications. Since, at the worst, no more and frequently fewer cold-cathode tubes are needed than thermionic valves in equivalent decade counters, then Florida and Williamson's observation implies a longer trouble-free life for a cold-cathode tube timer than the equivalent thermionic valve circuit.

Essential qualities of a time marker are that both the primary frequency standard and the subsequent sub-division ratios should be stable. It is best also that should the primary standard fail then all outputs stop immediately.

Some controlled relaxation oscillators, frequently used for time division, fall short of this ideal; after failure of the primary oscillator or some early dividing stage, the subsequent dividing stage can be self-oscillatory. Later stages, though continuing to divide correctly may then be controlled by this free running stage at a false frequency. Alternatively, component failure or ageing may allow incorrect division at some stage. This error is sometimes not apparent until after a long experiment has otherwise been successfully completed. In a phantastron divider, for example, a ÷ 11 ÷ 9 error in an expected ÷ 10 ÷ 10 pair leads to a 1 per cent timing error in the following stages. This would not often be instantly detected when most of the experimenter's attention is fixed on the generally complex physiological procedures; frequent inspection of the division ratios right back to the primary standard becomes essential. Non-oscillatory thermionic decade circuits are, of course, possible but usually require at least four valves per stage.

On the other hand, a standard oscillator followed by Dekatron tubes (which work well at input frequencies less than 20kc/s) have the advantage that, should the primary standard fail, all subsequent division ceases. Counting faults when they occur in Dekatrons are gross and by timing the output of lowest frequency, an error in that or any previous stage is at once detected. In faulty operation, a stage counting error must be 10 per cent or greater, and in this case a reduction of the error by a compensating fault in a succeeding stage is highly improbable. When, as here, the final stage gives outputs at 1sec intervals, timing the movement of the visible glow by stop watch is sufficient for checking the operation of all the dividers.

This note describes a Dekatron time marker used in electrophysiological work in this laboratory. The oscillator and dividing circuits are followed by pulse shaping and cathode-follower output stages. Time accuracy of the standard greater than a few parts in 10^4 is not usually sought in physiological work, so that thermal insulation of the crystal is unnecessary[3]. Overall reliability is, however, all important.

Circuits (Fig. 1)

Time marks are required at 100μsec, 1, 10, 100msec and 1sec intervals. The primary standard is a 10kc/s quartz crystal type 4023 by Standard Telephones and Cables Ltd. (The use of 100kc/s crystals for the primary standard, of which many are available "surplus", though tempting, is false economy here). The crystal is maintained in oscillation in a circuit which is non-oscillatory without the crystal. [Fig. 1(a)]. This is based on the circuit recommended by the manufacturers, as are the following four stages of division using Dekatrons by Ericsson Ltd[4] [Fig. 1(b)].

The GC10D Dekatron will satisfactorily divide a 10kc/s oscillation and the GTE175M trigger tetrode will handle the 1kc/s output for transfer to the next divider stage. [The usual zero resetting circuit, used for counters, is, of course, unnecessary here].

The pulses available in the Dekatron circuits are not directly suited to c.r.t. time marking. Each stage is therefore followed by a panel of pulse shaping circuits and cathode-follower output stages. Pulse width can be adjusted to any convenient value by manipulation of the time-constants, *RC*. [Fig. 1(c)].

Though permissible h.t. variation for satisfactory operation of the Dekatrons is 270 to 320V (h.t.1) with h.t.2 (referred to h.t.1) varying from 420 to 470V, it is preferable to stabilize the common h.t. supply and a cascode stabilizer similar to that described by Attree[5] is used.

Mixed outputs to give a time "ruler" can easily be arranged at the central panels but, since laboratory requirements vary from room to room, the inputs are left unmixed at low impedance and may be used mixed or unmixed as required in individual research rooms at higher impedance with series blocking resistors. The pulses are fed by cable to the five rooms where time is needed (30 to 40yd from the central panels); satisfactory transmission to greater distances will require some modification of the output circuit by standard techniques to reduce the output impedance further, providing enough current to charge the

* *The University Laboratory of Physiology, Oxford*

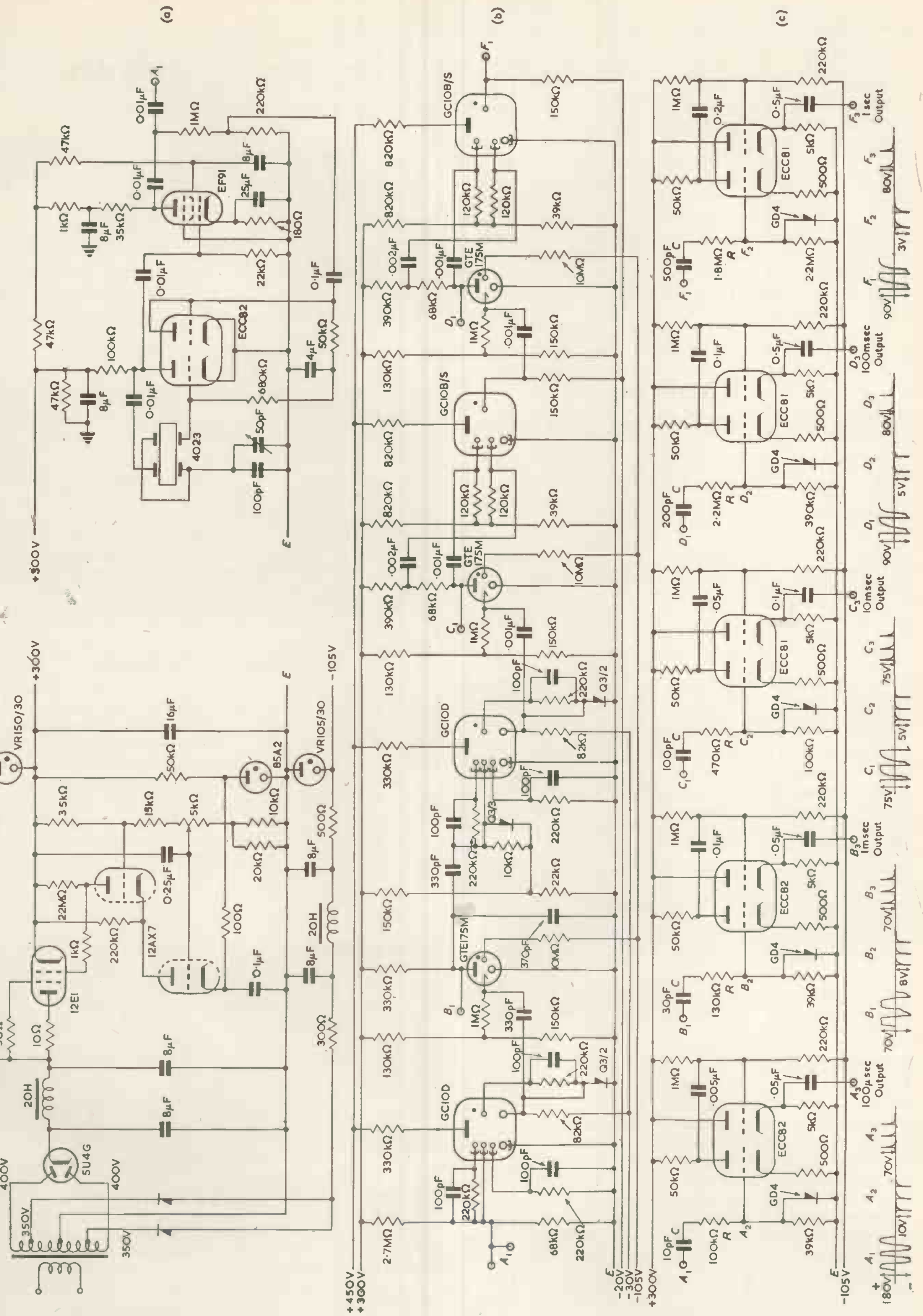


Fig. 1. The time marker circuit

cable capacitance sufficiently rapidly at the highest frequencies.

Conclusion

The Dekatron time marker described above has proved useful in electrophysiological work in this Laboratory and has advantages in this type of work over some relaxation oscillator frequency dividers, both in reliability and ease of testing. No originality is claimed for any of the circuits[5,6,7], but emphasis of the advantages of the method and publication of a tested circuit may help others with similar time-marking requirements. The apparatus has worked without servicing or adjustment for the last six months (July-December 55) and has been used an average of about six hours daily, supplying usually two or three individual rooms simultaneously.

Acknowledgments

The author wishes to thank Professor E. G. T. Liddell for the facilities available in this Laboratory; Ericsson Ltd for advice on the working characteristics of their tubes, supplementary to that published in Reference 4.

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7. Bullen, M. A., Daynes, L. A. A Time Marker for Electrocardiography. *J. Sci. Instrum.* 31, 6 (1954).
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JINDIVIK

(A Pilotless Target Plane for Guided Missiles)

A pilotless radio controlled target plane for use at the Joint British-Australian guided weapon development programme at Woomera, South Australia, has recently been announced by Sir Eric Harrison, Australian Minister for Defence Production. It was designed and built in Melbourne at the Government Aircraft Factories as one section of the joint Australian-British guided weapons development programme. A licence agreement for the manufacture of this plane has been made with an American Company, the East Coast Aeronautics, Inc.

The target plane—named Jindivik—has a wing span of 19ft, is highly manœuvrable and can fly at very high speeds at heights in excess of 50 000 ft. Because of the cost of the target aircraft, including its telemetering and remote control equipment, the objective normally is to have the guided missile seek out the target but not to destroy it. Cameras are therefore fitted to the target plane which record the distance by which guided missiles under development fail to strike.

The control room, showing the Skipper (right) and Navigator (left) controlling a Jindivik during its airborne period through a series of push buttons. Telemetered information of the plane's height and speed is displayed to them on the five dials of the monitoring panel. Radar screen (right) indicates aircraft's position throughout the flight.

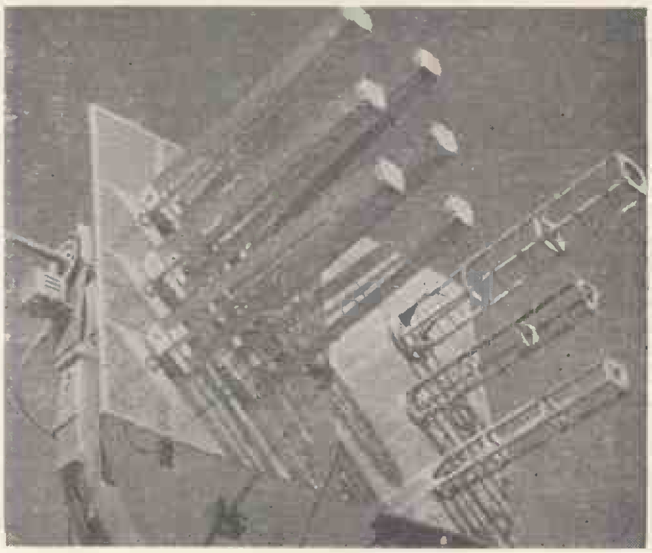
Launched from a take-off trolley, Jindivik is controlled in flight by a skipper and a navigator, who operate a series of push buttons to open the throttle to any position desired and to select any one of a number of flight conditions—climb, fast level, slow level, left turn, right turn, fast glide for descent from height and land glide to bring the aircraft back to earth on its retractable landing skid.

Jindivik—the pilotless target plane—being pushed on runway preparatory to take-off. The wing tip pods contain cameras which record the miss distance of weapons fired against it.

The target's height and speed are constantly telemetered back from the aircraft to a control room, while a radar screen indicates the position of the aircraft at all times. Long-range cameras record the flight photographically.

A pilot controls the take-off and the landing of Jindivik from a control point adjoining the flight strip with the aid of a " batsman " who performs a similar function to that of the " batsman " on an aircraft carrier in signalling the corrective action to be taken to line up the aircraft.

Aerial system of radar system used to plot the course of a target plane.



Notes from —————
NORTH AMERICA

Symposium on Optics and Microwaves

A symposium on Optics and Microwaves will be held at the Lisner Auditorium, George Washington University Washington, D.C., from 14-16 November, 1956. The meeting is jointly sponsored by the I.R.E. Professional Group on Antennas and Propagation, the George Washington University and the Optical Society of America. The technical programme will consist of six sessions, each embracing a subject of interest to persons who deal with optical phenomena in research or application in the fields of engineering, medicine or the related physical sciences. Survey and tutorial type papers will be presented to encourage understanding of the basic physics underlying fundamental characteristics which relate optics and microwaves as the two concepts now exist.

It is the purpose of the symposium to promote interest in the primary common problems associated with optics and microwaves and to demonstrate that these lie within the scope of modern theoretical and practical optics.

Educational Television Station

The first television station designed for exclusive educational use is being established in Puerto Rico and includes the purchase by the Department of Education in San Juan of an RCA 25kW transmitter, studio equipment, microwave links and a mobile television unit.

The equipment will have an effective radiated power of 100kW and will operate on Channel 6.

The transmitter will be located on the top of a mountain 15 miles from San Juan.

General Electric Equipment Leased to U.S. Air Force

The General Electric Company has been awarded the largest leasing contract ever signed by the U.S. Air Force Air Material Command for standard commercial two-way ground radio communication equipment. It is estimated that the lease will involve several million dollars worth of fixed station units and mobile radios.

Under the rental contract, General Electric will supply radio units for staff cars, carry-alls, station wagons, ambulances, fire trucks and fuel-servicing trucks which normally are equipped with such gear and will provide installation and maintenance of the units through the Company's authorized service stations.

New G.E. Computer Laboratory

First step in a long range programme for expanding engineering facilities of the General Electric Company in the industrial computer field has been announced with the establishment of a computer laboratory at Menlo Park. Calif. Engineering work at the new laboratory will initially be devoted entirely to the development of the ERMA data-processing system. ERMA, or Electronic Recording Machine Accounting is the electronic computer system developed for the Bank of America by the Stanford Research Institute.

The ERMA data-processing system is said to represent a revolutionary approach to the bank book-keeping problem, each ERMA performing daily book-keeping tasks for 55 000 commercial accounts.

Positive Temperature Coefficient Thermistors

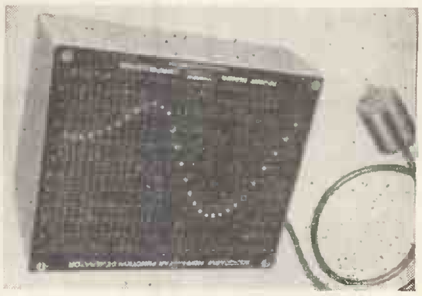
Fabrication of thermistor materials having large positive temperature coefficients was announced recently by Bell Telephone Laboratories. One material has a positive temperature coefficient from about −50°C to 110°C, with the coefficient reaching a value as high as 9 per cent/°C. Another material, of slightly different composition, has a positive temperature coefficient from about 50°C to 225°C with a maximum of 14 per cent /°C.

These materials in general consist of barium titanate or barium-strontium titanates to which small amounts of lanthanum have been added. By properly proportioning the various components, a wide variety of characteristics can be obtained. The resulting materials, after proper processing, are electrically and thermally stable over operating temperature ranges.

At voltages below which power dissipation causes no perceptible heating, these thermistors are ohmic in character, that is, the resistance does not change as the applied voltage is changed. Suitable ohmic contacts consist of an indium-mercury amalgam which is rubbed on at the desired contact point.

Non-Linear Function Generator
(Illustrated below)

A new device which will relate any non-linear function to a shaft rotation has been developed by the 'Vernistat' Division of the Perkin-Elmer Corporation.



The Non-Linear Function Generator is quickly adjustable to provide any mathematical or empirical function, including those with multiple slope reversals. Applications for the device are expected in the non-linear servo field, in computers, and for the correction of non-linear transducers.

The 31-pole 100-position switch has been designed in the form of a panel, which not only gives a visual presentation of the output function but allows for changes to be made instantly by means of switch sliders, as requirements dictate The x-axis of the panel represents shaft rotation and the y-axis represents output voltage.

Conference and Exhibit on Magnetism and Magnetic Materials

The second Conference and Exhibit on Magnetism and Magnetic Materials will be held in Boston from 16-18 October.

The conference is sponsored by the American Institute of Electrical Engineers in co-operation with the American Physical Society, the American Institute of Mining, Metallurgical and Petroleum Engineers, and the Institute of Radio Engineers. In addition to the programme of technical papers, the meeting will feature exhibits by leading manufacturers of magnetic materials and associated equipment.

Microwave Antenna for Scatter Propagation Studies

To study the characteristics of scatter propagation, Bell Telephone Laboratories have designed and built a precision microwave antenna at Holmdel, New Jersey. It is sixty feet in diameter and accurately steerable. Built of aluminium, the solid surface is a paraboloid, accurate to about 3/16in. The paraboloid alone weighs 5½ tons and, with its supporting and steering structure is designed to withstand winds of 100 miles/h.

The antenna is intended for use at 460 and 4 000Mc/s, but was also tested at 9 400Mc/s. Using calibrated pyramidal horns as standards, the gain was found to be 37·0 ±0·1dB at 460Mc/s, 54·6 ±0·2dB at 3 890Mc/s and 61·1 ±0·5dB at 9 400Mc/s. Half-power beam widths at these frequencies were 2·45°, 0·3° and 0·14°, respectively.

Sweep-Frequency V.S.W.R. System

Constituting a complete instrumentation system with output for connexion to a chart recorder, the Model 125A CTI Sweep-Frequency V.S.W.R. Measuring System, introduced by Color Television Incorporated, San Carlos, Calif., automatically sweeps an adjustable frequency range to permit the production of instantaneous plots of v.s.w.r. versus frequency. The preferred ratiometer system, with its advantages in speed and accuracy over slotted-line techniques is used.

The instrument is said to be ideal for wideband tuning operations both in the laboratory or on the production line and, where desired, it can be used in single-frequency operations.

Short News Items

The International Ferrite Convention, which is being organized in London by the Institution of Electrical Engineers, will be held from 29 October to 2 November. Some 50 to 60 papers dealing with Ferrites and their applications in electrical engineering will be presented and discussed by delegates from various countries. An introductory lecture will be given by Dr. Willis Jackson, Director of Research at Metropolitan-Vickers. Further information can be obtained from the Secretary, Institution of Electrical Engineers, Savoy Place, London, W.C.2.

The British Transport Commission is to use an electronic computer to calculate distances between all stations and depots on British Railways. Last year the Commission consulted Leo Computers Ltd on the possibility of using their computer for the work. As a result, a method has been devised whereby comprehensive new distances will be produced by "Leo" from basic material supplied by the Commission.

The Air Navigation Development Board, which co-ordinates civil and military radio-navigational requirements in the United States of America, has placed an order for Cossor Secondary Surveillance Radar equipment, including ground station units and airborne transponders.

Cable and Wireless Ltd announce that Mr. C. J. V. Lawson, at present Manager of the company's cable station and Engineering School at Porthcurno, Cornwall, will become Engineer-in-Chief on 1 April 1957 in succession to Mr. J. A. Smale, who will be retiring at the end of March.

Dr. H. W. Melville has taken up appointment as Secretary of the Department of Scientific and Industrial Research.

Dr. G. B. B. M. Sutherland is now Director of the National Physical Laboratory.

Elliott Brothers (London) Ltd, under a recently announced agreement with Giannini Ltd of 45 Gresham Street, London, E.C.2, are to manufacture and market Giannini Shaft-Rotation Digitizers. Giannini Ltd are the British affiliate of the Am ericancompany, G. M. Giannini and Co Inc, of Pasadena, California. These digitizers are a range of specially designed commutators which enable shaft positions to be converted without ambiguity to electrical signals.

The Royal Society announces that the Bureau of the Special Committee appointed by the International Council of Scientific Unions for the International Geophysical Year (CSAGI) 1957-8 has decided to appoint a full-time officer to assist in the co-ordination of the operations in order to ensure that the Year achieves its fullest promise. The Co-ordinator of Operations will have his office in Brussels alongside that of the General Secretary. Vice-Admiral Sir Archibald Day has been selected for this post.

Southall Technical College propose holding short courses on the following subjects, commencing this month. Advanced Mathematics for Engineers and Physicists; Analogue and Digital Computers; Pulse Techniques; Radar; Servomechanisms; Experimental Servomechanisms; Introduction to Transistors. Commencing in January 1957 a course of ten lectures on Colour Television will be held. Further particulars may be obtained on application to the College at Beaconsfield Road, Southall, Middlesex.

Bradford Technical College, Department of Electrical Engineering, have issued leaflets and prospectuses on courses for the 1956-57 session. These include part-time day and evening courses for Higher National Certificate and professional qualifications in Electrical Engineering, Electronic Engineering, Radio Engineering and Television Engineering, and Radio and Television Servicing. Particulars may be obtained from Dr. G. N. Patchett, Head of Department of Electrical Engineering, Technical College, Bradford 7.

Borough Polytechnic, Borough Road, London, S.E.1, announce a course of 23 lectures on The Fundamental Principles of Pulse Techniques, beginning on Monday, 15 October. For those students who wish to do practical work on Pulse Techniques, a Laboratory Course has been arranged, and is described in a leaflet available on request.

F. G. Miles Ltd of Shoreham Airport, Sussex, have formed an electronics division. Mr. C. H. Bickerdike is Manager and Chief Engineer of this new division.

Isotope Developments Ltd are running a comprehensive course, both theoretical and practical, on the industrial and research applications of atomic energy. This is primarily to train home and overseas sales representatives and service engineers. Further information and details may be obtained from the Sales Manager, Isotope Developments Ltd, Finsbury Pavement House, 120 Moorgate, London, E.C.2.

A new Anglo-American company, Ketay Ltd, has been formed for the production of precision synchros, servo motors, resolvers and tachometer generators for use in computers, radar sweep circuits, phase shifters and data transmission systems. Ketay Ltd is a joint company formed by the Plessey Co Ltd and Norden-Ketay Corporation of New York. The precision units will be produced to the specifications of the Plessey Co Ltd.

Three laboratories of The General Electric Co Ltd at Stanmore (Middlesex), Brown's Lane (Coventry) and Salisbury (South Australia) have been renamed under a group title of "Applied Electronics." Names and addresses of these establishments are now as follows. The General Electric Co Ltd, Applied Electronics Laboratories, The Grove, Stanmore, Middlesex; The General Electric Co Ltd, Applied Electronics Laboratories, Brown's Lane, Allesley, Coventry; The General Electric Co Ltd of England, Applied Electronics Laboratories, P.O. Box No. 127, Salisbury, South Australia, Australia.

Mr. R. Arbib, Managing Director of Multicore Solders Ltd, Hemel Hempstead, has announced that plans have been completed to manufacture Ersin Multicore 5 core solder in Australia. The sales offices will be located at 43-51 Nelson Street, Annadale, Sydney. A factory has been purchased at Alexandria, Sydney, and arrangements made for a complete manufacturing plant for Ersin Multicore Solder to be installed.

Alma Components Ltd are a newly formed company operating from 165 Ossulston Street, London, N.W.1. They have designed and are manufacturing an improved precision wirewound resistor. It utilizes a specially selected wire which is heat treated after careful winding. Special resistors can be supplied to customers' own specifications and deliveries are made promptly.

Erratum. The data given for the book Second Thoughts on Radio Theory, reviewed on p. 411 of the September issue, should read 409 pp., 271 figs.

LETTERS TO THE EDITOR

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

Magnetic Slip Rings

DEAR SIR.—In the E.M.I. Engineering Development communication under this heading, published in your June issue, it is stated that the need for symmetry must in general eliminate the use of stampings in this device. One of the forms of the device outlined in a Ministry of Supply Patent Application[1] envisaged the use of rectangular stampings with a rotating central leg made of a coil of thin high-permeability tape, wound on a shaft with which both transformer windings were concentric. For ease of construction a hollow shaft containing the leads to the rotating coil is advisable; while the stampings can be in two stacks separated by spacers slightly thicker than the diameter of the shaft, which passes between the stacks.

The sketches published show arrangements in which shaft translational movements cause first order changes of effective permeability. Such changes can readily be made second order by various alternative designs. The device is expected to have applications where the rotating part is supported on a low-torque bearing of compressed air or oil, or is in a corrosive atmosphere or in vacuo, as well as in communication circuits where low noise is required.

Yours faithfully,

G. J. DALTON,
Royal Aircraft Establishment,
Farnborough,
Hants.

REFERENCES

1. DALTON, G. J. U.K. Patent Application. 25721/55 (Sept. 1955).

The Contributor's Reply:

DEAR SIR.—With regard to Mr. Dalton's letter on Magnetic Slip Rings, our note was intended to be informative and to reveal to other workers in the art a useful artifice which might help them out of their troubles. We first made these slip rings about 1953 in connexion with some Government apparatus so they were in existence long before Mr. Dalton's patent application which is dated September 1955. We had been asked by the Government Department concerned to couple two relatively moving circuits in a magnetic manner rather than in the normal manner using slip rings.

It is, of course, difficult to comment on Mr. Dalton's invention so far as it relates to the information given in our communication since it has not yet been published and we have no copy.

Yours faithfully,

E.M.I. ENGINEERING DEVELOPMENT LTD.,
Feltham,
Middx.

Reliability as a Design and Maintenance Problem

DEAR SIR.—There are several points with reference to the article by Mr. Matthews on page 310 of your July issue, which I would like to make. Equation (7) in the article which shows the relative improvement in gain-stability of the system advocated, over a single valve without feedback, is only strictly true for very small variations, since the analysis is based on the infinitesimal calculus. For large variations in mutual conductance this factor is considerably reduced and, when the maximum permissible decrease in g_m is 40 per cent (which is not so excessive as it might appear, since the tolerance on mutual conductance for most types of valve is greater than ± 20 per cent), the nominal gain of the system must be greater than 5 if the two valves with feedback are to show higher stability. In fact, even when the gain of the system is considerably higher than 5, it is debatable whether the improvement obtained warrants the extra valve and components.

If gain stability is an important parameter in the system design, then it would appear that the application of negative feedback over the complete amplifier, if this is possible, offers considerable advantages. We may take as an example an amplifier with a nominal gain of 28dB (×25). When the mutual conductance decreases by 40 per cent, the gain of a single valve without feedback is reduced by 4·4dB, the gain of two valves with cathode feedback by 2·2dB and if two valves with overall negative feedback (each stage similar to the single-valve amplifier) are used, the gain is only reduced by 0·6dB. In addition to greater independance from valve parameter variations, the use of overall negative feedback also provides compensation for variations in resistor and other component values, and ensures that the bandwidth is not reduced (or rise time increased) with the introduction of the extra stage.

The suggested method of marginally checking valves by lowering the heater voltage and so reducing their emission, has certain disadvantages. From Table 2 in the article it can be seen that a given reduction in heater voltage has very diverse effects on the performance of valves of different types, so that the degree of marginal check applied varies widely from valve to valve. A second disadvantage is that the valves only are checked, although in some systems, especially those with direct coupling, variation in other components may be equally critical. A more fundamental criticism of the method, however, is the operating of valves with low heater voltage which is contrary to the recommendations of the manufacturers and which may have adverse effects on valve life.

Yours faithfully,

W. RENWICK
The University Mathematical Laboratory,
Cambridge.

The Author Replies:

DEAR SIR.—An increase in the reliability of electronic equipment can be achieved by various design procedures provided they are backed up by an appropriate maintenance technique. The use of overall feedback, in this connexion, suffers from problems associated with h.f. stability (when applied to multi-stage amplifiers (and servicing difficulties ("hot" points in the circuit, and the advanced level of "know how" that may be required.) Since many amplifiers are required to function as waveform generators, the use of overall feedback has its justification for this specific purpose anyway, and attempts to design stable, repeatable and serviceable circuits by ignoring local feedback technique constitutes an unnecessary hazard.

In particular, for operational amplifiers with gain figures of the order of 30dB and with, say, 50 per cent more stages than may be needed in the "straight" case, changes in g_m can be tolerated far in excess of the CV register limits. It should be noted that local feedback does confer the benefits of increased bandwidth and, since it can often be applied as a d.c. element, stabilizes the operating point on a.c. coupled amplifiers.

Marginal checking by heater current reduction does bear the stigma of contradicting the requirements of both the British Standards recommendations on the use of thermionic valves, and the published findings on research into the production of long life valves. In both cases the heater current is required to be controlled to a close tolerance.

In making the suggestion that marginal checking by heater current reduction can contribute to reliability, therefore, the assumption has been made that existing recommendations are either too general or, for the newer type valves, obsolete. For example, it might be held that if the equipment is to be switched on and off, this represents a 100 per cent variation of current and a procedure such as routine checking cannot represent any aggravation of this condition. Or, again, that problems involving thermal cycling of the cathode have been overcome and that in those valves that now make use of improved techniques no deterioration in performance results from marginal checking.

It is to be hoped that further recommendations can be made to cover this point.

Yours faithfully,

R. MATTHEWS
Sheerwater,
Surrey.

BOOK REVIEWS

Electronic Measurements and Measuring Instruments

By F. G. Spreadbury. 459 pp. 60 figs. Demy 8vo. Constable & Co. Ltd. 1956. Price 50s.

CHAPTER 1 entitled "Valve and Component Characteristics and Their Relation to Measurement" comprises a mixture of valve theory with practical snippets such as that leakage grid current can be reduced by treating the envelope with "paraffin wax, ceresin or, preferably, a silicone coating such as B.T.H. Teddol".

On page 7 it is stated that "The anode current/grid voltage characteristics of triodes and pentodes are similar in form to that of the diode, but are displaced to the axes by amounts depending on the anode and screen potentials and the valve parameters"—it is news that diodes have an anode current/grid voltage characteristic! On page 9 we are told that "Since the anode voltage of a diode is usually provided either directly or indirectly by whatever is being measured, variation of the mains supply affects only the heater and cathode conditions with results already discussed."

On page 11 dealing with Input Impedance the author sketches a hypothetical i_g/e_g triode characteristic intersecting what is presumed (since there are no scales in Fig. 1.11) to be the abscissa at a point designated *P*. He states that, since the current is zero at this point, "it is apparent that the input resistance of the valve is a maximum at a grid potential corresponding to this point"—why a maximum? "However, owing to the relatively high rate of change of grid current at *P* it is evident that a small variation in grid voltage at this point would convert the valve to one having relatively low resistance. Because of this it is customary to operate a valve at a point to the left of *P* when very high input resistance is desired." There is here confusion of thought between static and dynamic characteristics and no appreciation of the real factors in input impedance.

On page 27 we learn that "Valve characteristics change with use, even when aged, and, since this cannot be entirely prevented, it is desirable to render instruments using valves independent of such changes, as far as this is possible. Complete independency of changes in characteristics would, of course, mean that an instrument would be more likely to retain its accuracy of calibration and that this accuracy would be unaffected by a change of valves." Later in the chapter when dealing with components we are told that "The resolution of a potentiometer is the resistance per turn of the winding and it is evident that the magnitude of this must have some effect on the tolerance. For example, a winding having 1 000 ohms with 1 000 turns of wire has a resolution of 1 ohm and evidently cannot have a tolerance smaller than 0·5 per cent. The tolerance of a well-made potentiometer, without special correction, can be expected to be better than $\pm 1{\cdot}0$ per cent. With special cam-corrected potentiometers the tolerance can be held within $\pm 0{\cdot}04$ per cent."

If the reader has the patience to proceed to Chapter II entitled "Valve Voltmeters and Their Applications" he will find therein detailed descriptions of four voltmeters all designed by the author. The standard of these designs is much inferior to current practice; one is quite alarmed by statements such as "However, many 100μA meters will readily withstand an overload of 9 times normal for the cathode-heating time and, with such meters, a delay switch is unnecessary."

Further chapters deal with Frequency and Time Measurement, Oscillators, Amplifiers, Stroboscopes, Cathode-ray Oscillographs, Photo-electric Cells, Miscellaneous Electronic Instruments and finally Transformers, Meters and Construction Practice. All these chapters abound with false or vague statements; scores of examples could be quoted if space permitted—the following is typical of the style. "The amount of power needed from such oscillators is usually small, seldom exceeding 10 watts, but there is a number of features that they must possess besides several which are desirable, if not necessary. These features include simple tuning arrangements extending over a wide frequency range, frequency and amplitude stability, freedom from harmonics with sinusoidal oscillators, and constancy of output over the working frequency range. The oscillator is usually of the master-oscillator/amplifier type, i.e. the oscillator drives a Class A amplifier from which the output is derived. By this means the oscillator proper is unaffected by the load."

The general impression obtained is that no one but the author has ever designed electronic instruments; with only one exception every instrument described in the book has been designed by the author—even a standard cathode-ray oscillograph. There is an almost complete neglect of other people's work; for example, of the 22 footnotes, 17 refer to the author's publications, three to manufacturers' literature, one to a standard book on algebra—because the reader is not supposed to know what is the "decimal system"—and only one to someone else's published paper. Even in the chapter on Miscellaneous Electronic Instruments all the examples given have been designed by the author. The majority of the instruments described throughout the book have little, if anything, to commend them and are, in fact, at least a decade behind current instrument design and practice; the examples of recommended construction given in Fig. 13.13 would have been considered poor in 1930.

The bibliography is most curiously unbalanced and limited—why, for instance, is there not a single reference to oscillators and amplifiers and yet ten to cathode-ray oscillographs?

With the exception of seven figures borrowed from manufacturers, the remainder have been poorly drawn by the author (with errors in several cases) and reduced by varying degrees. There is no standard symbolism, no printed symbols, no uniformity, and no captions; it is surprising that neither the author nor the publisher seems to be aware that there are recognized and standard symbols for components. Most of the freehand symbols have been reduced to such an extent that, even with the aid of a magnifying glass, it is difficult to read them.

The lists of components are usually on a different page to the figure to which they refer, as are also the figures with respect to the text. The reader becomes irritated by the continuous references backwards and forwards to figures with no page reference. It is astonishing that the numerous errors in figures and tables should not have been detected during the proof reading.

H. A. THOMAS

Scattering and Diffraction of Radio Waves

By J. R. Mentzer. 134 pp., 35 figs., Demy 8vo. Pergamon Press Ltd. 1955. Price 30s.

IN the early days of radar, calculations of the approximate signal strength to be expected by reflection or scattering from typical targets were made by simple methods. As the operational techniques developed, and were extended to higher frequencies, the desire for more precise theoretical data led to a variety of mathematical treatments. These have been described in published papers and are summarized and compared by Dr. Mentzer.

The book should perhaps be regarded as a progress report, because solutions have been obtained to only a few problems of practical importance and some of these are approximate and lack experimental proof of their validity. The methods of formulating the problems in mathematical terms are well established: they include classical and integral equation methods, and approximations such as geometrical and physical optics, Babinet's principle and the variational method. The main difficulty in the work lies in the solution of the mathematical equations, and treatments have been given only of a few diffraction problems and of scattering by simple bodies such as spheres, cylinders, cones, thin wires and plates. These treatments are presented as illustrations of the theoretical techniques, and the comparisons between different methods of approach are particularly useful. In this respect the book should satisfy the needs of the student who, starting with a sound knowledge of vector analysis, wishes to learn the present state of scattering theory.

Those who are primarily interested in using the end-results may find some difficulty in extracting the information they need. This is partly due to a tendency to quote results from published papers without all the required explanatory material, and to the presentation of a number of solutions to the same problem with insufficient comment. The treatment of the thin wire may be taken as an example, since it is studied in considerable detail and by different methods. Graphs taken from one of the references include results by an "e.m.f. method" which is adequately defined in the original paper, but not in the book. Also the various solutions differ considerably, and while it is suggested that some are better than others, the criteria by which they are judged are not clear. Certainly the existing experimental data appear to be inadequate to differentiate between the solutions and some do not agree with any of them. For example experimental data have been published which indicate that as the length of a thin wire is varied, the broadside response exhibits well defined peaks when the length is an odd multiple of a half-wavelength, even for wire several wavelengths long. The theoretical curves for slightly thicker wires show quite different characteristics for lengths greater than the wavelength. Some comment on these apparent discrepancies would have been valuable, but unfortunately these particular experimental results are not quoted.

Generally, however, the book is well produced and easy to read. The usefulness of the references is somewhat impaired by the omission of many of the titles of papers, while several others are reports with limited circulation and will not be available to many readers.

F. HORNER.

Television and Radar Encyclopædia

Edited by W. MacLanachan. 216 pp., 219 figs. Demy 8vo. 2nd edition. George Newnes Ltd. 1956. Price 30s.

THIS book contains informative articles contributed by leading authorities in their respective fields, and will be of interest both to the qualified technician and to the non-specialist reader.

Many new definitions have been included and others have been revised in the light of latest practice. Developments such as automatic picture control, compatible colour television systems, flywheel synchronization, thermistors and transistors are included.

At the end of the book there is a selection of tables and data of use to all who are concerned with the installation and maintenance of television and radar equipment.

Industrial Research

Edited by P. Dunsheath. 444 pp. Demy 8vo. 3rd edition. Todd Publishing Group Ltd. Distributed by George Harrap & Co. Ltd. 1956. Price 63s.

THIS edition includes contributions from Sir Norman Kipping, the Director-General of the Federation of British Industries, and Sir Ben Lockspeiser, secretary of the Department of Scientific and Industrial Research, 1949-1956.

There are reference sections on careers, technical colleges, university laboratories, research by private firms, industrial research consultants and books and periodicals. Statements of the activities of official and unofficial organizations are given together with directories of officials and classified lists of official and unofficial bodies at home and overseas.

An entirely new section covers the whole of the activities of the United Kingdom Atomic Energy Authority which includes a directory of the chief official and departmental heads.

Elements of Pulse Circuits

By F. J. M. Farley. 143 pp. 74 figs. Pott 8vo. Methuen & Co. Ltd. 1956. Price 8s. 6d.

THIS book provides a concise introduction to pulse circuits for those who have no experience in the field, but who have an elementary knowledge of thermionic valves and radio. The emphasis throughout is on physical understanding rather than on mathematical analysis.

S.B.A.C. EXHIBITS

A description, compiled from information supplied by the manufacturers, of a few of the electronic exhibits shown at the recent exhibition of the Society of British Aircraft Constructors at Farnborough.

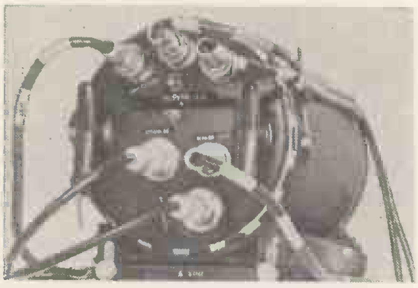
RADIO ALTIMETER

(Illustrated below)

The General Electric Co. Ltd, Magnet House, Kingsway, London, W.C.2

THIS instrument gives a precise indication of the height of an aircraft above ground, i.e., terrain clearance from 0 to 5 000ft, with cyclo-meter type presentation for units of thousands of feet and a pointer reading continuously between the zero and 1 000ft markings on a complete circular scale.

Signals are radiated continuously by a u.h.f. oscillator which sweeps at a known speed through a band of 50Mc/s. The difference in frequency between an echo received at the aircraft and the frequency of the transmitter at that



instant is a measure of the altitude and is converted into an i.f. signal for amplification in a double-superheterodyne receiver giving an a.f. output suitable for operating the indicating devices. Automatic control is applied to the transmitting oscillator so that the beat frequency produced with the echo signal does not exceed 10kc/s at any altitude within the range of the instrument, and the consequent restriction of the a.f. bandwidth necessary in the receiver minimizes noise.

The scale and pointer indications are supplemented by light signals which can be preset by the pilot so that a green light shows when he is flying within ±15ft of his chosen height above the ground, with red and amber signals respectively if he descends below or climbs above these limits. A power supply failure causes simultaneous display of the red and amber lamps.

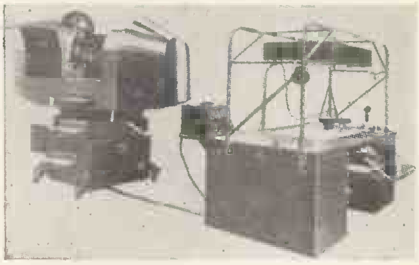
FLYING TRAINERS

Air Trainers Ltd, Bicester Road, Aylesbury, Buckinghamshire

Type Trainers

TYPE Trainers enable pilots to undergo proficiency checks and conversion courses and to familiarize themselves with the procedures and emergency drills necessary for the operation of a particular aircraft under all conditions.

The trainer incorporates a full scale mock up of the cockpit of the aircraft in question, all the controls, instruments and switches being properly disposed and



faithfully represented, those not required for training purposes being installed as dummies which operate in the correct sense, so enabling full cockpit drills to be carried out. Flight and engine characteristics are reproduced by means of a separate electro-mechanical computer.

Movement of the fuselage in pitch and bank is effected by means of hydraulic jacks, the pivot being placed to the rear well behind the pilots' seats. This movement being independent of instrument operation, the trainer may also be flown in a static condition.

Instrument Procedure Trainers

(Illustrated above)

The lay-out of these trainers does not conform to that of any particular aircraft, but the main controls to be found in single seat aircraft are present.

The controls, instruments and performance characteristics of the A.T.12 are similar to a piston-engined aircraft, while those of the A.T.50 conform more closely to those of a jet aircraft.

The associated instructor's desk provides certain repeat instruments together with facilities for the introduction of the more common failures, and appropriate signals for radio navigational training.

RADAR SIMULATOR

The Solartron Electronic Group, Ltd, Thames Ditton, Surrey

THIS Radar Simulator consists of a dual aircraft target control/computer console and an antenna pattern drum system.

The control/computer console is, in effect, an "aircraft". The control panel carries the necessary knobs and dials to enable the aircraft to "fly" in three dimensions. They show velocity or speed, rate of climb, dive and turn. Dials show the height and heading angle of the individual aircraft. This information with that of the air speed is passed on to the computer unit where the target's bearing angle, slant range and elevation angle are worked out.

The antenna, or aerial pattern drum unit consists of an azimuth bearing angle gearbox assembly with the antenna drum mounted on it. A signal source is fed into the coupling probes, and the output from the device, which is a typical aerial radiation pattern, is fed to a Solarscope oscilloscope to enable it to be seen.

Other uses for Solartron Radar Simulators, besides that of training personnel, include acting as an evaluation device for new radar systems and the development of radar jamming counter-measures.

AIRBORNE SEARCH RADAR

(Illustrated below)

Ekco Electronics Ltd, Southend-on-Sea, Essex

LONG-RANGE Airborne Search Radar Type E120, currently being fitted in the B.O.A.C. fleet of Bristol "Britannia" turbo-prop airliners, is used for detection of dangerous cloud formations and high ground ahead of the aircraft and for providing map-painting facilities.

Its main features are:—

(1) High sensitivity, providing detection of cumulo-nimbus clouds up to 120 miles distant.

(2) A p.p.i. providing high brightness display.

(3) Iso-echo contour circuits to distinguish between dangerous and non-dangerous centres in cumulo-nimbus clouds.

(4) The Scanner Unit is stabilized with limits of +18° to −22° in pitch ±45° in roll.

The electronic units of the E120 are unpressurized and are for installation in the pressurized cabin.

1KW V.H.F. TRANSMITTER

Pye Ltd, Newmarket Road, Cambridge

TYPE PTC 3600 transmitter has been designed for airport ground-to-air operations and also for teleprinter and v.f. point-to-point links. The r.f. and modulator sections are assembled in self-contained cubicles which are combined into a composite equipment for r.t. service.

The drive unit consists of a crystal oscillator followed by three harmonic generator stages, providing a frequency multiplication of twelve times the crystal frequency. These stages are followed by two push-pull stages which drive the final amplifier. Any frequency in the range can be set up with ease and rapidity. All coupling circuits up to carrier frequency are fully screened and double tuned.

The transmitter may be remotely controlled and is protected against damage due to overloads or maladjustment. All valves are accessible from the front of the unit; doors are provided at the rear to facilitate inspection and maintenance.

The transmitter may be operated unattended in tropical climates. Forced-air cooled tetrodes are used in the r.f. output stage and radiation-cooled triodes are used in the modulator.

- Output power: 1kW unmodulated carrier.
- Service: A3 (radio telephony).
- Frequency range: 115 to 140Mc/s continuous coverage.
- Frequency stability: 0·005 per cent.
- R.F. output impedance: 50Ω unbalanced.
- A.F. response: -3dB at 300 and 3 400c/s relative to response at 1kc/s.
- Modulator sensitivity: -10dBm for 100 per cent modulation at maximum gain.
- Attenuator range: 14dB in 1dB steps.
- A.F. distortion: Less than 10 per cent total harmonic distortion at 95 per cent modulation level.

SIX DECADE COUNTER/TIMER

(Illustrated below)

Marconi Instruments Ltd, St. Albans, Herts

THE Electronic Counter/Timer TF. 922/1 is an a.c. mains operated, direct-reading, six-decade instrument either for counting a million periodic or random-pulses at rates up to one million per second, or for the measurement of time intervals up to 1sec in microsecond steps.

The equipment comprises a 1Mc/s crystal-controlled oscillator, an electronic switch and a series of decade counters with visual indicators.

When employed as a timer, externally derived starting and stopping pulses operate the electronic switch and cause the counter circuits to determine the number of cycles of the oscillator occurring in the interval, the reading, to the nearest micro-second, appearing in illuminated figures. When used purely as a counter the oscillator is switched off and the impulses are applied directly to the counter train. One design feature is the employment of scale-of-two counter trains, with their reliability and positive action, while retaining the material advantages of direct decade reading. The application of feedback advances the count so that the complete cycle is achieved in ten impulses.

ROTARY TRANSFORMERS AND CONVERTORS

Newton Brothers (Derby) Ltd, Alfreton Road, Derby

THESE Rotary Transformers will provide an h.t. output between 250 and 1 200V d.c. when supplied with an l.t. of between 12 and 24V d.c. Conversely, an l.t. output can be provided when only h.t. supplies are available.

Standard machines are of the enclosed ventilated type. Dual output machines provide, simultaneously, both a.c. and d.c. outputs.

The rotary convertors will provide a 230V single phase 50c/s output from a 12, 24, 110 or 220V d.c. input supply, though machines can be supplied for other voltages and frequencies up to 100c/s if required. In the case of variable voltage input supplies the output voltage can be stabilized to within ± 2 per cent by one of a series of carbon pile voltage regulators.

Depending upon requirements, the regulator, which is of the series type, can be used to stabilize either the input voltage or the output voltage of the machine over the range of the supply voltage variation.

RADAR INFORMATION LINK

Marconi's Wireless Telegraph Co. Ltd, Chelmsford, Essex

RADAR information was transmitted from the Marconi S.232 crystal-controlled radar operating at London Airport to viewers on the Marconi stand while television pictures of aircraft activity at London Airport were relayed over the same link.

This demonstration was made possible by the use of a new microwave radar link, equipped with repeaters using travelling-wave tubes, and capable of relaying three radar or television pictures.

The use of the new microwave radio link enables the radar head and the operations centre to be miles apart if so required; the system also makes possible the routing of 'raw' radar information from a number of remotely sited heads to one suitably positioned operations centre.

MOBILE RADAR SITE

(Illustrated above right)

A.C. Cossor Ltd, Cossor House, Highbury Grove, London, N.5

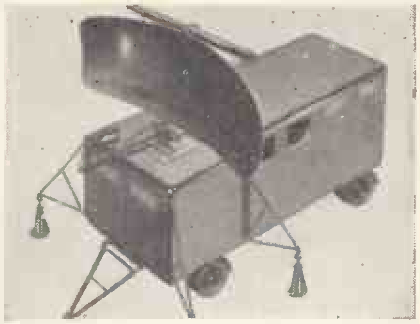
TYPE 21 is a high power surveillance radar operating in the "S" (10cm) band.

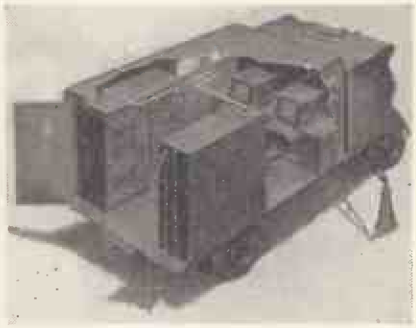
A 16ft horizontal aperture reflector is used to give high gain and narrow azimuth beamwidth. Solid vertical coverage of the cosecant squared pattern is provided by using a shaped, continuously-surfaced reflector fed by a single waveguide horn. The vertical coverage extends from 0° to 45° above the horizon, without tilting or switching the beam. A 15m^2 target is seen at a range of 60 sea miles and up to 30 000ft. A circular polarizing filter, under the control of the operator, effectively removes rain echoes. A discrimination of 20dB in favour of an aircraft target as against rain clutter is obtained.

A single cabinet houses the main electronic unit, connected to the aerial head by standard waveguide. The equipment is shock-mounted for vehicle transit over rough surfaces. An ambient temperature of up to 122°F (50°C) permits operation in almost any climate.

The display units are in two parts: a compact portable viewing unit and a desk unit containing associated power supplies, the parts being connected by cable.

Type 21 is offered as a complete radar station, installed in a robust four-wheeled trailer, weighing approximately five tons and suitable for transit over second-class roads and for air transportation in large aircraft.





GUIDED MISSILE TELEMETRY

E.M.I. Electronics Ltd., Hayes, Middlesex

RADIO telemetry as an aid to missile system design was demonstrated under simulated flight conditions using a guided test missile 15ft long suspended several feet above ground level and vibrated by an E.M.I. Type EMV/5 heavy duty vibrator to produce an approximation to actual flight conditions.

Two radio telemeters were installed in the missile, one measuring the effects of vibration and the other measuring scientific data as transmitted from the missile. In both cases, the transmitted information was displayed on the telemetry ground equipment.

Telemetry can provide a means of gathering data on upper atmosphere research, aero-dynamic tests, rocket-motor performance, etc., and can be called upon to measure and transmit a wide variety of information including position, velocity, acceleration, pressure, temperature, stress, fuel-flow and voltage.

Meetings this Month

THE BRITISH INSTITUTION OF RADIO ENGINEERS

Date: 31 October. Time: 6 p.m.
Held at: The London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1.
Annual General Meeting followed by Presidential Address of G. A. Marriott.

North-Western Section

Date: 4 October. Time: 6 p.m.
Held at: Reynolds Hall, College of Technology, Sackville Street, Manchester 1.
Lecture: Education for Electronics.
By: R. H. Garner.

South Midlands Section

Date: 5 October. Time: 7 p.m.
Held at: North Gloucestershire Technical College. Cheltenham.
Lecture: Television Lighting Effects.
By: A. E. Robertson.

West Midlands Section

Date: 10 October. Time: 7.15 p.m.
Held at: Wolverhampton and Staffordshire Technical College, Wulfruna Street, Wolverhampton.
Lecture: Colour Television (speaker not announced).

Scottish Section

Date: 11 October. Time: 7 p.m.
Held at: The Institution of Engineers and Shipbuilders, Elmbank Crescent, Glasgow.
Lecture: The Digital Computer and its Applications.
By: Dr. Barnett.

South Wales Section

Date: 31 October. Time: 6.30 p.m.
Held at: Cardiff College of Technology and Commerce, Cathays Park, Cardiff.
Annual General Meeting followed by Lecture: Applications of Transistors to Radio Reception.
By: L. E. Jansson.

THE RADAR ASSOCIATION

Date: 10 October. Time: 7.30 p.m.
Held at: The Anatomy Theatre, University College, Gower Street, London, W.1.
Lecture: Automation-Electronic Sub-Unit Assembly Systems.
By: G. W. A. Dummer.

THE TELEVISION SOCIETY

Date: 5 October. Time: 7 p.m.
Held at: 164 Shaftesbury Avenue, London, W.C.2.
Lecture: Impressions of Commercial Television.
By: Leslie Mitchell.

THE INSTITUTION OF ELECTRIAL ENGINEERS

All London meetings, unless otherwise stated, will be held at the Institution, commencing at 5.30 p.m.
Date: 4 October.
Inaugural Address as President by Sir Gordon Radley.

Measurement and Control Section

Date: 9 October.
Chairman's Address: The Measurement of Radioactivity.
By: Denis Taylor.
Date: 23 October.
Discussion: The Use of Electronic Computers in Nuclear Reactor Design Studies.
Opened by: R. W. Sutton.

Informal Meeting

Date: 15 October.
Discussion: Telephone Development in the United Kingdom.
Opened by the President.

Radio and Telecommunication Section

Date: 17 October.
Chairman's Address: The Electronic Age.
By: R. C. G. Williams.
Date: 22 October.
Informal Evening on The Use of Transistors in Radio and Television.
Talks by: A. J. Biggs and E. Wolfendale.

Education Discussion Circle

Date: 19 October.
Discussion: Experiments for the Electronics Laboratory.
Opened by: V. Attree.

East Midland Centre

Date: 9 October. Time: 7 p.m.
Held at: Loughborough College.
Chairman's Address by H. L. Haslegrave and Annual General Meeting.
Date: 23 October. Time: 6.30 p.m.
Held at: The College of Art and Crafts, Waverley Street, Nottingham.
Lecture: Atomic Energy Programme.
By: R. A. Peddie.

Cambridge Radio and Telecommunication Group

Date: 9 October. Time: 6 p.m.
Held at: The Cambridgeshire Technical College, Collier Road, Cambridge.
Chairman's Address by J. G. Yates.

East Anglian Sub-Centre

Date: 8 October. Time: 6 p.m.
Held at: Crown and Anchor Hotel, Ipswich.
Chairman's Address by J. A. Sumner.
Date: 23 October. Time: 8 p.m.
Held at: The Cavendish Laboratory, Cambridge.
Lecture: The Generation and Synthesis of Music by Electral Means.
By: A. Douglas.

Mersey and North Wales Centre

Date: 1 October. Time: 6.30 p.m.
Held at: The Liverpool Royal Institution.
Chairman's Address by P. d'E. Stowell.
Date: 15 October. (Time and place as above).
Lecture: Germanium and Silicon Power Rectifiers.
By: T. K. Kinman, G. A. Carrick, R. G. Hibberd and A. J. Blundell.

North-Eastern Centre

Date: 8 October. Time: 6.15 p.m.
Held at: The Neville Hall, Newcastle-upon-Tyne.
Chairman's Address by J. Christie.

North Midland Centre

Date: 2 October. Time: 6.30 p.m.
Held at: The Central Electricity Authority, 1 Whitehall Road, Leeds.
Chairman's Address by W. K. Fleming.
Date: 11 October. Time: 7.15 p.m.
Held at: The Yorkshire Electricity Board, Ferensway, Hull.
Lecture: Protection of Electrical Supply Networks.
By: E. G. Hopper.

Sheffield Sub-Centre

Date: 17 October. Time: 6.30 p.m.
Held at: The Grand Hotel, Sheffield.
Chairman's Address by G. G. Nicholson.

North-Western Centre

Date: 2 October. Time: 6.30 p.m.
Held at: The Engineers' Club, 17 Albert Square, Manchester.
Chairman's Address by T. E. Daniel.

North-Western Measurement and Control Group

Date: 23 October. Time: 6.15 p.m.
Held at: The Engineers' Club, Albert Square, Manchester.
Lecture: The Manchester University Mark II Digital Computing Machine.

North-Western Radio and Telecommunication Group

Date: 10 October. Time: 6.45 p.m.
Held at: The Engineers' Club, Albert Square, Manchester.
Lecture: The Generation and Synthesis of Music by Electrical Means.
By: A. Douglas.

North Lancashire Sub-Centre

Date: 10 October. Time: 7.15 p.m.
Held at: The North Western Electricity Board Demonstration Theatre, 19 Friargate, Preston.
Chairman's Address by E. H. Scholes.

North Scotland Sub-Centre

Date: 11 October. Time: 7 p.m.
Held at: The Electrical Engineering Department, Queen's College, Dundee.
Chairman's Address by F. M. Bruce.

South-East Scotland Sub-Centre

Date: 2 October. Time: 7 p.m.
Held at: The Carlton Hotel, North Bridge, Edinburgh.
Chairman's Address by F. M. Bruce.

South-West Scotland Sub-Centre

Date: 3 October. Time: 7 p.m.
Held at: The Institution of Engineers and Shipbuilders, 33 Elmbank Crescent. Glasgow.
Chairman's Address by F. M. Bruce.
Date: 16 October. (Time and place as above).
Sub-Centre Chairman's Address by J. W. Macfarlane.
Date: 25 October. (Time and place as above).
Lecture: An Introduction to Computers.
By: P. A. V. Thomas.

Rugby Sub-Centre

Date: 9 October. Time: 6.30 p.m.
Chairman's Address by J. H. Cansdale.
Held at: The Rugby College of Technology and Arts.

Southern Centre

Date: 3 October. Time: 6.30 p.m.
Held at: The Central Electricity Authority, 111 High Street, Portsmouth.
Chairman's Address by H. Robson.
Date: 10 October. Time: 7.30 p.m.
Held at: The R.A.E. Technical College, Farnborough.
Lecture: An On-Off Servomechanism with Predicted Changeover.
By: J. F. Coales and A. R. M. Norton.
Date: 17 October. Time: 6.30 p.m.
Held at: The University, Southampton.
Lecture: The Potentialities of Railway Electrification at the Standard Frequency.
By: E. L. E. Wheatcroft and H. H. C. Barton.

Western Centre

Date: 8 October. Time: 6 p.m.
Held at: The Lecture Hall, Engineering Laboratories, University Walk, Bristol.
Chairman's Address by G. H. Rawcliffe.

Western Supply Group

Date: 15 October. Time: 6 p.m.
Held at: The Demonstration Theatre, South Western Electricity Board, Colston Avenue, Bristol.
Chairman's Address by C. J. R. Blackett.

South-Western Sub-Centre

Date: 18 October. Time: 3 p.m.
Held at: The Electricity Showrooms, Bedford Street, Exeter.
Chairman's Address by W. R. Rowe.

Oxford District

Date: 10 October. Time: 7 p.m.
Held at: The Southern Electricity Board, 37 George Street.
Lecture: A Transatlantic Telephone Cable.
By: M. J. Kelly, Sir Gordon Radley, G. W. Gilman and R. J. Halsey.

PUBLICATIONS RECEIVED

RCA TRANSMITTING TUBES is a comprehensive book containing technical data on 112 types of power tubes having plate-input ratings up to 4kW and on 13 types of associated rectifier tubes. Maximum ratings, operating values, characteristics curves, outline drawings and socket-connexion diagrams are given. Radio Corporation of America, Tube Division, Harrison, New Jersey, U.S.A. Price $1.00.

CORRECTING TELEVISION PICTURE FAULTS by John Cura and Leonard Stanley was published in July. This booklet was formerly under the title "Television Picture Faults." Iliffe and Sons Ltd, Dorset House, Stamford Street, London, S.E.1. Price 3s. 6d.

THE MEASUREMENT OF SMALL HOLES is a translation of a Russian book published by the Department of Scientific and Industrial Research. One of the major problems in metrology is the accurate measurement of holes in the range up to 18mm. The problems involved in making these measurements are discussed in the publication. Her Majesty's Stationery Office, Kingsway, London, W.C.2. Price 8s. 6d.

THE BIOLOGICAL EFFECTS OF ATOMIC RADIATION is the title of a report to the public from a study by the National Academy of Sciences, National Research Council, Washington, D.C., U.S.A.

EXPERIMENT AND THEORY IN PHYSICS by Max Born is an expanded version of an address given by the author, a Nobel Prize Winner, at King's College, Newcastle-on-Tyne, in 1943. It examines the nature of experiment and theory in theoretical physics, discussing conflicting opinions as to their relative values, weight, etc. Dover Publications Inc, 920 Broadway, New York 10, N.Y., U.S.A.

JUNCTION TRANSISTORS IN AUDIO APPLICATIONS is a new Mullard leaflet. The 200mW audio amplifier described will be of interest both to the trade and to home constructors, as it makes possible a compact low battery consumption portable audio system. Mullard Ltd, Press Department, 1 Gerrard Place, London, W.1.

RECOMMENDED PRACTICE FOR ELECTRICAL INSTALLATIONS IN CARAVANS. 2nd edition, has been issued by the Institution of Electrical Engineers. The Recommendations deal in particular with methods of connexion of the electricity supply and with provisions for earthing. The installation of an earth-leakage circuit-breaker in every caravan is recommended. Copies are obtainable from The Institution of Electrical Engineers, 2 Savoy Place, London, W.C.2. Price 1s. 3d. including postage.