ELECTRONIC ENGINEERING

VOL. 29 No. 353

JULY 1957

Commentary

THE Annual Report of the National Physical Laboratory has recently been published and the account of the work carried out during 1956 makes very interesting reading, not only for those whose main interest lies in the long-term academic project, but also for those who are concerned primarily with the immediate application of scientific knowledge to everyday problems. This, of course, is as it should be for the N.P.L. is, after all, part of the Department for Scientific and Industrial Research.

One important change took place in the administration of the laboratory in the year under review—the change of Directorship. The resignation of Sir Edward Bullard became effective at the end of 1955 and from then, until Dr. G. B. B. M. Sutherland assumed his appointment on 14 September 1956, Dr. R. L. Smith-Rose, Director of Radio Research, was Acting Director of the N.P.L.

Electronic and electrical engineering in their various forms play a considerable part in many of the laboratory's activities, but the bulk of the work of direct interest to the electronic engineer is carried out in the Control Mechanisms and Electronics Division and the Electricity Division.

Of particular interest among the activities of the former division is the work which has been done on the new ACE computer which is being assembled on a temporary site in the room which used to house the 7ft wind tunnel. Several typical problems have been programmed for the computer and on these ACE will be about eight times as fast as DEUCE, which is a greater advantage in speed than was expected.

In order to gain experience in problems involving massive data an investigation is being made into the possibilities of using a computer for a large index (for about 30 000 000 people) which the Ministry of Pensions and National Insurance maintains. This is a particularly interesting type of problem since it involves the technique of 'learning'. This index gives National Insurance number, age and address; filed under name. The technical problem is complex since names are often misquoted. If the given name is found and the age and address found are not unreasonable when compared with given age and address, the N.I. number found is accepted. If the name is not found, or the other data does not seem reasonable, variants of the name are tried to see if a reasonable trace can be found. It is intended to solve this problem by using a learning machine, which judges what variants to try on past experience. Several successful programmes converting DEUCE into a machine capable of learning have been made up to give experience in this field and the perfecting of this technique will be of great value in extending the usefulness of computers, particularly for clerical work of the type common in large insurance companies and business houses. Considerable work has been carried out on input and output mechanisms, particularly the magnetic tape variety which, although powerful, have the advantage of being both simple and cheap.

Another important function of the Control Mechanisms and Electronics Division has been to give advice on the design of industrial control systems, and to use the electronic simulator to study their behaviour. Problems of this kind studied on the simulator during the year have included a proposed system for operating the control surface of a high-speed aircraft, a commercial pressure regulator and a device for locking-on to television carrier signals. The simulator has also been used to study the progress of a chemical reaction under various conditions, and the spread of disease in a population. The work on models of economic systems has also been continued.

The Division has also given considerable assistance to other Divisions in the application of electronic engineering to their work. A notable example is the production of a precision bath thermostat for the Metrology Division. This instrument has a stability of 1 to 2 millidegrees over long periods; a performance better than any previously attained.

In the Electricity Division the caesium atomic resonator has been maintained in operation throughout the year and has served as the N.P.L. primary standard of frequency and time. Following some improvements in the electronic circuits a precision of ± 2 parts in 10^{10} can now be obtained for the calibration of the quartz clocks. As a result of this the m.s.f. standard frequency transmission are now maintained within ± 5 parts in 10^9 of their nominal values as measured by the caesium standard and the actual deviations are published to ± 1 part in 10^9. The standard has thus been made available throughout a large part of the world and, it may be remarked, the laboratory still leads the world in this field.

The foregoing is a very scant account of a very small portion of the work that has been carried out at the laboratory in the past year, but it is hoped that it is sufficient to show that the N.P.L. is not interested only in abstruse academic problems, as is supposed by many engineers, but that it provides a real service to industry and carries out many investigations and developments of immediate application. It is, in fact, well worth the time of any engineer concerned with industrial problems, to acquaint himself with the services which are available through the N.P.L. and other branches of the D.S.I.R.

LACE

(The Luton Analogue Computing Engine)

(Part 1)

By **R. J. Gomperts***, M.A., Lic. es Sc., and **D. W. Righton***, B.Sc.

Experience has indicated the need for a general purpose analogue computer. A brief account is given of the requirements and the construction of the general purpose analogue computer built at the Guided Weapons Division of the English Electric Company, Luton.

THE art of analogue computing and the use of simulators is probably very old. From very early ages ingenious man must have tried to gain a better understanding of the world around him by making representative models of what he perceived to be the relationship between certain events. These models he used, no doubt, not only to clarify his own mind but also to convince his fellows of the righteousness of his views.

One can well imagine the students at the Academy or the Library in Alexandria to be confronted with a model consisting of a number of smaller and larger spheres describing circles and epicycloids said to represent the Ptolemaic picture of the universe and instructed in the use of this simulator. Modern versions of this type of simulator still exist and in the form of Planetariums attract considerable attention.

The construction of simulators for didactic purposes is thus very old and continues to this day. They are even used in the realm of pure mathematics†.

The next step occurred when a practical engineer of those days faced with some particular difficulty in the construction of a water wheel or screw of Archimedes made a model to find out what was wrong. Thus, to improve his work, the use of simulators for design purposes had started. From then on the art of analogue computing was born and has become an essential part of our civilization. Ships are designed as a result of their performance as models in hydraulic tanks; the flow of rivers is studied by means of laboratory models, aircraft performance is evaluated on the basis of wind tunnel results and where no models exist in this world to study certain phenomena, astronomers and astro-physicists are called in to study the extra-terrestrian events to give information on fusion reaction.

It is to be noted, however, that all the examples quoted are scaled versions of the original problem and are working in the same medium as the problem. The introduction of the mathematical model removed this restriction and a great stride forward was taken in the art of using analogues. To be more explicit as soon as a mathematical formulation is given between certain events a mathematical model or analogue has been constructed. The original physical embodiment of this relationship has been abstracted away and one is left with its precise description. It must be appreciated that this mathematical analogue will suffer just like the physical model from scale effects, etc., since to obtain a concise statement of the relationship between the physical quantities a number of simplifications have been made. Describing the oscillation of a mass-spring combination one does not include the detailed description of the molecules making up the mass and the spring. Almost always the distributed mass of the spring is neglected because inclusion of this does not effect the issue in most cases. One is only interested in the phenomena as formulated by the mathematical model, the macroscopic oscillations of the mass-spring system. In setting up the mathematical model one should be aware of what has been left out.

Now the importance of the mathematical model is, as has been said earlier, that one is left only with the relationships between certain physical quantities and that all the physical systems which obey the same mathematical relationships are *mathematically congruent*. Therefore one can look at the result of experiments on one physical system and obtain results valid for another system of a different physical nature, provided one remains in the realm covered by the *common mathematical* relationship.

This is why the mass-spring combination is said to be analogous to an *RCL* circuit, provided one does not extend the equivalence beyond the mathematical relationship, e.g. that one is not going to determine the crystal structure of the spring by studying the flow of electrons in the tuned circuit.

Having accepted this mathematical congruence, then it becomes obvious why, for example, potential field structure in an electrolytic tank can represent so many systems, including steady-state hydrodynamic flow, aerodynamics, heat flow, servo problems, since the solutions to all these problems satisfy Laplace's equation in two dimensions. It becomes equally apparent why tuned circuits will represent a mass-spring combination and aircraft flutter (as approximated by the theory of small motions of a system with many degrees of freedom) can be simulated by a system of filters, girders by linear resistance networks, etc.

It is seen then that simulation or analogue computing in its wider sense is the representation of the mathematical model of the system to be studied. In this sense one may say that a digital machine is just as much a simulator or analogue machine as what is conventionally called a simulator or analogue computer, it simulates the mathematical model.

It is strange therefore that analogue computers are considered in such a different light from the digital machines, seeing that they are intended to perform the same function, and it is even stranger to think that what are now analogue machines are generally thought of as specific purpose machines while the claim for generality is reserved for the digital simulators‡ in spite of the fact that a general purpose analogue computer—the slide rule—is in daily use. The reason for this is not obvious but one might suggest that the digital machines were essentially developed for the

* *The English Electric Company, Guided Weapons Division*

† *In one of the author's geometry lessons, models were introduced to explain the intricacies of ruled surfaces and one was told to generate new ones with the available materials ; edges. wires and supporting stands. The webbed spider constructions thus obtained are of considerable appeal and they would not be amiss among the better exhibits of modern sculpture.*

‡ *In future a simulator or machine which represents the mathematical model by digital means will be called a digital machine or simulator, while a machine performing the same function using continuous variables will be called incongruously and illogically, an analogue machine.*

use of mathematicians—extended desk machines—whereas the analogue machines have been mainly built by engineers for engineering purposes and therefore *ipso facto* of a restricted nature.

That this might be so is partly borne out by our own experience at Luton. The original analogue machines were all specific purpose machines only dealing with one class of problems, the number of variable parameters was in general restricted. It was soon realized that this approach suffered from restrictions. If a simulator was built to study a certain problem it was found in the main that the scaling was wrong and the machine needed re-designing. This could not be prevented because to know the scaling one should know the solutions of the problem to be studied and if one knew the solution it would not be necessary to build a simulator. Further it was found that the simulator or special purpose machine had to be continuously modified to be able to deal with variations on the original problem. Its range was never quite large enough for changing requirements so that the simulator was always suitable for the last problem but never for the present one.

For these reasons it was decided to abandon the special purpose analogue machine and direct our efforts towards a general purpose analogue computer.

To summarize the arguments so far, we have tried to indicate that there is no reason why the predicate 'general' should only be associated with digital machines. In fact, both types of machines, albeit using different techniques, simulate the mathematical model which is an abstraction of the physical problem. Further we have tried to indicate some of the reasons why a general purpose machine might be more suitable than a special purpose computer. (This point has been acknowledged for the digital machines.)

Before proceeding any further, the following question must be faced. Why bother with a general purpose analogue machine? Why not use a digital machine instead, especially since these machines are readily available? This is a fair question and cannot be dismissed out of hand. The answer is that it depends entirely on the problem and the circumstances.

There are a great number of problems which can be done with profit on a digital machine rather than an analogue machine. On the other hand there are an equally large number of problems when an analogue machine seems to have the advantage.

Some of the reasons why we believe analogue machines to be more suitable for many engineering problems are listed below.

(1) Programming of the problem takes less time and the problem can be more easily modified.

(2) The analogue machine is faster, and can be used on a one to one time scale.

(3) It can more readily deal with complicated systems.

(4) It can be readily monitored at all times during the running of the problems.

(5) The operator has physical access to the important parameters and can see immediately what the effect is of parameter changes.

(6) They are in general easier to service and faults can be diagnosed more readily.

Against this, the digital machines are much more accurate while certain applications related to accountancy and book-keeping cannot be done by analogue machines.

In the following paragraphs we shall outline what we conceived to be the requirements for a general purpose machine. This led to the development of the general purpose analogue computer assembly known as Luton Analogue Computing Engine (LACE) and the remainder of this article will be concerned with the solutions adopted and a description of the construction.

Requirements

Based on past experience we were able to list a number of requirements which led to the construction of LACE (see Fig. 1). These requirements will be discussed briefly and it will be indicated how we have tried to meet them. It is realized, of course, that the list is by no means exhaustive.

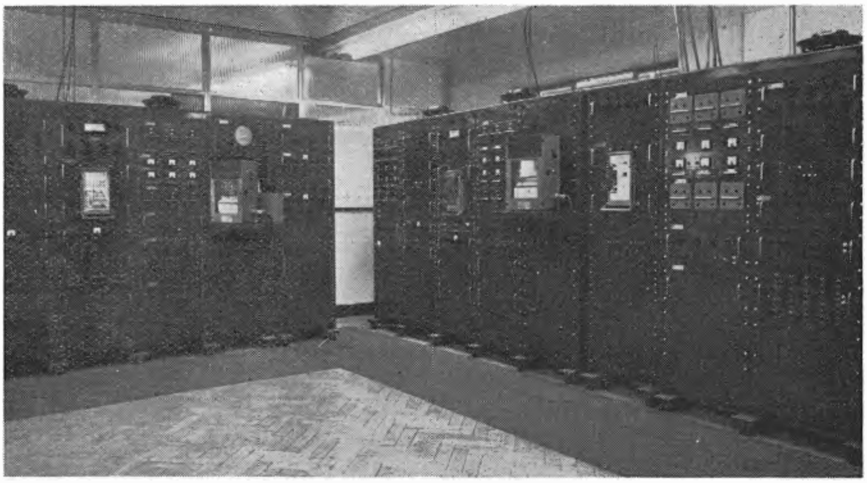

Fig. 1. The general purpose analogue computer used by the English Electric Co at Luton

THE EQUIPMENT IS TO BE TRULY GENERAL PURPOSE

By this is understood that the equipment should be capable of tackling all kinds of problems expressed by linear and non-linear equations such as closed loop problems, partial differential equations such as heat flow, Monte Carlo problems, trajectory evaluations, auto-correlation processes and spectrum analysis, problems involving axis transformations, etc.

This means that apart from providing a sufficient number of linear units a liberal provision must be made of non-linear units. These take two forms, fast electronic multipliers and function generators and electro-mechanical multipliers and feedback resolvers. Also provision has been made to include limiters, facilities to put in special circuits, relays for switching, etc.

To be truly general purpose it must also be possible to start a problem with any required set of initial conditions even when working on a repetitive basis. This implies facilities for zero setting, freezing, etc.

HIGH UTILIZATION AND GROWTH FACTOR

It has been our experience that however large a computing facility is planned there always comes the problem for which it is not large enough. On the other hand if one caters for all eventualities the machine becomes inevitably unwieldy and not economic to run if it is designed as one unit.

With this in mind LACE has been planned and built on a brick basis (see Fig. 3). Each brick is completely self contained, has its power supplies, linear and non-linear units, reference voltage and switching facilities and is capable of dealing with a medium sized problem (twelfth order system). It is also arranged that these bricks can be connected together via a central connecting panel and used as one machine. In this way a number of smaller problems (two or three) can be run concurrently or one very large problem utilizing the whole machine. The optimum size of a brick is difficult to assess, but the choice has so far been found reasonable.

Another advantage of this approach is that the growth factor has been catered for at the same time, since it will be easy to extend the existing facilities.

Flexibility, Ease of Changing Problems

These two points are to some extent related to the utilization factor but warrant separate treatment.

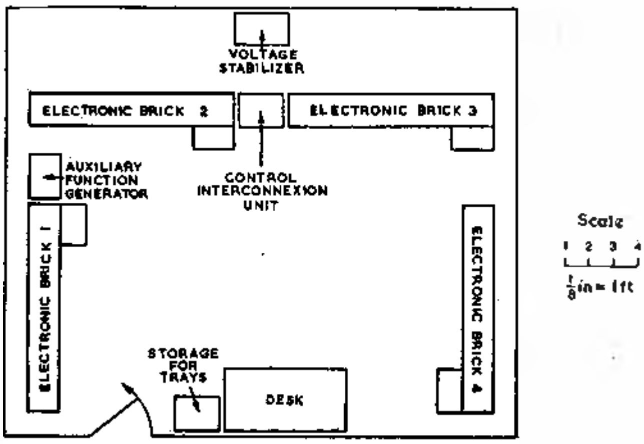

Fig. 2. Plan of LACE installation

Flexibility is achieved by performing all the linear operations by the same basic unit (Figs. 5 and 6), the operational amplifier. Its particular function is determined by an associated tray on which the input and feedback components are connected (see Fig. 7).

All interconnexions between units are made on the patch panel (Fig. 9) which is detachable. This means that a problem can be easily removed and stored, the collection of trays and patch panels constituting the problem. Furthermore, a large amount of preparatory work can be done without having to utilize the machine so that a problem can be virtually set without having been near the machine.

Mode of Operation

It was thought preferable for the machine to operate either in single shots or in a repetitive manner. In the former case permanent records can be very easily obtained, while in the latter case it is easy to see what the effect is of changing a parameter. This is particularly useful when studying servo-response problems.

Overall Accuracy of 1 per cent

It was felt that a useful accuracy which would meet engineering requirements would be an overall accuracy of 1 per cent. To achieve this the operational amplifiers have been given enough gain to eliminate their inaccuracies and the main inaccuracies in the linear operation are caused by the component values in the operational networks. These can be measured to one part in a thousand, while their stability is 0·1 per cent.

The multipliers used have an accuracy of 0·2 per cent of full scale and the general purpose function generators can be set up to represent a continuous single valued curve to an accuracy of 1 per cent.

Allowing for the distribution of errors and exercising reasonable care it would appear that an accuracy of 1 per cent can be readily achieved.

Adequate Input and Output Facilities

One of the applications for which the machine is intended is the solution of ' Monte Carlo ' problems. These are problems in which the input or a parameter will vary in a statistical manner. By doing a number of sums it is possible to obtain an ensemble of results resulting from an input ensemble. The statistical properties of the output ensemble can then be determined and such quantities as the variance, mean, etc., evaluated.

To do this kind of work adequate input facilities must be provided and one must be able to generate arbitrary sequences which, if necessary, can be repeated. The solution followed is to code a tape or film and then replay it through a reproduction mechanism.

The present favoured medium is magnetic tape. The replay unit accepts either analogue or digitally coded tapes. The output of the machine can be recorded on meters, long after-glow c.r.o., pen recorders and magnetic tape. The latter facility is intended for such problems where one of the results is needed as the input to some other system or further computation.

Description of the Equipment

In this section the construction, which was evolved to try to meet the requirements set out above, will be described.

A general view of the computer as it exists at present is shown in Figs. 1 and 2. As will be seen there are four main electronic units or bricks, a central interconnexion unit, an auxiliary function generator unit together with a mains voltage stabilizer and storage for computing network trays.

The electronic unit (Figs. 3 and 4) contains:

(a) Twelve operational amplifiers (1) together with their associated computing network trays (2) relays for controlling their operation and meters (3) indicating their outputs.

(b) Potentiometer panel (4).

(c) Two general purpose function generators (5).

(d) Two electronic multipliers (6).

(e) Common apparatus to function generators and multipliers (7).

(f) A six-channel diode limiter unit (8).

(g) Computing relays (9).

(h) Six passive network trays (10).

(j) Special circuits unit (11).

(k) The patch panel (12).

(l) The reference divider panel (13).

(m) Two channel pen recorder (14).

(n) Cathode-ray oscilloscope (15).

(o) The control panel (16).

(p) Power supplies and stabilizers.

Details of Units

The Operational Amplifier (Figs. 5 and 6)

This is a high gain d.c. amplifier incorporating chopper drift correction and a medium gain sign reversing amplifier.

The circuit employs balanced triode stages throughout, except for the output stages and the chopper amplifier, thus making the amplifier unresponsive to fluctuations in its h.t. supply. The wiring is printed.

Specification:

Main amplifier

Gain (open loop) 6×10^4 to 100c/s (3dB point)

Output ± 50V into 10kΩ

Drift corrector.

Gain 100 to 1c/min (3dB)

The combination of amplifier and corrector has a drift not greater than 0·5mV referred to the input grid over a 10 hour period.

The frequency response of the amplifier has been tailored so that all combinations of input and feedback components normally encountered may be connected without instability.

Sign reversing amplifier.

Open loop gain: 3×10^3, to 300c/s (3dB)

Output ± 50V into 10kΩ load.

Drift less than 10mV over a 10 hour period.

The Computing Network Tray (Fig. 7)

This contains the input and feedback components which determine the role of an operational amplifier.

Provision is made for a maximum of six input connexions. The tray shown in the figure contains six 1MΩ input resistors and a feedback capacitor of 1μF and so forms with its amplifier a six input summing integrator of 1sec time-constant.

Relay and Meter Panel

Meters indicate the outputs from the amplifiers. Switches are in circuit between the amplifier output and the patch panel making it possible to break a closed loop without modifying the patch panel connexions. Relays are arranged to switch the input and feedback components of an amplifier, under the control of the control panel, to any of the following conditions (Fig. 8):

(1) Discharge—no inputs to integrators, all capacitors discharged.

(2) Zero set—all amplifier inputs connected via resistors to ground. This makes any amplifier drift obvious.

(3) Initial set—no inputs to integrators but their capacitors are charged to predetermined voltages. This is to set the initial conditions appropriate to the problem.

(4) Compute.

(5) Freeze. The input networks are disconnected from the amplifiers. Any output existing on an integrator is retained and its value may be read.

The Potentiometer Panel

This contains 18 potentiometers. These are commercial grade wire-wound 50kΩ components. One side of each is commoned and connected to earth, the other side and wiper are taken to the patch panel. These may be connected into a computing circuit to enable parameters to be varied readily or as preset trimmers to enable, for example, an amplifier gain to be set with greater accuracy than that given by the input and feedback resistors used.

The Function Generator

This is to be the subject of Part 2 of this article. It is of the diode type wherein a desired function is approximated by a series of straight line segments. Considerable difficulty is found in setting up any given function with most previous types as the adjustments of slopes and break points interact and in fact they have usually been made for particular functions only. On our function generators the adjustments are independent of one another thus making setting up very easy.

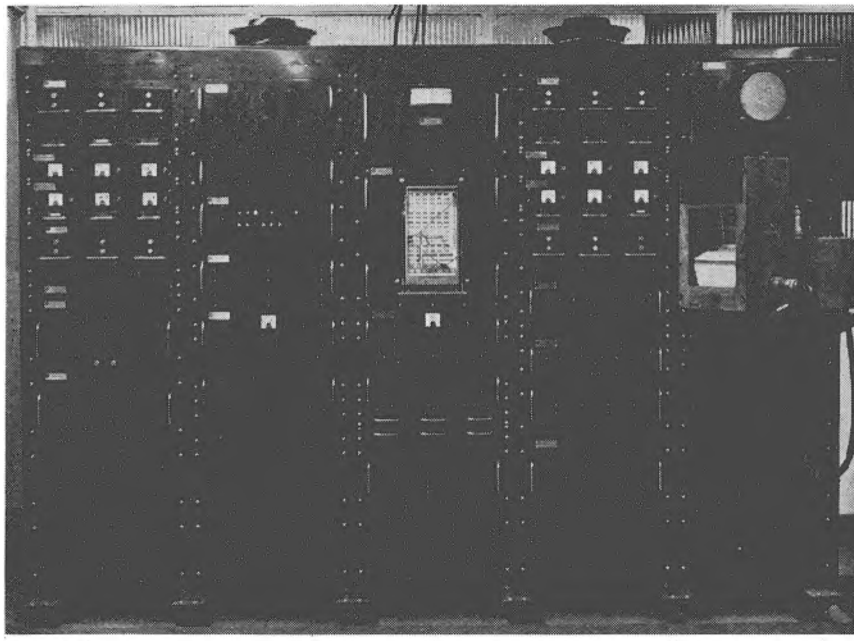

Fig. 3. An electronic brick

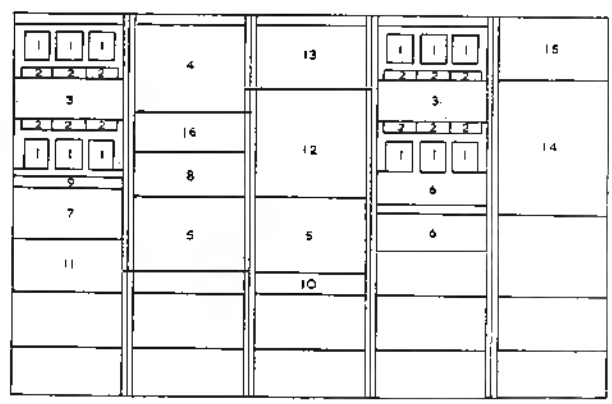

Fig. 4. Schematic of electronic brick

The junctions between any pairs of straight lines may be rounded off to any desired degree. Eight separate slopes are available.

The Multiplier

This is also to be the subject of Part 2.

It uses the relationship $xy = \frac{1}{4}\{(x + y)^2 - (x - y)^2\}$. The squaring is accomplished by clipping a triangular wave at a height determined by the value of the variable it is desired to square.

The accuracy is of the order of $\frac{1}{4}$ per cent of full scale and the response is flat within 3dB to about 8kc/s with a phase shift of 45° at 4kc/s.

Common Apparatus

This supplies the 20kc/s triangular wave required by the multipliers and the function generators (for rounding off).

It also supplies a sawtooth of either 50c/s or 0·1c/s which may be used in setting the function generators.

The Diode Limiters Unit

Six independent limiter circuits are provided. The positive and negative limits are independently adjustable between 5 and 50V. Linearity between limits is better than 1 per cent.

The Computing Relays

Two relays each with six changeover contacts are contained in this unit. The relay coils may be driven by the output of an operational amplifier. The coil connexions and all contacts are taken to the patch panel. This unit is provided to enable changes to be made in the parameters of a problem under the control of one or two of its variables.

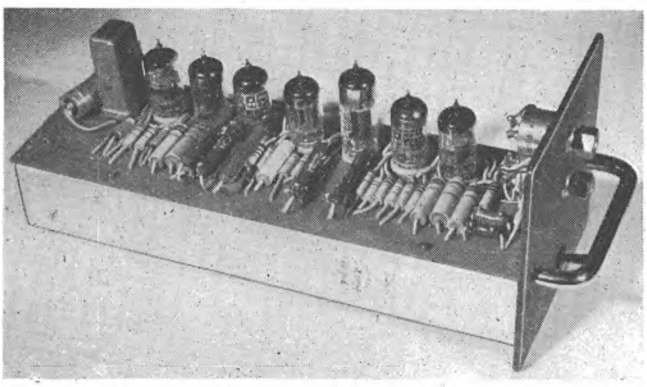

Fig. 5. The operational amplifier

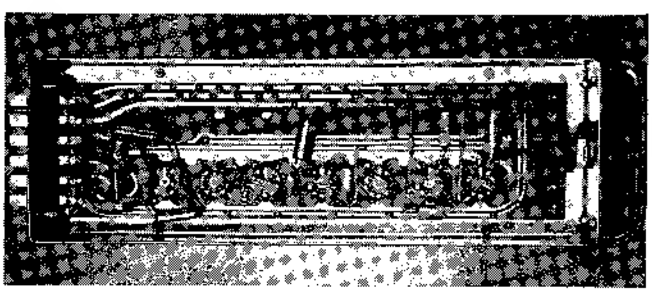

Fig. 6. The operational amplifier (underside view)

For example, in a servo system employing fine and coarse position data the source of the data is determined by the misalignment of the system.

Passive Network Trays

Six trays similar in construction to those used for the computing networks are provided. These are to contain components which cannot be associated specifically with an amplifier input or feedback network.

Special Circuits Unit

This is a blank chassis to which are taken power supplies and has twelve connexions to the patch panel. Certain systems to be analysed may contain circuits which are conveniently fitted into this space rather than simulating them using the other facilities. For example a modulator may use the control and suppressor grids of a pentode to mix two signals. To simulate this the two signals would probably have to be passed through separate function generators, to simulate the non-linear control of the grids, and the resultant signals then multiplied together. Even so it is improbable that a satisfactory result would be obtained for large values of the input signals. In such a case the special circuits unit might well be used.

The Patch Panel (Fig. 9)

All interconnexions between the units so far described are made on the patch panel, together with connexions to input mechanisms, recorder and other bricks of the computer (if used).

The mechanism and patch panel was obtained from The British Tabulating Machine Company.

As can be seen, the board on which the connexions are made, by means of wires with small plugs on each end, may be removed from the machine so that a problem may be patched up without consuming machine time, and, moreover, once this has been done the board may be stored and used on any occasion that that particular problem arises.

The following terminations are on the patch panel

(1) Amplifier and computing network—6 inputs and 2 outputs each.

(2) Potentiometer panel—18 inputs and outputs.

(3) Function generators—1 input and 2 outputs each.

(4) Multipliers—2 inputs and 1 output each.

(5) Limiters—6 inputs and outputs.

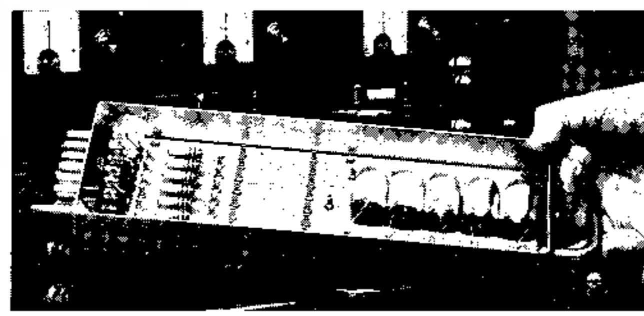

Fig. 7. The computing network tray

(6) Computing relays—2 coil terminations and 18 contacts per relay.

(7) Passive networks—3 terminations per tray.

(8) Special circuits—12 terminations.

(9) Positive 50V supply—8 terminations.

(10) Negative 50V supply—8 terminations.

(11) External units, e.g. inputs, recorders other computing units—24, of these, six are also connected to the selector switch on the reference divider panel.

In addition to the above there is a number of conference strips, i.e. groups of terminals which are connected among themselves only, used when it is desired to make multiple connexions to one point. The remaining terminals are all connected to computing earth.

The Reference Divider Panel

This contains a precision three dial decade potentiometer, a moving-coil microammeter, a twenty-four position selector switch, and a range switch.

The microammeter may be connected either as a voltmeter or as a null indicator, in which case the movement is protected by a rectifier circuit. It is thus possible to obtain a meter indication of the p.d. at the point defined by the selector switch position or to measure that p.d. accurately by a potentiometric method, clearly a potentiometer on the potentiometer panel may be set accurately to a required ratio by this method.

The points available on the selector switch are the twelve amplifier main outputs, an earth position (to check the meter zero), the 50V supply, the multiplier and the function generator outputs and six connexions to the patch panel.

The Two-Channel Pen Recorder

This is an Evershed and Vignoles high speed recorder and is used for recording phenomenon occurring on a slow time scale (maximum frequency of interest about 10c/s) and where accurate records are required.

Cathode-ray Oscilloscope Unit

Many systems of interest are conveniently examined on a repetitive basis. For example, when examining the stability of a servo system it may suffice to obtain a purely qualitative survey of its response to a repetitive input, while parameters (gain, time-constants etc.) are varied.

This unit produces a square wave output (probably the most generally useful), synchronized to the time-base. The frequency is variable in seven discrete steps between 0·2c/s

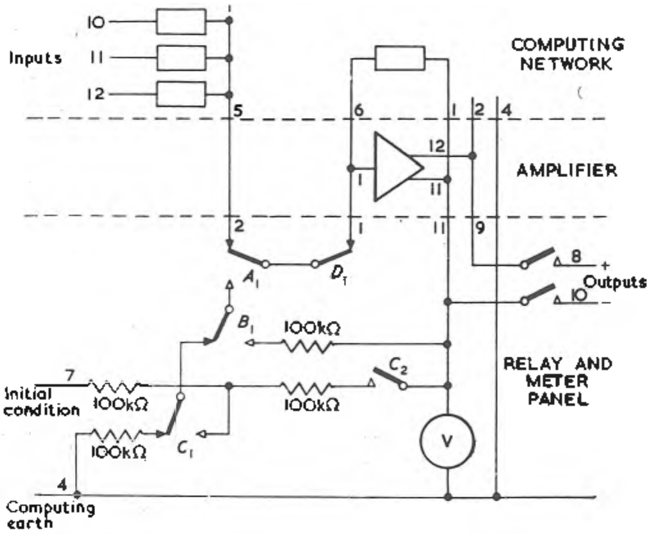

Fig. 8. Schematic of amplifier switching

and 20c/s. It is also possible, at the lower speeds, to use this output to drive the computer between the two conditions of initial set and compute so that the recovery of a system from a given set of initial conditions may be examined.

The Control Panel

Normally push-buttons select the condition of the computer and lamps indicate the condition. A switch is provided which transfers the control to an external source, so that several bricks may be operated together.

In addition circuits are provided which detect if any amplifier output exceeds its nominal 50V. If this happens a warning lamp is lit and the computer is put to 'freeze.' The operator may then, by examining the meters, determine which amplifier has overloaded and modify the conditions, or scaling, of the problem to prevent this happening.

Power Supplies

A brick is completely self-contained and requires only a single-phase 50c/s 240V supply of about 3¼kVA. This is preferably stabilized against gross variations. The type of stabilizer which employs a motor-driven variable transformer has been found most satisfactory. Inside the equipment the main supplies used apart from heaters etc. are ± 250V and -500V regulated d.c. as h.t. and bias supplies to the various units and the ± 50V regulated computing signal supply.

The Central Interconnexion Unit

This comprises a patch panel of the same type as used on the electronic units. The sets of 24 connexions from the electronic units are brought to this panel together with two sets of 48 intended for the electromechanical units and a further set of 48 for external connexions.

Above the patch panel is a set of rotary switches by which the control of the units may be connected together so that any groupings of units may be brought under common control.

The Auxiliary Function Generator Unit

A certain problem (non-linear heatflow) was found to require more function generators than had been provided in the electronic units. This unit, self-contained in its power supplies and containing two function generators and a common apparatus was added.

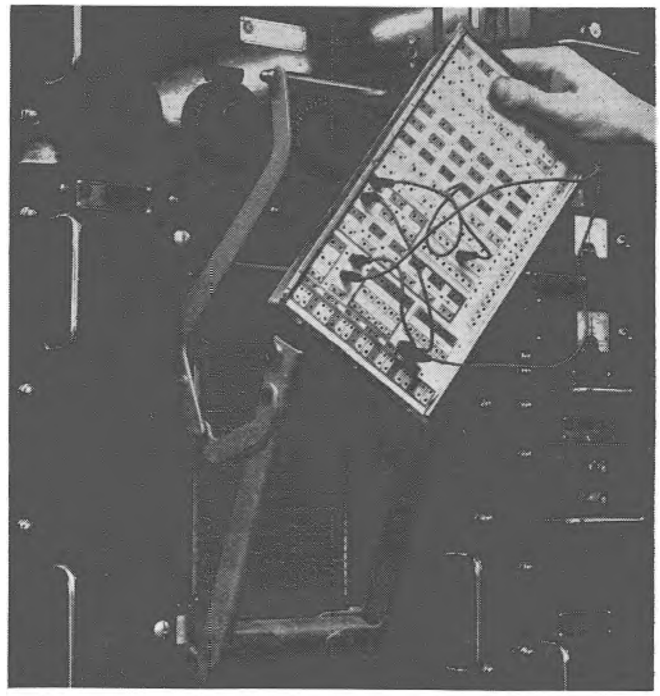

Fig. 9. The patch panel

Proposed Further Facilities

Electromechanical Units

In some problems it is required to multiply several variables by one other variable, the latter only changing comparatively slowly. A similar class involves axis transformation with slow variation of the angles between the axes. The multiplications are most conveniently performed by having shafts whose rotations are proportional to the slowly changing variables carrying potentiometers whose exitation is proportional to the other variable. The most convenient means of axis transformation is the resolver synchro, this unfortunately requires a.c. signals so that modulation and demodulation is required for use in LACE.

It is proposed to provide a number of shafts driven by servos and carrying precision potentiometer and feedback resolver synchros and sin-cos potentiometers.

It will be possible to use the servos either as position servos or as integrators, the function being determined by the circuits in an associated network tray.

The potentiometers will be provided with taps so that non-linear multiplications may be performed, again the resistors which set the p.d.'s between taps will be mounted in trays.

Magnetic Tape Recording Equipment

Tape recorders will be used to provide inputs to the equipment and where required to record outputs. It is considered that a pulse width modulation system will provide adequate accuracy (about 1 per cent) for most purposes together with the simplest circuits. Some applications may require higher accuracy than this and the problem of using pulse code modulation is being examined.

Operational Experience

The equipment has now been in almost continuous use for about nine months during which period a considerable variety of problems have been solved on it.

RELIABILITY

It has proved extremely reliable, in fact far more so than the designers had expected from so complex a piece of equipment—it contains about 1 250 valve envelopes. This is probably due to having all components rated conservatively and to having good air circulation and generous spacing round all units.

No appreciable time has been lost through faults as an adequate supply of spare units is available and a faulty unit may be detected and replaced in a matter of minutes.

The relays used in the drift correction of the amplifier have been found very reliable, in spite of being a much cheaper component—high speed relay type SM-8-5—than that usually used for the purpose.

FLEXIBILITY

The operators have found the flexibility quite adequate and have used the machine in ways that have astounded the designers. Frequently multipliers and function generators in one brick are used in conjunction with amplifiers in another to solve one problem, while the first brick is engaged on another—this clearly requires co-operation between the people working on the problems as the function generator and multiplier connexions are taken via the patch panel of their brick and the central patch panel to the brick with which they are used.

Setting up a problem has been found to be quite straightforward and the operators find it no hardship to have to use a soldering iron to change components in the computing networks.

The ability to work repetitively with given initial conditions has been found very useful.

ACCURACY

It is very difficult to assess the accuracy of such an equipment, but it has been found to be quite adequate in all cases where check solutions have been available. For example the problem of non-linear heat flow* used twelve operational amplifiers two multipliers and seven function generators and in two cases where hand computed results were available the agreement was to better than 1 per cent.

* *The method of solution followed that given by E. L. Albasing at the I.E.E. convention on digital computer techniques, 9-13 April, 1956, in his paper "The Solution of Non-linear Heat Conductive Problems on the Pilot Ace".*

(To be continued)

A New Telecine Equipment

The ever-increasing use of film in television programmes, both as a means of entertainment in its own right and for continuity inserts in talks and plays, makes heavy demands upon the telecine equipment, which should not only provide a picture comparable in quality with a 'live' production but also be robust in order to stand up to continual use, and extremely flexible so as to meet the onerous demands of the producer.

Until fairly recently it had been thought that the flying spot technique was the only way of achieving the quality requirement. However, the 1in diameter Vidicon pick-up tube has been developed to such an extent that it provides a completely adequate source of video signals when used with film equipments, and after laboratory development the Marconi Company have produced their Type BD.844 Vidicon Telecine Camera Channel based on the use of this tube.

One of the advantages of using a camera tube over the flying spot technique for telecine work is that several projectors can be multiplexed on to a single camera tube, very much in the same way that film and slide projectors are integrated to provide a continuous performance in the cinema. In the past the majority of these optical multiplexers have used either semi-silvered mirrors or very thin 'pellicules' to mix the light beams, but the former invariably give a second reflection from the un-silvered surface which can be very objectionable, while pellicules suffer from extreme fragility.

With the problems of colour television in mind, Marconi's have produced a design of optical multiplexer which uses only front-surface-silvered mirrors, which therefore cannot produce second reflections and which can be made extremely robust and stable. A further advantage of these mirrors is that they can be made sufficiently large to ensure that definition and registration problems are minimized.

Another important asset of the Marconi multiplexer is its ability to provide a local optical preview of what is in the gate of the next projector to come into operation. The operator is thus always sure that his 'next channel' contains the right material.

The BD.872 multiplexer consists of a six-sided cabinet standing approximately 5ft high and is designed to accept the light beams of any normal film and slide projectors at the standard optical centre height of 48in from the ground. It contains all the necessary relays for actuating the moving mirrors, the action being such as to produce the effect of a 'wipe' of approximately three frames only, when changing from one source to another. Associated with the moving mirrors are switching circuits for the sound outputs.

Should it be considered necessary to superimpose two sources, a new type of mixing mirror can be fitted which has a second reflection of less than 1 per cent and a very high optical efficiency. Primarily designed for colour television operation, this mixing mirror represents an important advance in optical coating techniques.

The multiplexer has inputs for a maximum of four projectors which will generally be two film and one or two slide, but an additional lens system can be added to view standard 9in by 12in caption cards or opaque displays of the same dimensions. Thus the telecine equipment can be used to show small animated displays or products mounted on a turntable. The depth of focus is sufficient to deal with packages which fall within these dimensions.

The BD.844 Vidicon camera channel consists of the small vidicon camera itself, rack mounted processing and deflexion chassis, power supplies and a camera control unit. The latter is of a form similar to the camera control of the Image Orthicon channels and is suitable for mounting under the standard picture and waveform monitor.

As alternatives to the use of the type BD.844 camera channel the multiplexer is equally suitable for use with the three-Vidicon colour camera channel or with the broadcast Vidicon type BD.864, the new Marconi lightweight studio camera, the latter arrangement forming a cheap and elegant telecine equipment.

Problems in Protection of Radar Receivers

By G. D. Speake*, M.A.

The protection of a radio receiver from damage caused either by the associated system transmitter or from external sources is discussed. The main emphasis is placed on t.r. devices based on a gas discharge, and the advantages and limitations of these components are outlined. The use of other forms of protection, based for example on ferrites, and of travelling wave tubes as receiver components capable of withstanding relatively high pulse powers is briefly described.

THE association of delicate receivers with high power transmitters in pulsed radar systems has necessitated the development of switches capable of providing a large measure of isolation between receiver and transmitter during the period of the pulses. The use of some form of gas discharge, initiated by the pulse, as a switch has in most cases solved the problem satisfactorily and the greater part of this article will be devoted to a survey of the requirements of such a switch, and of the methods which have been adopted to fulfil them. Other methods of isolation, such as the use of uni-directional waveguide components will also be mentioned and modern developments in thermionic valves which may reduce the degree of protection demanded by the receiver will be described.

Historical Survey

The isolation of the receiver from the damaging effect of transmitter pulses presented no serious problem in the design of early radar systems. In general transmitter and receiver had separate aerial systems and operated at frequencies for which the use of conventional thermionic valves as amplifiers was practicable. Pulses coupled directly from transmitting to receiving aerial, or received by reflection from objects at short range, therefore caused only temporary paralysis of the receiver input stages and no permanent damage was sustained. However, the necessity for more accurate positional information on targets led system designers from the metric into the centrimetric wavebands of the spectrum, so that a very narrow bandwidth could be achieved without increasing the physical size of the antenna to unmanageable proportions. The desired information was then obtained by rotating the aerial systems and it was clearly imperative that transmitting and receiving aerial should point in exactly the same direction at any instant in order that the strength of the received signal should be a maximum. In some cases this has been achieved by putting both aerials on a common mounting, but where the physical dimensions of the system were large there was an obvious advantage in using the same aerial for transmission and reception. This became possible because t.r. and a.t.r. switches, based on the breakdown of a gas under the influence of the strong radio frequency field from the transmitter pulse, were developed for the purpose. The function of the t.r. tube was to divert power from the transmitter into the aerial, and of the a.t.r. tube to ensure that all signals reaching the aerial during the period between transmitter pulses were fed unattenuated to the receiver.

Another consequence of the increase in frequency was that conventional valve amplifiers were no longer satisfactory and it became necessary to convert to a lower frequency at the input stage of the receiver. The device which proved to be most satisfactory as a mixer was a silicon crystal, and a very large proportion of radar receivers have used this as the input stage, followed by conventional valves amplifying at an intermediate frequency of a few megacycles per second. This places a severe requirement on the t.r. switch, because the crystal is damaged by relatively low levels of 'breakthrough' power. Until very recently, therefore, the system designer has been much concerned with the limitation so imposed and much ingenuity has gone into solution of the t.r. problem.

Requirements of the Switch

The characteristics required in the switch must be considered in the light of the effect of breakthrough on the crystal. If the switch is triggered by the transmitter pulse itself there will be a time lag before the gas is fully broken down during which a signal of very large amplitude but of short duration (perhaps 50 to 100mμsec) will pass through to the receiver. After the gas is broken down the amplitude of the signal breaking through is considerably reduced but in general will still be significant. The silicon crystal is therefore subjected first to a 'spike' of very large amplitude, but of duration short compared with the time-constant of the crystal, the effect of which is ballistic, i.e. is dependent on the total energy passed during this period rather than on the maximum amplitude of the signal.

The 'spike' is followed by a 'flat'; that is, a period lasting until the end of the transmitter pulse during which the signal leaking through to the receiver is constant. Damage will be caused to the crystal if either the energy within the spike is too large, or the amplitude of the signal over the flat is too great. In the specification for a t.r. tube it is therefore usual to quote a maximum permissible spike energy and an upper limit of power permissible over the 'flat' period.

During the quiescent periods between pulses the switch must, of course, be open for the passage of received signals and it is therefore necessary that the discharge shall be extinguished quickly and that the attenuation of the tube shall then be very low. For a short range radar equipment, e.g. an airfield control or marine radar, a recovery time as long as 1μsec may be a disadvantage since it implies that signals received from targets less than 150m from the system will be attenuated, but for long range radars the requirements are less stringent.

It is also desirable that the t.r. tube shall be capable of use over the whole frequency region in which the equipment may be required to operate. It must therefore either have an intrinsically large bandwidth or be capable of simple tuning.

Thus the switch requirements may be summarized as follows:

(1) Low 'spike' energy.
(2) Low flat power.
(3) Rapid recovery.
(4) Low attenuation when the discharge is extinguished.
(5) Bandwidth comparable with that of other system components.

Properties of the Gas Discharges

The phenomenon of breakdown in a gas under d.c. conditions is fairly well understood and during recent years

* *Marconi's Wireless Telegraph Company Limited*

considerable attention has also been given to breakdown at microwave frequencies[1]. Breakdown under the influence of a radio frequency pulse of very large amplitude and fast rise time, such as is encountered in pulse radars is, however, much less amenable to theoretical interpretation. At the onset of the pulse any electrons which may be present in the gas begin to oscillate under the influence of the field and secondary electrons are produced by collision processes, an equilibrium condition being achieved when the rate of production of electrons is balanced by diffusion away from the discharge area or by some other loss mechanism. In most practical cases these processes are not calculable and the design of individual tubes is largely empirical.

The use of noble gases in t.r. tubes is attractive both because they have low ionization potentials and therefore break down relatively easily and also because they are not lost by chemical action with the metallic parts of the tube. The processes of electron loss within a noble gas, namely recombination with positive ions or diffusion to the walls of the tube are both, however, relatively improbable[2]. (The effect of the ions on the r.f. field may be ignored because of their heavy mass when compared with the electrons). A tube with a noble gas filling will therefore usually have a prohibitively long recovery time. In most t.r. tubes this difficulty is overcome by adding a gas, such as water vapour, which has a high 'attachment coefficient', i.e. in which the capture of an electron by the gas molecule is a relatively probable event. This unfortunately increases the level of both spike and flat, but the price is one which has to be paid in order to obtain satisfactory short range performance of the system. If it is possible to use an inert gas alone there is some advantage in using the heavier gases, krypton or xenon, since they break down more easily, but if water vapour is added there is little difference between the gases and argon is most commonly used. In some cases the oxidizing action of the water on the metallic electrodes of the tube has proved to be a disadvantage and tubes containing hydrogen as recovery agent have been described. The mechanism of electron loss is not in this case fully understood since hydrogen would be expected to have an attachment probability of zero. It is possible that the active hydrogen reduces either a metallic oxide within the tube or silica from the glass wall to form water, but this seems unlikely in view of the result reported by Walsh[3] that the recovery time is directly related to gas pressure. It is usual to include a replenisher in these tubes to maintain the hydrogen pressure constant.

The breakdown phenomenon described above requires the presence of primary electrons, which oscillate under the influence of the r.f. field and produce further electrons by collision. In some cases, where the recurrence frequency of pulses is very high there may be some carry-over of electrons from one pulse to the next, but generally it is necessary to supply a permanent source of electrons, which usually takes the form of a d.c. discharge shielded from, but from which electrons diffuse into, the r.f. field. This is known as a 'keep-alive' discharge. The density of electrons must, however, not be sufficiently large to cause appreciable attenuation of received signals and it is necessary to control the position of the keep-alive electrode during manufacture and to specify a working current. A possible arrangement of the keep-alive system is shown in Fig. 1.

There are attendant disadvantages to this arrangement. The cathode of the keep-alive discharge will, during the life of the tube, be bombarded by positive ions and will sputter. There is therefore a likelihood of build-up of a bridge of sputtered metal (which may, for instance, take the form of a thin whisker) between cathode and anode of the discharge. The discharge is then extinguished and damage to the receiver will ensue due to a large increase in 'spike' energy. Moreover, the electrons of the discharge gap form a capacitance short-circuited by the discharge itself and it is therefore possible for relaxation oscillations to be set up, the capacitance being alternately charged from the supply and discharged through the gas[4]. During the charging periods the electron density in the gap will be extremely low and the spike energy from pulses arriving at this time will be excessive. To reduce the likelihood of this happening some tubes have been run at high keep-alive current densities so that the discharge was 'abnormal', i.e. so that the voltage drop across the discharge increases with current (Fig. 2). When breakdown occurs the voltage drop will then settle at a value such that the current from the power supply will maintain it, and the discharge is sustained. In

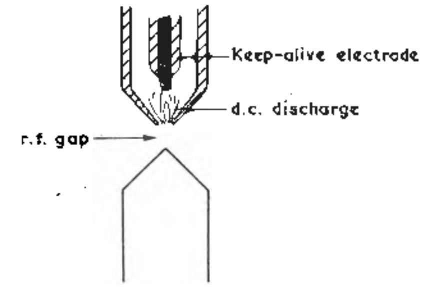

Fig. 1. Arrangement of keep-alive electrode

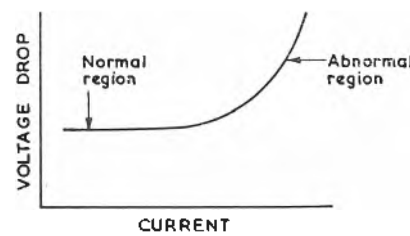

Fig. 2. Characteristics of glow discharge in a gas

recent years, however, it has been reported that relaxation oscillations are more related to the water vapour content of the tube than to the region of the discharge curve in which the keep-alive is operated[5], and the work of the author and his colleagues has shown that the tubes with noble gas fillings can be operated safely in the normal region. It has also been reported that a t.r. cell which has functioned satisfactorily for many hours will suddenly allow a damaging pulse to pass, but will function normally again afterwards. Bridges, Hawkins and Walsh[6] have attributed this to a transition from a glow to an arc discharge, during which the stray capacitances are discharged and protection is lost until they can be recharged and the glow re-established. This effect also is more probable when water vapour is used in the gas filling, but it can be insured against by incorporating two keep-alive discharges in the same tube, the probability of the phenomenon occurring simultaneously in both discharges being insignificant.

Finally it should be appreciated that the keep-alive discharge allows electrons with random energies to escape into the r.f. field and therefore constitutes a noise source internal to the receiving system. The effective noise temperature at the receiver input is given by the equation[7]

$$(T_{eff} - T_o) = (1 - (1/L))\,(T_D - T_o)$$

where T_o is the ambient temperature

T_D is the electron temperature in the gas discharge

L is the loss (defined as the ratio of input to output power) caused to an r.f. signal by the discharge.

As L approaches unity T_{eff} becomes a minimum, i.e. low loss is advantageous not only because of its effect on the signal but also because it leads to low noise at the receiver input.

Types of Gas Switch

HIGH Q T.R. CELLS

The most direct method of ensuring that breakdown of the t.r. switch is rapid, so that minimum power breaks through to the receiver, is to design it in such a fashion that the gas is subjected to as high a stress as possible. This is best accomplished by making the t.r. element part of a resonant cavity which is included in the system coupling transmitter, receiver and aerial. Breakdown of the gas takes place first in the region of maximum stress and the resultant detuning of the resonant structure causes rejection of the transmitter pulses. The magnitudes of the spike breaking through to the receiver and of the flat which follows it are both reduced by sharpening up the resonance curve, and a single sharply tuned cell may be made to give very effective protection. The use of high Q tubes has, however, operational disadvantages. In order that they may be used over a frequency band of a few per cent, which may be necessary in a typical equipment, some form of tuning must be incorporated. This may be within the cell itself (for example, the gap between the electrodes may be adjustable), or may be an element such as a screw introduced into the cavity of which the cell forms a part. Slight detuning will cause a considerable loss of signal and the performance of the system depends to a large extent on the skill and patience of the operator in setting the tuning control. It may, however, be necessary to repeat the operation at relatively short intervals since the frequency both of the transmitter and of the t.r. cavity may be temperature dependent.

BROADBAND CELLS

Many of the operational disadvantages of the t.r. switch are overcome if it can be made sufficiently broadband for use, without tuning adjustment, over the whole frequency range of a particular radar system. This may be accomplished by a combination of two processes; the bandwidths of the individual elements are made as large as possible consistent with a permissible spike, and the number of elements is increased. It may be shown[8] that the designer has some degree of freedom in optimizing the bandwidth of a single element by adjustment of the geometry of the electrodes, but the maximum achievable in this way is likely to be much less than the system demands. The use of two elements spaced a quarter wavelength apart increases the bandwidth and, moreover, reduces the 'flat' breakthrough since each element will contribute some attenuation when broken down. The addition of two further elements of lower Q (i.e. higher intrinsic bandwidth), spaced a quarter wavelength on either side of the first two, lead to a structure having a still larger bandwidth. The most common form of broadband cell is formed in this way and is shown in schematic form in Fig. 3. It is a length of waveguide sealed at either end by a glass window in a suitable matching iris, and containing two centre elements, each of which consists of a pair of opposed electrodes matched by an inductive iris. The windows are the lower Q elements which form part of the broadbanding structure. The keep-alive discharge is excited in the gap remote from the transmitter and in operation breakdown occurs successively at this gap, at the preceding gap and at the input window. The spike is therefore determined by the keep-alive gap, and all three elements add some attenuation during the flat, although the main discharge takes place at the window. Tubes of this type are now in common use.

Both broadband and high Q t.r. cells usually contain some water vapour to assist in recovery after the breakdown, and the danger of relaxation oscillations being set up or of glow-arc transitions occurring may therefore exist.

PLUG-IN TUBES

Among recent developments in t.r. switch design have been plug-in tubes designed for use as elements in a broadband system[9]. In the arrangement described in the previous paragraph each of the centre electrode pairs is enclosed in its own glass envelope and forms a valve which may be replaced by a simple 'plug-in' operation as in normal circuit practice. The end windows are, of course, no longer required for sealing purposes, but it may be desirable to replace them by resonant irises to increase the bandwidth of the system. Plug-in tubes are attractive, particularly at wavelengths of 10cm or more because they are much smaller and more easily replaced than the broadband cell. Moreover, the tube nearer to the transmitter can be relatively simple and cheap since it does not need a keep-alive electrode. The incorporation of a keep-alive electrode adds considerably to the cost of the other cell, but it is still much simpler than the broadband tube. Where two tubes are used in this way the main discharge is concentrated in

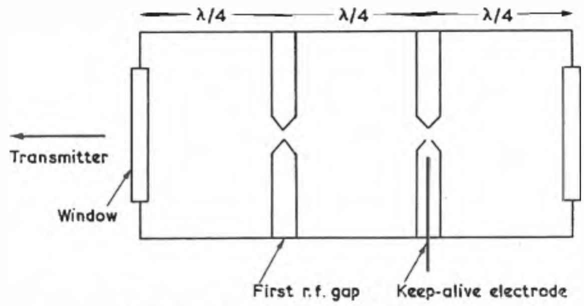

Fig. 3. Schematic diagram of 4-element Broadband t.r. tube

the one nearer to the transmitter and it largely determines the recovery time of the system; the other tube, however, breaks down first because of the presence of the keep-alive electrons and therefore determines the magnitude of the spike. The author and his colleagues have found it possible to use a combination in which the first tube only contains water vapour to act as recovery agent and the second has a pure noble gas filling. This considerably lengthens the life of the more expensive tube because the probability of a short-circuit in the keep-alive system due to electrode sputtering is reduced. Moreover, glow-arc transitions and relaxation oscillations are much less likely than if water vapour is included in this tube.

For longer wavelengths therefore the greater flexibility and lower cost consequent on the use of plug-in cells make them very attractive to the system designer.

PULSED ATTENUATORS AND PHASE-SHIFTERS

The problem of making a t.r. cell with a satisfactory keep-alive discharge is by no means a simple one. The position of the keep-alive electrode must be carefully controlled so that the electron density within the gap between the main electrodes is sufficient to ensure rapid breakdown of the gas, but not high enough to cause noticeable attenuation of received signals. Moreover, as mentioned earlier, the possibility of crystal damage due to a glow-arc transition is difficult to eliminate entirely.

The problem has been solved in some equipments by the use of a tube in which the gas discharge is initiated by means of a subsidiary pulse applied just before the main transmitter pulse. The structure may take a number of forms, several of which have been described by Bradley and Pringle[10], but it is general to make it so that a d.c. pulse applied between suitably disposed electrodes gives rise to a high electron density and therefore to considerable attenuation of signals. Deionization must, of course, take place as rapidly as possible after the transmitter pulse has passed, and water vapour or some other recovery gas will usually be included for this purpose. Bradley and Pringle[11] have also described phase-shift tubes which could conceivably be used in duplexing systems. Here the electrical length of the tube is different according as the gas is ionized or not and by enclosing it in a suitably designed transmission line system it may be made to switch transmitter signals to the aerial and received signals to the receiver. It is, of course, presupposed that the phase-shift can be controlled by application of an ionizing pulse and the arrangement will not be satisfactory if the transmitter pulse itself influences the electron density in the discharge. It is likely therefore to have only a very limited use.

Either pulsed attenuators or phase-shifters, which are 'triggered' devices, will, of course, afford protection against only those signals which are synchronized with the triggering pulse and will not be effective if the system is subjected to other r.f. pulses of large amplitude. They may not therefore be suitable where a number of radar systems are operating in the same area. They have as yet had a very limited practical application.

MICROWAVE CIRCUIT COMPONENTS

Some mention should be made of the microwave circuit components with which the t.r. cell may be associated because, as has been mentioned in the case of phase-shifters, the effectiveness of the cell may be determined, or at least improved, by proper circuit design. In the simple form of duplexer illustrated in Fig. 4(a) the t.r. cell is placed a quarter wavelength from the main transmission line, so that when it is struck by the transmitter pulse a high impedance is presented at the junction and the transmitter power passes through to the aerial. The length of line from the transmitter to the junction is adjusted so that, during the quiescent periods a high impedance is presented at the junction by this line and all the received power passes through the t.r. cell to the receiver. Clearly this arrangement is dependent on the impedance of the transmitting tube when quiescent, but this feature may be eliminated if desired by the inclusion of an a.t.r. switch (Fig. 4(b)) the function of which is to present the desired high impedance to the junction during the receiving period. In either case, however, all that power which breaks through the t.r. cell is fed to the receiver. Fig. 4(c) shows a 'balanced' form of duplexer in which the circuit is designed to supplement the protection obtained from the t.r. cell.

The signal from the transmitter is divided equally between the paths A and B by the first 3dB coupler. It breaks down t.r. cells in the two paths and the phase of the reflected signals is such that on passing through the 3dB coupler again they add in the aerial branch. Received signals on the other hand are split by the first coupler, pass through the t.r. tubes unattenuated, and recombine in the second coupler, the output from which goes along path D to the receiver arm. The t.r. cell does not reflect the whole of the transmitter pulse, but that part of it which does break through is in the correct phase relationship with respect to the similar signal from the other cell to add in the second 3dB coupler and feed into arm C, which is terminated in a dummy load. The receiver is therefore protected not only to the extent afforded by the t.r. cells but also by the isolation effect of the 3dB coupler system. It should be appreciated that to obtain maximum benefit from a system of this sort the attenuation and phase-shift of signals passing through the two t.r. cells should be the same. With this end in view dual cells have been made, in which the two halves are geometrically identical and are physically connected so that the gas filling is the same in each[12].

Other forms of circuit have been used to achieve the same end, the detailed arrangement in any individual case being determined by a number of factors such as the space and components available for duplexing purposes.

Other Forms of Switch

In spite of considerable advances during the past decade the t.r. cell is still a source of petty irritation, and sometimes of major concern, to the radar designer. Its life is limited by factors such as sputtering of the keep-alive electrode and clean-up of water vapour, which cannot be eliminated, and it is subject to relaxation oscillations, glow-arc transitions and other idiosyncrasies of gas discharges. Other mechanisms which are capable of providing high speed switching actions are therefore of considerable

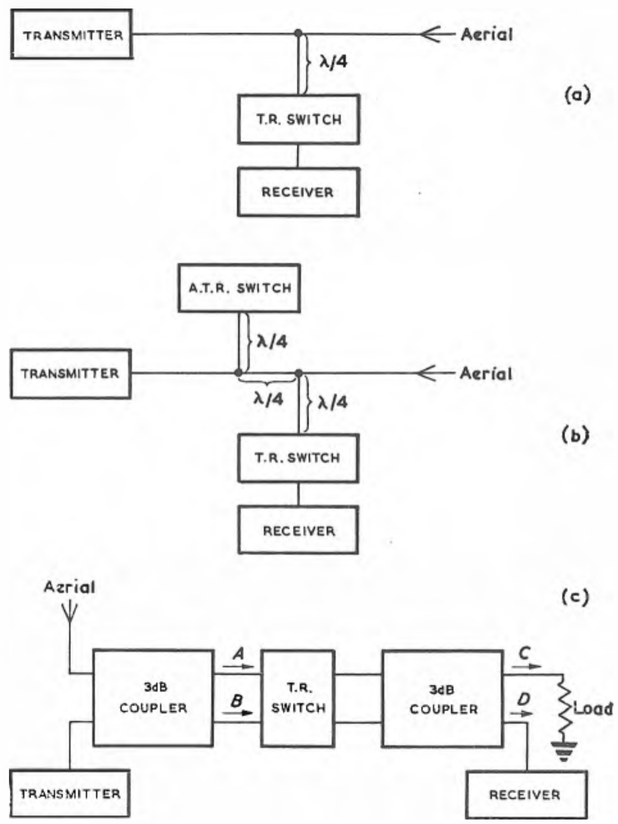

Fig. 4. (a) Simple duplexer not employing a.t.r. tube. (b) Duplexer with a.t.r. tube incorporated. (c) Balanced duplexer. The 3dB couplers may take a number of different forms

interest and among these are the properties of the class of materials known as ferrites. If a plane polarized wave is propagated through a ferrite medium and a magnetic field is applied along the axis of propagation the plane of polarization rotates as the wave progresses. Moreover, the sense of the rotation is determined by the direction of the magnetic field and is independent of the direction of propagation. A simpler form of duplexer based on this property is shown in Fig. 5.

A specimen of ferrite is mounted in circular waveguide between transmitter and aerial and a magnetic field is applied along the axis. The length of ferrite is such that the rotation of the plane of polarization as the wave traverses it is 45°. A further 45° rotation in the same sense is applied to signals returning from the aerial so that at the junction A the planes of polarization of transmitted and received signals are at right-angles. The branch guide connecting the receiver to the main run is arranged so that it couples only to the returning signals, and a substantial degree of isolation between transmitter and receiver is achieved. Unfortunately, however, the isolation is affected not only by the properties of the waveguide junction, which limits it to perhaps 30dB, but also by the mismatch of the aerial and feeder system since all reflected signals will, of course, be passed to the receiver. If, for example, the voltage standing wave ratio were 1·2, which in many systems would not be regarded as excessive, the maximum isolation obtained would be only 20dB. In many high power systems 80 to 90dB of isolation may be necessary and it is not therefore possible to use this form of duplexer alone. It may, however, have uses as a primary duplexer to be followed by one or other form of t.r. cell.

Another switching device uses the change of permeability with magnetic field to give phase-shift in a rectangular guide. The velocity of a wave travelling through a ferrite medium will therefore vary with the magnitude of the field, and a variable phase-shifter may be made by mounting a specimen of ferrite in a length of waveguide

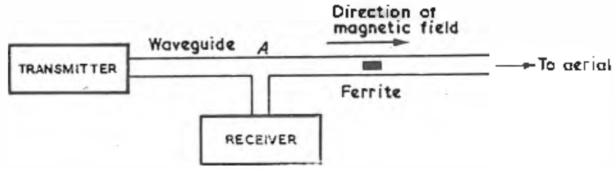

Fig. 5. Duplexer using rotational characteristics of ferrite

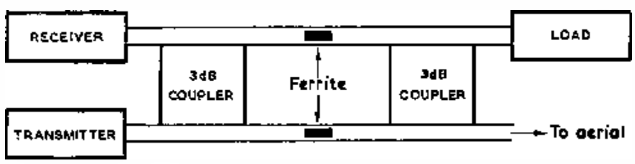

Fig. 6. Balanced duplexer, based on phase shift in ferrite on application of magnetic field

and changing the applied magnetic field. A possible form of duplexer based on this property is shown schematically in Fig. 6.

Here the power is split into two equal parts by a 3dB coupler, as in the balanced duplexer described previously. During the transmitter pulse a magnetic field is applied to one specimen of ferrite causing a phase-shift 180° greater than that in the other specimen. The power from the two branches then recombines at the second coupler and is fed to the aerial. Immediately after the transmitter pulse the magnetic field is removed and received signals then undergo the same phase-shift in each path and recombine into the receiver instead of the transmitter. The degree of isolation between transmitter and receiver is here limited by the properties of the 3dB couplers and again is not likely to exceed 30dB or so, so that a back-up tube will in most cases be necessary.

One disadvantage of either of these duplexers is that there is an intrinsic power loss in the ferrites themselves and especially where the power levels and pulse recurrence frequencies are high, the heating effect may be an embarrassment. Continuous improvements in the properties of the materials, are, however, being made and practical duplexers using them have been developed for use at X-band[13]. For the reasons mentioned above however they are likely to remain only a partial substitute for gas discharge devices, except for very special duplexing systems.

Recent Receiver Developments

The necessity for t.r. devices capable of giving very high isolation between transmitter and receiver has arisen because the silicon crystal, which being a low noise device and therefore more suitable as the input stage of a microwave receiver than a conventional thermionic valve, is damaged by very low levels of breakthrough power. During recent years, however, a thermionic valve of fundamentally new design particularly suitable for microwave amplification, the travelling wave tube, has been developed to an advanced stage. Moreover the noise figures* of these tubes may be made to compare very favourably with those achievable using silicon crystals. (At S-band, for example, noise figures better than 7dB are being consistently achieved on tubes from normal production[14].) The travelling wave tube is therefore as good as or better than the crystal as the receiver input stage, and will withstand breakthrough pulses many times greater than those which would cause serious damage to crystals. It is still possible to use the crystal as a mixer stage should that be necessary because the travelling wave tube limits the output signal to a magnitude which can be safely accommodated by the crystal. In many cases this will not however be necessary because the gain of the travelling wave tube stage is sufficiently large to make the noise generated in the mixer of relatively minor importance, and a conventional thermionic tube may therefore be used. Perhaps the most obvious disadvantage of the travelling wave tube is that it utilizes a magnetic field to focus the electron beam, and in some systems, for example, for airborne applications, the weight of the magnet may be prohibitive. In general, however, it seems that the travelling wave tube, perhaps with alternative and less weighty forms of focusing, such as periodic electric or magnetic fields, with a relatively simple duplexer will replace the crystal and the very sensitive t.r. cell particularly in the longer wavelength systems.

Conclusion

The gas discharge tube in one form or another is most widely used for protection of radar receivers because it best fulfils the requirements of the silicon crystal mixer which is the usual input stage of most receivers. With the advent of the travelling wave tube, however, more robust receivers of equal sensitivity may be designed and simpler forms of duplexer, some of which may employ ferrite materials, will become commonplace.

Acknowledgment

Acknowledgment is made to the Engineer-in-Chief, Marconi's Wireless Telegraph Company Limited, for permission to publish this article.

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* *The noise figure may be loosely defined as the degradation of signal-to-noise ratio on passing through the device, and for a theoretically perfect amplifier is unity (0dB)*

A Very Low Frequency Three-Phase Oscillator

By M. D. Armitage*, B.Sc., A.Inst.P.

A cathode feedback circuit to increase the time-constant of the resistance-capacitance networks in a phase-shift oscillator is discussed. It is possible to increase the time-constant by a factor of 100; *the preferred circuit gives a factor of about* 18. *A complete oscillator for the frequency range* 0·01 *to* 40*c/s, using only five valves, is described. Amplitude limitation is obtained by incorporating 'Metrosil' non-linear resistors in the anode loads. A three-phase output of* 150*V peak-to-peak is obtainable with about* 1 *per cent distortion, or* 60*V with less than* 0·2 *per cent of hum and distortion.*

THERE have been published within the last few years several papers dealing with oscillators for what is sometimes called the 'servo' range of frequencies[1,2,3,4]. Another recent paper[5] has described three-phase oscillators covering the range 20c/s to 10Mc/s and their use to synthesize a voltage of known amplitude and phase, while another[6] described a low frequency oscillator suitable for polyphase operation.

A very-low frequency source of reasonable waveform is of great value in the teaching of a.c. theory; centre-zero moving-coil meters can be used and the student is able to see directly the nature of the waveform, the meaning of phase difference, distortion, etc. The current through a capacitance, the relation between input and output of an amplifier, modulation and mixing, phase relations, etc. in three-phase circuits, can all be demonstrated visually.

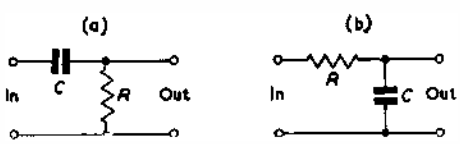

Fig. 1. (a) CR network. (b) RC network

Mechanical methods of generating a v.l.f. sine wave have been tried; a slowly rotating capacitor has been used to frequency-modulate an oscillator, a discriminator then extracting the modulation. An alternative is to use a sine potentiometer, fed with d.c. Preliminary experiments with a sine potentiometer driven by a geared d.c. motor were discouraging; the current through a capacitor showed violent fluctuations, due to variations in the speed of the motor. In addition, the frequency range was limited. The phase-shift oscillator has no inherent low frequency limit provided the capacitors used are of good power factor and small dielectric absorption, and the circuit described here enables polystyrene capacitors, of moderate size and cost, to be used. The method of increasing the time-constant has been noted previously[7]; the circuit is highly degenerative and avoids direct couplings.

The Choice of Phase-Shift Circuit

To obtain the lowest possible frequency with a given time-constant, it is desirable to isolate the separate sections of the phase-shift network from each other by valves, which leads automatically to the use of a polyphase circuit. Attention here is confined to the three-phase oscillator, which is obtained with three phase-shift networks, each contributing 60° phase-shift, separated by three amplifiers, each with a limiting gain of -2. Several factors enter into the choice between the *CR* and *RC* network configurations (Fig. 1). These may be summarized as:

(1) Relation of oscillation frequency to time-constant

(2) Danger of spurious modes of oscillation

(3) Attenuation of harmonics

and will be considered in turn.

Frequency of Oscillation

The requirement of 60° phase-shift leads to

$$\omega_0 = 1/\sqrt{3}\,.\,CR \quad \ldots\ldots\ldots\ldots \quad (1(a))$$

for the *CR* circuit and

$$\omega_0 = \sqrt{3}/CR \quad \ldots\ldots\ldots\ldots\ldots \quad (1(b))$$

for the *RC* circuit,

where ω_0 is the angular frequency at which oscillation is possible. Clearly, for a given time-constant, the *CR* configuration gives a frequency three times lower than the other.

Spurious Modes

The chief danger of spurious modes involving the whole loop of the oscillator (rather than a single valve) arises with the *CR* circuit. Stray capacitances to earth can combine with the effective internal resistance of each amplifier, to give an oscillator of the *RC* type, at a frequency high enough for the attenuation of the *CR* coupling network to be negligible. The unwanted mode can be suppressed by the use of stoppers, or by shunting one of the anode loads with a small capacitance to reduce the loop gain at the spurious frequency.

Attenuation of Harmonics

The integrating circuit of Fig. 1(b), considered in isolation, gives greater harmonic attenuation than does the differentiating circuit of Fig. 1(a). However, this does not necessarily apply when the networks are used as part of a closed feedback loop. As an indication of this, it may be remarked that a high-order harmonic generated at one point in the loop will be fed back to that point almost in anti-phase, and amplified nearly 8 times. The situation is less clear for the more important harmonics (2nd, 3rd, etc.), but an analysis based on the assumption that each amplifier of the three operates under identical conditions, suggests that for either circuit the feedback will reduce the distortion. This conclusion is supported by the results of experiments in which oscillation was stopped by reducing the gain, and the feedback loop then broken. A signal was then fed to one of the amplifiers and the distortion measured; on re-closing the loop and reducing the signal to give the same level as previously, the distortion was found to have been reduced.

In the absence of any major disadvantages, the lower oscillation frequency, and the fact that no d.c. blocking capacitors are needed in addition to the phase-shift com-

* *South-East Essex Technical College*

ponents, suggest that the CR configuration is to be preferred for a v.l.f. oscillator, and is used in the circuits discussed below.

Multiplication of the Time-Constant

The simple circuits of Fig. 1 do not allow a time-constant of more than a few seconds to be obtained with capacitors of reasonable size and cost. This is particularly the case when polystyrene capacitors are used to avoid the difficulties associated with dielectric absorption in paper and mica types. It is possible, however, to increase the effective time-constant by the use of one of the circuits

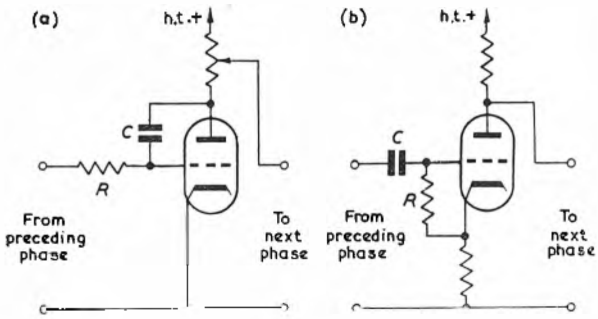

Fig. 2. Circuits for increasing the time-constant

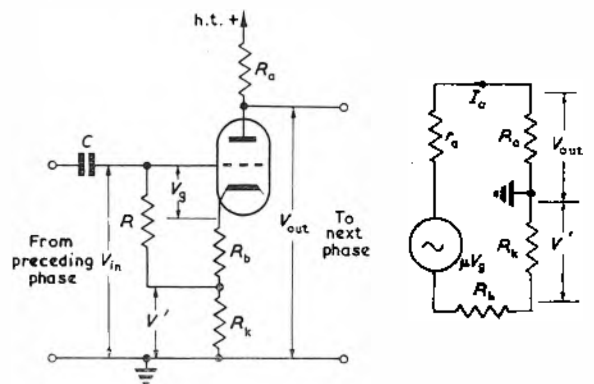

Fig. 3. One phase of basic circuit

shown in Fig. 2. The circuit of Fig. 2(a) takes advantage of the Miller effect to give an effective capacitance $C' = (1 + A)C$, where A is the gain of the valve; in the case of Fig. 2(b), the cathode feedback effectively increases R to $R' = R/(1 - A_k)$, where A_k is the 'gain' from grid to cathode. Circuit (a) needs a direct coupling between phases and a large stage gain, which limits the use of negative feedback; circuit (b), on the other hand, uses C as a blocking capacitor and is inherently degenerative, the overall stage gain required being only 2. This degeneration improves the stability of the oscillator and reduces the distortion; the circuit is discussed in detail in the next section.

The Basic Oscillator Circuit

A simple oscillator, using only one triode per phase, but which nevertheless gives good performance and is easy to set up and use, can be derived from the circuit of Fig. 2(b). The practical form of the circuit is shown in Fig. 3, together with its equivalent anode circuit. The resistor R_b is to provide bias. R_a and R_k have to be chosen so that $V_{out} = 2V_{in}$. To calculate the oscillation frequency, let R' denote the effective input resistance between grid and earth and let the factor by which the time-constant is multiplied be M. Then:

$$M = (R'/R) = V_{in}/(V_{in} - V'),$$

where V_{in} = alternating voltage between grid and earth,

V' = alternating voltage across R_k

while $\omega_0 = 1/\sqrt{3}\,.\,MCR$. From the a.c. equivalent anode circuit, it is easy to show that:

$$M = 1 + \mu R_k/[r_a + R_a + R_b(\mu + 1) + R_k]$$
$$\simeq 1 + \mu/[1 + (r_a + R_a + \mu R_b)/R_k] \quad \ldots\ldots (2)$$

and that the overall gain of the stage is:

$$A = V_{out}/V_{in} = \mu R_a/[r_a + R_a + (R_b + R_k)(\mu + 1)] \quad .. (3)$$

The condition that the gain must equal 2 gives for the critical value of R_a:

$$R_a(\mu - 2) = 2r_a + 2(R_b + R_k)(\mu + 1) \quad \ldots. (4)$$

It is of interest to glance at typical numerical values. For the ECC83 triode, $\mu = 100$, $r_a \simeq 50\text{k}\Omega$, and R (the grid leak) can have a value of 2·2MΩ. Taking a typical operating point (see below), with $R_k = 100\text{k}\Omega$, $R_b = 2{\cdot}0\text{k}\Omega$, and $R_a \simeq 220\text{k}\Omega$, and assuming $C = 0{\cdot}2\mu\text{F}$, one obtains $M \simeq 18$, which gives a frequency of approximately 0·015c/s.

The Effect of Variations in Valve Parameters

In considering this problem, it is assumed that valve ageing and changes in supply voltage will mainly affect the value of r_a, while valve replacement will have its most serious effect on μ, since there is no convenient way of compensating for variations in this parameter. In view of the large amount of series (current) feedback it is to be expected that the critical value of R_a needed to maintain oscillation will be largely independent of both μ and r_a; on the other hand, the value of M (and hence the frequency) inherently depends on μ and, to a lesser extent, on r_a. These conclusions can be tested, in the case of R_a, by differentiating equation (4) which (with the assumption $\mu \gg 1$) yields the following results:

$$d(R_{crit})/R_{crit} = (d\mu/\mu)\left[\frac{-r_a}{r_a + \mu(R_b + R_k)}\right] \ldots. (5)$$

and

$$d(R_{crit})/R_{crit} = (dr_a/r_a)\left[\frac{r_a}{r_a + \mu(R_b + R_k)}\right] \ldots. (6)$$

where R_{crit} denotes the critical value of R_a.

Insertion of typical values for the ECC83 (see later) gives:

$d(R_{crit})/R_{crit} \simeq -0{\cdot}005\,.\,(d\mu/\mu)$ and

$d(R_{crit})/R_{crit} \simeq 0{\cdot}005\,.\,(dr_a/r_a)$.

A similar differentiation of equation (2), with the substitution $R_T = r_a + R_a + R_k + R_b$, yields two further equations:

$$(dM/M) = (d\mu/\mu)\left[\frac{\mu R_k R_T}{(R_T + \mu R_b)(R_T + \mu R_b + \mu R_k)}\right] .. (7)$$

$$(dM/M) = (dr_a/r_a)\left[\frac{-\mu R_k r_a}{(R_T + \mu R_b)(R_T + \mu R_b + \mu R_k)}\right] . (8)$$

which in turn lead to the numerical approximations:

$(dM/M) \simeq 0{\cdot}7\,.\,(d\mu/\mu)$ and $(dM/M) \simeq -0{\cdot}1\,.\,(dr_a/r_a)$.

Examination of equations (5) to (8) and the numerical results quoted confirms that the necessary setting of R_a and, hence, the amplitude of oscillation, should be reasonably stable, but that the frequency of oscillation, only slightly affected by ageing and supply variations, will be affected by valve renewal. Some arrangement for trimming is therefore necessary, a convenient variable being R_k, which affects the value of M to approximately the same extent as does μ. If it is desired to maintain accurately the 120° phase difference, each valve will require individual trimming, although this is not necessary if the actual frequency only is important. In addition, provision must be made for re-setting the bias resistor if the maximum undistorted output is desired; this will also affect the value of M.

The Useful Tuning Range

In the derivation of equation (2) and (4), the valves and the phase-shift networks were treated in isolation. If, however, the output impedance of the amplifier is comparable with the input impedance of the network, the frequency of oscillation will differ from that calculated. From the more accurate equivalent of Fig. 4, it can be shown (allowing for the phase-shift produced within the amplifier as well as the extra resistance in the CR network) that if $R_a/MR = s$, then s is approximately equal to the fractional error in frequency. Thus, if R is used as the fine tuning control, as its

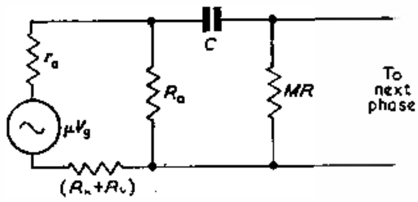

Fig. 4. Equivalent circuit showing amplifier impedance

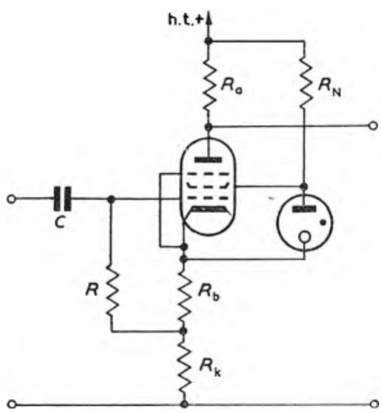

Fig. 5. Pentode circuit

value is reduced it will progressively affect the frequency and reduce the gain. This sets a lower limit to the value of R, while an upper limit is set by the maximum safe grid-cathode resistance for the valve used. It is not difficult to achieve a tuning range of 10:1 for each capacitor used, and if a larger range were needed, a cathode-follower could be used to drive the network. The range can be changed by switching different values of C, the upper limit here being set by the size and cost of the components and the lower by the effects of stray capacitance. An overall tuning range of perhaps 10^4 (e.g., from 0·01 to 100c/s) is possible; for higher frequencies it is better to use a conventional circuit.

Modifications to Increase M

If it is important to obtain the lowest possible frequency, it is possible to increase the value of M, although at the expense of simplicity and ease of operation. Some ways of doing this are examined in this section.

Pentode Circuit

An obvious way to increase M is to use a pentode instead of a triode to get a larger value of μ. Equation (2) can then be re-written thus, assuming r_a to swamp $(R_a + R_k)$:

$$M \simeq 1 + g_m R_k/(1 + g_m R_b) \quad \ldots\ldots\ldots\ (9)$$

This makes a higher value possible than with a triode, but the need to maintain the screen grid at a constant potential relative to the cathode presents a difficulty. If a neon tube is used, as in Fig. 5, the dropping resistor R_N is effectively in parallel (to signal currents) with R_k and so reduces the effective value of the latter in equation (9). In addition, the d.c. required to operate the neon passes through R_k, increasing the h.t. voltage needed for a given undistorted output.

Cascode Circuit

A dry battery would provide an alternative to the neon tube suggested in the previous paragraph, but if this course is chosen it is probably better to replace the pentode by a cascode of two triodes, as shown in Fig. 6, so that the battery is under no-load conditions. To solve the equivalent anode circuit of Fig. 6(b), note that the effective grid-cathode signal of the upper valve is equal to the negative of the anode-cathode voltage across the lower valve, i.e.,

$$V_g' = (\mu V_g - I_a r_a),$$

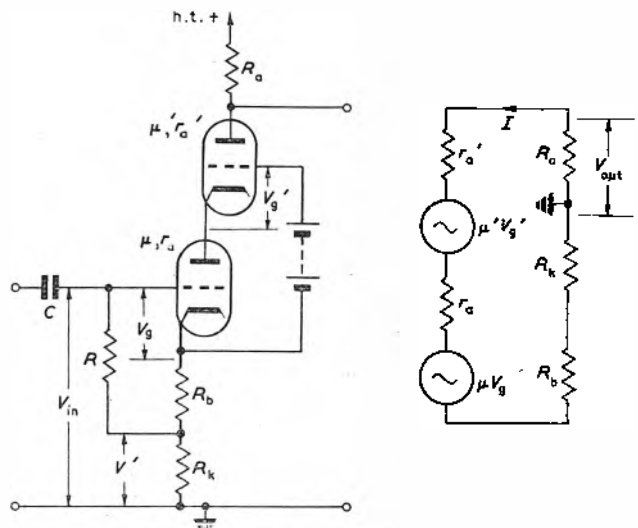

Fig. 6. Cascode circuit

considering only alternating components. Then:

$$V' = I_a R_k = \frac{(\mu V_g + \mu' V_g')R_k}{r_a + r_a' + R_a + R_b + R_k}$$

from which the mutiplication factor can be shown to be:

$$M = 1 + \mu R_k \Bigg/ \left[\frac{\mu + 2}{\mu + 1} r_a + \frac{R_a}{\mu + 1} + \frac{\mu^2 + \mu + 1}{\mu + 1} R_b + \frac{R_k}{\mu + 1}\right]$$

assuming the two valves to be identical. Taking $\mu \gg 1$, this equation reduces to:

$$M = 1 + g_m R_k/(1 + g_m R_b) \quad \ldots\ldots\ldots\ (10)$$

while the expression for the stage gain is also a close approximation to that for a pentode.

Cathode-Follower Circuit

A second triode can also be introduced, without the awkward direct coupling in the cascode, if the basic circuit is split into its separate functions of time-constant multiplication and amplification. This leads to Fig. 7, in which one triode acts as a cathode-follower and provides the multiplication, while the other gives the gain. Although a direct coupling is involved, the difference in h.t. between the two valves is easily obtained from resistance bias, common to all three phases. (No signal current will flow in supply leads common to all three phases). The expression for M is obtained by setting $R_a = 0$ in equation (2), and is:

$$M = 1 + \mu/[1 + (r_a + \mu R_b)/R_k] \quad \ldots\ldots \quad (11)$$

The gain provided by the second valve will be as given by equation (3), setting $R_b = 0$ and writing R_k' for R_k. The value of R_k in the cathode-follower can be at least twice that in the basic circuit, so that a considerable increase in M is possible. The upper limit to the value of R_k is set by the h.t. available for the second valve, which has its grid connected directly to the cathode of the first. This limitation can be overcome if the second valve is fed from a tapping on R_k. The cathode-follower can then run from the full h.t. voltage and have a larger cathode load. The attenuation introduced can be counteracted by reducing the cathode feedback resistor of the second valve (R_k') and increasing the bias resistor to restore its operating point. This circuit is shown in Fig. 8.

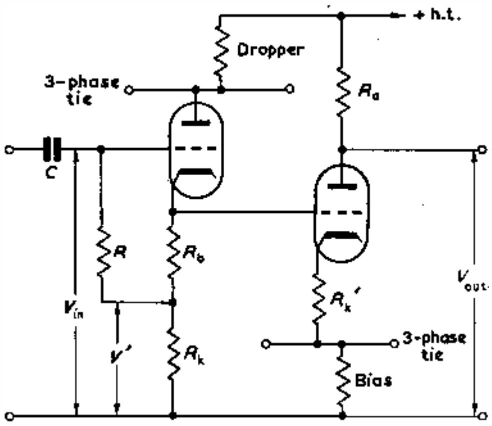

Fig. 7. Cathode-follower circuit

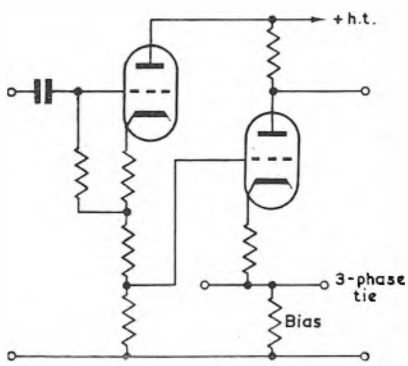

Fig. 8. Modified cathode-follower circuit

USE OF CONSTANT-CURRENT CATHODE LOAD

It is clear in each circuit that increase of R_k will increase the value of M; for a given h.t. voltage, the effective, or dynamic, value of R_k can be increased if a 'constant-current' circuit is used in place of a resistor. For example, a pentode such as the EF86 with fixed screen voltage and a cathode feedback resistor can give a dynamic resistance of several megohms for a d.c. drop of only 100V.

USE OF BATTERY BIAS

From the various equations for M, it can be seen that reduction of R_b, the bias resistor, will increase the value of M, so that if the bias is obtained by the use of a dry battery in series with each grid leak, a greater multiplication factor can be expected.

COMPARATIVE SUMMARY OF MODIFICATIONS

The values of M to be expected with the ECC83 triode and 500V h.t. are given in Table 1, together with the resistance values assumed in the calculations. The last column also shows which parameter mainly determines the value of M. It must be emphasized that where r_a or g_m is important, not only will the frequency stability be affected, but with a large amplitude signal the instantaneous value of M will vary during the cycle, causing distortion. The circuits where μ is the determining parameter are therefore to be preferred; r_a is swamped by the circuit resistance to the greatest extent in the circuits of Fig. 3 and Fig. 8.

It can be seen from the Table that the use of a pentode as cathode load gives a considerable increase in M, but

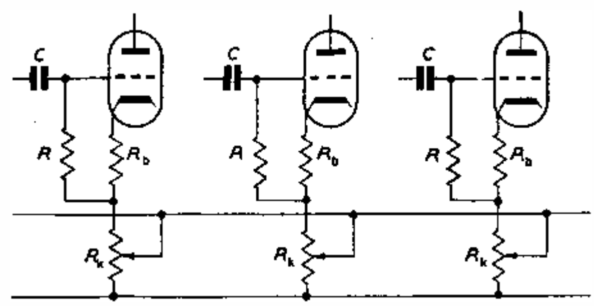

Fig. 9. Tuning by adjustment of 'M'

the difficulty of the additional d.c. adjustments makes it a doubtful advantage. Similarly, in nearly every case, the use of battery bias (indicated in the Table by $R_b = 0$) increases the value of M, but the difficulty of bias adjustment (using high-μ valves) is a serious disadvantage. If it is very important to obtain the lowest possible frequency (e.g. in an oscillator for students' use), the circuit of Fig. 8, with a single mercury cell to provide bias and the h.t. adjusted to suit, is probably best, but for a signal generator, the basic circuit of Fig. 3 is not only the easiest to adjust, but will give the best results. Test results on such an oscillator are given later.

Practical Forms of Circuit

CHOICE OF OPERATING POINT

If cathode bias is used, it is desirable to work with as small a bias as is consistent with low distortion, owing to the appearance of terms μR_b, or $g_m R_b$ in the denominator of expressions for M. For the same reason, and to avoid excessive variations in r_a during the cycle, the static anode current should not be too low. On the other hand, R_k has to be as high as possible, so that some compromise is necessary. The circuit of Fig. 3 may be taken as an example again. For the ECC83, the value of r_a begins to rise rather

TABLE 1

CIRCUIT OF FIG.	R_a (kΩ)	R_k (kΩ)	R_b (kΩ)	M (calc.)	IMPORTANT PARAMETER
3	220	100	2·0	18	μ
	220	100	0	27	μ
	220	(EF86)	2·0	90	g_m of EF86
5	220	100	2·0	21	g_m
	220	100	0	60	g_m
6	200	90	2·2	30	g_m
	200	90	0	100	g_m
7	—	220	2·2	43	μ
	—	220	0	70	μ
8	—	330	2·2	51	μ
	—	330	0	75	μ
	—	(EF86)	2·2	90	g_m of EF86

steeply if I_a is much less than 1mA, while it is considered that the bias should not be less than about 1·5V to allow a reasonable swing. A load line drawn through the points (I_a = 0·9mA, V_g = −1·5V) and (I_a = 0, V_a = 500V), has a slope corresponding to about 330kΩ. With the requirements that R_a shall be rather more than twice R_k, this leads to the values used in compiling Table 1. The value of M is about 18 and an anode voltage of about 60V peak-to-peak may the use of a thermistor, or a filament lamp, with a thermal time-constant at least equal to a number of cycles of the oscillation frequency. A voltage sensitive limiting arrangement is therefore necessary. One oscillator which has been described[1], uses three double-diodes (one per phase), normally biased in the reverse direction by a floating d.c. reference voltage. Whenever the line voltage exceeds the reference voltage, the diodes couple a star-connected load

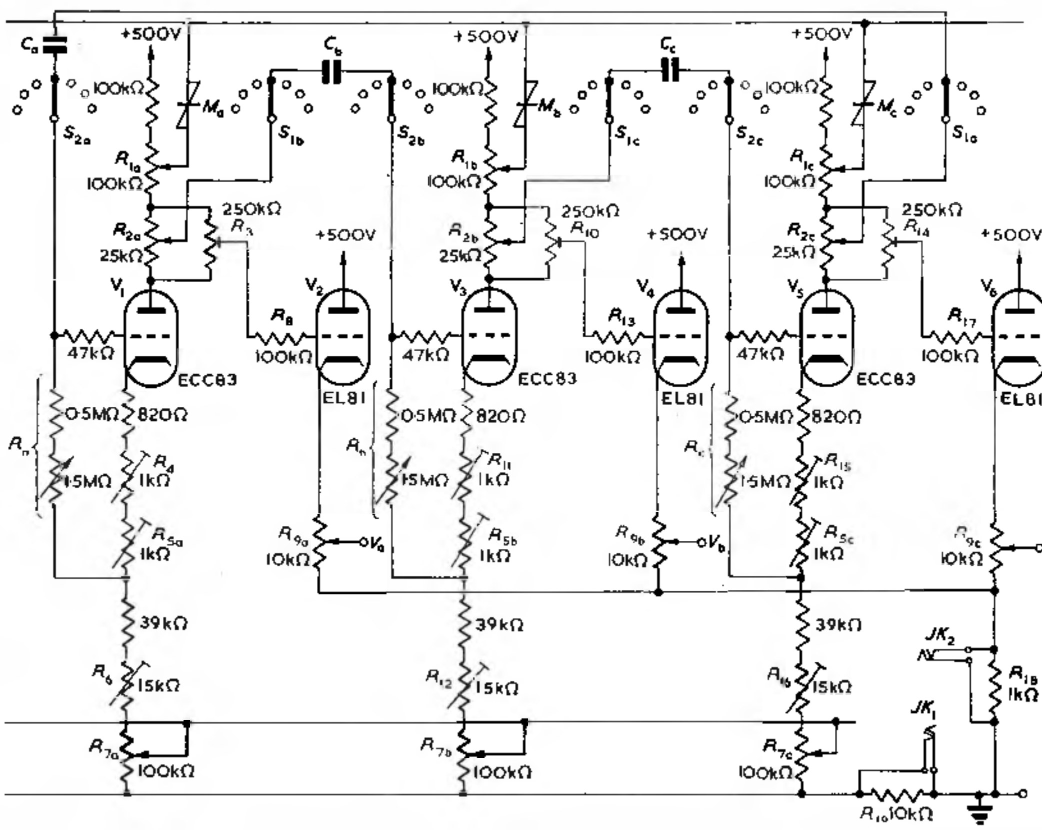

Fig. 10. Circuit of complete oscillator

Freq. range (c/s)	*0·01–0·04*	*0·03–0·12*	*0·1–0·4*	*0·3–1·2*
Ca, Cb, Cc (pF)	*270 000*	*90 000*	*27 000*	*9 000*
Freq. range (c/s)	*1·0–4·0*	*3·0–12*	*10–40*	
Ca, Cb, Cc (pF)	*2 700*	*900*	*270*	

Fixed resistors: ½ *watt carbon, 10% tolerance*
Potentiometers: *4 watt, wire-wound, except:*
R_9 *(a, b, c)* *14 watt wire-wound, 3-gang,*
Ra, Rb, Rc *carbon, 3-gang*
R_3, R_{10}, R_{14} *carbon.*
Ma, Mb, Mc—"Metrosil", 1MΩ resistance at 20V.

be expected. As a 4 per cent change in R_b is needed to produce a 1 per cent change in frequency, the bias can be adjusted in practice for minimum distortion.

In the two-valve circuit of Fig. 8, the whole of the 330kΩ load is in the cathode circuit and the cathode will be at about 300V positive. If the grid of the amplifier valve is tapped half-way up the load of the cathode-follower, it can be given the correct operating point by allowing a drop of about 35V in its cathode feedback resistor, and about 115V in the bias resistor common to the three phases. The anode load will then have to be about 4 times the cathode resistor. This arrangement will leave about 200V across the valve in the static condition, assuming 500V h.t.

The conditions quoted in Table 1 for the other circuits were chosen in a similar way.

Methods of Amplitude Limiting

The limiting circuits commonly used with RC oscillators are not suitable for very low frequencies, as they rely on to the anodes of the amplifiers, thus effectively reducing the loop gain.

The oscillator described below uses silicon-carbide non-linear resistors, whose resistance falls steeply with increasing p.d., as a three-phase load. Either star- or delta-connexion can be used, the non-linear resistor being chosen so that its resistance is, for example, 50 times R_a when the desired peak voltage is reached. Control of amplitude can be obtained if the non-linear resistors are connected to tappings on the resistors R_a, using a three-gang potentiometer. Provided that only a small fraction of the anode current is allowed to flow in the non-linear resistors, little distortion is caused.

Methods of Tuning

Continuous tuning by variation of C is clearly impracticable, but it is possible to vary either R or M, the latter by controlling the effective value of R_k as illustrated in Fig. 9, which shows how this can be done without upsetting the d.c. conditions. The only advantage of this method is that a wirewound potentiometer can be used for R_k, but is impracticable for R, where values up to 2MΩ are needed. It is best to restrict the adjustment of R_k to a small range, for trimming purposes; if it is made too low in value, the available undistorted output will be limited and the stage gain affected. A three-gang carbon potentiometer can then be used for R, with switched capacitors to give different ranges.

Experimental Results

Fig. 10 shows the circuit of a complete oscillator which has been extensively tested in the laboratory. It covers the range 0·01 to 40c/s in 7 ranges, each having a 4:1 sweep. The frequency is controlled by the switched polystyrene capacitors C_a, C_b, C_c and by the three-gang 1·5MΩ carbon potentiometer forming part of R_a, R_b, R_c. The three-gang potentiometer R_7 is the main trimming control, while R_6, R_{12}, and R_{16} are to allow for differences between individual valves. The total current through the oscillator valves V_1, V_3 and V_5 can be observed on an oscilloscope plugged into the jack point JK_1; if the three phases are balanced only third harmonic will be observed at this point. Individual bias controls R_4, R_{11}, R_{15} and a three-gang bias control R_5, are provided so that the operating points of the oscillator valves can be adjusted for minimum distortion. In the anode circuits, the three-gang potentiometer R_1 sets the level at which the limiting circuit operates, while R_2 (also three-gang) adjusts the loop gain.

The three outputs are taken from power valves used as cathode-followers, with the three-gang potentiometer R_9 as load. The pre-set controls R_3, R_{10} and R_{14} are to enable the three outputs to be balanced; the waveform of the total current through the output valves can be observed on an oscilloscope plugged into JK_2. Three centre-zero voltmeters connected in delta across the three outputs act as monitors.

Frequency of Output

The frequency was measured at the audio frequency end of the range by obtaining Lissajous figures with the output of a calibrated audio oscillator and at lower frequencies by recording the voltage waveform between two phases with a pen recorder. In addition some observations were made of all three outputs on a multi-channel pen recorder, in order to verify the balance of the circuit. Fig. 11 shows an example. The value of the multiplication factor M was calculated from the observed frequency and the values of C and R used; it was found to be between 17 and 20 according to the setting of the trimming control R_7. This agrees well with the value calculated from equation (2). A tuning range of 4:1 approximately is obtained with the tuning resistances made up as shown in Fig. 10; the difference between observed and calculated frequencies with R set to its minimum value of 0·5MΩ is about 2 per cent.

Distortion

To facilitate measurement of the distortion on a wave analyser (Marconi type TF455), the frequency was increased to about 120c/s. The balancing and bias controls were then adjusted to give approximate equality between the phases, and minimum distortion, and the harmonic content of each phase was measured. With an output of 60V peak-to-peak (per phase), the oscillator operated with 0·10 per cent to 0·15 per cent of second harmonic and about the same amount of third; other harmonics were too small to measure easily except for the fourth, fifth and tenth, each of which was well below 0·1 per cent. With the heaters earthed, the hum in the output was less than 0·1 per cent of the fundamental. With the loop gain increased, and the bias controls re-adjusted, an output of 150V was obtained for a total distortion of about 1 per cent, mainly second and third harmonics.

To verify that distortion was not introduced by operation at the low frequencies, the waveform at a frequency of about 0·014c/s was recorded on a Honeywell-Brown self-balancing potentiometer. This gives a linear trace with a sweep of 11in and runs at a maximum chart speed of 2in/min. The records obtained were analysed in the usual way, taking the amplitude at five points in the cycle. The accuracy is, of course, limited when the harmonic content is small, but for a number traces, the second harmonic was estimated to be not more than about 0·7 per cent, the third was very small, and the fourth not more than about 0·25 per cent.

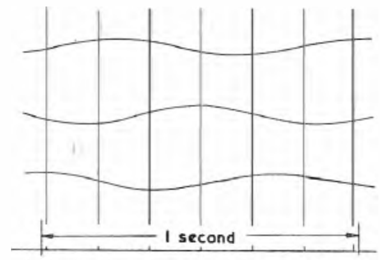

Fig. 11. Three-channel recording of output

Frequency Stability

As a check on stability, the oscillator was run continuously for nearly five hours on an unstabilized power supply, the waveform being recorded. The record obtained was measured at five places in all, and the frequency calculated. It was concluded that the frequency had not varied by more than about 1 part in 300. Tests made on different days showed that the frequency is unlikely to vary by as much as 1 per cent over short periods. The effect of variations in h.t. supply was also investigated, and it was found that 10 per cent change (i.e., 50V) caused about 1½ per cent change in both frequency and amplitude. The h.t. supply should be well filtered, but need not be highly stabilized owing to the balanced nature of the three-phase circuit, there being theoretically no signal frequency current in the supply.

Test of Modified Circuit

To test the performance predicted for the modified circuits, the circuit of Fig. 8 was set up, using the same valves. The oscillation was recorded and the frequency found to be about 0·003c/s, with $CR = 0{\cdot}4$sec, corresponding to a value of M of about 77, which agrees with the value in Table 1.

Acknowledgments

The loan of a four-channel high-speed Teledeltos recorder, used to obtain Fig. 11, from Messrs. Kelvin Hughes Ltd, is gratefully acknowledged, as is the gift of 'Metrosils' by the Metropolitan-Vickers Electrical Co., Ltd.

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An Improved Circuit for Reliable Operation of Nomotron Counter Tubes

By T. M. Jackson*

The nature of changes in characteristics which have hitherto restricted the circuit application of cold-cathode multi-electrode counter tubes is described. Details of new operating conditions are given which extend the range of application and greatly enhance tube reliability and performance.

IT is known that cold-cathode multi-electrode tubes operating on the glow transfer principle are subject to changes in characteristics in start-stop operation. Satisfactory conditions exist for continuous operation down to speeds of a few cycles per second but further reduction in operating frequency produces adverse conditions which become more pronounced when the glow is required to remain for long periods on individual cathodes. The fault observed is that the tube either fails to start on the first pulse of the next applied pulse train or, in extreme cases, will not restart at all. The effect is attributed to cataphoresis and its incidence and cure in the Nomotron tube (G10/241E) have been carefully studied with results described below.

Description of Tube and Glow Transfer Mechanism

Detailed information on the design and operation of the Nomotron has previously been published[1] but, for completeness, a brief description of the tube and the mechanism of glow transfer will be given. The Nomotron is a ten point counter or distributor tube having one set only of commoned transfer electrodes and providing ten output cathodes operating at a nominal current of 3·6mA into a 15kΩ load. The tube is undirectional, the cathode directivity being obtained by cathode geometry and the transfer directivity by means of residual bias level on controlled cathode time-constant circuits. The tube operates on a rectangular input pulse and is capable of operating at input recurrence frequencies up to 20kc/s. The diagram of Fig. 1 shows the cathode and transfer cathode arrangement. Assuming a glow discharge to be established on K_2, the glow will be located on the plate portion in distinct preference to the edge, or so-called tail portion. The common transfer electrodes are biased positively with respect to cathode and are held off. In this condition the forward transfer electrode to the conducting cathode is primed to a much greater extent than any other transfer electrode due to its close proximity to the cathode glow. Lowering of transfer potential by application of a negative pulse transfers the glow from K_2 to T_2 and provided the transfer voltage is sufficiently reduced, the cathode glow will be extinguished and the cathode output signal will decay according to the time-constant of the cathode circuit. When this time-constant is large compared with the applied pulse width, a positive bias voltage will remain on K_2 at the end of the pulse, when the anode voltage becomes sufficient to cause breakdown of an adjacent gap. The choice is between K_2 and K_3 but the residual bias on K_2 makes K_3 preferential, glow is established on the tail portion of K_3 and rapidly spreads on to the plate section when the glow on the tail is extinguished.

Identification of Abnormal Behaviour

Having described the normal glow transfer mechanism, the effect of a non-uniform transfer surface will now be considered. Supposing the surface state of a transfer electrode to be modified to the extent that an area of low work function exists at the tip, such as marked on T_3 in Fig. 1. A glow discharge at this electrode would show a preference for the low work function region and though it may, at high current, spread to cover the entire surface, it would recede to the shaded area when the current was again reduced. Considering the case where glow transfer

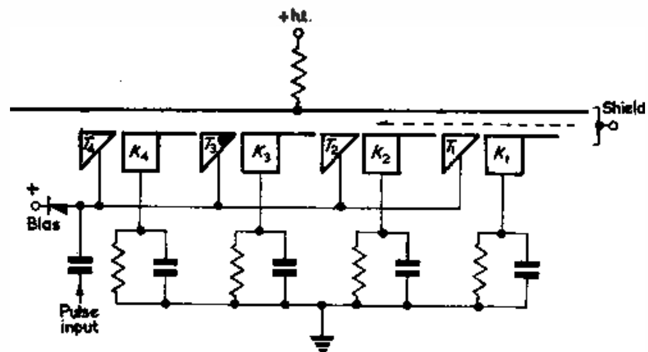

Fig. 1. Diagrammatic representation of electrode structure and basic circuit connexions

is to be effected from K_3 to K_4, the process would be identical to that described above, until the termination of the stepping pulse when, as before, a choice would have to be made, in this case, between K_3 and K_4. The ionization coupled breakdown of any gap is a function of the spacing and the effective change in spacing brought about by the localized glow position can be sufficient to overcome the differential produced by the residual bias on K_3. Consequently, K_3 may refire, constituting a failure to step.

This behaviour has been observed in tubes after long resting periods on individual cathodes and is attributed to cataphoresis—a phenomenon in gas discharges, by which impurities are carried towards the cathode and concentrated in this region, the accumulation of impurities being a function of current and time. The design of the Nomotron is based on a relatively high cathode current density and, consequently, close inter-electrode spacing is necessary to obtain the degree of ionization coupling required for fast operation. Under nominal operating conditions the cathode is in the abnormal glow region and the outer edge of the negative glow envelopes the extreme tip of the adjacent transfer electrode—the actual portion in which surface changes have been observed. The nature of the effect, being a surface change, caused some difficulty in studying the condition because very short periods of conduction restored the homogeneous surface and the effect disappeared. Testing was therefore carried out on a single pulse basis, applied after a period of continuous cathode conduction and, in this way, the effect of various processing and ageing techniques was investigated, with the aim of removing

* *Standard Telecommunication Laboratories Ltd.*

contaminants and depositing the remainder on parts of the tube remote from the glow areas. Substantial improvement in stability of characteristics was obtained by these methods but a low incidence of the effect was still present.

Stabilization of Transfer Characteristics

Conduction tests carried out with various transfer bias settings indicated two settings which appeared to produce stable transfer characteristics. These are shown in Fig. 2, on a typical transfer *I-V* characteristic adjacent to a conducting cathode.

Point A, corresponding to zero transfer electrode current, at a bias setting of approximately 180V positive and point B, where the transfer conducts appreciable positive ion current. The former was unattractive due to the high pulse voltage required, operation at point B, however, was examined further and was later shown by large scale tests to be a satisfactory solution. By this means, the part of

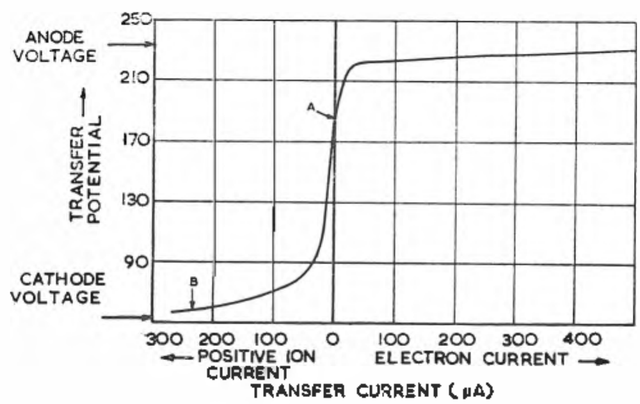

Fig. 2. Transfer electrode current voltage characteristic adjacent to a conducting cathode

the transfer electrode liable to contamination due to the relatively high current density of the adjacent cathode discharge, is continuously cleaned by the transfer conduction current. This is in itself of such low current density that the effect on the forward part of the transfer electrode is negligible. The requirement therefore was to maintain sufficient transfer current to stabilize the transfer characteristic but insufficient to reduce the breakdown of the next forward cathode. Automatic biasing by a high resistance leak to earth is preferred to direct biasing, because of the current sensitivity at this point of the characteristic. The value of the transfer leak resistance is important and is selected to give the maximum permissible leak current below the minimum self-maintaining current of an independent discharge. The I_a-V_a characteristic of an independent transfer discharge shows a negative slope below about 350μA and is self extinguishing at a slightly lower current value, whereas, adjacent to a conducting cathode discharge current is maintained to very low values. A leak resistance value of 220kΩ passes a clean-up current of approximately 250μA and due to the factors described above, it follows that conduction only takes place on the transfer electrode in front of a conducting cathode.

Modified Circuit and Testing Conditions

A complete circuit is shown in Fig. 3.

In the static condition the Q6/4 selenium rectifier isolates the input circuit from the transfer electrode, the automatic bias level being approximately 50V. The negative pulse is applied to the input capacitor and is restored to a bias level of +75V. During the pulse the Q6/4 diode conducts and glow stepping is effected in the normal manner. The anode resistor is replaced by a network as shown and assists in two functions, the cathode current is adjusted to compensate for transfer conduction and during the pulse, the by-pass capacitor provides a lower impedance to pulse current. The input impedance of the valve in the circuit is approximately 16kΩ and in order to maintain the correct operating conditions it is necessary to match the driving valve to the Nomotron, so that the 120V pulse appears at the input capacitor with the valve operating.

With the circuit as described above, test circuits were set up, using tubes in scales of three. The first tube of a scale was supplied with input pulses arriving in bursts of nine pulses, occurring at approximately one per second, each pulse spacing during a burst being 200μsec. The pulses

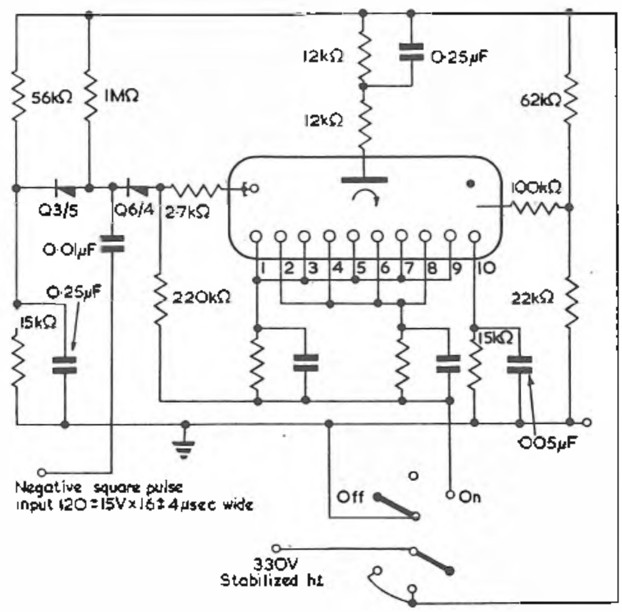

Fig. 3. Circuit diagram for operation up to 5kc/s input recurrence

were gated by one output on to the second tube of the scale, the glow stepping on single pulses at approximately one step per second. By gating again from the second tube, the third tube received one stepping pulse every 10sec. Twelve such scales of three were operated in parallel. The pulse system was controlled by a mechanical switch and was set so that pulses were applied for about two minutes at fifteen minute intervals. A detector system was arranged so that any mis-step was immediately detected and the pulses disconnected, the tube involved was then identified by visual examination of the glow positions. Other tests were carried out using functional equipments, several operating in tandem and involving over 100 tubes. A similar start-stop duty cycle of approximately 5:1 was maintained in this case but with somewhat different sequence, tubes remained with stationary glow for periods of several hours followed by a glow stepping period. All tubes were examined before and after running tests by means of an automatic routine tester which varied all parameters individually while the tube was operating on a start-stop basis, 18 test conditions appear for each cathode position, i.e. 180 tests carried out in a period of about one minute.

Tests were also carried out involving long periods of continuous cathode conduction which represents the worst operating conditions, corresponding to zero duty cycle. In this case a number of sockets were provided with connexion made to one cathode only, together with the appropriate transfer input circuit. The tubes were removed periodically and tested by measuring the minimum pulse amplitude required to step the glow from the cathode under test. This was done on a single pulse basis, care being taken to apply the minimum number of pulses to avoid further changes in transfer characteristics. Fig. 4, curve C, shows a typical result obtained with improved processing and modified input circuit. Curve A shows the behaviour of an unprocessed tube under the original circuit conditions and B indicates the degree of improvement obtained by processing only. The points at which the pulse amplitude required for transfer becomes greater than the specified limits are marked and represent the useful life of the tube under these conditions. The exact mechanism of the subsequent restoration of transfer sensitivity illustrated in A and B is not perfectly understood though it is clearly associated with the quantity of current conducted in the transfer electrode, i.e. at some stage during the deterioration of the transfer sensitivity the current value becomes sufficient to clean up the transfer tip, and so tends to restore the normal characteristic. The stage at which the actual reversal takes place and the transfer sensitivity begins to improve was found to vary between tubes which suggests control by an ageing process at the cathode.

Incidence of Failure

Good performance has been obtained at all times under continuously operating conditions at frequencies above a few cycles per second. Under start-stop conditions, changes in characteristics have been observed in some cases after periods as short as five minutes of glow resting on one cathode. Under the new conditions, tubes survive periods of 1 000 hours continuous conduction on one cathode without change in characteristics. Operational tests on several batches under the stop-start conditions described above have indicated an overall performance of between 12 000 and 30 000 tube hours per tube failure. Tests which have been extended to 4 000 hours under these conditions show no deterioration in reliability and performance with time.

Switching On

In order to eliminate the occasional breakdown of two cathodes when switching on, which prevents glow stepping, it is recommended that switching on be accomplished in two stages, by arranging initially to disconnect the common transfer leak resistance and all cathodes except that required for initial discharge. This may be achieved by the use of a double pole, three-way switch, with make before break contacts.

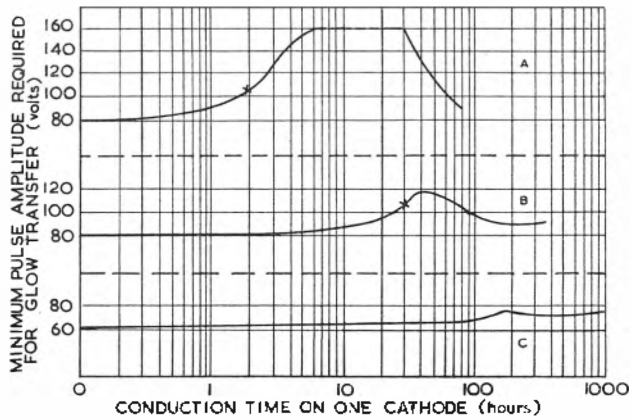

Fig. 4. Results of tests after long periods of continuous cathode conduction

Conclusions

As a result of the investigation briefly described above, large scale testing has been carried out on production valves. The tests have covered operating conditions likely to be encountered in all types of application, including long periods of conduction on individual cathodes. It is concluded that the Nomotron tube compares well, both in reliability and life, under all conditions of operation, with other electronic devices.

Acknowledgments

The author wishes to acknowledge the contribution of his colleagues at Standard Telecommunication Laboratories, and the work done by the several other parties involved in this work. In particular, Mr. G. F. Klepp of the Valve Division of Standard Telephones & Cables, and Mr. T. D. Sherlock of Standard Telephones & Cables, Newport, who has been responsible for the long term equipment reliability tests. The author is indebted to Mr. A. H. Beck, under whose guidance this work has been carried out and, also, to the management of Standard Telecommunication Laboratories and Standard Telephones & Cables for permission to publish this article.

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A Variable Slow-speed Uniselector Drive

By R. Selby*

A circuit is described which employs a small thyratron to drive a uniselector without the use of relays or auxiliary power supplies. Wide variation in stepping speed is easily obtainable, and for some purposes the shield of the thyratron may be utilized in a gating circuit for over-all control.

In some circumstances, uniselectors provide a convenient method of testing or monitoring a considerable number of circuits or channels automatically in a regular predetermined order. A system has been described in which a uniselector is used in the high-speed production testing of radio equipment, and the writer has for some years used uniselectors for monitoring a number of audio-frequency channels in connexion with wired radio services. They are clearly of greatest utility where a considerable number of channels or circuits are required to be subjected to a uniform or limited number of types of test, and where the necessary points of access are few.

A self-driving uniselector runs at a speed of the order of fifty steps per second, which is usually too fast for the purposes under consideration. The circuit to be described permits the uniselector to dwell on each or any contact for periods of up to two or three minutes, and possesses the further advantage that this period may be of different

* *Metropolitan Relays Ltd.*

duration for each contact position, if desired. In addition, it can readily be arranged for the stepping of the uniselector to be contingent on some other factor, such as the result of the test.

The availability of the small gas-filled thyratron type EN32 having a maximum peak rating of 2A permits a very simple circuit to be devised, which requires no auxiliary relays. Considering the basic circuit shown in Fig. 1, the start of the cycle of operation may be taken at the point where C holds no charge. The grid will therefore be at zero potential with respect to cathode, and the thyratron will fire, energizing the uniselector driving magnet DM. A potential of 50V is developed across DM and charges the capacitor through the diode MR, biasing the grid negatively. Towards the completion of the armature stroke, the interrupter contacts dm open, thereby removing the anode supply, so that the necessary conditions are established for non-conduction. The uniselector has now stepped one position only and cannot re-operate until C has discharged through R to a point where the critical grid voltage has been reached, allowing the thyratron to fire again. The rate of stepping may clearly be adjusted by varying the value of R. By utilizing an additional contact bank to switch in different values, the timing may be set to as many different periods as required. By adjustment of the shield to cathode potential, it is possible to arrange for an independent control of firing. It is unnecessary for the power supply to have particularly good regulation, and all that is required is that it shall be capable of supplying approximately 60V (uniselector operating voltage plus arc drop in the valve) at the necessary operating current of 0·67A for periods of about 20msec per step.

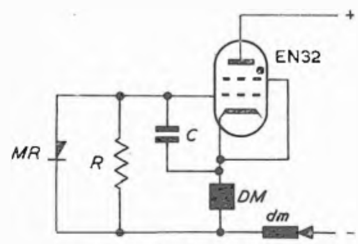


Fig. 1. The basic circuit

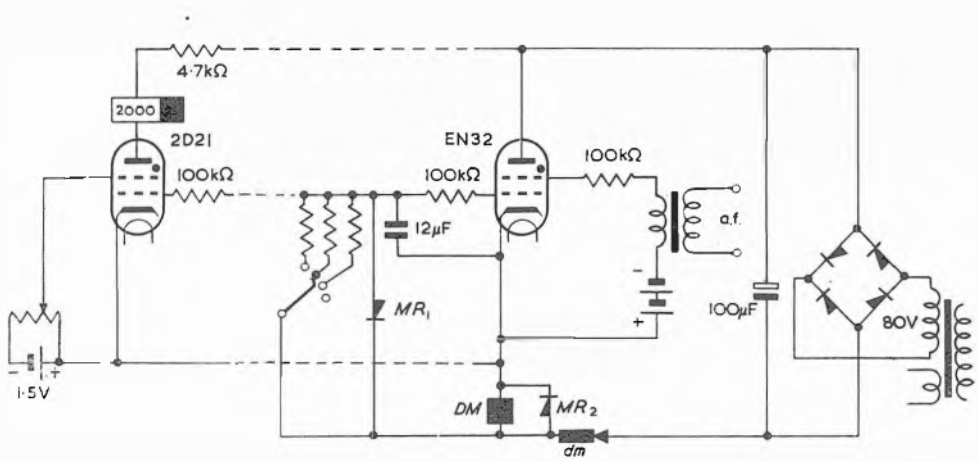


Fig. 2. A practical circuit

A practical circuit is shown in Fig. 2. The usual method of spark quenching by shunting the interrupter contacts with a 1μF capacitor in series with a low value resistor cannot be used, since the anode voltage would not be definitely removed and conduction would tend to be continuous. A similar CR combination connected directly across the driving magnet would be effective in quenching the spark and in suppressing an excessive peak inverse voltage on the thyratron, but unless R is made considerably higher than normal, an excessive peak anode current will be passed when the thyratron fires. The method adopted is therefore to shunt the driving magnet by the metal rectifier MR_2 (STC type RM3). The slugging effect is not material in this application.

The maximum average current rating for the EN32 is 300mA averaged over any period of 15sec. Assuming the average current required by a 50V uniselector to be about 0·6A, the maximum number of steps permissible in any period of 15sec is therefore about 375, or allowing a factor of safety, say 250. This point must be considered in design, particularly if it is required to self-drive through a number of unused contact positions at frequent intervals, but for the purposes under consideration will not usually present an obstacle.

The resistors connected directly to the grid and the shield fulfil the normal requirements to limit the negative voltage during conduction.

A negative bias of about 6V may be applied to the shield if it is desired to prevent conduction entirely, and may be conveniently obtained from a half wave rectifier fed from the heater supply. In the particular application illustrated, an audio frequency signal is applied in series with this standing bias, so that the thyratron will fire only if a signal is present, when the positive peaks oppose the bias.

The rectifier MR_1 must obviously have a very high reverse resistance, and consists of two S.T.C. miniature units type M3 in series. The new silicon diodes now becoming available would appear to offer an improved choice. It should be noted that firing occurs on a very flat portion of the capacitor discharge curve and timing is therefore likely to vary with changes in valve characteristics. More consistent operation may be secured by returning the leak resistor R to a point of positive potential, but the timing period will clearly be reduced.

Some circumstances may call for supervisory action to be initiated should the uniselector fail to step on after the appropriate period, e.g. an alarm to be given in the event of absence of signal in the circuit shown. This may easily be arranged by the addition of a second thyratron (2D21) in parallel with the EN32, but having an alarm relay in its anode circuit. By adjustment of bias on the shield of the 2D21 (and/or reduction in its anode supply voltage) its critical grid voltage may be made to be slightly nearer zero than that of the EN32. Thus if the EN32 does not fire, then the 2D21 will do so after a slightly longer delay period. The arrangement is shown to the left of Fig. 2 with the connexions in broken lines. Sufficient experience has however not yet been obtained to indicate whether the variations with life in the parameters of the two thyratrons will make frequent re-adjustment necessary.

The Allen Organ

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

In contrast to all other American manufacturers, the Allen company builds instruments to special order, and to any specification. Advantage is taken of the inevitable increase in cost resulting from this policy to fit components of unusual reliability and there is a closer tonal correspondence between Allen organs and pipe organs than in any other instrument.

A four manual Allen organ

BECAUSE these products are designed to give a comparable performance and to embody the same manipulative devices as modern pipe organs, it does not mean that they are devoid of technical interest. One may at once ask, does not the cost of such an instrument correspond closely to that of a pipe organ, and if so, why not have a pipe organ? In fact, the prices are very similar, although there is some advantage in the larger sizes. It is an interesting fact that whereas in a pipe organ a rank of heavy pressure reeds may cost many times as much as a rank of low pressure flue pipes, electronically the difference in cost may be reckoned in shillings. The real value of the instrument will depend to some extent on its tonal content. But there remain the potent attributes of constancy of tune—many times better than any wind instrument over long periods; ease of servicing, with a clean and accessible mechanism; full tropicalization of components; and the ability to regulate the tonal texture or volume level on site.

The American manufacturer starts with advantages over us. Valves are inexpensive and of similar characteristics as between one maker and another. Press tool equipment and woodworking machinery have been brought to a high degree of perfection. Special loudspeakers are available, and there is no purchase tax to consider. Above all, there are more people able to spend money on this type of merchandise.

The Allen company began to make electronic organs in 1940. They have therefore had plenty of time to consider the pros and cons of electro-mechanical generators compared with valve systems. A mechanical method has great advantages where it is necessary to borrow or derive frequency sources from one part of the system to combine with other derivatives. Constancy of tune is assured by a fixed mechanical coupling. For a large instrument, however, the advantages of many independent tone sources each having its full complement of relevant harmonics are undeniable, provided always that they can be kept in tune. It is only by having a multiplicity of free phase oscillators that a true chorus effect can be obtained. The Allen company chose valve oscillators of the Hartley type. Much has been written on the dependence of frequency stability on waveform; in a forthcoming article the Hartley oscillator will be treated in detail as a music generator. Suffice it to say that as interpreted by the Allen company, this circuit has an hour-to-hour stability of about one part in ten thousand, and a stability over six to nine months better than one part in a thousand.

Fig. 1 is the oscillator circuit used throughout the instrument.

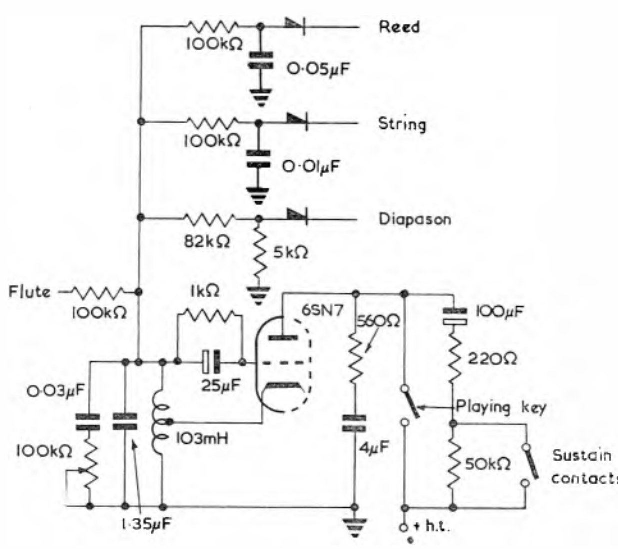


Fig. 1. Typical oscillator

ment. Air-cored inductors are employed and thus not only is a high degree of frequency stability ensured but there is no tendency for this to vary during the discharge of the 4μF capacitor C_1. Since there is no adjustable air-gap, tuning is carried out by the shunt network shown. Each coil is wound to approximately the required inductance and a variation of about one semitone is possible. All instruments are tuned to A = 440·0c/s. It can be seen that keying is in the h.t. line. By this means, quite long leads can be used, several installations reaching about 100ft. The tuning inductor is heavily loaded by capacitance and this, in conjunction with the reservoir capacitor C_1 ensures a comparatively slow attack. As C_1 discharges into the anode circuit on releasing a playing key, the decay is also acceptably slow. Thus the sound has a starting and stopping characteristic closely resembling that of flue pipes. The actual time-constants vary over the compass. The stability of the oscillator is well illustrated by the fact that over the whole of the discharge range of the capacitor C_1 there is no perceptible change in frequency.

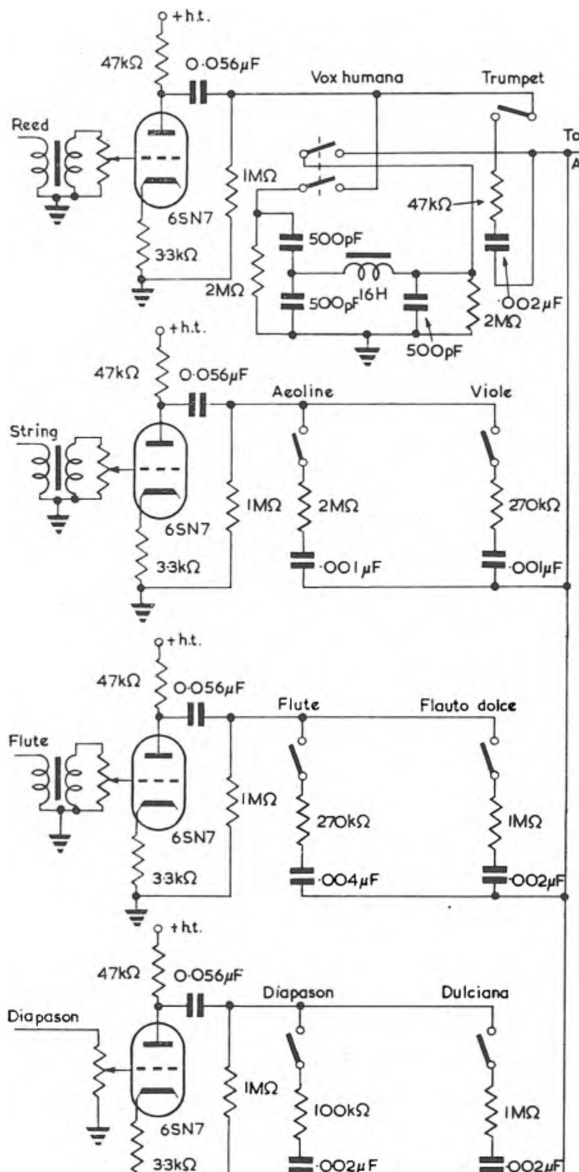


Fig. 2. Part of tone-forming circuit

By an extension of the discharging network, using a much larger electrolytic capacitor inserted by auxiliary contacts, the decay time may be much extended and a rather chime or bell-like effect is produced.

The oscillator delivers a sine wave which is used for flute-like sounds. From this, other waveforms are obtained by the metal rectifier shaping circuits shown in the diagram. The harmonics from these are used to energize tone filters in subsequent circuits. So as to reduce cross modulation to a minimum, each group of rectifiers is connected to an isolating valve by a transformer. These valves are also pre-amplifiers, so that no very high gain is required of the main amplifiers and the possibility of spurious pick-up on long lines is reduced. Following the valves are tone-forming circuits of conventional type, shown in Fig. 2. It is thus possible to mix these tone qualities with a considerable amount of realism, although it must be admitted

Fig. 3. (right). Tone generator rack

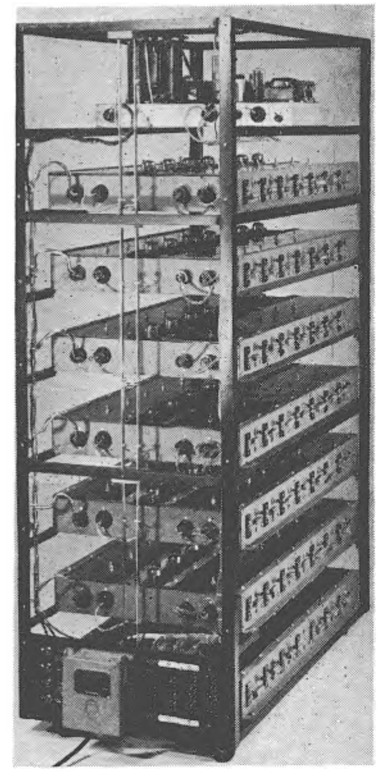
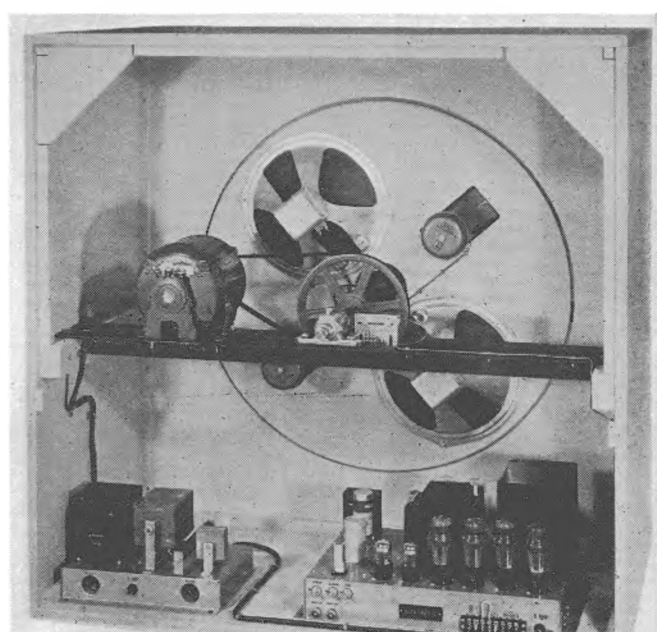


Fig. 4. (below). Rear view of a rotating loudspeaker unit



that the derivation of all voices at, say, 8ft pitch from one rank of oscillators causes considerable masking of quieter sounds by the louder ones. But after all, this happens with pipes as well, so that although the maximum possible chorus effect is not obtained, results are far better than when filters of the normal type are all combined from a single input waveform. No frequency division is used in this organ, as with this method the chorus effect is lost completely. Consequently we find (for each manual) one rank of oscillators for all 8ft tones, one for 4ft and one for 16ft. This can be extended as in the large instrument of which the console is shown. The apparatus for one single generator rank is shown in Fig. 3 and this is a convenient way of building up an instrument; each rack is complete with tone-forming circuits and the relays by which these are controlled from the stops. There is then one such rack for each pitch range.

Since there is no tone apparatus inside the console, this can have full-size keys, stops and pedalboard and there is ample space for high-grade components. The author has played one of the three manual organs and found the console arrangements admirable.

The Allen company has experimented with more methods of sound distribution than any other concern, and has evolved some ingenious loudspeaking systems. The current arrangement is to use multiple units for each manual and fixed grouping of 27in units for the pedal department. The sound dispersing cabinets for the manual loudspeakers are shown in Fig. 4 and each cabinet is equipped with a separate amplifier, following usual American practice. The object of the rotating units is to produce some degree of dispersion of the sound as would be the case with a pipe organ. Unconventional though this arrangement may be, there is no doubt of its effectiveness for this purpose. 12in or 15in units are combined with high frequency horn units on the rotating baffle, which is driven by a d.c. motor. The motor fields and armatures are supplied from separate rectifiers to ensure steady speed, and that of the armature is controllable. By increasing this sufficiently, a vibrato effect is produced by Doppler action.

Space will not permit giving the full specification for the four manual organ illustrated on page 328, but the completeness of the tonal scheme is illustrated by the Great department—

Double Diapason	16ft
Gedackt	16
Diapason	8
Principal	8
Flute	8
Flauto Dolce	8
Gamba	8
Gemshorn	8
Octave	4
Flute d'amour	4
Nazard	$2\frac{2}{3}$
Super Octave	2
Fifteenth	2
Mixture	III rks
Mixture	II rks
Trumpet	8
Clarion	4

Other departments are equally complete and there are 34 couplers.

Acknowledgments

Acknowledgment is made to the President of the Allen organ company for permission to publish some of the technical data in this article.

A New Semiconductor Factory

Mullard Ltd. have recently completed the first stage of a long-term project for the establishment of a completely independent manufacturing centre for semiconductors.

It is believed that this plant is the only one in the country which is being built specifically for this purpose, and that when complete will be the greatest single mass-production unit for semiconductors. It is to operate as a self-contained centre containing research, development and application laboratories, and, in addition, has its own tool room, drawing office, library, etc. Basic research will continue to be undertaken at the central Mullard research laboratories.

So far, only about one-third of this new plant has been completed. The section now completed will be in production while building is proceeding.

Employment will eventually be given to something like between 1 500 and 2 000 people. The present staff is about 400, which includes 60 graduates, of whom 6 are women.

The factory site is at Millbrook Trading Estate on the outskirts of Southampton and is conveniently situated from both staff and transport considerations.

The production programme is based on an estimated output of several million semiconductor devices of all kinds for 1958, of which a considerable proportion will be transistors.

The following paragraphs give a short résumé of the chief processes in the manufacture of germanium transistors which will form a large portion of the work to be undertaken at this new factory.

The germanium is purified by a process known as zone-refining, using heat induced in it by an r.f. generator. An ingot of germanium is loaded into a graphite 'boat', which travels through a silica tube. A series of r.f. inductor coils gird the tube at intervals along its length, and as the graphite boat passes along the tube each coil produces a molten zone in the germanium. Since the solubilities of any impurities present are greater in liquid than in solid germanium, the impurities collect in the molten zones, and as the ingot travels through the successive coils, are swept to the end of the ingot, where the final piece is discarded.

After purification, an ingot of the semiconductor material consists of many small crystals of differing sizes and orientation. Before it can be used for transistors, the ingot must be transformed into a single large crystal.

This is done by mounting the ingot in a silica boat, along with a short length of single crystal germanium which is used as a seed. The loaded boat is then placed in a furnace and the region of contact between seed and ingot melted. By moving the boat slowly through the furnace the molten region is extended along the ingot, the original seed crystal growing behind it, so that eventually the ingot consists entirely of a single crystal.

Transistor germanium must have a certain value of resistivity, depending on the particular type of transistor for which it is intended. Resistivity is governed by the amount of impurity contained in the ingot, and a calculated quantity is therefore added during this levelling process.

The next step is to machine the single-crystal ingot into wafers of suitable size and shape. First, the bar is cut into very thin slices by a fast-rotating cutting wheel. The slices produced in this way have a thickness of about 0·5mm, whereas the final thickness required is 0·15mm. Part of the surplus is removed by grinding, and part by etching at a later stage. Before the etching process takes place, the slices (now about 0·25mm thick) are cut into dice approximately 2mm by 2mm.

After etching to obtain the required final thickness, the dice of germanium are then ready to receive the pellets of indium which constitute the emitters and collectors. These are alloyed to either face of the germanium in a multi-stage furnace containing a controlled gaseous atmosphere.

The alloyed dice are mounted on glass bases, ready for the nickel connecting wires to be attached, and are then etched in a chemical solution to remove surface contamination, before being pre-tested and having their envelopes fitted.

The connecting wires are first tinned on an ingenious rotary machine developed by Mullard engineers, and then soldered to base, collector and emitter. A stream of hot gas is used for soldering, the operation being extremely critical and requiring the use of optical aids to ensure accuracy.

The transistors are now ready for their envelopes. These contain a special grease which protects the transistors from moisture, and the encapsulating process is done in a special controlled-humidity chamber. Finally, the finished transistors are subjected to a series of exhaustive tests to ensure their high quality and reliability.

THE INDUCTOSYN

and its Application to a Programmed Co-ordinate Table

(Part 2)

By L. H. R. Harrison*, B. A. Horlock*, A.M.Brit.I.R.E., Grad.I.E.E., and F. D. Hunt*

There are many machining applications where all that is required is a small precision work table used in conjunction with a vertical milling machine or jig borer. Small, hand operated co-ordinate tables are readily available for this purpose.

Such an application concerns the accurate positioning of gear centres in small gear box castings which are used for precision actuators in the aircraft and allied industries (Fig. 9(a)). Frequent short-run production quantities of these boxes are required so a method of setting up each co-ordinate automatically is desirable for many reasons. The size of these gear boxes enables them to be readily accommodated on a table measuring 8in by 10in, many advantages are gained by using a table of this size, not the least of which are that it may be mounted on a variety of machines, and that the power requirements to move the table are kept sensibly low.

The positioning data for any job must first be prepared in a suitable tabular form. In the case of a manually controlled machine this data will be transferred in groups, each group containing the data needed to define one position, to the manually set selector switches. In the case of the automatically programmed machine, however, the total data must first be transferred to the input medium, the individual groups of data then being read in to the programme control unit as and when required to set up the selector switches.

Thus in the case where both manual and automatic programme facilities are required, the sequence may be described diagrammatically as in Fig. 8(a). Simplification of this sequence, and reduction in the size of the digital-analogue convertor, may be gained by choosing selector switches which can be set either manually or automatically (Fig. 8(b)).

Choice of Input Medium

The use of punched cards as the input medium provides the following advantages over the possible alternatives of punched paper tape and magnetic tape:

(1) Punched card readers are widely available in various reliable forms. The card reader used for the programme co-ordinate table is actually built around the standard 'Hollerith' card transport and sensing mechanism.

(2) Desirable ancillary equipment such as card verifiers for checking the accuracy of the card punching, and card reproducers, for producing duplicates of cards which have deteriorated through excessive use, are readily available and are, in fact, often already available within many organizations.

(3) Simple visual checking of the accuracy of the punched data is possible when using cards.

Choice of Switching Components

Considering the requirements of the selector switches in the digital-analogue convertor as described in the first section, the basic requirements are for 4-pole 10 position switches in the case of switch X_3 and Y_3, and for 2-pole 10 position switches in the case of switches X_1, X_2, X_4, X_5, Y_1, Y_2, Y_4 and Y_5. Eight level, double-ended P.O. type 2 uniselectors form efficient and reliable elements as these switches, 2 or 4 of the levels, as necessary, being used for the transformer switching, 1 level being wired to the display unit to display the contents of the selector switch and 3 levels being used for control and checking functions.

Control of the automatic data input is carried out by two uniselectors, termed the sequencing unit and the pulsing

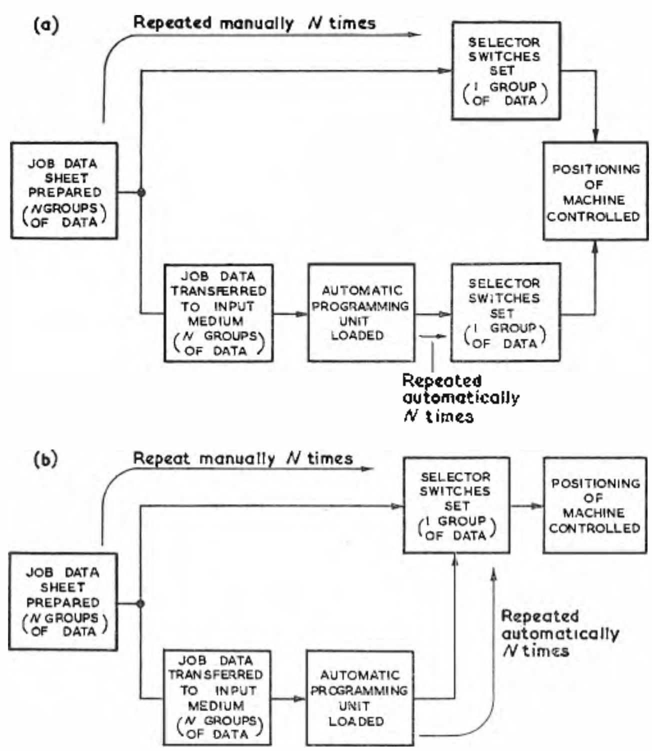


Fig. 8. Provision of manual and automatic programme facilities

unit. The sequencing unit, as its name implies, controls the overall sequence of operation needed to transfer the data from the punched cards located in the card feed hopper to the selector switches as and when required. The function of the pulsing unit is, on initiation, to repeat a cycle of operations consisting of the routing of trains of pulses to the sensing brushes of the card reader, and at the end of each cycle, to shift the card through the sensing station by one column.

Card Preparation

The first stage in the programming of a job is carried out in the drawing office where a drawing of the job is prepared having the hole position dimensions expressed in cartesian co-ordinates. The origin is selected so that the

* The Plessey Company Ltd.

co-ordinates of all the hole positions are positive and the positions are then numbered in an order such that the total distance between consecutive positions is minimized (Fig. 9(b)). A card preparation table is then prepared from this drawing showing the co-ordinates of the positions in their optimum order together with the remaining necessary data such as size and type of tool, drill speed and rate and depth of feed (Fig. 10). The positioning data is then punched on the card or cards from this table (Fig. 11). The cards, standard business accounting cards, are divided lengthwise into 80 columns, each of which provides 12 possible punching positions of which 10 cater for the decimal digits 0 to 9 and one is reserved for the indication of the last group of data in any one job. The size and accuracy of the co-ordinate table necessitates the use of 2 five digit numbers for the definition of any one position, one number defining the x co-ordinate and one the y co-ordinate. The positioning data for each hole thus occupies 10 columns of card, each card therefore being able to contain the data needed for a maximum of 8 positions. This is sufficient to cater for many jobs but for those cases where more than 8 positions are involved the data may be recorded on extra cards up to a maximum of 200.

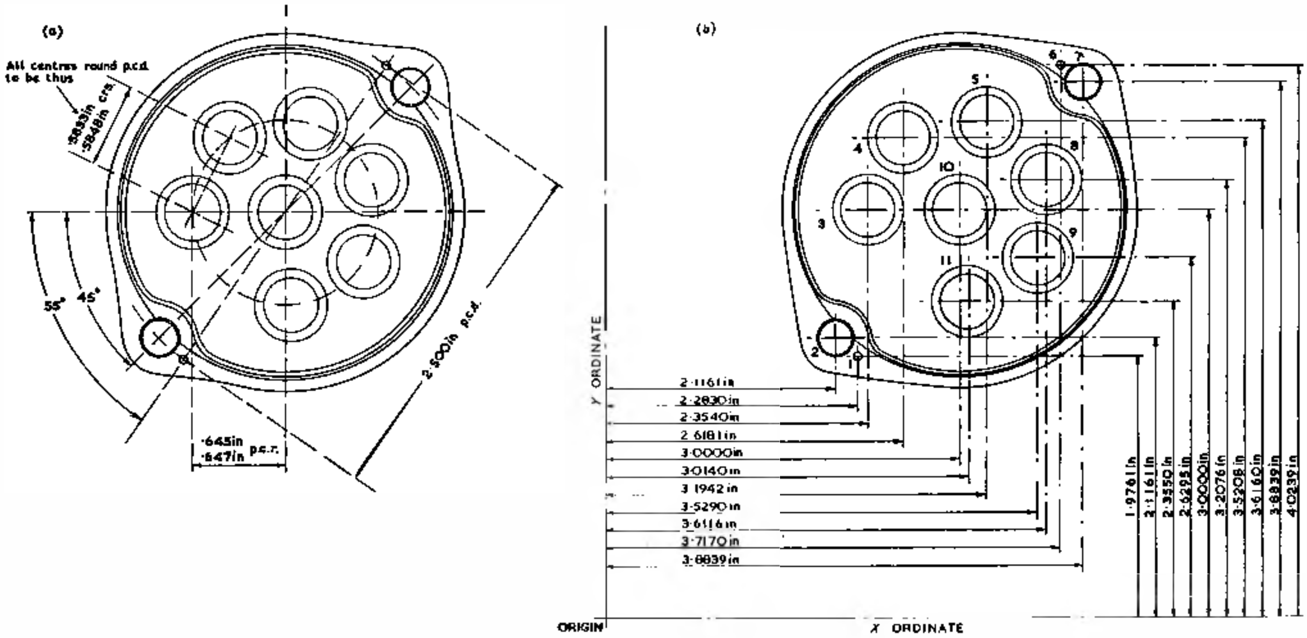


Fig. 9(a). Actuator gearbox (b). Actuator gearbox—co-ordinate presentation

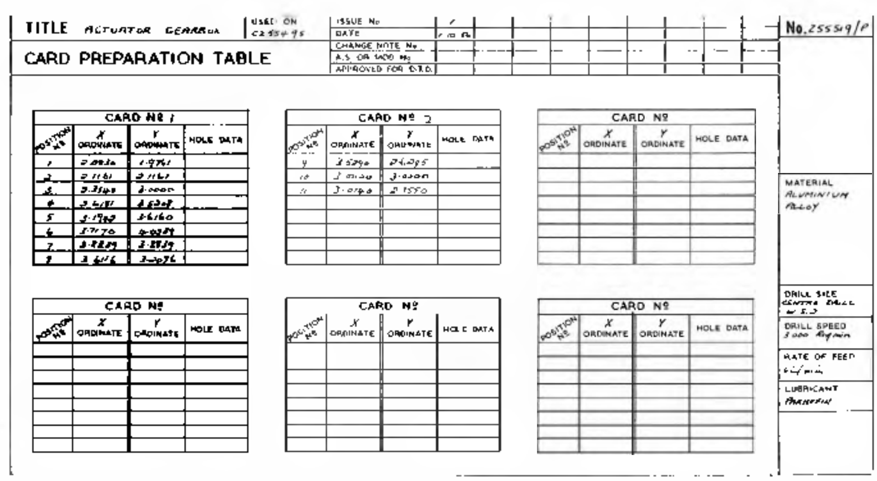


Fig. 10. Card preparation

The card, or cards, containing data needed for the complete job are loaded, in their correct order, in the card feed hopper. Operation of the 'Initiate Data Input' push-button first checks that all switches are in their dormant position and then, assuming that this check is satisfactory, causes the first card to be transferred from the feed hopper to the reading station where column 1 is sensed by the sensing brushes. The sequencing unit then checks mechanically that a card has been shifted to the reading zone and, assuming this check is satisfactory, arranges a circuit to route any pulses appearing on the common brush to step selector switch X_1. Initiation of the pulsing unit will thus result in X_1 being stepped $(N + 1)$ times by the end of the pulsing unit cycle, where N is the digit punched in column 1. At the end of this cycle the card is shifted to bring column 2 under the sensing station and the sequencing unit arranges a circuit to route any pulses appearing on the common brush to step selector switch X_2. Initiation of the pulsing unit is then repeated and the cycle of events is repeated a further 9 times until all of the selector switches

Automatic Data Input

The card reading utilizes a standard card transport and sensing mechanism. This enables individual cards to be shifted laterally through a reading station which consists of 12 sensing brushes arranged in line across the width of the card such that wherever a hole is punched in the particular column in the reading station the corresponding sensing brush will make contact with a common brush on the other side of the card.

X_1 to Y_5 have been set up according to the digits punched in columns 1 to 10 respectively.

The sequencing unit then checks that all of the selector switches have in fact been stepped to a valid position and, assuming this check is satisfactory, power is fed to the servo motors to allow the table to start moving to the position defined by the selector switches. When the table reaches this position, the output from a null-detector monitoring the error signal is used to disconnect power from the servo-motors, to initiate the machining operation and to initiate clearance of the selector switches to their dormant positions (Fig. 12). As soon as the clearance of the selector switches has been completed, the sequencing unit controls the repetition of the previous sequence of events to result in the setting up of the selector switches according to the digits punched in columns 11 to 20. When the machining operation is completed, the operation complete pulse is arranged to feed power to the servo-motors to allow the table to move to the next position now defined by the selector switches. These processes are repeated, with automatic card changing being carried out where necessary, until the 'job complete' punching is detected when the sequencing unit initiates the machining operation for the last position defined and then arranges for the card to be ejected into the receiving hopper.

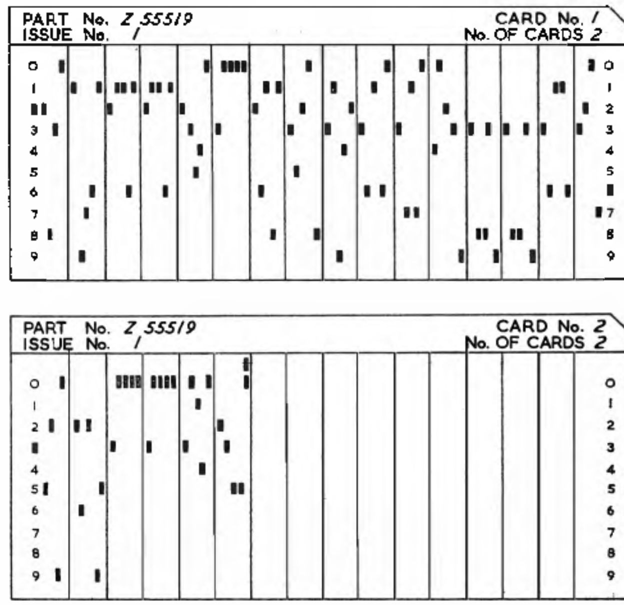
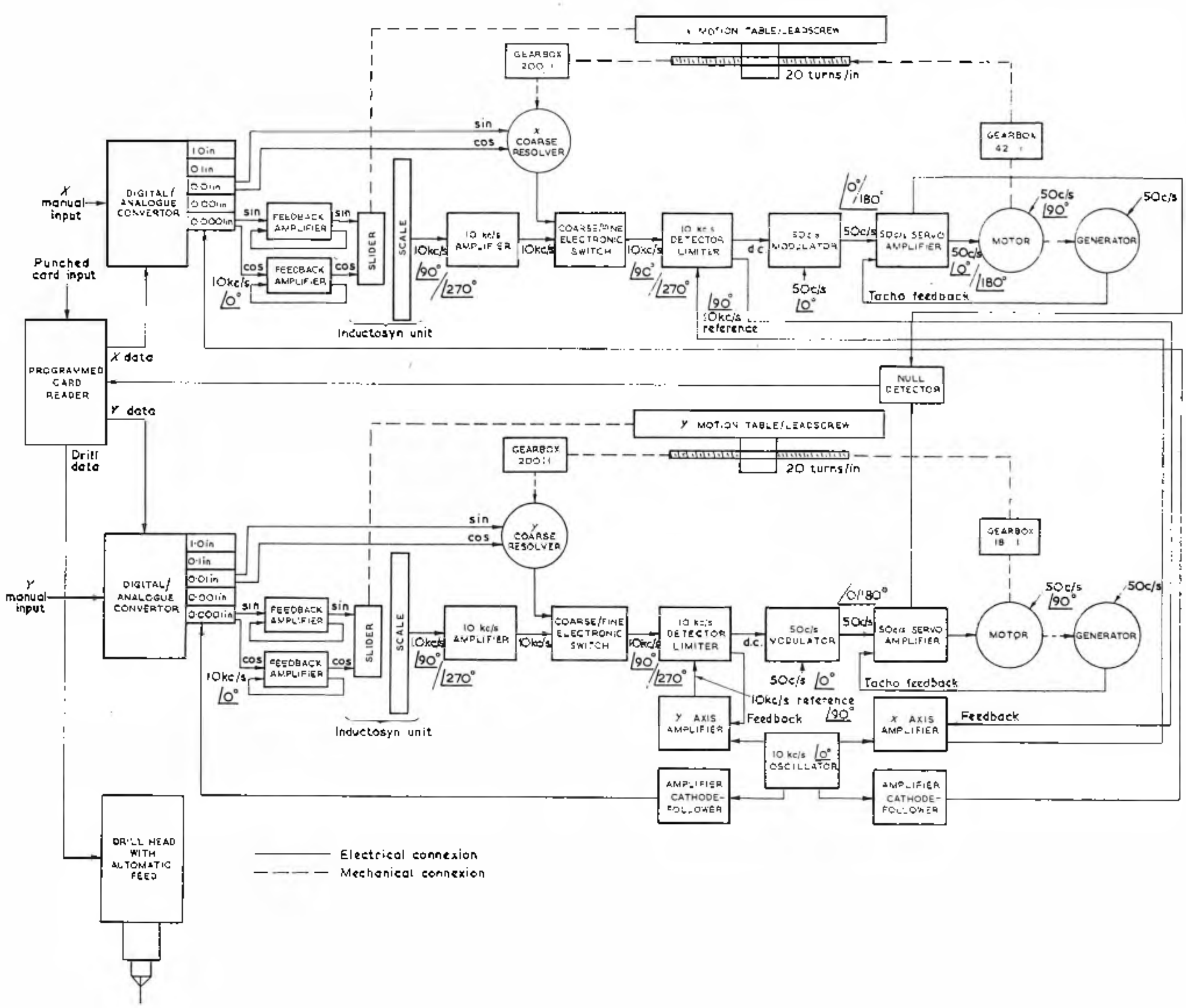


Fig. 11. Punched cards for positioning data

Fig. 12. Block diagram for programmed input co-ordinate table using the Inductosyn



MANUAL DATA INPUT

The selector switches are wired to a display unit on which the contents of the selector switches at any instant are displayed. Manual control of the machine utilizes this display unit together with ten digit push-buttons, each of which is associated with one of the selector switches. Depression of any of these digit push-buttons causes a relay oscillator to feed stepping pulses to the common control line of the selector switches, of which the one corresponding to the particular digit push-button depressed will actually step. Thus to set a selector switch manually, the appropriate digit push-button is simply depressed until the required digit appears on the display unit when it is released. The data, when using manual control of the machine, is conveniently taken from the card preparation table. The 10 digits defining the first position are set on the selector switches by means of the digit push-buttons as described above. Operation of the 'Initiate Data Input' push-button then supplies power to the servo-motors to allow the table to move to the position defined by the selector switches. When the table reaches this position, the output from the null-detector monitoring the error signal is used to disconnect power from the servo-motors, to initiate the machining operation and to light a 'tool' indicator lamp situated on the control panel. This indicator thus informs the operator that the Table has completed its movement to the required position and that the machining operation can commence or is in progress. The machining operation complete pulse is used to turn the 'tool' indicator off, thus informing the machine operator that the digits defining the second position can be set on the selector switches. These processes are repeated as necessary for the completion of the job.

OPERATION USING ALTERNATIVE DRILL UNITS

The operation of the machine, as described above, has assumed the tool unit has power feed which is automatically initiated when the table has completed its movement to the required positions. However, in the interests of flexibility in the use of the machine, the control has been arranged to cater for some variation in the tool unit as follows:—

(1) The tool unit may have power feed but be manually initiated when required. This is useful, for example, during testing of the machine and when tool and depth of feed changes are required during a job.

(2) The tool unit may have simple manual feed.

Fig. 13 shows the sequence of operations to be carried out by the machine operator for the possible combinations.

Construction and Layout

The complete equipment comprises a modified co-ordinate table connected via a multi-way cable to the programme control unit.

As already stated the worktable measures 8in by 10in, this is carried in a vee slide and is moved in this slide by a 20 turn/in lead screw. A similar vee slide assembly, but at right-angles to the top slide, carries this top slide, again motion is effected by a 20 turn/in lead-screw. The bottom slide is contained in the base which may be bolted

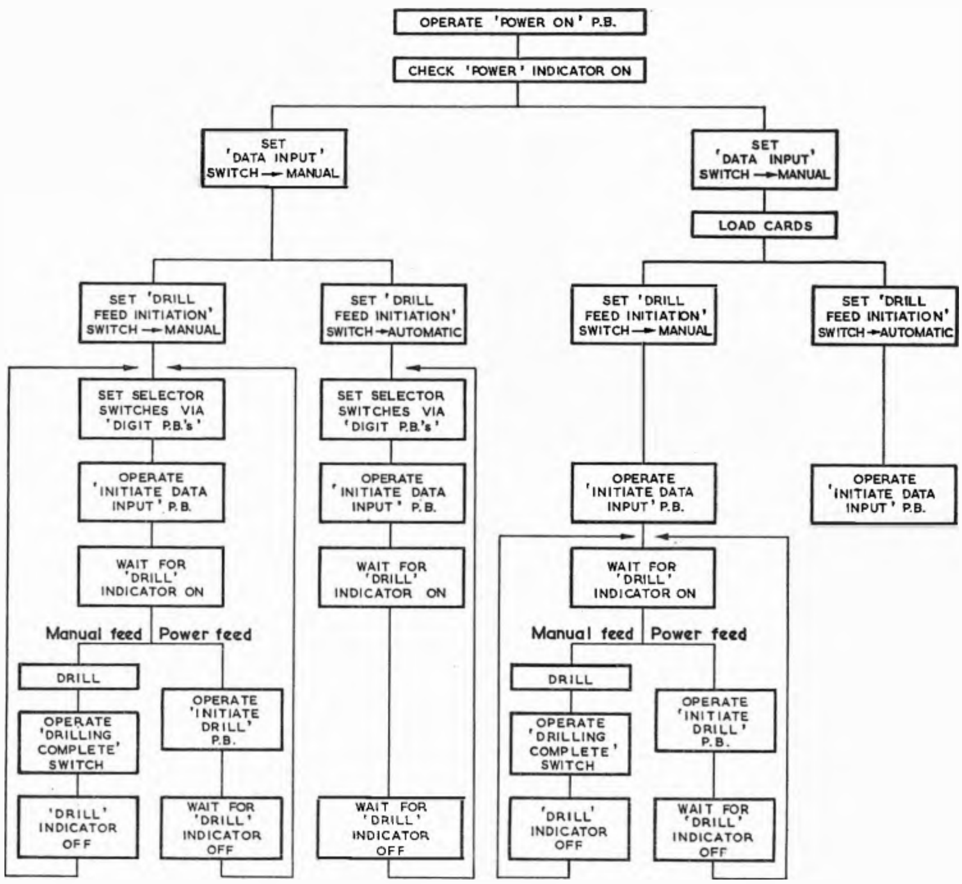


Fig. 13. Operating sequences

to any suitable machine tool table. Provision is made for mounting the following components on each axis of the table:—

(1) The Inductosyn element, mounted so that the slider moves parallel to the scale and the direction of motion.

(2) A coarse position resolver geared to the lead-screw by a 200 to 1 reduction gear. This ratio together with the 20 turn/in of the lead-screw enables 10in of linear motion to be represented by one complete revolution of the resolver. A resolver type 10502C in a size 15 frame is used.

(3) A servo-motor geared to the lead-screw by a reduction of 18 to 1 on the top slide. On the bottom slide this ratio is increased to 42 to 1 as this slide carries not only the weight of the workpiece but also that of the whole top slide assembly. Motor generators type FAF are used, the generator supplies the velocity feedback voltage.

All gearing from the motor to the lead-screw to the resolver is contained in one gear-box, for each axis. These gear-boxes are mounted at one end of both the top and botton slides so that direct coupling to the lead-screws may be obtained. The calibrated hand wheels at the other end of the lead-screws are retained. The servo-motors and resolvers are mounted on the gear-boxes direct while the Inductosyns are carried on arms cast integral with the gear-boxes.

Mounted on the top of the desk are the card transport and sensing mechanisms, and the control panel, while the complete control equipment is housed in the base.

Three sub-panels make up the control panel, one sub-panel has all the control switches and indicator lamps, the

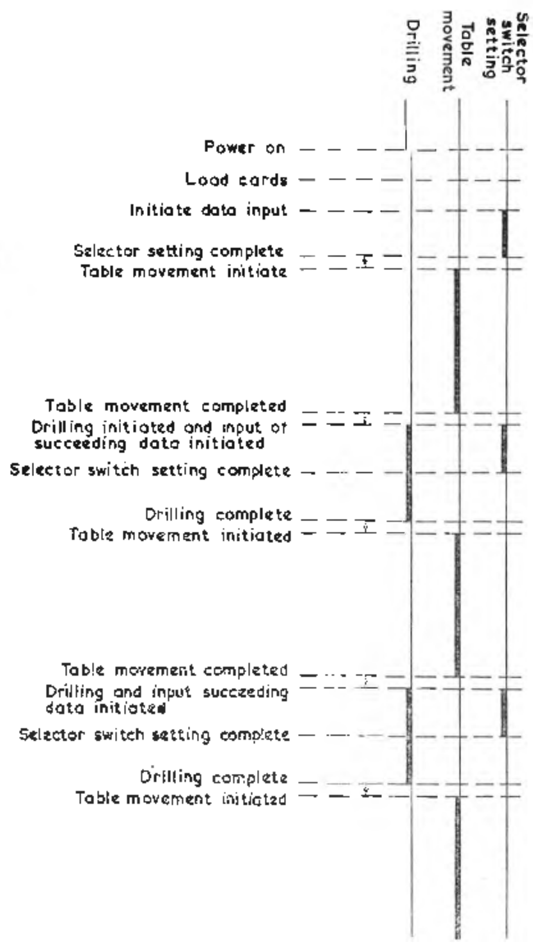


Fig. 14. Sequence chart for fully automatic control

other sub-panels are both identical, one for the x axis and one for the y axis, comprising five vertical columns of lamps indicating the ten digits 0 to 9, and one push-button for each row. Every defined co-ordinate is displayed on these sub-panels whether it be set automatically by the card reader or manually by the push-buttons.

A knee-hole is provided in the desk giving a right-hand, a left-hand and a rear centre compartment. By sub-dividing the control equipment each of these compartments is used for a particular section, in the right-hand side is contained the program unit which includes the uniselectors and digital-analogue transformers, the left-hand side contains the electronic section mounted in sub-unit rack form, the power supplies are contained in the rear centre compartment.

To assist in servicing and maintenance of the equipment the components in each of these compartments are readily accessible. A multi-range meter is built into the power supplies to enable spot checks to be made on all supply lines as well as to enable balance conditions to be set in the detector modulator circuits when setting up. Valve types have been kept to a minimum, CV455's (12AT7) forming the largest group, CV2136's (6BW6) are used for the power output valves of the servo amplifiers and the power unit utilizes a CV2523 (6AS7) as the series regulator and a CV449 (85A2) as the reference valve. All rectifiers used are selenium types.

The power supply requirements are as follows:—

Input: 100 to 250V at 50/60c/s single-phase.

Output: 315V d.c. at 120mA maximum for servo amplifiers.
250V d.c. at 120mA stabilized for all other valve circuits.
150V d.c. at 2A average for the card reader.
-20V d.c. bias line.
40V at 50c/s centre-tapped for modulators.
6·3V at 50c/s for heater supplies.

in all this represents a power consumption of only 500W approximately.

Summary of Performance

Co-ordinate Table

(1) x and y co-ordinates may be specified up to 9·9999in and 7·9999in respectively, and positioned to an accuracy of $\pm$0·0002in.

(2) Movement in the two axes is 7$\frac{1}{2}$in/min for the top slide and 3in/min for the bottom slide. As the total movements envisaged are small the time taken for the table to move from one specified co-ordinate to the next is not great.

(3) An area of approximately 24in by 18in is required to allow full operation of the table, thus it may be accommodated on a variety of machine tools.

Program Unit

(1) On automatic data input, the machine will program for jobs requiring any number of positions to be defined up to a total of 1 500 without any intermediate operator control.

(2) The alternative of manual data input is provided, the operating requirements having been simplified as far as possible to reduce operator fatigue.

(3) The reading-in and setting-up time of the program unit on automatic data input is of the order of 4sec for each position. For all positions except the first this is carried out coincidentally with the drilling operation so that for the majority of cases where drilling takes more than 4sec the effective reading-in and setting-up time tends to zero.

(4) Any length of time may be specified for the machining operation so that all cutting speeds and feeds may be accommodated.

Acknowledgments

The work described was carried out as part of a research programme on numerically controlled machine tools under the direction of Mr. H. J. Finden, M.I.E.E.

The authors wish to acknowledge the work carried out by the Farrand Optical Co. Inc., New York, U.S.A., in developing the Inductosyn and the help and advice on the application of the linear Inductosyn of that Company's President, Mr. C. L. Farrand.

Finally we wish to thank the Directors of the Plessey Company Limited, for permission to publish this article. This article has been based on a paper which will be read at the British Institute of Radio Engineers convention on 'Electronics in Automation'.

A Rapid Response Heart-Rate Meter

By D. G. Wyatt*

An instrument is described which is suitable for measuring the rate of incidence of equally spaced pulses. It is intended for use in physiological research, and covers the range 10p/min to 500p/min. The response time is short, and permits rapidly varying pulse rates to be recorded.

In a previous paper[1], a heart-rate meter was described which, at its fastest, took approximately 3sec to reach 99 per cent of a given change of rate. While this is sufficiently quick-acting for much physiological work, it is sometimes desirable to have a still shorter response time, especially at the higher rates. This article gives an account of a circuit which has been devised to achieve this.

The basic circuit (Fig. 1) consists of the components C_1, C_2, C_3, R, and the valve-voltmeter V_1. The capacitor C_1 is initially charged through the resistor R_1. When a pulse occurs, the relay contact A_1 closes for a time small compared with RC_2, thus allowing charge on C_1 to be transferred to C_2. A short time after relay A has closed, the relay B closes (also for a time small compared with RC_2) enabling the peak potential across C_2 to be measured by the electrometer valve-voltmeter. At equilibrium, the voltage measured by the electrometer is closely proportional to fRC_2 over a limited range (f is the rate in pulses per second). Also, the response time is approximately proportional to RC_2. Therefore rapid response at a given rate corresponds to a low value of fRC_2, and it happens that the response curve (electrometer voltage/rate) is non-linear in this region.

In the present instrument, a simple double-diode linearizing circuit has been used. It has thus been possible to design the ratemeter to operate with $\frac{1}{3} \leqslant fRC_2 \leqslant 1$, as compared with $0{\cdot}5 \leqslant fRC_2 \leqslant 5$ in the previous instrument. The disadvantage of this arrangement is the relatively narrow working range for a given value of RC_2. To offset this, there are twelve ranges, obtained by altering the resistor R.

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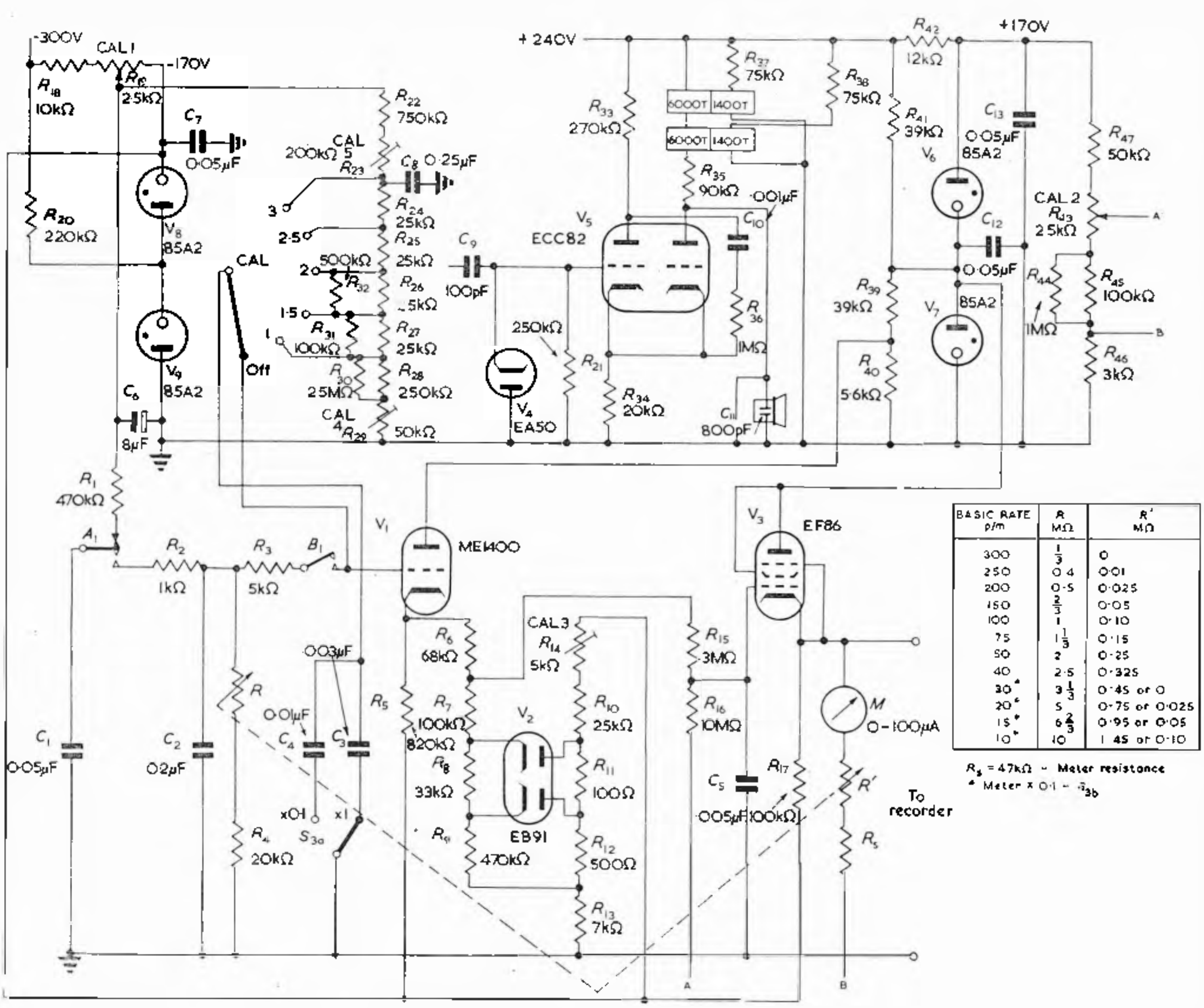
Fig. 1. Circuit diagram of ratemeter



BASIC RATE p/m	R MΩ	R′ MΩ
300	$\frac{1}{3}$	0
250	0·4	0·01
200	0·5	0·025
150	$\frac{2}{3}$	0·05
100	1	0·10
75	$1\frac{1}{3}$	0·15
50	2	0·25
40	2·5	0·325
30*	$3\frac{1}{3}$	0·45 or 0
20*	5	0·75 or 0·025
15*	$6\frac{2}{3}$	0·95 or 0·05
10*	10	1·45 or 0·10

R_s = 47kΩ − Meter resistance
* Meter × 0·1 − R_{3b}

The rate for which $fCR_2=\frac{1}{3}$ is the 'basic rate,' and in use this is made as high as possible, thus obtaining the lowest possible response time. Each range covers a factor 3 in rate e.g. 50/min to 150/min, and the basic rate can be altered from 10/min to 300/min by means of the range switch. The corresponding times for 99 per cent response are approximately 9sec and 0·3sec respectively, as compared with 15sec and 3sec for the previous instrument.

In order that the meter should read the correct rate on its single scale (0 to 500) irrespective of the position of the range switch, the meter sensitivity and the resistor R are altered together. When the rate is less than 50/min, the meter × 0·1 switch may be used, thus increasing the meter sensitivity by a factor 10.

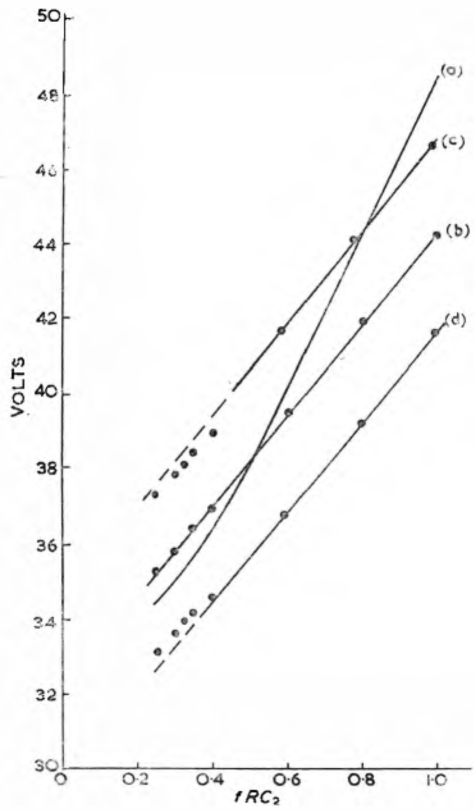


Fig. 2. Curves illustrating operation of the linearizing circuit

The output voltage can be taken from the cathode-follower for recording purposes. The voltage varies from 0 to −6V for the full variation of rate on each range.

Circuit Details

The electrometer valve V_1 is followed by the double-diode linearizing circuit. The diodes conduct successively as the voltage falls, thus automatically changing the ratio of a potentiometer. The uncorrected response curve (a) is shown in Fig. 2. The straight line (b) is obtained when the control CAL 3 is in correct adjustment. Curves (c) and (d) are obtained when the control is out of adjustment either side of the correct position. (For clarity, curves (c) and (d) have been shifted +2V and −2V respectively from their correct positions).

The × 0·1 switch, as well as increasing the meter sensitivity, is also used for increasing the value of the electrometer grid capacitor C_3. This reduces the effect of grid current at the lower rates. The ×0·1 contact support of this section of the switch is of polystyrene.

The two relays which are used are type 3G10, made by the Telephone Manufacturing Co. Ltd. In order to improve insulation, and to reduce pick-up from the coils, the contact connecting wires of each relay are passed through holes in the top of the relay cover, to which polystyrene terminal blocks are fitted. Also, polystyrene is used in lieu of mica for insulating the contact block (of B) which is connected to the electrometer grid contact.

The trigger pulse for operating the relay control valve V_5 is obtained from the Schmitt trigger valve of the heart pulse amplifier previously described[1]. The relays are adjusted so that A_1 is made for a period of 0·7msec, while B_1 is made 0·2msec after A_1, and remains closed for 0·25msec. The signals obtained from the relay armatures

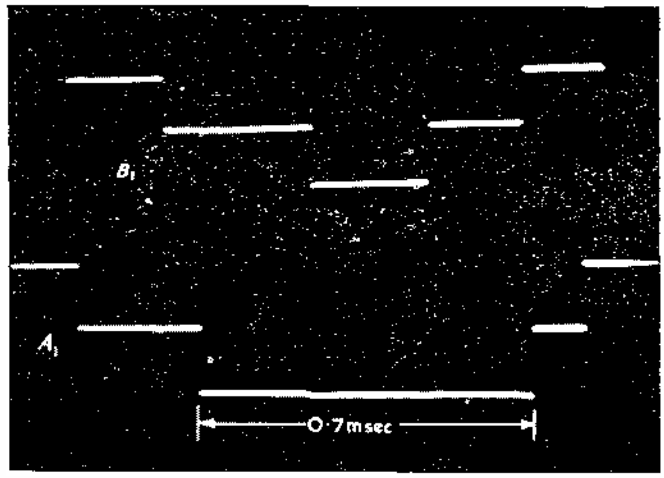


Fig. 3. Oscillogram showing synchronism of the relays

when equal and opposite test voltages are applied to the side contacts are shown in the oscillogram (Fig. 3). Although these contact times are short, they can cause slight non-linearity. This is corrected by including a fixed resistance of 20kΩ in series with the adjustable resistor R.

The setting-up procedure is as follows: the range switch is set to a basic rate of 100/min, and pulses at a rate of 300/min are applied to the ratemeter. The control CAL 1 is altered until the meter reads 300. The range switch is then altered to 150/min, and CAL 2 changed so that the meter again reads 300. These two adjustments are then repeated alternately until the meter reads correctly at both range settings. A similar process is carried out using controls CAL 2 and CAL 3 at range settings of 300/min and 150/min respectively.

The calibrating switch (CAL) has polystyrene insulation. The settings are multiples (1, 1·5, 2, 2·5, 3) of the basic rate, and completely cover each range. They are made to correspond with the meter deflexion by adjustment of the pre-set controls CAL 4 and CAL 5.

The CAL 2 control is fitted as a pre-set control to the front panel, in order that the slight drift which occurs over a period of several days may be corrected.

The meter reading is accurate to ±2 per cent when a first grade meter is used.

Acknowledgments

The mechanical design and construction of the apparatus was carried out by Mr. M. Ritchings. The author wishes to thank Dr. G. S. Dawes for discussion.

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A MODIFIED PERIODMETER

By V. Narayana Rao*, M.Sc.Tech., A.M.I.E.E., and K. Achyuthan*, M.Sc.

An instrument for observing small changes in the frequency of an audio signal of short duration is described in this article. The circuit of the instrument and the waveforms at the various stages are fully described. The circuit employed is based on the usual radar timing circuits. The information regarding the frequency changes is conveyed in the form of the position of a pulse on a cathode-ray tube of long after-glow characteristics.

IN order to observe small changes in the period of an audio signal from one cycle to the next, an instrument known as a Periodmeter has been designed by Barker and Cannon.[1] This instrument enables measurement, correct to 1c/s, of the change in period from one cycle to the next of a 10kc/s audio signal and this information is displayed on a cathode-ray tube as the height of the spot above a base line. This instrument is suitable for the study of frequency or phase modulation in an audio signal and also for detection of short time fluctuations in the frequency of an audio oscillator. Where the change in period does not take place from one cycle to the next, but takes place at a comparatively slow rate, a somewhat modified instrument described below can be used.

Here a pulse appears on the screen of a cathode-ray tube of long after-glow characteristics. The position of the leading edge of the pulse on a horizontal scale will depend on the frequency, and changes in this position will enable the measurement of changes in frequency. The instrument is designed to operate at a central frequency of 1kc/s and can detect changes of the order of 2c/s. Since a cathode-ray tube of long persistence is employed, audio signals of short duration can be studied with this instrument.

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Principle of Operation

Fig. 1 shows the circuit diagram of this instrument and Fig. 2 shows the waveforms at the various stages. The input signal of about 2V amplitude is amplified by the stage V_1 and squared by the stage V_2. This waveform is further sharpened by V_3 and, after differentiation, (see Figs. 2(c) and 2(d)) is applied to the Y deflexion plates of a cathode-ray tube having a long after glow.

The square wave voltage at the anode of V_2 is also differentiated and applied to the control grid of V_5. The two triodes V_4 and V_5 form a frequency dividing circuit. Normally V_4 and V_5 operate as a free-running multivibrator. The positive pulses fed to the grid of V_5 trigger

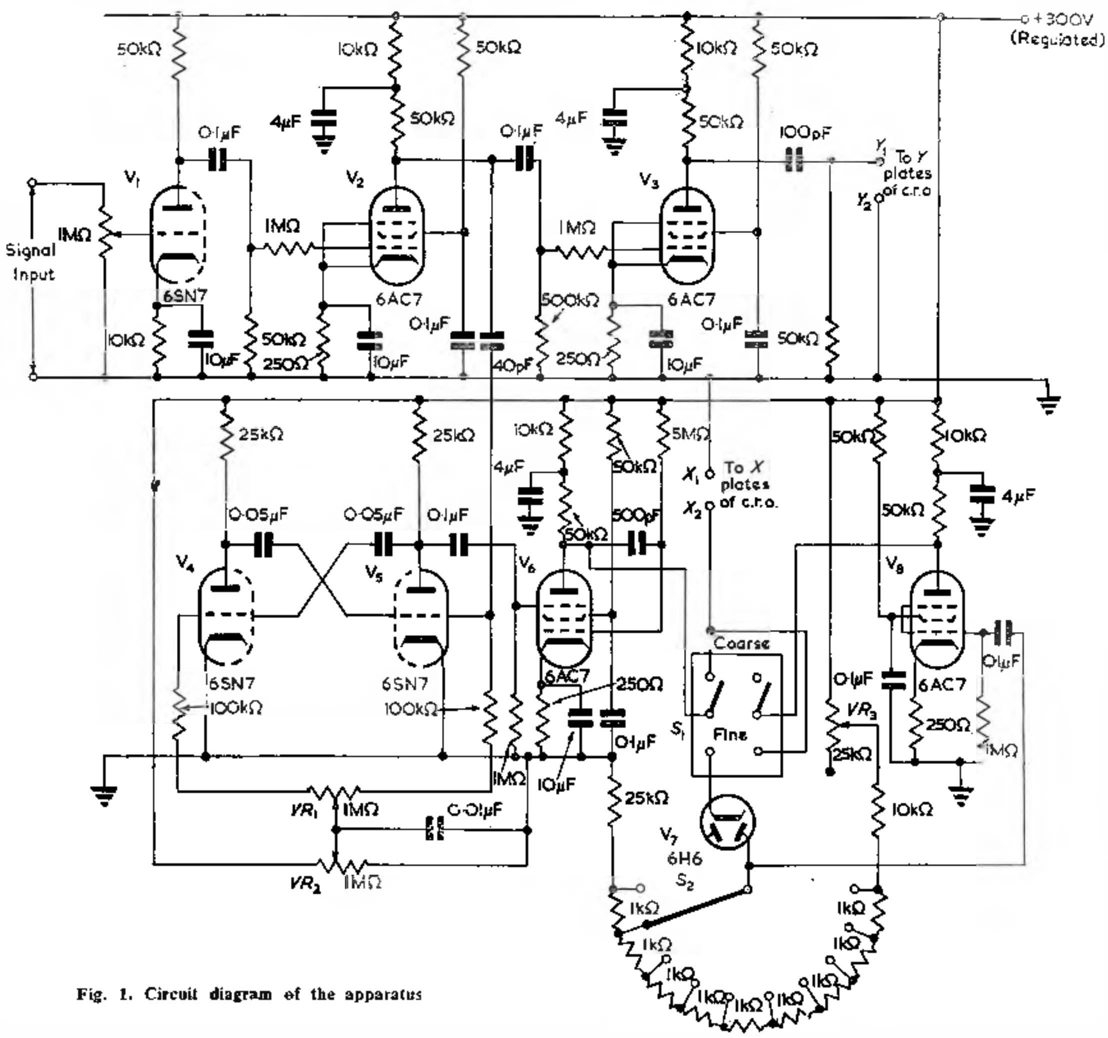

Fig. 1. Circuit diagram of the apparatus

the multivibrator into synchronism. The grid voltage of V_5 tends to rise exponentially to the voltage level set by the variable resistor VR_2. The higher this level becomes, the sooner the multivibrator is retriggered by another earlier occuring positive pulse. The triggering occurs when the potential on the grid becomes equal to or greater than the cut-off potential. The duration of the positive portion of the waveform (Fig. 2(e)) at the anode of V_5 can therefore be adjusted to correspond to one, three or five etc., half waves of the square wave present at the anode of V_2. In this appli-

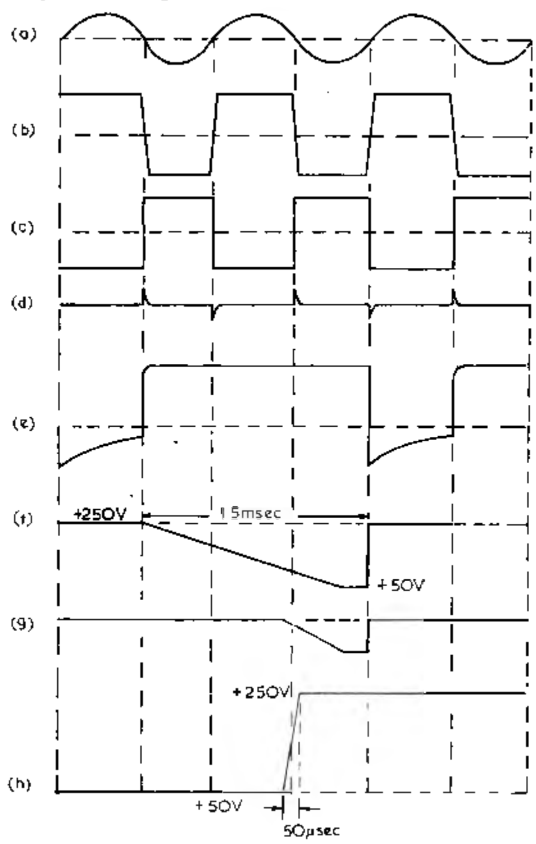

Fig. 2. Waveforms illustrating the operation of the apparatus

(a) Input signal. (b) Waveform at anode of V_2. (c) Waveform at anode of V_4. (d) Pulses derived from the differentiation of C and applied to Y plates of c.r.t. (e) Waveform at anode of V_5. (f) Waveform at anode of V_6, applied to X plates of c.r.t. (g) Waveform at anode of V_7. (h) Waveform at anode of V_8, applied to X plates of c.r.t.

cation it is set for three. The duration of the negative portion of the waveform at the anode of V_5 is set to one half wave and this setting is done by means of the setting of the variable resistor VR_1.

The rectangular waveform at the anode of V_5 is then applied to the suppressor grid of the pentode V_6 which is connected as a Miller integrator[2]. The Miller run-down (Fig. 2(b)) will commence from the instant the suppressor voltage of V_6 jumps from the cut-off to zero value. The time-constants are so adjusted that the Miller run-down takes about 1·5msec. The waveform (d), which is applied to the Y plates of the cathode-ray tube, seen in relation to the waveform (f) shows that if the Miller time-base is applied to the X plates of the c.r.t., then there will appear on the c.r.t. screen one positive pulse at the beginning and another somewhere in the middle of the trace. If the frequency of the input signal changes, the run-down time of the Miller will remain unchanged as this depends only on the circuit constants and hence the time separation between the two positive pulses will alter. Since the first positive pulse always coincides with the beginning of the trace on the c.r.t., the position of the second positive pulse will appear altered. If the c.r.t. screen is calibrated, the frequency of the input signal can be read from the position of the second positive pulse. Thus if the frequency changes from 1kc/s to 800c/s, the position of the second positive pulse will shift from the 1msec mark to the 1·25msec mark. This will correspond to about 0·7in on the oscilloscope, and, with this set up, the minimum change that can be detected will be about 0·1in or about 40c/s.

In order to achieve higher resolution, the Miller voltage (waveform (f)) is sliced by applying it to the cathode of the diode V_7, the anode of which is held at a certain positive potential. The sliced time-base waveform appearing at the anode of V_7 (see waveform (g)) is next applied to the control grid of the pentode V_8. Because of the short grid base of V_8, only a small portion of the time-base corresponding approximately to 50μsec is amplified and the remaining portion cut off. The anode voltage of V_8 (wave-

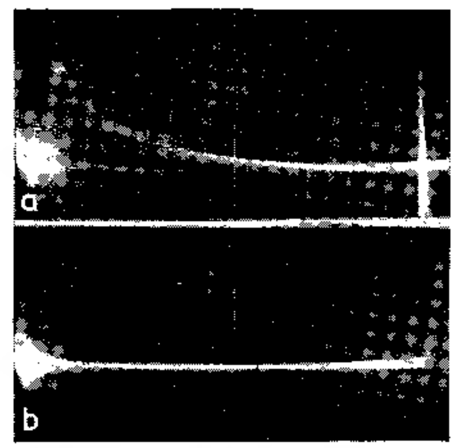

Fig. 3. Illustrates the effect of varying the frequency from 1 020c/s (Fig. 3(a)) to 980c/s (Fig. 3(b))

form (h)) will therefore be a linear time-base of short duration (50μsec) and its position in time relative to the input waveform can be adjusted by varying the potential to which the anode V_7 is returned. Nine fixed levels of voltage are provided for the anode of V_7 and any level can be selected by means of switch S_2. These levels are so adjusted that there is a small overlap of about 5μsec between the time-bases obtained from one setting and the next. Thus setting No. 1 will cover from 800μsec to 850μsec, setting No. 2 from 845μsec to 895μsec, and so on. There is also a variable control VR_3 which can be used for adjustment of the anode potential of V_7 while calibrating initially. This modified time-base voltage, which is of amplitude about 200V, when applied to X plates of the c.r.t. will produce a horizontal deflexion of about 4·5in. Assuming the smallest change in position of the leading edge of the pulse discernible to be 0·2in. the smallest change in frequency detectable will be of the order of 2c/s.

Normal procedure for using this instrument is to switch the time-base to the 'coarse' position by means of switch S_1 and to note the position of the positive pulse. The time-base is next switched to the 'fine' position and switch S_2 is changed to the appropriate setting which will bring the pulse near the centre of the display. The pulse can then be followed to detect the changes in frequency that may take place in the particular application of the instrument.

Fig. 3(a) shows the display obtained using an audio signal of 1 020c/s. The effect of changing the frequency to 980c/s can be seen in Fig. 3(b).

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A Foetal Phonocardiograph

By D. J. Dewhurst*, B.A., M.Sc., and J. F. Mainland*, B.Sc.

A simple amplifier is described which is suitable for the amplification of the heart sounds of a baby before birth. Included is an inertia type crystal microphone and a pen on paper recorder, with provision for listening to the sounds with a stethoscope headphone.

THE fundamental frequency of foetal heart sound is of the order of 16c/s and contains a varying proportion of higher harmonics[1]. Since the human ear is incapable of hearing sounds in the range of the fundamental, no audio reproducer used to generate such frequencies will be successful. Further, the higher harmonics are not always present[2]. For these reasons a pen on paper recorder was chosen to reproduce the sounds. A stethoscope headphone which reproduces only the higher harmonics was included to conserve paper while setting the microphone in position and, if necessary, to make rapid interpretation of the graph on the recorder during its operation. This type of headphone provides the most satisfactory form of coupling between the sound generating unit and the ear, and completely eliminates acoustic feedback.

The routine method used to listen for foetal heart sounds is the application of a physician's stethoscope to the mother's abdomen. These sounds are used diagnostically after the 20th week of pregnancy as a test for pregnancy itself, and also for assessing the condition of the foetus before and during birth. The definite absence of foetal heart sounds will mean a still birth.

On occasions differences of opinion arise as to whether the foetal heart sound is present or not. This apparatus was designed specifically to assist in settling this problem. A wave for each beat was required rather than an analysis of the foetal heart sound waveform. Ancillary recording equipment, such as a cathode-ray oscillograph, tachometer and loudspeaker, were purposely omitted.

While a cardiotachometer is an attractive addition to the apparatus, it adds complexity and is of no use if borborygmi or the maternal pulse in any form is picked up as well as the foetal heart sound. For this reason it was omitted.

Apparatus

This consists of:

(1) Microphone
(2) Pre-amplifier, amplifier and tuned amplifier
(3) Phase-splitter and cathode-follower output
(4) Recorder
(5) Power supply
(6) Audio amplifier

In the construction of the apparatus, unwanted inter-stage coupling and hum from the power supply made the use of two separate chassis desirable (Fig. 1).

(1) MICROPHONE

An inertia type crystal microphone loaded to give a peak response at 25c/s was used. The face of the microphone, measuring 1in in diameter, protrudes through a hole cut from the centre of a disk of 1/16in thick sheet rubber. A retaining ring holds this whole unit at the mouth of a metal cup. By this construction all unwanted extraneous noise is eliminated, except on extremely high gain. With this type of microphone an air column and diaphragm between the sound and the crystal are not required. Vibration received by the case of the microphone (in contact with the maternal abdomen) activates the crystal.

(2) PRE-AMPLIFIER, AMPLIFIER AND TUNING AMPLIFIER (Fig. 2)

This portion of the apparatus is on a separate chassis. It consists of 3 stages:

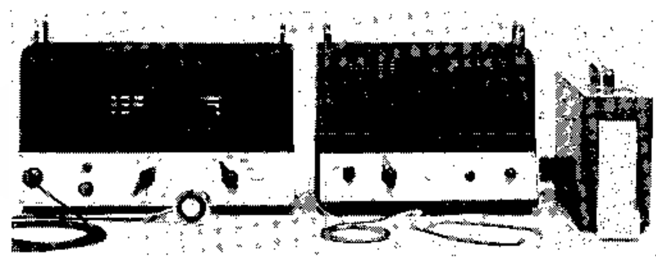

Fig. 1. The complete apparatus

(*a*) *Pre-amplifier*

A pentode V_1 together with its components is enclosed in a separate case and shock mounted beneath the chassis. A metal 6J7 valve was used for this stage. Although this type may be considered obsolete, it is particularly satisfactory in applications where low microphony, low hum, and freedom from low frequency noise are essential. A 90V h.t. supply for this stage, in the form of batteries, is contained in a shielded box above the chassis. The heater voltage to V_1 is derived from a separate 6·3V a.c. supply within the power supply unit.

All earth connexions, including the sub-chassis case and microphone cable shielding, are kept separate from the main chassis, except at one point.

A panel mounted neon tube with a series push-button switch is connected across this h.t. supply to provide a check on the battery voltage; a 20 per cent decrease is shown by failure of this tube to strike. In this apparatus this device was found as satisfactory as a conventional voltmeter.

(*b*) *Amplifier*

This consists of a metal clad pentode V_2, with the main gain control situated at its input. Sub-chassis shielding isolates this stage.

While the fundamental design of the amplifier is such that it is flat from 10c/s to 10kc/s, an anode to ground capacitor has been included in the first two stages to limit the high frequency response (Fig. 3). By the use of this frequency cut almost all high frequency extraneous room and skin noises are eliminated. Furthermore, the upper limit of frequency response of the recorder (approx. 150c/s) did not justify an amplifier with a higher response than this figure.

(*c*) *Tuned Amplifier*

A high transconductance pentode V_3 with fixed inductance and variable capacitance in its anode circuit achieves

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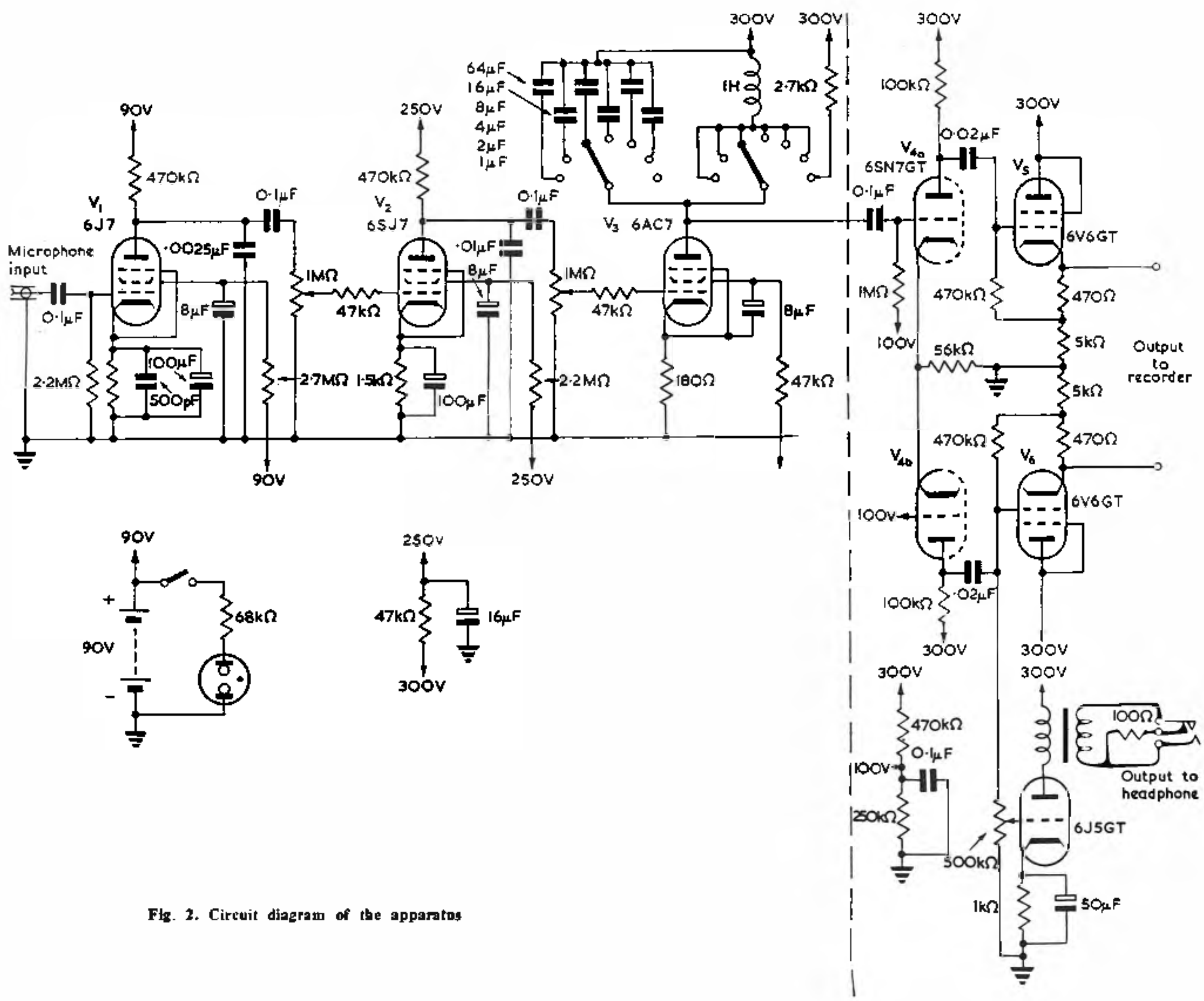
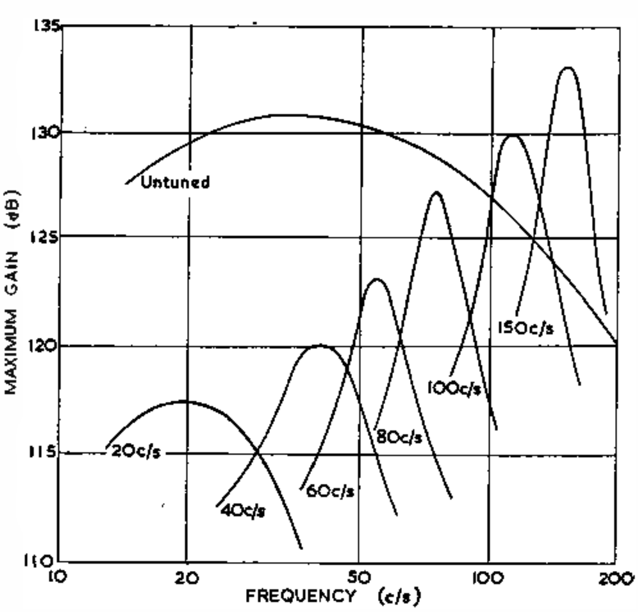


Fig. 2. Circuit diagram of the apparatus

Fig. 3. Frequency response curves showing the effect of various settings of the amplifier tuning switch on the overall gain and response

The untuned curve shows the result of the anode to ground capacitors included in the first and second stages



the tuning required. The inductor used was a stock design for audio filtering and had a nominal inductance of 1H, with a d.c. resistance of 90Ω. The capacitors were block paper types. Provision was made for switching to a fixed resistance anode load, thereby allowing the amplifier to be used untuned.

Grid stopper resistors are included in the grid circuits of the second and third stages. This addition was found necessary to eliminate very high frequency oscillation.

The effect of various settings of the amplifier tuning switch on the overall gain and response may be seen from Fig. 3. Since maximum available selectivity was required, no attempt was made to equalize the gains obtained at the various switch positions.

(3) Phase-Splitter and Cathode-Follower Output

A twin triode, V_4 with a large common cathode resistor ('long tailed pair') provides phase-splitting for the balanced output cathode-follower stage, V_5 and V_6: balanced output was required for the particular type of recorder used. The voltage level at the grid of one of these triodes is adjusted so that the phase-splitter will be over-driven before the pen recorder, thus protecting the pen recorder.

(4) Recorder

A commercially available moving-coil pen-on-paper electrocardiograph recorder is used. Alteration to the driving mechanism was made to give a speed of 5cm/sec (twice standard e.c.g. speed). The normal rate for foetal heart sounds is 120 to 160 beats/min.

(5) Power Supply

A conventional non-stabilized power supply provides the h.t. to all valves except V_1. Three separate windings are used for the heater voltage to V_1, to V_2, and V_3, and a further winding for V_4, V_5, V_6 and V_7. No special techniques were found necessary for hum elimination from the heater wiring except to run the leads to the first stage (V_1) in twin shielded cable.

(6) Audio Amplifier

A single triode amplifier V_7 is incorporated to provide the signal to the stethoscope type headphone. Provision is made for separate alteration of the audio signal level by for the heater voltage to V_1, to V_2, and V_3, and a further means of a screwdriver adjustable potentiometer in the grid circuit of V_7.

Isolation between the h.t. of this stage and the phones is for safety reasons. This is achieved by a conventional output transformer with a low resistance secondary winding to match the phones used.

Performance

The apparatus has been found most satisfactory in meeting the requirements it was designed to achieve. Furthermore, it has been found a successful adjunct in keeping a check on the heart sounds of a baby undergoing an exchange transfusion.

The maximum gain of the amplifier when set on the lowest tuning frequency range (20c/s) is sufficient to give full scale deflexion on the pen recorder (160V for side-to-side deflexion of the pen) for an input of 67μV r.m.s. All of this gain is usable if necessary. On higher frequency settings the gain of the amplifier rises to a figure of 8×10^6 times without oscillation, but only one quarter of this is usable.

A most interesting and comprehensive review of the recording of foetal heart sounds is to be found in the article by Gunn and Wood[3].

Acknowledgment

The authors wish to acknowledge with thanks the work which Mr. J. K. Ibbott put into the design and manufacture of the microphone used in the apparatus described.

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British Equipment for Russia

A fully automatic machine for making up panels from wood strips was recently despatched from Britain to Russia. This purchase by Russia of a G.E.C.-Fielding radio frequency edge-gluing machine is hoped to be the forerunner of further orders for this type of equipment.

The machine, a comparatively new innovation in the woodworking industry, reduces the operation of making up panels from strips of wood to the simplest possible form. The entire process is controlled by two operators, one assembling panels on the table and the other applying glue to the wood strips and stacking completed panels. Once a panel has been assembled on the feed table the remainder of the cycle is carried through automatically in the correct sequence, on pressing a single push-button.

The G.E.C.-Fielding radio-frequency machine is a complete unit comprising a pneumatically-operated press, with feed table and automatic loader, to which r.f. power is applied through a suitable load matching unit from a G.E.C. 25kW radio frequency generator.

One of the operators takes the wood strips to which glue has been applied and assembles them on the feed table. A pneumatically operated loading arm then pushes the assembled stock direct into the press. The remainder of the cycle is fully automatic and the operator is able to assemble the next panel while it is in progress.

The loading arm having moved the panel into the press returns to its normal position. Vertical pressure is applied to the panel in the press. After a short delay side pressure is applied. The radio frequency power is applied and the heating cycle begins. At the end of the heating cycle the radio frequency power is switched off, side pressure is removed and finally the vertical pressure is released. The glued board is ejected when the loading arm moves the next assembly into the press. The mechanical operations take approximately 10secs. Heating times range from 30 to 90secs depending upon the nature of the panel being glued. Due to the selective heating of the glue the panels remain comparatively cool and can be handled immediately.

Use of Analogue Computer for Vehicle Suspension Development

Use of an analogue computer to stimulate the effect of uneven road surfaces on projected vehicle suspension systems is one of the latest research techniques to be employed by the German car industry.

By adopting this new method, German engineers have been able to determine, in just one hour's work, the type of suspension system best suited to the needs of new lorries and heavy haulage vehicles.

For help in these investigations, Germany has made use of a Short analogue computer, installed in the Technical High School at Brunswick. The German Road Vehicle Research organization, which receives support from the Volkswagen and Büssing organizations, is one of the Institutes of the College.

The method used was to set up on the computer an equation in which factors such as the type of axle to be used, the suspension and chassis, and also various types of bumps and road depressions, were represented by electrical voltages of varying values.

When the simulated suspension system was 'driven' over the bumps a trace on the computer's cathode-ray tube indicated the actual movements of the chassis and axle arrangements. By simply turning the appropriate switches, it was possible to change such values as the stiffness of the suspension springs, pressure in the tyres, or damping of the shock absorbers, until a system was evolved which gave the best overall performance.

In this way, weeks of research were compressed into an hour's work at the computer. In addition, the results recorded were far more accurate than those previously obtained by other methods. The simplest of these was for vehicles fitted with suspension systems under development to be driven over specially designed ramps and round a 400-yard perimeter track having a series of built-in concrete bumps.

The results of the research are to be made available to the entire German car industry.

Some Characteristics of Saturated Diodes with A.C. Heating

By F. A. Benson*, M.Eng., Ph.D., A.M.I.E.E., M.I.R.E. and M. S. Seaman*, B.Eng.

Some characteristics of saturated diodes types 29C1, AV33 and A2087, when operating with a.c. filament supplies, have been examined. The investigations have been concerned with the shapes of anode-current/anode-voltage curves, the variations of mean emission currents with the filament supply frequency and the way in which ripples superimposed on the emission currents vary with frequency and emission current. Some information is also included about the variation of response time with emission current.

It is concluded that the 29C1 diode has a smaller response time than the AV33 when used with the same emission current, but it has more ripple on the emission current. An A2087 valve has a ripple of about the same magnitude as that of the 29C1 and has a better response time. The AV33 valve is unsuitable for controlling alternating currents at frequencies above the audio range.

SATURATED diodes now find wide application as controlling elements in certain voltage-stabilizer[1,2] and measurement[3] circuits. In order to determine the relative merits of different valves for this purpose the authors recently examined the characteristics of 29C1, A2087, AV33 and GRD6 types[4,5]. Short and long-term tests were carried out on the valves and several samples were also examined at ratings in excess of the specified limits. It was concluded that A2087 valves have rather poor long-term characteristics compared with the 29C1 diode which is capable of performing satisfactorily as a stabilizer controller, while the large filament-power requirement of the GRD6 valve is a disadvantage for continuous saturated-diode operation. After these tests were completed using, for convenience, direct-current heating of the filaments, it was decided to carry out some additional investigations on small numbers of 29C1, AV33 and A2087 valves using a.c. filament supplies because the diodes are often used as voltage-sensitive elements in a.c. stabilizers.

Hibberd[6] has analysed the behaviour of an ideal saturated diode under transient conditions generally and from his work it appears that the characteristics obtained with a.c. heating should be substantially the same as when the filament is supplied with d.c. The saturated diode has a finite response time, because of the thermal capacity of its filament, which gives rise to a delay between a change in filament power input and the resulting change in filament temperature. The electron emission under saturation conditions depends almost entirely on the filament temperature and, neglecting transit-time effects, responds instantaneously to changes in the latter. The response time has been shown[6] to be somewhat greater when the filament supply is at constant current than when it is at constant voltage, a fact which has been confirmed experimentally by Attree[3] who gives a time of response of 0·15sec for a 29C1 valve with an emission current of 2·5mA at constant voltage. As extra resistance was inserted in the filament supply Attree found the response time increased, the maximum value he obtained being 0·22sec. In practice, of course, the filament supply will generally be at neither constant voltage nor constant current.

Hibberd[6] has shown that at the temperatures at which saturated-diode filaments operate (usually above 2 000°C) the temperature variations of a filament when heated by a.c. will be a sine function of time with a frequency twice that of the filament current. The mean temperature should be the same as would be obtained with a direct current having a magnitude equal to the r.m.s. value of the alternating one provided that the variation in temperature during the heating cycle is not more than about 100°C. It is not possible to assume a linear relationship between filament temperature and emission current over a wide temperature range due to the exponential nature of Richardson's Law. Thus, when large temperature changes occur it would be expected that the mean emission current with a.c. heating would not be the same as for the corresponding d.c. heating.

The magnitude of the cyclical variations of the filament temperature when a.c. heating is used is inversely proportional to the frequency of the heating current according to Hibberd[6] who found that the temperature variation (neglecting second and higher order terms) is given by

$$\theta = L \cos (2\omega t - \alpha)/(2\omega C)$$

where θ is the difference between the instantaneous temperature and the mean temperature T,

L is the rate of heat loss from the filament, C is the thermal capacity of the filament, } both measured at the temperature T.

α is a phase-angle which is nearly 90° at ordinary mains frequency and approaches 90° as the frequency increases.

ω is the angular frequency of the heating voltage

t is the time.

If the temperature variations are so small that a nearly linear relationship between filament temperature and emission current can be assumed it would be expected that the a.c. ripple on the mean emission current would be inversely proportional to frequency.

To check his theories Hibberd[6] constructed some experimental diodes, but made measurements at only two frequencies, probably due to difficulties of obtaining suitable variable-frequency supplies.

The tests described here using a.c. filament supplies have been concerned with (a) the shapes of anode current/anode voltage curves, (b) the variations of mean emission currents with the frequency of the voltages applied to the filaments and (c) the manner in which the ripples superimposed on the emission currents vary with frequency and emission current.

Test Circuit

The circuit used for testing the valves was similar to that used for the earlier investigations[4,5], except that a suitable a.c. filament supply was installed instead of accumulators and provision was made for measuring the anode current ripple. The anode power was supplied from two h.t. secondary batteries. The method adopted for obtaining the filament supply was to use an audio frequency RC oscillator to generate a signal of the desired frequency and to feed this signal to a power amplifier whose output was used to heat the valves. With this arrangement it was

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thought that the percentage of harmonic voltages present at the valve base would be less than 1 per cent.

The filament voltage was measured with a suitable thermal milliameter in series with a decade resistance box. The use of an a.c potentiometer for this purpose was considered unnecessary. To measure the ripple component the anode current was passed through a high-grade decade resistance box, the alternating voltage developed across this box being measured by a calibrated valve millivoltmeter.

EXPERIMENTAL RESULTS

(a) *Anode Current/Anode Voltage Characteristics*

It was found that the shape of the anode current/anode voltage characteristic of a diode in the saturated region is unaffected by the type of heating current employed, the slopes of the characteristics being practically the same for both d.c. and a.c. As the tests were carried out at widely different frequencies in the audio band it would appear

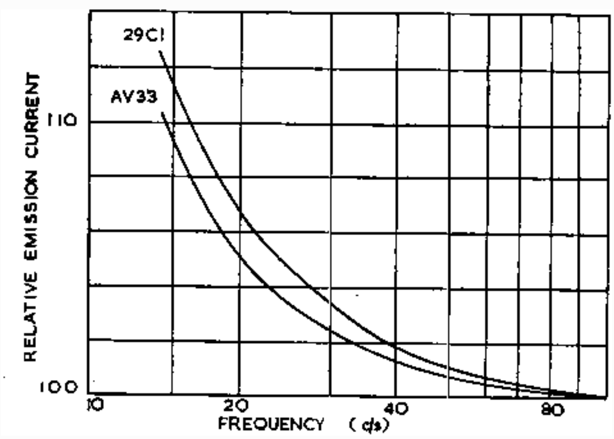

Fig. 1. Increase in emission current with low frequency a.c. heating

that the waveform of any current used to heat a valve would have a negligible effect on the shape of these characteristics although it is pointed out later that the emission current may vary if the waveform changes.

The characteristics at the lower end of the saturated region and also at the upper end of the unsaturated region are not necessarily the same as those obtained when d.c. heating is used. This is particularly so at low frequencies. This probably arises because temperature variations are such that the valve is operating in the saturated region at its lowest temperature and in the unsaturated region at its highest temperature. Also, due to the low anode voltage usually existing under such conditions, it is likely that various parts of the filament may be operating in different regions.

No detailed observations were made in the unsaturated region, but it is worth noting that at anode voltages of the order of the filament voltage the anode current of a valve is considerably in excess of that obtained with d.c. heating.

(b) *Variations of Emission Current with Frequency*

The mean emission current obtained with a.c. heating at moderate frequencies is the same as that obtained when using d.c. having a magnitude equal to the r.m.s. value of the a.c. At low frequencies the mean emission current is greater when using a.c. heating than when using d.c. which is consistent with Hibberd's theory that the filament temperature varies equally above and below the mean value during the heating cycle and the exponential nature of Richardson's Law. The magnitude of this increase varies with frequency, filament voltage and from valve to valve. In some cases, especially with the A2087 valves, the increase is measurable at a frequency of 100c/s, and at 50c/s the magnitudes of the increases are about 1 per cent for the 29C1 and AV33 diodes and about 3 per cent for the A2087. These changes in emission increase as the frequency decreases, being about 5 per cent at 25c/s for the AV33 and 29C1 valves, and become slightly larger as the

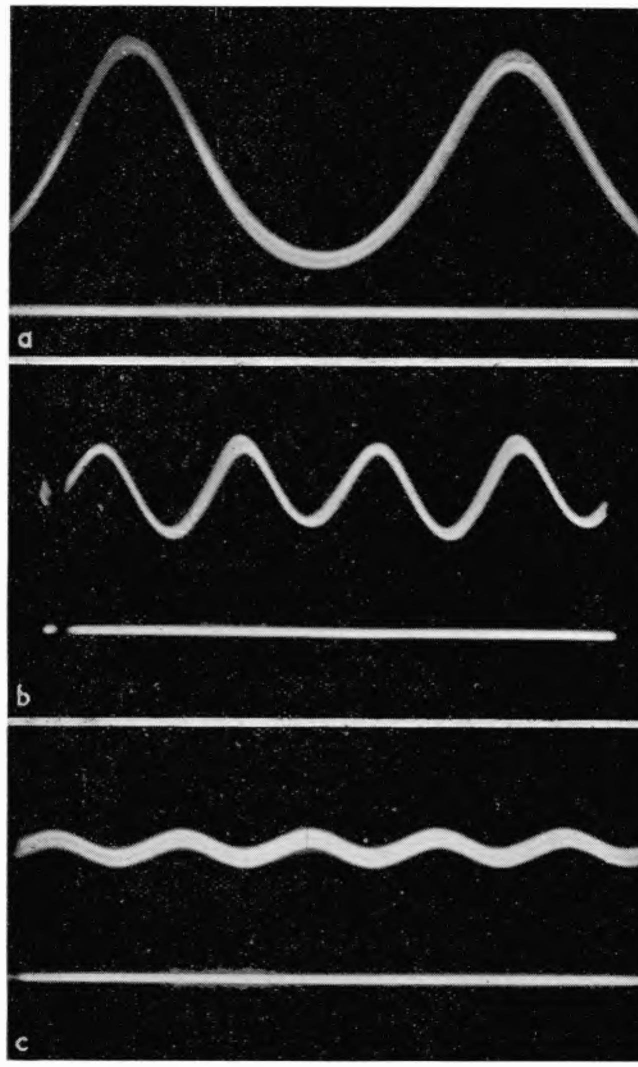

Fig. 2. Oscillograms for a 29C1 diode of the ripple on the emission current (all to the same scale)

Anode current—2mA. Anode load—2kΩ. Anode voltage (mean)—100V. (a) f = 18c/s. (b) f = 50c/s. (c) f = 200c/s.

filament voltage increases. Some typical results for the 29C1 and AV33 valves are shown in Fig. 1. No detailed tests have been carried out over this low-frequency range for the A2087 diodes. It seems that the increase in emission current with low frequency a.c. heating becomes greater during a valve's life.

Oscillograms of the ripple on the emission current show that the increase in mean emission current at low frequencies is due to the unsymmetrical nature of the ripple. Some typical oscillograms for a 29C1 diode are shown in Fig. 2; similar results have been observed with the AV33 and A2087 valves. It is seen that at very low frequencies the increase in emission when the filament temperature is above normal is greater than the reduction in emission when the filament temperature is below normal.

Tests were carried out on 29C1 and AV33 valves at frequencies up to 15kc/s. For 29C1's a slight decrease in emission (less than 2 per cent at 15kc/s) was observed which could be be attributable to experimental errors and stray effects. For AV33's, however, there was a noticeable falling off in emission at frequencies greater than about 500c/s which amounted to about 2 per cent at 1kc/s and about 15 per cent at 10kc/s as is shown in Fig. 3. The reason for this behaviour seems to be the different constructions of the AV33 and 29C1 valves. The 29C1 filament consists of two inverted V's, all the power leads being at the bottom end of the anode structure. In the AV33, however, two filament wires lie inside the anode structure, the return lead being outside the anode. Thus, in this case, there is a net flow of filament current through the anode structure. As a result the filament current will induce para-

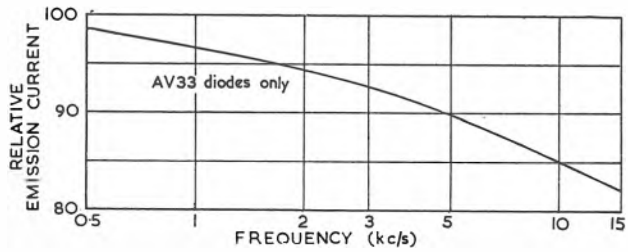

Fig. 3. Decrease in emission current with high frequency a.c. heating

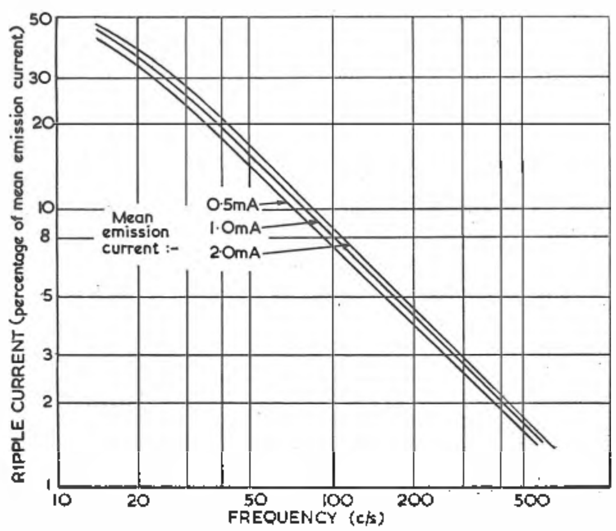

Fig. 4. 29C1 characteristics

sitic currents in the anode structure, which appears to be of nickel, since it is magnetic. The effect of this will be to increase the impedance of the filament which will reduce the emission current for a given voltage across the valve pins. Tests on A2087 valves were only carried out at frequencies up to 1 500c/s, but there was no falling off of the emission with frequency in this range. The A2087 valve has a single horizontal V filament so that this result is to be expected.

(c) *Emission-Current Ripple*

The frequency of the ripple superimposed on the emission current is, as shown by Hibberd[6], twice the supply frequency. The magnitude of the ripple current varies with both frequency and emission current. Typical graphs showing the variations of ripple current against frequency for several constant mean emission currents are shown in Figs. 4, 5 and 6.

The variation in the magnitudes of the ripple between new valves of a given type, for given anode voltage, anode current and filament supply frequency, is fairly small being about 5 per cent for 29C1 diodes and about 3 per cent for A2087 ones. The three AV33 valves tested gave almost identical amounts of ripple. Over the majority of the frequency range covered (up to 500c/s) the ripple current varies almost inversely as the frequency as expected. At frequencies below about 40c/s, however, the measured ripple is less than the theoretical value.

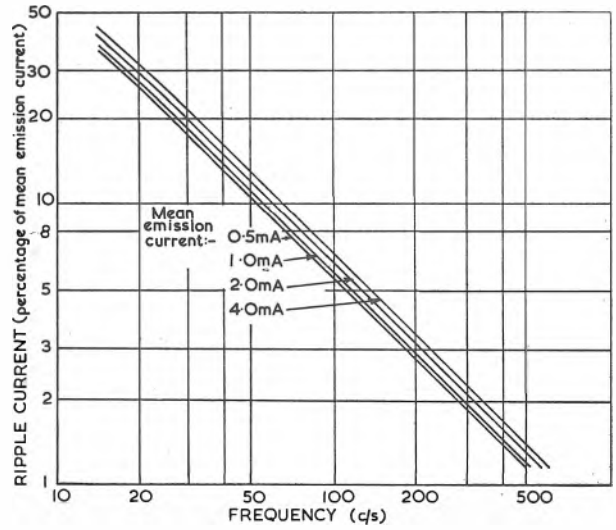

Fig. 5. AV33 characteristics

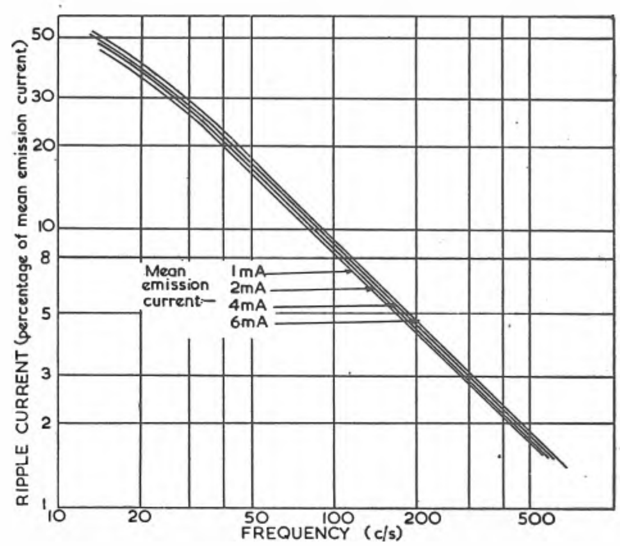

Fig. 6. A2087 characteristics

No detailed measurements were made of the ripple current outside the saturation region. Observations showed, however, that there was very little ripple in the unsaturated region. In the 'transition' region between the two well-defined regions there is a large amount of ripple, its magnitude depending on the value of the anode load. This again is probably due to the various parts of the filament operating in one region or the other for varying time intervals. In both the saturated and unsaturated regions the ripple current magnitude is independent of the anode load.

As will be seen from Figs. 4, 5 and 6 an increase in emission current increases the amount of ripple. This increase is about 8 per cent if the emission of a 29C1 diode is doubled, the corresponding figures for the A2087 and

AV33 valves being about 5 per cent and 7 per cent respectively; the value of this factor varies somewhat from valve to valve.

Since the filament diameter gradually decreases with age, it would be expected that the emission current ripple would increase. This has been found to be so with all the valves life-tested[4,5] (with d.c. filament supplies). Typical curves showing the variations of ripple with frequency before and after life test are shown in Figs. 7 to 9, from which it will be seen that the ripple increases by about 10 per cent during 100 days running with 29C1 valves and 7 per cent during 100 days running with AV33 valves. For A2087 valve No. 1 the corresponding figure is about 10 per cent for 100 days running (the behaviour of valve No. 2 may lead one to believe that this sample is a freak[7]).

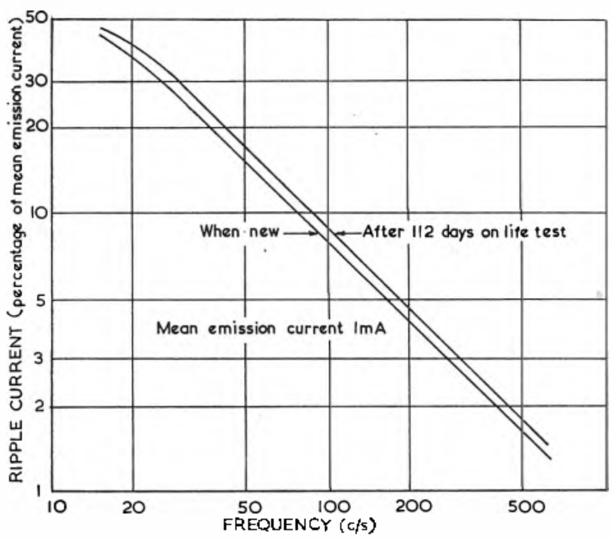

Fig. 7. 29CI characteristics

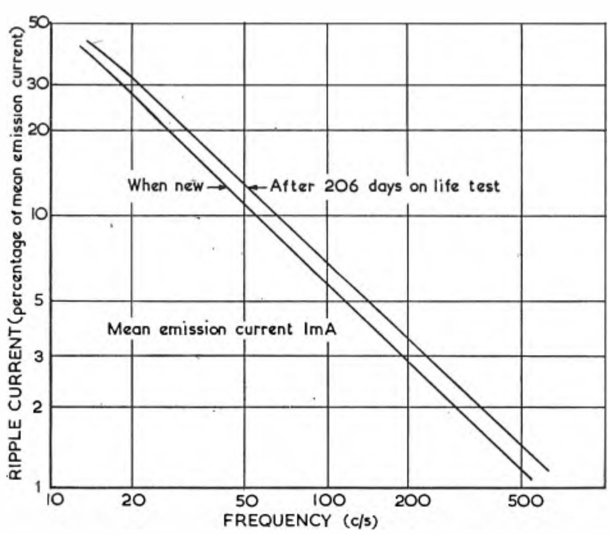

Fig. 8. AV33 characteristics

Variations of Response Time with Emission Current

The variation of response time with emission current can be deduced from the known ripple component in the emission current using formulae given in Hibberd's paper[6].

Hibberd defines a transient function Z which is given by

$$Z = CT/hL$$

where T is the filament temperature in degrees absolute, C and L are the same quantities as defined already and h is the temperature coefficient of L.

This function Z is an intrinsic property of the filament although it will vary with filament temperature since all the quantities defining it vary with temperature and must obviously all be measured at the same temperature. The time of response of a saturated diode is equal to this transient function multiplied by a constant which is determined by the regulation of the filament power supply. From Hibberd's data this constant varies from about 0·8 for a constant-voltage supply to about 1·3 for a constant-current one. In practice the regulation of the supply will be somewhere between these two extremes with a corresponding value of the constant somewhere between 0·8 and 1·3. Thus it is advantageous to use the valve with a filament supply as near constant voltage as possible in order to obtain a fast response although a constant current supply gives a greater sensitivity.

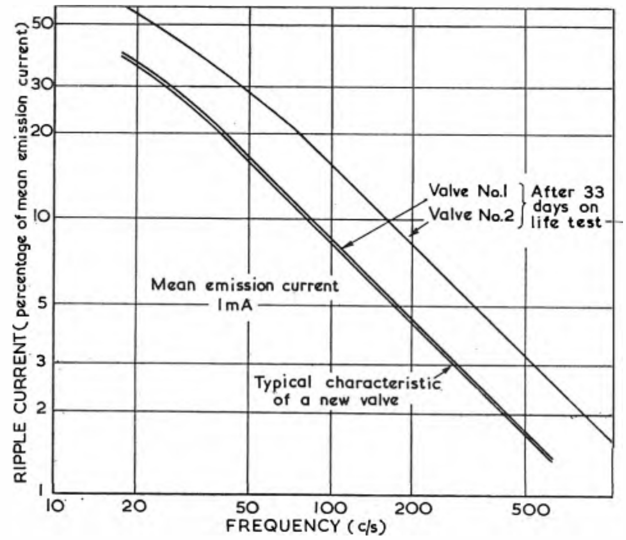

Fig. 9. AV2087 characteristics

If the amount of ripple on the emission current at a given frequency is known then Z can be calculated from the expression

$Z = (b/T+2)/h\omega F$. (neglecting higher order terms)

where b is the temperature equivalent of the thermionic work function in degrees absolute.

h, ω and T have the same meanings as before

and F is the logarithmic ripple i.e., $\ln (I_{max}/I_{min})$

$= \ln [(I + \Delta I)/(I - \Delta I)]$

where I is the emission current at the mean temperature T, and I_{max} and I_{min} are the emission currents at the highest and lowest filament temperatures during the heating cycle. Thus, ΔI is the emission current deviation $= (I_{max} - I) = (I - I_{min})$.

It will be seen, therefore, that as the filament temperature is increased Z will decrease since F will also increase. Hence, when a saturated diode is used to control an alternating current a decrease in response time can be obtained only at the expense of an increase in the ripple.

The expression $Z = CT/hL$ also shows the effect of filament radius on response time. C is proportional to the filament volume and L is proportional to the surface area. Hence, for an ideal filament, the ratio C/L, and therefore Z, is independent of filament length and for a filament of circular cross-section it is proportional to radius. From the life-test results discussed in the previous section one would expect the response time of the diodes to decrease with life.

Both expressions for calculating Z given above entail a knowledge of the filament temperature. As no methods were readily available for doing this during the present investigations, except indirect methods using published data concerning filament lamps, no attempts were made to calculate the response times of the particular diodes under consideration.

Conclusions

From the results it appears that the 29C1 valve will have a better response time than an AV33 when used with the same emission current, the ratio of the response times being about 2:3. This is not surprising considering that the diameter of the AV33 filament is slightly greater than that of the 29C1 (as is shown by its larger filament current) and operates at a slightly lower temperature on account of its larger emitting area, thus giving rise to less ripple on the emission current.

Although the filament of the A2087 valve appears to be about the same diameter as that of the AV33 from considerations of filament consumption this valve should have a response time better than that of the 29C1 since its ripple is about the same and it operates at a higher filament temperature. Although no tests were carried out on GRD6 valves consideration of their filament consumption (which is about four times that of the other diodes) show that they will have comparatively long response times.

The relatively simple construction of the AV33 valve appears to make it unsuitable for controlling alternating currents at frequencies above the audio range.

Acknowledgments

The authors wish to thank the University of Sheffield for facilities afforded in the Department of Electrical Engineering. The kindness of The Amalgamated Wireless Valve Co. Pty. Limited, Sydney, Australia, in supplying the AV33 valves for test is also gratefully acknowledged.

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Electronic Lift Control for Hong Kong

A lift installation recently completed by The Express Lift Co. Ltd in Alexandra House, Hong Kong, incorporating an electronic traffic control system, is now moving 33 000 people per day—over twelve million a year.

Alexandra House was built in two sections with two separate lift installations. The first section was completed in 1953 and the second in 1956 and it is of interest to note how the lessons and experience gained from the first installation were incorporated in the second.

For the first section it was considered that a passenger/service lift with signal collector control and four passenger lifts with a capacity of 15 persons per lift and a speed of 500ft/min, controlled by 'Express traffic control' would be sufficient. Using this electronic control system, all lifts automatically answer all registered calls from car and landings, with a supervisory system automatically despatching the lifts at pre-determined, but variable, timed intervals. The variation is carried out simply by the operation of a rotary switch which selects the most suitable time interval according to the traffic flow.

This flow is divided into three distinct periods. They are: (1) up-peak, when the tenants of the building are moving into their offices first thing in the morning and again immediately after the luncheon interval; (2) down-peak, when the passengers are hurrying to have lunch or to catch ferries after work; (3) off-peak periods between periods 1 and 2, when normal two-way traffic is prevalent.

This system in stage one of Alexandra House worked efficiently and economically moving a very large number of people and above all, clearing the lift lobby on the ground floor of waiting passengers. However, two objections were raised. The first was that the lift cars were always packed to capacity, a particularly trying situation in hot weather. The second was that tenants of the upper floors had too many stops en route.

To meet these objections a zoning scheme was introduced in which one lift served the ground to the 4th floor, one lift served from the 5th to the 7th floor, and a third lift from the 8th to the 11th floor, the fourth lift taking care of interfloor traffic and serving all floors. Although this satisfied the objections raised, it created delays and congestion on the ground floor, and slowed up the overall movement of passengers. There are only about 1 300 persons in this section of the building, but a recent survey showed that over 14 000 passengers a day were being moved by these four lifts.

Accordingly, when the second stage of Alexandra House was being planned it was decided to install five passenger lifts in this section and to divide the building into high and low zones; the line of demarcation being from ground to fifth floor for the low zone, and from ground to sixth-eleventh floor for the high zone. The 'Express traffic control' is again used with certain modifications catering for this peculiar type of lift traffic.

A further development introduced in stage two is an arrangement whereby, should it be apparent that high zone cars are exceptionally busy, a low zone car can be transferred to operate in the high zone, or vice versa, and thus help clear the passengers. A further arrangement is that any 'up' calls, whether in the high or low zone, will be answered automatically by a high-zone car as the ultimate destination might be in the high zone which a low-zone car could not reach.

To ensure a minimum waiting period on the ground floor, when two or more lifts are standing empty on the ground floor, a 'close door' button can be operated in each car. This prevents passengers entering more than one car per zone and leaving no car available, even though the lifts are not fully loaded. As soon as one car is full and starts on its journey the next waiting car on the ground floor receives a signal from the supervisory system which opens its door and allows passengers to enter.

BOOK REVIEWS

Linear Transient Analysis Vol. II Two Terminal-Pair Networks Transmission Lines

By E. Weber. 452 pp. 137 figs. Medium 8vo. John Wiley & Sons, Inc, New York. Chapman & Hall Ltd, London. 1956. Price 84s.

PROFESSOR Ernst Weber is Head of the Department of Electrical Engineering and Director of the Microwave Research Institute at the Polytechnic Institute of Brooklyn. This volume, the second of his new two-volume work *Linear Transient Analysis*, is concerned with the response of concentrated and distributed parameter 2-port networks studied by the methods of the Laplace and Fourier transformations. The first volume of the work was published three years ago and dealt with the response of 1-ports with concentrated parameters. Written from the point of view that no particular mathematical method should be given preference to any other, it contained a vivid account of the classical method, the operational methods of Heaviside and Jeffreys, and the transformation methods based on the Laplace and Fourier integrals. As the complexity of the network increases, however, the transformation methods emerge as the more powerful and are adopted exclusively for the study of the response of 2-ports in the second volume.

In order to make the second volume self-contained the first chapter reviews briefly the methods of the transformation calculus. The Fourier integral is introduced as the basis of modern transformation theory and the Laplace transform is interpreted as a generalization of the Fourier transform. The next four chapters are devoted to 2-ports with concentrated parameters. Chapter II defines the concept of 2-port (called four-pole) and introduces a time-domain adaptation of the Strecker-Feldtkeller matrix theory of 2-ports in tandem connexion. Certain basic passive 2-ports and their time responses are then considered in detail and the chapter concludes with a section on the envelope response of passive 2-ports to amplitude modulated signals.

Chapter III begins with a treatment of the general problem of iterated passive 2-ports as a preparation for the study of wave-filters. The topics discussed include the finite resistance-capacitance line, the indicial admittance of finite ladder configurations, the propagation characteristics of ladder filters, the lattice section, and the infinite wave-filter. The final section draws attention to analogous phenomena in mechanical, acoustic, and thermal systems.

In Chapter IV the author considers the response of ideal systems. The involved nature of the rigorous mathematical treatment of complicated 2-port configurations impedes theoretical investigation and the practical significance of the response functions is difficult to determine. The concept of an ideal system, although physically unrealizable, facilitates the study of more complex structures and affords a deeper appreciation of network behaviour. With the aid of the Fourier transform the time and frequency responses of ideal filters are discussed and deviations from ideal operation are examined. The chapter includes an exposition of the work of Bayard and Bode on the relations between the attenuation and phase characteristics of linear passive 2-ports and of methods of approximating distortionless transmission.

The thermionic valve and the transistor are introduced as linear active 2-ports in Chapter V. The author gives a convincing demonstration of the advantages to be gained by the use of the Strecker-Feldtkeller transmission matrix in the analysis of tandem connected active 2-ports but some of the elegance of the method is lost by avoiding the use of the immittance and hybrid matrices. This is particularly noticeable in the section on feedback amplifiers. An unfortunate error occurs on page 247 in connexion with the treatment of a single stage voltage-feedback amplifier. Because the problem is wrongly specified, the final expression (Eq. 94) for the gain of the system contains a minus sign which, if the amplifier load is capacitive, leads to possible instability for a step voltage input. The system is, in fact, inherently stable.

Distributed parameter 2-ports constitute the subject of the last three chapters of the book. Beginning with a critical study of the transmission-line concept, Chapter VI introduces the notion of travelling waves and solutions for non-dissipative and distortionless line problems are derived. Chapter VII deals with the ideal cable for which purpose new extensions of the inverse Laplace transform are developed. In the final chapter a more general treatment of transmission line problems is presented and the book concludes with five appendices giving lists of symbols and brief reviews of relevant mathematical principles.

The mathematical level of the book is higher than that of the first volume and, because the Laplace and Fourier transforms are used immediately, the reader is expected to be familiar with complex variable function theory. The considerable teaching experience of the author is reflected in the clarity of explanation and the well-planned sequence of theoretical development. Any engineer who strives to keep abreast of current developments in electrical engineering science will recognize the book as a significant modern treatise on the response of linear transmission systems.

S. R. DEARDS.

Electronic Analog Computers

By G. A. Korn and T. M. Korn. 452 pp. 80 figs. Demy 8vo. 2nd Edition. McGraw-Hill Book Co. 1956. Price 106s. 6d.

THE first edition of *Electronic Analog Computers* is already well known as the forerunner of books on such computers. Shortly after the publication of this edition, which took place at a time when the development of electronic analogue machines was gaining momentum, a number of important new techniques came into general use and consequently these were not covered by the first edition. The second edition, now published, rectifies this situation by the inclusion of much new material and the important developments of recent years, principally the drift-stabilization of direct-coupled amplifiers, are now covered. There are now signs that the period of rapid development of these machines may be over and consequently one might expect the contents of this new edition to remain representative of electronic analogue computer design for some years to come.

After an introductory chapter, basic procedures are outlined for setting up a d.c. analogue computer to solve a given set of differential equations. A large chapter is then devoted to examples of the application of d.c. analogue computers to representative practical problems relating to dynamics, servomechanisms and flight control. The remainder of the book deals with the design of computers and all important aspects are covered; including the basic components, drift-stabilized d.c. amplifier design, multiplication systems, diode function generators, controlling and programming systems and the layout of complete installations. Stress is rightly placed on the importance of adequate fault-finding facilities and checking procedures. An extensive bibliography covers all aspects of analogue computing.

A great deal of detailed information on alternative circuit arrangements, etc., is given in the form of figures and tables. While such a form of presentation makes the book valuable as a work of reference, the complex figures distract and the result is a book which is not easy to read. For this reason, and also because the examples illustrating the applications of electronic analogue techniques tend to be elaborate, this book would seem to serve best as a work of reference for those who have already some knowledge of analogue computers.

J. J. GAIT.

Electricité

By Y. Rocard. 614 pp. 652 figs. Demy 8vo. 2nd Edition. Masson et Cie, Paris. 1956. Price paper covered 3 000 Fr, bound 3 500 Fr.

THIS is the second edition of a book published first in 1950 which was based on a course of lectures held at the Sorbonne in 1941-42. It is a remarkable book in so far as it confines itself not only to a comprehensive treatment of electrical theory on classical lines but that it is brought very much up to date. So for instance it gives brief accounts of such recent developments as radar, transistors, the use of very short waves for radio communications, the electromagnetic pump as used for moving liquid metal for cooling nuclear reactors, the magnetic mine, interplanetary communication, radioastronomy, the klystron and travelling wave tubes—to mention only a few of those new applications.

There are nine sections, each consisting of several chapters. The first four sections deal with electrostatics, magnetism, electrokinetics and electrodynamics. In this last named section Maxwell's equations are given and direct current machines are briefly dealt with. The fifth section is devoted to alternating current. In dealing with impulse and transient phenomena use is made of Heaviside's operational calculus. Propagation and radiation form the subject of the sixth section which contains chapters on waveguides and diffraction problems. Priority as regards radar techniques is claimed for the tests made in 1934 by Gutton and Ponte on SS. *Normandie*. In the seventh section dealing with the free electron the influence of relativity theory and quantum mechanics is briefly dealt with, electron optics, photoelectric effects, the electronic valves and the influence of the upper atmosphere on radio communication are discussed. The eighth section is devoted to electrolysis and the semiconductors. The ninth and final section deals at some length with the question of unit systems. While admitting the advantages of the rationalized Giorgi system the author expresses his doubts whether the time is ripe for introducing it generally into French technical education.

Some less known historical data enliven the text. A few critical remarks may be made. While descriptions are given of the Van de Graaf particle accelerator and the betatron no reference could be found to the cyclotron. Owing to the great wealth of subjects dealt with only little space could be devoted to some of them and some more references to the respective literature might have been desirable.

But these are minor criticisms and there is no doubt that this well produced book is very suitable for the instruction of students of physics and electrical engineers on a somewhat advanced level. They should be familiar with the elements of vector analysis.

R. NEUMANN

Proceedings of the Second RETMA Conference on Reliable Electrical Connections

103 pp. 53 figs. Demy 8vo. Engineering Publishers, New York. 1957. Price $5·00.

THIS book is the proceedings of a conference sponsored by the Radio-Electronics-Television Manufacturers Association and the Department of Defence Advisory Group on Electronic Parts, held in Philadelphia on 11-12 September last, with the co-operation of the University of Pennsylvania. The conference was attended by engineers, management personnel and U.S. government representatives.

Vacuum-Tube Circuits and Transistors

By L. B. Arguimbau and R. B. Adler. 646 pp. 70 figs. Demy 8vo. Wiley & Sons, Inc, New York. Chapman & Hall, Ltd, London. 1956. Price 82s.

WITH the exception of the chapters on transistors the material in this book is essentially the same as that given in the first author's *Vacuum-Tube Circuits* published in 1948. The subject matter is mainly concerned with electronic circuits as applied to the communications field with a marked bias towards the various aspects of frequency modulation. The properties of electron devices themselves are mentioned only briefly and the reader would need to have studied these previously.

The book is unusual in that considerable use is made of examples in order to illustrate points not fully explored in the text. Some of these examples are by no means easy and it is clear that the reader is expected to have a good prior knowledge of circuit analysis and a.c. theory. The benefit derived from this unconventional approach depends on the reader's energy. A capable student working through perhaps half of the examples would have little need for further instruction on the material in the book. However, an engineer engaged in electronics is unlikely to be enthusiastic about examples and may well regard this feature as a disadvantage.

The first three chapters deal with the diode rectifier and with the use of the equivalent circuit to solve simple triode and pentode problems. The discussion on valve parameters (p.54-55) is somewhat confused and no mention is made of the fact that valve parameters vary with the operating conditions. Chapters IV and V which deal with the physics of semiconductors (some 50 pages) and with the use of transistors in linear amplifiers are written by Professor Adler of MIT. The various equivalent circuits applicable to transistors are developed in a logical manner and the limitation of the high frequency performance is explained. The argument is developed, as in the main part of the book, by the frequent use of problems.

The remainder of the book deals with the application of the basic ideas of the earlier chapters to various communications topics. These include video and power amplifiers, oscillators, feedback and modulation. There is also a chapter on television, based on the U.S. system, and one on transit time effects leading to the properties of the klystron valve.

The book is well written and has numerous circuit diagrams and graphs. However, there are already several excellent texts which cover roughly the same material and requiring less prior knowledge of both circuit analysis and of the nature of electron devices; this makes it difficult to visualize the type of reader to whom this book would particularly appeal.

V. H. ATTREE

The Electrical Production of Music

By Alan Douglas. 223 pp. 152 figs. Demy 8vo. Macdonald & Co. (Publishers) Ltd. 1957. Price 28s.

THE creation of musical sounds by electrical means involves much of that technique which concerns sound reproduction and, in addition, an understanding of the physics of sound, some knowledge of the characteristics of existing musical instruments and of music itself.

While many electrical engineers are familiar with sound reproduction, few have any particular knowledge of music or musical instruments.

Here, conveniently in one volume, are concise details of the physics of known instruments, explanations of relevant musical matters—scales and so on—and an approach to the intricate study of starting conditions and noise content of present instruments. There is an account of various methods of generating suitable waveforms by electrical methods and of forming musical tones from them. A chapter is usefully devoted to the loudspeaker, ultimate producer of created tones. The last chapter—to the reviewer the most interesting and disturbing—explains what the author considers to be the limitation of existing instruments and suggests possible methods of "improving" them. It also contains a hint of present and future research into new sounds, and indeed, new music.

Composers are seeking means of expanding musical expression. They have apparently exhausted the harmonic and melodic possibilities of the present twelve-tone octave; they look for new sounds and the ability to use new scales. The next logical step seems to be from the half tone to third or quarter tones. It does seem that electronics may offer one possible way of providing these intermediate tones in such a way that they can be played. This was formidably difficult by mechanical methods. If any worthwhile new tone colours are waiting to be found, they may well be produced by electrical means. The only new instruments in the last fifty years have been electrical and at least two of them are being used by serious composers for important works. Notably, the Ondes Martenot and the Trautonium.

Now there is a real danger that the electrical engineer may be overcome by his creative urge and usurp the composer as is in fact happening to some extent in the recent Musique Concrete in France. To quote a reviewer of records. "This is neither music nor concrete. . . ."

As a musician, the reviewer hopes that Mr. Douglas' suggestions of the limitations of existing instruments and his hints of "improvements" will not be taken too seriously. Such "improvements" could be the end of music as an art.

Nevertheless, this book will be a most useful companion to those interested in the making of electrical musical instruments or for seekers of new sounds.

STANLEY L. MILLER

Impulse und Schaltvorgänge in der Nachrichtentechnik (Impulses and switching operations in communications engineering)

By Dr. Heinrich Kaden. 304 pp. 192 figs. Large 8vo. R. Oldenbourg. München. 1956. Price DM 32.

THE author of this book is a chief scientific officer of the central laboratory of the Siemens works and a lecturer at the Technical University of Munich. It is a highly theoretical treatise giving the mathematical background for quite a number of practical applications mainly in communication engineering, but partly also of importance in power engineering. Wire and wireless telegraphy and telephony, television, switching operations on transmission systems using cables or overhead lines are dealt with.

The book has nine chapters, the first one giving a brief introduction. In the second chapter the Fourier integral is derived starting from the Fourier series. A number of examples both for the application of the series and of the integral is given and both are expressed either in their real or their complex form. Statistical methods essentially due to the work of Norbert Wiener are introduced in the third chapter. Autocorrelation function and power spectrum are defined, and as examples a triangular, an exponential and Gauss error function are discussed. These same functions are also used to show the determination of mean values. Other examples concern the thermal noise and the black body radiation. In order to show the application of the Fourier integral on switching operations the transmission factor and its reciprocal, the "Stammfaktor", are introduced in the fourth chapter and examples for the latter are given. Then it is shown how Fourier integrals may be evaluated by the aid of the theory of functions and particularly by the use of the residue theorem. After a brief explanation of Heaviside's formula the distortion of impulses on homogeneous cables is investigated for the three cases of an open, a short-circuited and a characteristic impedance loaded end of the cable. Then some television problems and the delay of magnetic switching operations due to eddy currents are discussed. In the brief fifth chapter the Laplace transformation is treated as a special case of the Fourier transformation. In the sixth chapter the communication systems are schematically treated and the connexion between attenuation and phase is discussed. The seventh chapter deals with signal distortion in telegraphy. D.C. systems and a.c. systems with amplitude and frequency modulation are investigated. In the eighth chapter the transmission of television signals with special regard to single-sideband systems and to non-linear distortions are discussed. The ninth and final chapter deals with pulses and particularly with their use for measurements on lines. A name and subject index conclude this well produced book which should be of special value to students and research workers in this field.

R. NEUMANN.

Transistor Engineering Reference Handbook

By H. E. Marrows. 288 pp. Demy 4to. John F. Rider Publisher, Inc. 1957. Price $9·95.

THIS book is divided into five major sections. The first section deals with the discussion of transistor materials, structures and manufacturing techniques. Section II gives information on some 200 types of commercial transistors in the form of technical specification sheets.

Section III is devoted to components designed for use with transistors. Physical and electrical specifications are listed for over 200 different types of transformers, 450 capacitors, more than 100 cells and batteries, a selection of thermistors, and a variety of miscellaneous components.

Section IV gives reference data on commercial applications of transitors.

Induction and Dielectric Heating

191 pp. 154 figs. Demy 8vo. British Electrical Development Association. 1957. Price 9s.

THIS book indicates how vital a part electricity plays in a wide range of new processes; how, with the aid of dielectric heating, new uses of synthetic materials have revolutionized the conception and design of many articles in everyday use; and how the adoption of well chosen applications of induction heating or dielectric heating results in better factory conditions and increases productivity.

Short News Items

The opening ceremony of the 1957 Electronics Exhibition and Convention (11-17 July), organized by the Northern Division of the Institution of Electronics, will be performed at the College of Science and Technology, Manchester, at 2.30 p.m. on Thursday, 11 July, by Rear-Admiral Sir Philip Clarke (Retd), K.B.E., C.B., D.S.O. The patron of the exhibition, the Right Worshipful the Lord Mayor of Manchester (Alderman Leslie Lever, J.P., M.P.), will be present. The exhibition will include a Manufacturers' Section with displays from over fifty manufacturers, and a Scientific and Industrial Research Section with displays from the British Railways Research Department, the United Kingdom Atomic Energy Authority establishments and from H.M. Services, etc. The convention will include lectures and film shows on a wide range of electronic topics. Complimentary admission tickets may be obtained from the Hon. Exhibition Organizer, Mr. W. Birtwistle, 78 Shaw Road, Rochdale, Lancs.

An Institution of Electronics lecture will be held at 6 p.m. on Friday, 5 July, in the Beveridge Hall of Senate House, University of London. It will take the form of a joint lecture, illustrated by sound film and slides, on the following topics: The Theoretical Problems of Television Astronomy by P. B. Fellgett and The 1956 Opposition of Mars by B. V. Somes-Charlton. The meeting is open to members and friends and non-members are also invited. Admission tickets are available from the Hon. General Secretary, Mr. W. Birtwistle, 78 Shaw Road, Rochdale, Lancs, or from Mr. C. H. Messenger, 38 Hainault Court, Forest Rise, London, E.17.

The Women's Engineering Society is organizing a Conference to be held in Coventry on 13 and 14 July, to bring together representatives of industry, the Youth Employment Service, schools, technical colleges, universities and the Society's own members. The intention is to encourage an exchange of ideas and information on the whole subject of the technical training and employment of girls. Further information may be obtained from the Conference Headquarters, 26 Victoria Street, London, S.W.1.

The Physical Society has announced that a conference on Materials for Nuclear Engineering will be held at The Associated Electrical Industries Ltd., Aldermaston, Berks, on 11 and 12 July.

The Television Society has awarded the following premiums for outstanding papers read before the London meeting in 1955/56.

The Electronic Engineering Premium to Mr. D. C. Birkinshaw (BBC Television) for his paper on Progress in American Colour Television.

The Pye Premium to Mr. R. A. Dilworth (Post Office Engineering Department, Radio Branch) for his paper on Interference with Television Reception: Its Causes and Cures.

The E.M.I. Premium to Mr. A. H. Atherton (E.M.I. Research Department) for his paper on The Secondary Emission Valve and its Applications.

The Mullard Premium to Dr. R. L. Smith-Rose (D.S.I.R. Radio Branch) for his paper on Properties and Problems of Bands IV and V.

The Mervyn Premium to Mr. H. A. Fairhurst (Murphy Radio Ltd) for his paper on The Development of a 21in Colour Television Receiver.

The Wireless World Premium to Mr. A. V. Lord (BBC Research Department) for his paper on Some Problems in a Band-Sharing Colour Television System.

The Royal Air Force College at Henlow, Bedfordshire, is to buy an Elliott G-PAC analogue computer for use in the study of guided weapons problems, and for instruction in the latest techniques of simulating problems encountered in this work. Another Elliott G-PAC computer has been ordered by Dowty Fuel Systems Ltd of Cheltenham, Gloucestershire, for the study of fuel systems and other allied problems.

The new transmitting station now being built by the Independent Television Authority at Black Hill, Lanarkshire, will provide a service for about three-quarters of the population of Scotland.

The Independent Television Authority has now carried out its decision to appoint a Scottish Committee which will advise it concerning the general conduct of independent television in Scotland. The Chairman of the Committee is Dr. T. J. Honeyman. Mr. H. N. C. Stevenson, O.B.E., has been appointed Executive Officer in Scotland.

George Ellison Ltd of Birmingham have announced that their branch office in London, and that of their associate company, Tufnol Ltd, has been transferred from Victoria Street to Ellison House, Connaught Place, London, W.2. The telephone number is Ambassador 3121.

Mr. H. F. Smith, Editor of Wireless World since 1941, has retired after thirty-two years' service with this Associated Iliffe Press journal. Mr. Smith's successor is Mr. F. L. Devereux, who has been with Wireless World for thirty-three years.

Mr. Brian Bromwich has been appointed Chief Press Officer of the General Electric Co Ltd, in succession to Mr. D. C. Rogerson, who has been appointed Deputy Publicity Manager (Engineering).

Mr. P. R. Coursey has retired from his position as Technical Director of the Dubilier Condenser Co Ltd, but he is remaining on the Board as an Ordinary Director and being retained as a Technical Consultant. Mr. Coursey was first associated with the company in 1912. His activities connected with the electrical industry have been extensive; he is a member of various professional and technical institutions in this country, the U.S.A., and France; Chairman of the BEAMA Power Capacitor Technical Committee and a member of various committees of the E.R.A., all of which he is hoping to continue. Mr. Coursey has published many technical papers to institutions and societies and is the author of several books concerning capacitors.

The Solartron Electronic Group Ltd, as a result of arrangements finalized by Mr. J. E. Bolton, Chairman and Managing Director, during a recent visit to the United States, will manufacture the Rheem F.151 Gunnery Trainer under licence in Britain.

E.M.I. Electronics Ltd of Hayes, Middlesex, have announced that, under an agreement between them and Log-Etronics Inc, of Alexandria, Virginia, U.S.A., the former have secured the rights to manufacture under licence in this country automatic photo printer exposure control equipment and to sell it throughout the British Commonwealth and other countries. The agreement also provides for joint participation in and integration of future development work for this and kindred devices in the photographic and other fields.

The new factory extension and plant at English Abrasives Corporation, Tottenham, were officially opened on 31 May.

LETTERS TO THE EDITOR

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

High Current Low-Tension Transistor Stabilizers

DEAR SIR,—A lot of thought has been given to stabilized power supplies using transistors[1,2,3,4], since they are much more attractive from the viewpoint of efficiency than valves[5]. The following circuit may be of interest.

In Fig. 1 X_1 represents the series regulating (power) transistor. The voltage necessary to drive this transistor will only be a little more negative than the output voltage. However, the current gain β of X_1 will be small for large emitter currents. Therefore X_1 is driven by emitter-follower X_2. For an output of 3A the base-current of X_2 will be of the order of some milliamperes; this is supplied through the emitter resistor R_3 of npn transistor X_3. The base-voltage of X_3 will have to vary between $-0{\cdot}5$ and $-1{\cdot}5$V approximately with respect to the emitter of X_1 for output currents from 0·5 to 3A, V_{out} being constant within 100mV.

In order to minimize loss of signal voltage over the potentiometer R_1, the voltage of the emitters of X_4 and X_5 should be near the output voltage; this fits in very well with the voltage requirement for X_3.

It is necessary to introduce a second supply voltage E_2 (e.g.—23V) to derive any appreciable gain from X_4. As the power dissipation limits of X_1 (which has already to be mounted on a heat sink of $25\times25\times0{\cdot}5$cm of aluminium) should not be exceeded, the voltage drop over X_1 must be kept low. Thus it is impossible to use the input voltage of the stabilizer for E_2. The current which must be delivered by this second supply is quite negligible, 10mA being sufficient. Usually there is no need to stabilize E_2.

Of course, transistor X_5 can be discarded when the reference voltage (14V, supplied by two Zener diodes) is applied to the emitter of X_4. However, using the longtailed-pair arrangement[6] the temperature stability of the circuit is increased. As the bases of both X_4 and X_5 are driven from a low impedance, any increase of I_{c0}' flowing through R_2 which is fairly large, will be heavily counteracted by a decrease of base-current.

The circuit, which is still in the development stage, will supply 0·5 to 3A at 16V ±100mV, while an ambient temperature variable between 20 and 40°C, causes an output voltage variation of less than 50mV. These figures were obtained with a source voltage E_1 of 23V, R_1 being 1·6Ω.

Investigations are being carried on to make it possible to use a larger R_1 and/or to obtain better stabilization. The use of a transistor parallel to X_1 was considered, but this implies the use of separate collector resistors for the parallel series regulating transistors to keep the collector currents more or less equal[2].

It seems a better idea to use a complementary (npn) transistor between E_1 and earth, connecting the respective bases of the series transistors to some kind of phase invertor (Fig. 2). Then the voltage drop over R_1 can be compensated by two transistors, each dissipating approximately half as much as X_1 in Fig. 1. In this way R_1 could be approximately doubled. Of course, there is a difficulty in obtaining equal voltage drops over both series transistors. Unfortunately, npn power transistors are as yet difficult to obtain in this country.

To increase stabilization, transistor

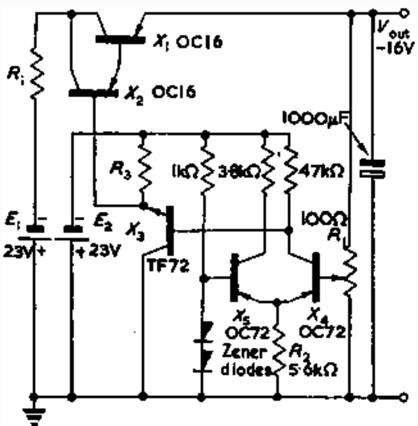


Fig. 1. Basic stabilizer circuit

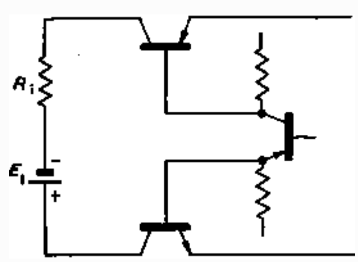
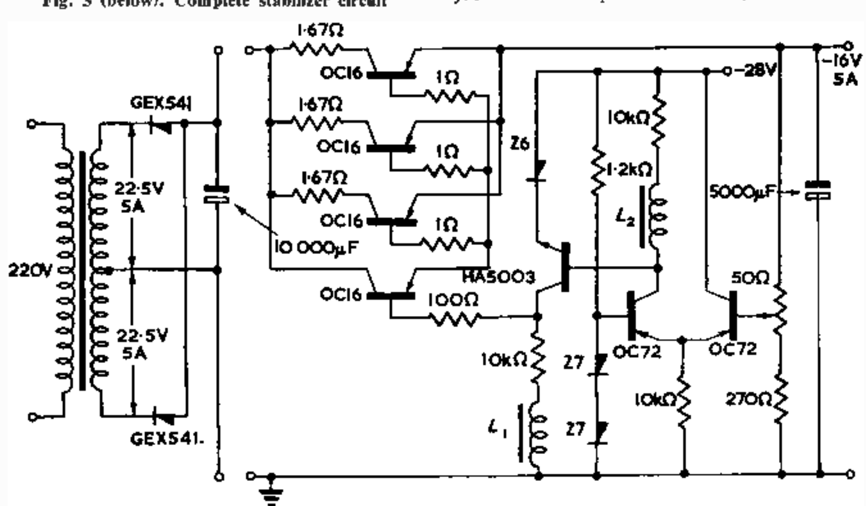


Fig. 2 (above). Phase invertor

Fig. 3 (below). Complete stabilizer circuit



X_5 (Fig. 1) can be used in a common emitter configuration. Then it is convenient to insert a Zener diode (instead of R_2) in the emitter lead, keeping the voltage difference between the base of X_3 and the collector of X_4 within reasonable limits. Of course, the base of X_3 cannot be connected directly to the collector of X_5 as the collector resistance of X_5, and hence its voltage amplification, would become negligible. A series-resistance of about 1 000Ω seems to be an optimum. Then the base of X_2 is connected to the collector of X_3, which is returned to earth through a resistance of about 5·6kΩ. Another way coupling X_3 in its common emitter configuration to X_5 is the use of a sixth transistor as an emitter-follower between X_5 and X_3.

In order to obtain a better frequency response of the d.c. amplifier, inductors can be connected in series with the collector resistors. With these inductors it should also be possible to suppress any tendency of the circuit to oscillate, due to the feedback becoming positive at higher frequencies.

It is believed that the use of appropriate temperature-stabilizing measures will be less complicated than reverting to any form of a.c. amplification[2].

Further developments are illustrated in Figs. 3 and 4.

The stabilizer of Fig. 3 was developed along the lines indicated above. Zener diode Z6 is inserted in the emitter load of transistor HA5003 as maximum peak voltage on this transistor should not exceed 20V. As the output voltage of the stabilizer illustrated in Fig. 4 had to be constant within 1 per cent and the gain of the amplifier illustrated in Fig. 3 could not be boosted, parallel stabilization was reverted to. The parallel regulating transistor OC16 being connected in a common emitter figuration the over-all voltage gain is increased. Thus the preceding amplifier had only to be altered slightly. These 2 units have been subjected to temperature tests; the −16V

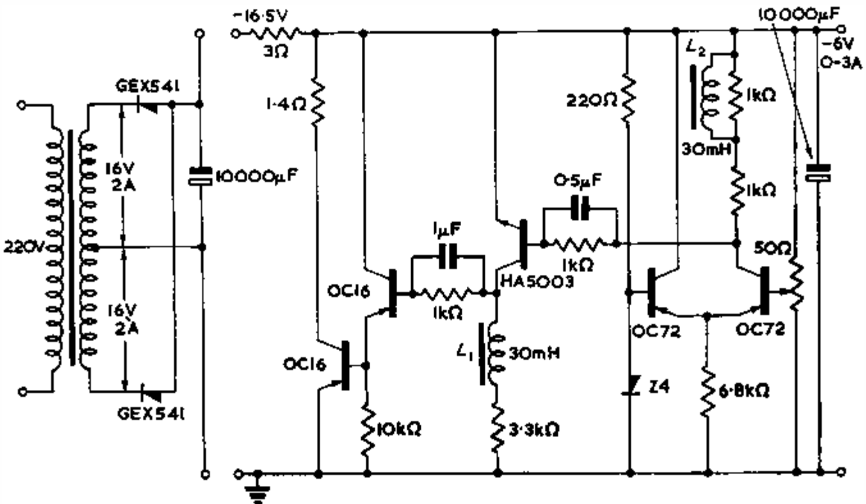


Fig. 4. Parallel stabilizer

supply will vary less than 200mV, the −6 less than 60mV over a temperature range of 20 to 40°C. This is mostly due to a variation of Zener breakdown voltage of the reference diodes.

Stabilization is better than 1 per cent for no load to full load, for frequencies from 0 to 250kc/s with simultaneous mains fluctuations of ±10 per cent.

The writer is indebted for assistance to N. Baesjou and R. Lapierre Armande.

Yours faithfully,

W. VAN DE STADT,
Computer Laboratory,
Mathematisch Centrum,
Amsterdam.

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3. JOHNSON, K. C. A Power Stabilizer Using Transistors. *Electronic Engng*. 29, 95 (1957).
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5. HAYWARD, R. K. JENNINGS, J. C., BARKER, R. C. Regulated D. C. Power Supplies at Low Voltages. *Electronic Engng*. 27, 304 (1955).
6. SLAUGHTER, D. W. Feedback-Stabilized Transistor Amplifier. *Electronics*. 28, 174 (May, 1955).

Waveguide Surface Finish and Attenuation

DEAR SIR,—In their paper in the November 1956 issue, Dr. Allison and Dr. Benson report the results of waveguide attenuation measurements and quote experimental figures for α'/α in copper and brass guide in the ranges 1·102 and 1·060 −1·074. Since α for 1in by 0·5in copper guide is only 0·1dB/m, the figures indicate that the authors have achieved a very high accuracy in attenuation measurement. It would be of interest to know the authors' estimate of the accuracy of the method, the length of guide employed and the reflection coefficient of the short-circuit termination.

Yours faithfully,

N. E. GODDARD,
London S.E.26.

The authors' reply:

DEAR SIR,—We thank Mr. Goddard for his letter. In our latest measurements the attenuation of each waveguide sample was obtained by a technique similar to that due to Vogelman[1] which is a modification of the Roberts and von Hippel method. Vogelman claims that his technique can be used to evaluate attenuations as low as 0·001dB and accuracy of ±5 per cent is attainable when measuring an attenuation of 0·01dB at wavelengths around 10cm. Although it was not found possible to measure attenuations as low as those recorded by Vogelman the method was found to be extremely useful and accurate when measuring attenuations around 0·2 to 0·3dB. This required lengths of copper guide of the order of 6 to 9ft.

The main source of error is due to the very small distance w to be measured between the half-power points of the standing wave pattern. For example, if the attenuation to be measured is 0·3dB, there will be a voltage standing-wave ratio r of the order of 30 and w will be around 0·04cm. With the slotted line available, micrometer location of the probe enabled such resonance-curve widths to be measured to an accuracy of ±2 per cent. Again, the loss in the short-circuit termination as measured by the same method was 0·06dB ±10 per cent (i.e. $r \simeq 150$). Since the measuring technique takes account of the loss in the slotted-line and the mismatch between it and the test sample, the overall accuracy of one measurement of a length of copper waveguide of length say 9ft can be estimated as of the order of ±4 per cent. Since the measurements were carried out several times on the same sample, however, and repeated on other lengths of the same waveguide to obtain a mean value for the attenuation per unit length, the overall figure for the error in this mean value is likely to be less than ±4 per cent.

Yours faithfully,

J. ALLISON,
F. A. BENSON,
Department of Electrical Engineering,
University of Sheffield,

REFERENCE

1. VOGELMAN, J. H. "Precision Measurement of Waveguide Attenuation." *Electronics* 26, p. 196. (December 1953).

PUBLICATIONS RECEIVED

CAREERS IN THE TELECOMMUNICATION INDUSTRY is the subject of a recent booklet produced by the Telecommunication Engineering and Manufacturing Association, 40-43 Norfolk Street, London, W.C.2.

SILICONE COMPOUND MS 5 is the title of a recent publication issued by Midland Silicones Ltd. This compound, originally developed as a lubricant for silver plated switch contacts and instrument movements, subsequently found other fields of application due to its ability to retain excellent dielectric properties after long exposure to wet or humid conditions. In addition to its high degree of water repellency, it is resistant to chemical attack, salt spray and fungi. Copies of the publication are available on request to Midland Silicones Ltd, 19 Upper Brook Street, London, W.1.

WORKSHOP AUXILIARY EQUIPMENT by BTH is a booklet which includes interesting information on electrical, mechanical and electronic aids to productivity, the equipments described being of the kind frequently needed by the works engineer when planning industrial installations. The British Thomson-Houston Co Ltd, Rugby.

M.E.L. MAGNESIUM FABRICATION FACILITIES is the first of a series of publications to be published by Magnesium Electron Ltd, 21 St. James's Square, London, S.W.1. The booklet has marginal notes to enable readers to find the points in the text in which they are particularly interested. The cover symbolizes M.E.L.'s production of magnesium rolling slabs for rolling down into sheet and the forming of this sheet into finished products.

THE RADIO AMATEUR'S HANDBOOK Thirty-fourth edition, has recently been published by the Headquarters staff of the American Radio Relay League. It has been revised and restyled in the light of current needs as a radio construction manual, reference work, and training text for class or home study. The American Radio Relay League Inc, West Hartford 7, Connecticut, U.S.A. Price $4·50 outside the United States, U.S. Possessions and Canada.

SIMONSTONE is a brochure which describes and illustrates one of the new Mullard factories. It gives some idea of what is involved in the manufacture of modern television tubes. Mullard Ltd, Mullard House, Torrington Place, London, W.C.1.

U.H.F. TUBES FOR COMMUNICATION AND MEASURING EQUIPMENT and TUBES FOR COMPUTERS are two recent additions to the publications of Philips' Technical Library, Holland. Distributed in the United Kingdom by Cleaver-Hume Press Ltd, 31 Wright's Lane, Kensington, London, W.8.

THE INDEX OF TECHNICAL ARTICLES is a monthly index of articles published in British technical periodicals, the first issue of which was published in February. IOTA Services Ltd, 38 Farringdon Street, London, E.C.4.

TUBE SELECTION GUIDE 1956-1957 has recently been published by Philips' Technical Library, Holland. Distributed in Great Britain by Cleaver Hume Press Ltd, 31 Wright's Lane, Kensington, London, W.8.

THE SOLARTRON ELECTRONIC GROUP ANNUAL REVIEW 1956 includes a survey on 'Electronics—The Spearhead of Automation' by Mr. Bowman Scott, a director of the Group and also the Managing Director of Solartron Electronic Business Machines Ltd. Some of the examples of the applications of electronics in automation are illustrated by reference to Solartron electronic instruments. Copies of the review are available on request to the Solartron Electronic Group Ltd, Thames Ditton, Surrey.

ELECTRONIC EQUIPMENT

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

CABLE-FORM TESTER

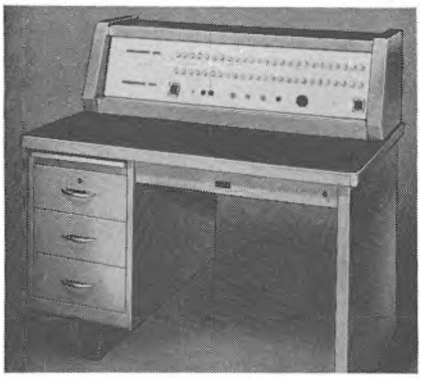
(Illustrated below)

Gale Electronics Ltd, Tudor Grove, London, E.9

THE ATC 25 is an electromechanical instrument developed to facilitate the speedy checking of cable-forms in production quantities, or the determination of the connexions of an unknown cable-form up to 25 ways.

Two functions are provided, namely auto and manual, selection being made by a simple changeover switch.

In automatic use the machine will run continuously after being started off by operation of the push-button mounted on the front edge of the test bench, and will stop only on the discovery of a fault or at the end of a test sequence. The test



consists of a comparison of continuity between a cable-form connected between the adapter boxes and a master circuit plugged into the front panel of the instrument. Any discrepancy between the two will cause the machine to stop, and the reason for the stoppage will be indicated by lamps on the front panel. A note of the fault indicated can be made, and a further operation of the start button will cause the test to continue.

Each wire is tested with respect to all other wires, the testing times being of the order of 16sec for a simple 25-way cable-form.

To avoid the time which would otherwise be wasted by using the complete 25-way system when a lesser number of wires are involved, an automatic homing switch is incorporated which can be set at the positions 6- 12- 18- 25-way. The machine will test up to and including the number set and then immediately 'home' to its normal rest position. This facility is available on either position of the function switch.

The comparator effect of the machine can also be used to determine the wiring of an unknown cable-form since, by running without a master circuit in position the machine will seek, stop at, and indicate (as a connexion fault) all the connexions made in the unknown cable-form.

The manual position of the function switch will cause the machine to stop not only at faults but also at all correct connexions. A cable-form can thus be tested one wire at a time when investigating intermittent conditions.

The test voltage applied to the cable-form under inspection is 6V and current does not exceed 70mA.

The standard equipment is provided with 25-way Unitor type sockets into which adaptor boxes for any type of termination may be plugged. When testing cable looms, spring connexions are provided on the wiring board which are connected to the test equipment.

The 'master' cable-forms used can be actual cable or, where storage of standards is a problem, special 'program' plugs.

MATCH TEST INDICATOR

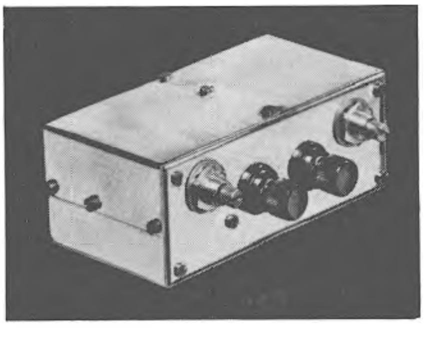
(Illustrated below)

Millett, Levens (Instruments & Engineering) Ltd, Stirling Corner, Barnet-By-Pass, Borehamwood, Hertfordshire

A USEFUL type of symmetrical directional coupler employs coupled transmission lines. One physical form of the device employs lead-covered cable. The manufacture of such a coupler entails accurate milling of the flats on the cable, a great care in soldering lest the polythene insulant should melt. By employing strip-line instead of cable, a printed circuit equivalent is possible and an actual coupler, comprising a through line and two auxiliary lines, has been manufactured. The instrument serves as a match indicator, reflectometer, and true output power monitor over the frequency range 150 to 500Mc/s. Standing-wave ratios down to 1·2 to 1 can be measured at 500Mc/s with an accuracy of 20 per cent. It is simple, compact and robust.

The printed circuit is made from a laminated paper board copper clad on both sides. One side of the board consists of three short sections of transmission line, each having a characteristic impedance of 75Ω. On the other side of the board the copper is retained. The transmission lines are therefore single strip above and earth-plane type, with laminated-paper dielectric.

The middle strip-line carries the radio-



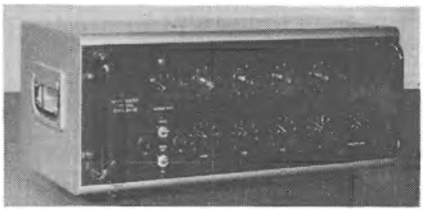
frequency energy and the two auxiliary strip-lines, one on each side of the main line, are coupled to it by virtue of their mutual capacitances and inductances. The direction of the current so induced in each auxiliary line due to the couplings is such that the two components will tend to cancel in one direction and add in the opposite direction. The resulting voltages obtained across the auxiliary line terminations are, therefore, dependent on the direction of power flow in the main line; i.e., the unit will exhibit directional properties.

BATCH COUNTER

(Illustrated below)

Ericsson Telephones Ltd, High Church Street, New Basford, Nottingham

THIS industrial batch counter, now being produced by the Instrument Division of Ericsson Telephones Ltd., has



a maximum counting speed of 350p/s and has been designed for counting into batches of any given number of objects of varying size and shape. The count is displayed on Dekatron tubes and the required count per batch is set up on rotary switches and can be any number up to the total count of 10 000. The instrument can also be used for the measurement of lengths.

The necessary input pulses can be obtained from mechanical, photo-electric or electromagnetic devices and output facilities suitable for the control of chute flaps and other equipment are available.

When the selected count per batch has been completed, the instrument automatically resets and the counting of a further batch commences. Seven paralysis times for overcoming the spurious pulses which sometimes arise in counting irregularly shaped objects are selected by means of a rotary switch.

A manual reset switch is also provided.

Additional equipment can be incorporated in the batch counter type 108 to give the following facilities:—

An electrochemical register for recording the total number of batches.

A warning signal unit for the operation of a lamp or bell 10 or 100 counts before the end of a batch.

A control unit which provides alternate output pulses each having the duration of a batch. These are suitable for alternately operating a pair of solenoids which can be used to control two chute flap mechanisms.

All the necessary photo-electric heads, lamp housings and chute mechanisms suitable for certain applications can be supplied with the instrument.

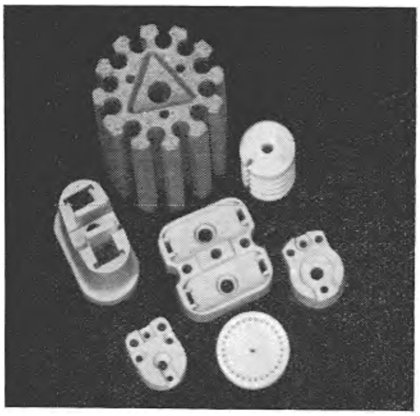
CERAMIC PRODUCTS

(Illustrated below)

Distributed by: W. Greenwood (London) Ltd, 110 Peters Court, Porchester Road, London, W.2

IN addition to offering a wide range of standard insulators Sembach & Co, of Germany, will manufacture any type of electro-ceramic product from customers' drawings.

The materials available include 'Steatite', 'Stealon' which is a low loss material for radio and high frequency applications; 'Pyrostat' which is suitable for heating element supports, and 'Super-Pyrostat' which can be used for insulating beads and thin walled tubes for immersion heaters, etc.



The illustration shows a few typical products.

RADAR TRACK INDICATOR

(Illustrated above right)

The Marconi International Marine Communication Co. Ltd, Marconi House, Chelmsford, Essex

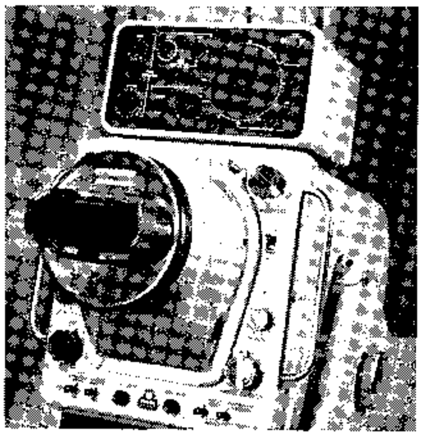
A NEW radar track indicator has been designed for use with Marconi Marine 'Quo Vadis XII' and 'Radiolocator IV' radar equipments. The new system can be added to existing installations with a minimum of modification, and enables the navigator to select, at the turn of a switch, the type of presentation best suited to his immediate needs—north stabilized, ship's head up, or track indication which enables the true course and speed of other vessels to be seen on the display.

The control unit of the radar track indicator can be conveniently mounted on top of the display unit, and does not interfere with the conventional use of the equipment for navigational purposes.

When the track indicator is in use, the course, speed and tidal drift of the observing vessel are applied, through the track indicator, to the centre of the p.p.i., which therefore traverses the display in a manner representing the actual track and speed of the vessel. As this same movement is applied automatically to all echoes on the screen, the true track and speed of a vessel under way can be seen at a glance, while stationary targets will remain stationary on the display.

All information concerning course, speed and tidal conditions, is fed into the track indicator continuously and automatically. The true course is obtained directly from the gyro compass, and as with all Marconi radar equipment, the scanner is inherently aligned with the display. The observing ship's speed can be set on an artificial log on the control unit, or fed in from a suitable type of ship's log. It can also be obtained directly from many of the systems which indicate engine revolutions, in which case an allowance for slip can be set on the control unit. Tidal information is also set on the control unit, and once the rate and direction of drift have been set this correction is applied continuously to all echoes regardless of the course steered.

As the observing ship's position approaches the edge of the screen in its traverse, a warning note informs the



navigator that the display requires no resetting. The starting point of the traverse and the boundary point at which the warning note sounds can be selected by the navigator.

During the traverse of the display across the face of the cathode-ray tube, the true bearing of any target can be determined by switching on an electronically generated flash which radiates from the observing ship's position in the form of a dotted line. This is a compass stabilized bearing indicator, the dotted formation of which renders it easily distinguishable from the heading marker, which is a full line. A bearing control enables this dotted line to be set to cut any target on the display, and the true bearing can then be read off from the bearing indicator scale on the control unit.

The illustration shows the track indicator unit fitted to the 'Radiolocator IV' radar equipment.

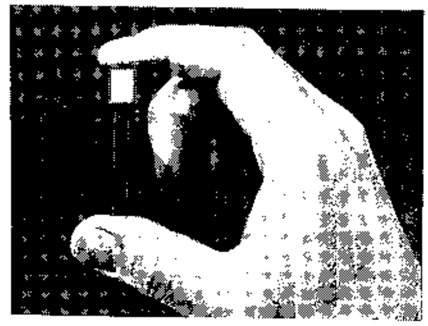
SUB-MINIATURE CRYSTAL

(Illustrated above right)

Cathodeon Crystals Ltd, Linton, Cambridgeshire

THIS sub-miniature crystal, known as the 'Cub', measures only 0·517in × 0·421in × 0·171in.

The 'Cub', which has a frequency range of 20 to 60Mc/s, has been designed for very high frequency applications where space is at a premium, and can be soldered directly to miniature switches or



into printed circuits. It is particularly suitable for frequency synthesizing in transmitters and receivers and for use in guided missiles.

Without oven control this new crystal gives frequency tolerance of ± 0·005 per cent over a range − 55°C to + 105°C.

ULTRA LIGHTWEIGHT BATTERIES

(Illustrated below)

Chloride Batteries Ltd, Exide Works, Swinton, Manchester

TWO new lightweight, unspillable batteries have recently been introduced by Chloride Batteries Ltd. They are the 6-MNA17 and 4-MNB17 units—each with a capacity of 4Ah at 12V and 8V respectively.

In basic design the two batteries are very similar, but their applications differ. The 6-MNA17 12V battery is primarily designed to operate portable and airborne v.h.f. equipment and other special electronic devices, while the 4-MNB17 8V unit is intended for valve-operated electronic apparatus. The unusual nominal voltage of 8 is planned to meet the demand for batteries required to work with 6·3V valves where designers specify that the terminal voltage should not fall below 6V. This is difficult to obtain with a 6V battery but an 8V unit with a small ballast resistor gives a satisfactorily flat discharge curve down to an end voltage of 6V.

The 6-MNA17 battery measures 3·9in wide × 4·8in long × 4·25in high. It weighs approximately 4¼lb filled and charged.

The 4-MNB17 measures 3·9in wide × 3·5in long × 4·25in high and weighs approximately 3lb 6oz filled and charged.

Notes from ——————

NORTH AMERICA

I.R.E. News

ENGINEERING WRITING

Formation of a new IRE Professional Group on Engineering Writing and Speech (PGEWS) was approved by the IRE Executive Committee at its meeting in New York City on 14 May. This Group, which will become the 26th Professional Group within the Institute of Radio Engineers, has as its objective "the study, development, improvement and promotion of the techniques for preparing, organizing for use, processing, editing, collecting, conserving, and disseminating any form of information in the electronics and related fields by and to individuals and groups by means of direct or indirect methods of communication".

In contrast to other IRE Groups which are concerned with specific branches of engineering research and development, the PGEWS will be concerned with the techniques used in written and oral communication of engineering information. Its objectives will include the development and promulgation of acceptable standards for writing, editing, illustrating, oral delivery and the like and the improvement of writing and speaking by engineers. It is believed that the Group will consist not only of engineers whose primary concern is with the presentation of technical information in written, oral or graphic form, but also of other engineers who will join in order to participate in the services the Group can offer.

INSTRUMENTATION CONFERENCE

Recognizing the growing importance of the South in the electronic industry, Dr. Ben Dasher, Chairman of the Atlanta IRE Instrumentation Conference, announced recently that the Third Annual IRE Instrumentation Conference will be held this year in Atlanta, Georgia on 11 to 13 November. The theme of this conference will be 'Instrumentation for Data Handling'. Special symposiums on 'Electronic Instrumentation as Applied to Medicine' and 'Sales and Purchasing Aspects of Electronic Instrumentation' are also being planned.

Silicon Power Transistor

An experimental silicon power transistor, capable of providing an output of 5W at 10Mc/s either as an oscillator or an amplifier, has been developed at Bell Telephone Laboratories under the sponsorship of the Joint Services. Unilateral gain is in excess of 20dB, and a collector efficiency of better than 40 per cent has been achieved.

The unit is a pnip diffused emitter and base transistor, in which a near-intrinsic or 'neutral' layer of silicon separates the collector from the other elements. Introduction of an intrinsic layer to improve the high-frequency performance of transistors was announced by Bell Laboratories in 1954.

Alpha cut-off is about 100Mc/s, and some laboratory samples have provided as much as 1W output as an oscillator at 100Mc/s. Input and output impedances are of the order of 20Ω and 300Ω, respectively.

Original design objectives have been met in the laboratory models and development work on this unit is continuing. Steady improvement in the diffusion process, packaging, and other features are expected to result in a transistor which is highly reliable and relatively easy to manufacture.

Ferro-Electric Material

The discovery of a new ferro-electric material by B. T. Matthias at Bell Telephone Laboratories was announced recently. Known chemically as triglycine sulphate, the material has a rectangular voltage hysteresis loop and other desirable properties which make it very promising for switching circuits and memory devices.

The most popular ferro-electric crystal previously investigated is barium titanate. Triglycine sulphate is superior in that it has a much lower coercive field (220V/cm), thus permitting switching with a lower voltage. Its polarization results in a lower output pulse when switched, but the size of the pulse can be increased by increasing the area of the switching electrodes.

Triglycine sulphate is stable chemically and does not decompose when exposed to moisture or to the atmosphere. It has adequate mechanical strength to permit handling in thin sheets. Large single crystals can be grown quite easily, and a number of large-area slices can be cut from each crystal.

Repeated switching does not cause any fatigue in triglycine sulphate, as it does in barium titanate, and a given area will retain a given polarization indefinitely without any deterioration. Although heating beyond the Curie point causes the material to lose its ferro-electric properties, these properties are regained in full when it is cooled.

The Curie point of this material is about 47°C. However, by replacing some of the hydrogen atoms with deuterium, easily accomplished when the crystal is grown, the Curie point can be raised to 60°C.

Switching time, an important characteristic in any switching or memory device, depends on the characteristics of the material and the switching voltage. It appears that switching times of the order of one to two microseconds can easily be attained with this new material.

Electrodes can be applied to a slice cut from a single crystal by evaporating thin strips of metal on each side of the slice, the strips on one side being perpendicular to those on the other. Using this technique, thirty or more strips per inch can be applied, resulting in a memory or switching device capable of storing 900 or more 'bits' of information on a square inch of crystal. A number of such slices can be assembled in a relatively small volume, resulting in a very compact assembly.

Thickness of the slice can be from 5 to 10 mils, depending on the available pulsing voltage and the desired output. Switching can be accomplished with about 20V. The actual power required for switching is very small, thus minimizing internal heating.

Shaft Mounted Control Potentiometers

The Jordan 'Shaftrol', manufactured by the Jordan Co. Inc. of Milwaukee, Wisconsin, is a new shaft mounted gear-motor incorporating a potentiometer which provides remote electrical control with indication of position, speed, valve setting etc, on a calibrated meter. The potentiometer may also serve in bridge circuits of automatic control systems. Control may be by dial control, by push-button or it may be automatic from limit switches, controllers or proportioning devices.

The 'Shaftrol' mounts on shafts from ½in to 1in diameter. Installation is quickly made through use of a mounting shaft collar. 'Shaftrols' are furnished with a torque arm that compensates for any runout that may be present in the shaft on which the 'Shaftrol' mounts. A wide range of operating speeds and torques can be had by specifying the desired ratio of the 3 or 4 stage reduction gearing. A variety of potentiometer gear ratios may also be had so that full scale deflection of the calibrated meter may be obtained for rotation of the driven shaft from 1/6 revolutions to 40 or more revolutions. Limit switches, which are optional, may be set to limit travel to any desired amount.

'Shaftrols' can be furnished with built-in single or multi-turn precision potentiometers having a wide range of specifications. When the potentiometer is used as a part of a bridge circuit, the standard 'Shaftrol' provides follow-up accuracies of plus or minus 1/5 per cent of full scale. With precision multi-turn potentiometers accuracies of 1/25 of 1 per cent can be had with counter read out if preferred. 'Shaftrols' are available for use on single or three-phase circuits with drip proof, totally enclosed or explosion proof enclosures. Low inertia rotors provide fast response without over-correction. Built-in brakes can be furnished with the larger models.

Since the 'Shaftrol' mounts on any shaft that normally takes a handwheel, knob or lever, machinery manufacturers can use the "Shaftrol' to provide remote or automatic control without redesign of their equipment.