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Commentary

STEREOPHONIC reproduction of sound was the dominant feature of this year's Radio Show which was held at Earls Court last month. The majority of radiogramophone and sound-reproducing equipment manufacturers are now offering various forms of stereophonic equipment, while the major gramophone record companies already have on the market a number of stereophonic disks, with the promise of many more to come, at prices very little different from those of the present monaural ones. In the U.S.A., too, interest in this type of equipment is widespread.

Interest in stereophonic reproduction is not, however, limited to the record companies; the BBC is also participating. They have announced that, following the wide public interest in the previous experiments in January and May of this year, they are to start a further series of experiments this month (October). The Third Programme transmitters, both medium-wave and v.h.f., will be used for one channel and the Band I television transmitters for the other. The programmes will probably take place on alternate Saturday mornings between 11 a.m. and noon. Although such experiments are interesting and may, perhaps, be useful in gauging the public interest in such a project, their technical merit is likely to be rather small since, at the receiving end at least, it is most unlikely that the two-channels will make a very close approach to similarity, which is, after all, a prerequisite for stereophonic reproduction. Whether the experiments foreshadow a regular stereophonic service, or even the serious consideration of one, is somewhat problematical. From a technical viewpoint, it is obviously possible to propagate such a service on v.h.f. and, indeed, this is already being done experimentally in the U.S.A. using f.m. multiplex systems. Whether or not it is desirable to do so is, however, a somewhat different matter. But, be that as it may, it would, in any case, be a fairly long-term project, and the stereophonic reproduction of records is of much more immediate concern.

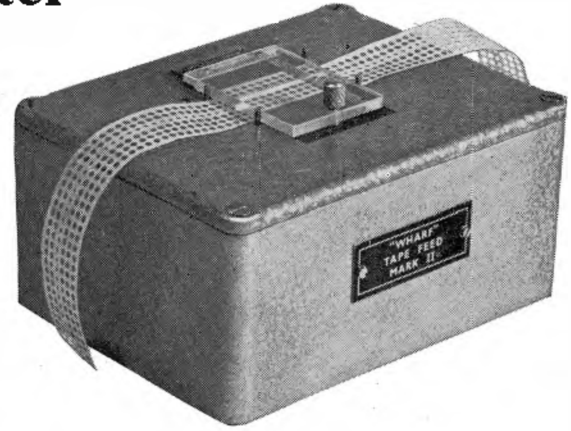
The idea, or indeed the principle now used for the stereophonic recording and reproduction of sound from disks is not new. In 1931, the late A. D. Blunlein proposed two methods: the first consisted of a combination of lateral and 'hill-and-dale' recording; while the second method, and the one now being exploited, was known as the 45/45 system. In this each signal is recorded at 45° to the surface of the record, and, naturally, at right-angles to the other signal, as a consequence of which both the width and the depth of the groove vary continuously. At the time no great progress was made with either system, due mainly to the facts that the materials available for record manufacture were inadequate for the purpose and the techniques of recording and pick-up manufacture were insufficiently advanced.

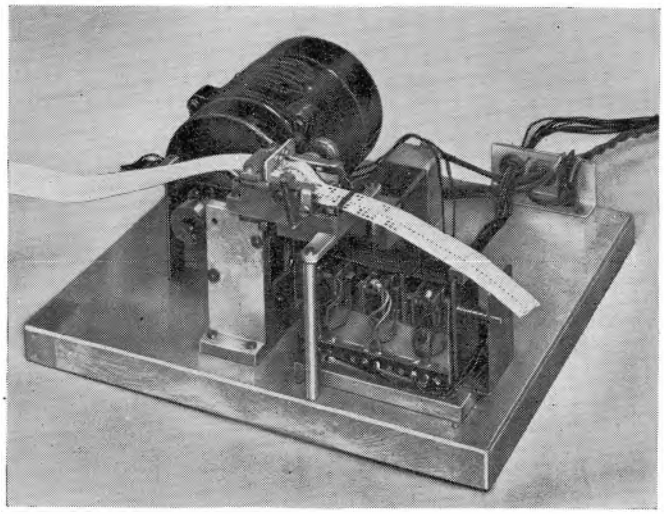
With the advent of tape-recording the interest in stereophonic reproduction revived, since the difficulties to overcome when using this medium are relatively slight. However, it would appear now, that if this form of entertainment is to become popular, the medium employed will be disks. The reason for this is not the technical superiority of the record but the fact that it is a better commercial venture. The public are familiar with records, they are easily handled, the basic equipment for playing them is widely available and they are more easily mass produced; added to this is the fact that all the existing monophonic records can be played equally well on stereophonic equipment.

The quest for perfect reproduction is a stimulating challenge to the electronic and acoustic engineer, though in many ways it is a frustrating one since, no matter how perfect the equipment, normal domestic conditions do not lend themselves to even a near approach to the simulation of a concert hall. However, any step forward is to be welcomed, and its sponsors congratulated, but if it is to redound to the future credit of the industry it is encumbent upon those responsible to ensure that it really is a step forward. The demands of a stereophonic system are, if anything, more exacting than those of a monaural system: due to the nature of the recording and the consequent necessary vertical compliance of the reproducing stylus the turntable needs to be of good quality to avoid 'rumble'; the pick-up needs to be carefully designed and produced to avoid crosstalk; the amplifiers and loudspeakers need to be at least as good as would be demanded for a single-channel equipment. In addition, the equipment needs to be designed with the requirements and limitations of the average living room and its seating accommodation well in mind. At a first approximation, it would seem either that record-reproducing equipment will become inordinately expensive or that the general standard will fall below that at present accepted for monophonic listening.

The Physical Realization of an Electronic Digital Computer—

INPUT...





...and OUTPUT

By Andrew D. Booth*, D.Sc., Ph.D.

The input-output equipment associated with the APEXC and M.2 computers are described and it is shown how relatively simple electro-mechanical devices enable high speeds of punching and reading of paper tapes to be attained.

In previous articles in this series[1,2,3], some of the design features of our series of computers, ARC, SEC, APERC, APEXC, were described and the last of the publications mentioned gave promise of a further instalment which would deal with the input-output equipment.

During the last two years, however, with a reliably operating machine in the background, the department has been exploring various methods of dealing with the input-output problem and two of the electro-mechanical devices have now been in service for a sufficient period to justify their description.

Input

After a brief period of experiment with punched card equipment this particular medium was abandoned for two reasons:—

(1) That the available reader was rather larger than the computer itself.

(2) That an electro-mechanical card punch was not available in the laboratory.

These objections are not in any way generally valid and obtain only in the special case of the APEXC machine. It is the author's opinion that, if any extensive set of calculations is required where mainly decimal data are to be processed, the punched card medium, with automatic scale conversion, is not at present superseded by any other available medium.

To achieve a speed of input which matched the internal speed of the machine it was considered that 5 hole punched tape was adequate if a reading speed of 50 characters per second was available and if, furthermore, the reading operation itself occurred after a time of only a few microseconds from the read signal. This implies that the actual tape feeding operation takes place after the tape has been read and that the reader is interlocked with the machine in such a way that computation proceeds while the tape is being advanced but that a further reading operation cannot be initiated until the current one is complete.

The reader eventually adopted was the Wharf Engineering Laboratories medium speed reader MK. 2, shown above. In this the tape is read by means of a wire brush system which has been found to produce negligible wear and, by virtue of the multiplicity of independent contacts which it applies to each hole, to be extremely reliable. The unit shown can actually be adjusted to suit 5-, 6- or 7-hole tapes although, at present, only the former is available.

The advance mechanism consists of a pawl operated by a rotary solenoid and acting on a pin-wheel via a ratchet wheel in a manner shown schematically in Fig. 1. The pawl, P, is carried on a shaft attached to a plate, R, which is a part of the rotary solenoid. The plate, which is held in its initial position by the spring S, rotates about the solenoid axis O when current is applied to the solenoid winding and,

* *Director, Department of Numerical Automation, Birkbeck College.*

The above photographs show the Wharf Engineering Laboratories' medium speed tape reader (right) and the 'Birbeck' tape punch (left) in this way, the pawl advances the feed wheel F and thus moves the tape.

To make the device self motoring, and to produce the necessary drive-thyratron suppression, a mechanical hysteresis device, L, is provided. Current is normally applied to the solenoid coil via the contact pair AB. Towards the end of the 25° solenoid rotation the pawl mounting pin strikes the hysteresis link, L, and thus opens the contact. This shuts off the drive current and, in due course, the solenoid returns to its initial state under the action of the spring S. Because of a frictional couple which is applied to its axis, the link L retains the contact AB in the open condition until the solenoid is almost in its unexcited condition, only then does the pawl mounting pin strike the left-hand edge of the link L and thus allow AB to close.

This simple mechanism allows the tape to be motored through the feeder without complex control circuits and it also permits an effective interlock as will be described later.

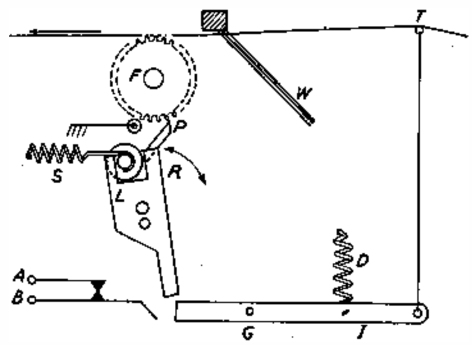


Fig. 1. Tape reader mechanism

Before leaving the feed mechanism, however, mention must be made of the tight-tape contact T. It is not adequate merely to open a microswitch when the tape becomes tight since such opening might occur in the middle of an operation and thereby produce a mis-feed. The scheme adopted here is to operate an interposer, I, via the tape bar T. I, which is pivoted at G and held off by the spring, D, can only engage L when the solenoid is fully operated. At this point AB is in the open state and I prevents L from being removed until the tape tension is relieved.

The electronic circuits which are used to connect the feed mechanism to the computer are shown in Fig. 2. The feed contacts, AB, are placed between the solenoid coil and the anode of a thyratron as shown. When a read operation is required the function table of the computing machine applies a positive potential to F which, in the absence of this signal, is held at a potential adequate to keep the 2D21 thyratron cut off. The apppearance of the read signal at F causes the thyratron to fire and a negative step formation of voltage appears at its anode. This, after passage through isolating capacitors, is applied to the common bar of the tape sensing system and thus passes through any reading brushes which are situated over punchings to set the appropriate register flip-flop via isolating diodes $D_1 \ldots D_5$.

At the same time as the register flip-flops are being set, an operation complete pulse is emitted to the control of the machine via the diode D_6. The fact that this is co-incident with the setting pulses to the register flip-flops is not important since there is a built in delay at a later point in the control.

Once the thyratron has struck it can only be extinguished by the removal of its anode supply, the act of striking removes the biasing potential from the upper end of the grid resistor R so that the setting potential at F is no longer able to cause conduction if the latter is not already occurring.

In due course the solenoid of the feed will react and open the contact AB. This extinguishes the thyratron and, because of the hysteresis in the contact actuating link, potential is not restored until the feed operation is complete. Since AB is open, the potential at F is still below cut off despite the extinction of the thyratron and, if a further read operation is signalled before the current one is complete, no harm results because the reading system is inactive until recharged by the re-connexion of B to the supply potential. It may be remarked that transients appearing at B on make and break have insufficient power content to cause trouble by recharging the read out and operation complete capacitors.

Using this system the feed completes its read out phase and is isolated from the remainder of the machine in less than 5μsec.

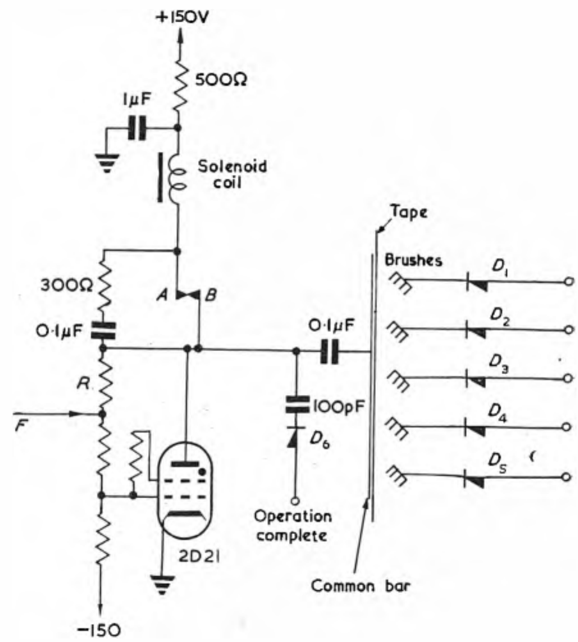


Fig. 2. Tape reader circuit

Output

In early models of APEXC type machines the output took the form of a Creed teleprinter or a Creed reproducer, the appropriate unit being plugged in as required. A point worthy of mention in this connexion is that both pieces of equipment were modified so that their mechanism, after starting, emitted a series of timing impulses to the main machine so that appropriate impulses could be delivered to the drive magnet at the correct times. It cannot be too strongly emphasized that the reverse process—synchronizing the printer or the punch to the machine—is to be deprecated. The method of synchronization adopted made the equipment quite reliable even when it was turned over by hand, it also proved possible to remove the speed governors and thereby double the punch/print speeds which could be attained.

Some workers have suggested the fitting of a set of solenoids to teleprinters and reproducers to obtain parallel working, experiments suggest, however, that solenoids of sufficient power to operate the selector fingers are too sluggish in action to prove reliable even at the 7 character per second rate.

When the Creed high speed (25 character/second) punch became available this was fitted to the machine as the standard output, and typing relegated to separate tape reproducing equipment entirely unconnected with the main machine and this system, after initial reluctance on the part of the users, was found to be quite acceptable.

The speed of the Creed punch was, however, considered to be too slow, especially for the new M.2. machines which have considerable fast access storage, and work has been in progress to develop a simpler and faster punch. These experiments have now been brought to a successful conclusion and the punch now available has a speed of up to 100 characters per second although, because it too has interlocking facilities, a speed of only 50 characters per second is used in order to minimize wear.

The principle of operation is shown in Fig. 3. For each punch knife, *K*, there is a rocker bar, *R*, having the shape shown. All of the rocker bars are connected together by a common shaft, *C*, and this end is oscillated up and down by means of a motor and mechanism to be described later. In the quiescent state all of the rockers oscillate about the axis *A* but if a punching operation is required an appropriate combination of the selector magnets, *S*, is set up. These magnets cause the interposer bars, *I*, to move to the right and thus to prevent the downward motion of the end, *B*,

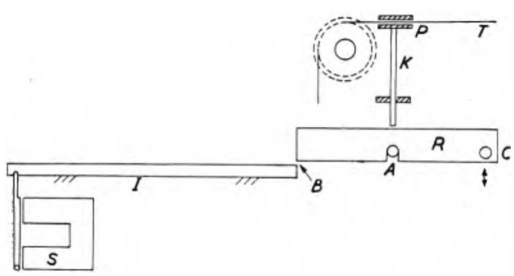


Fig. 3. Punch mechanism

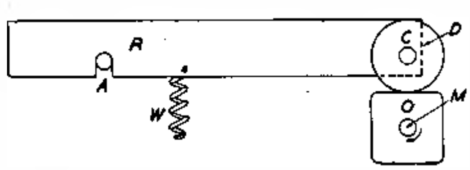


Fig. 4. Simple cam drive

of the appropriate rocker bar. The result is that the rocker bar pivots about *B* and its centre rises through approximately one half of the distance traversed by *C*. In rising the rocker bar centre drives the punch knife *K* through the tape *T* via the punch block *P*.

Since the interposers are extremely light and move through a horizontal distance of only 0·003in to 0·005in against negligible resistance there is no difficulty in attaining transit times of a few milliseconds. The device has no start-stop mechanism the rocker bars oscillating continuously about *A* in the absence of a punching signal. It might appear that zero (i.e. no holes in the tape) would be unavailable to a mechanism of this type, in fact the punching of the sprocket hole in this case provides the actuating impulse for tape feeding.

Several methods for oscillating the end, *C*, have been tested The first, for low speed operation, is shown in Fig. 4; here the common shaft, *C*, has affixed to its end two roller disks *D*. These bear on a cam *O* which is attached to the shaft of the drive motor *M*. The disadvantage of this system, for high speeds, lies in the fact that spring, *W*, must be provided to maintain contact between rollers and cam and the tension of these resists the punching motion. This is not serious at 25 characters per second but causes very considerable wear at 100. The second scheme, shown in Fig. 7, employs the well-known principle of the toggle press, it has the advantages of producing two punching strokes for each revolution of the motor shaft, *M*, and of power driven return of the rocker arms, *R*, so that no springs are required. Since motors are readily available for the 3000 rev/min speed this mechanism will give the 100/sec punching rate without difficulty. The third method proposed uses two grooved cams, one at each end of *C* as shown in Fig. 6. These cams are attached to the motor shaft and produce the necessary drive and return of *C*. For speeds higher than 100/sec a multi-lobed cam of the type shown, with motor speed 3000 rev/min could be used. From the manufacturing point of view the toggle is the easiest to produce and it has been adopted in the present design.

The next point to be considered is the stripping of the punch knives from the tape and the advance of the latter after punching. These functions are performed by the system shown in Fig. 7. The rising of any rocker arm, *R*, pushes its associated punch pin, *K*, through the tape. In rising the

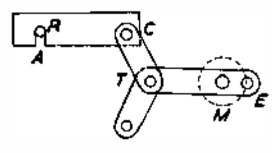


Fig. 5. Toggle drive

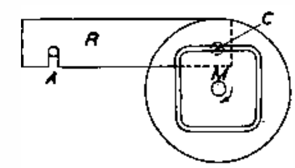


Fig. 6. Double cam drive

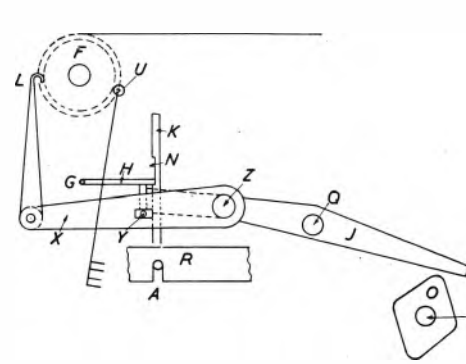


Fig. 7. Tape advance and punch stripping mechanism

bottom of a notch, *N*, in the punch pin moves the stripper plate, *H*, in an anti-clockwise direction about its axis *G*. On one side of the stripper plate is a pin which passes through a slot *Y* in the tape advance lever, *X*. As *H* rotates this pin causes *X* to follow suit and to rotate about its own pivot, *Z*. In rotating about *Z*, the arm *X* advances the pawl, *L*, on the feed sprocket ratchet wheel, *F*, which is prevented from rotating by the spring roller, *U*. When punching is complete, an auxiliary cam, *O*, attached to the motor shaft strikes the lever, *J*, pivoted at *Q*, which has been set by a pin on the side of the stripper plate remote from *Y*. The stripper plate is thus forced to rotate about *G* in a clockwise direction and, in so doing, pushes on the bottom side of the notches, *N*, and strips the punches from the paper. After the punches have stripped the stripper plate returns *X* to its initial position, the delay between stripping and operating *X* being obtained by virtue of the fact that the slot *Y* is slightly wider than the diameter of the driving pin on *H*. As *X* returns to its initial position it rotates the ratchet wheel *X* via the pawl *L*. Exact location at the end of the operation is ensured by the spring loaded roller *U*.

A photograph of the complete unit is shown on page 570.

Since a punch of this type is not provided with a clutch mechanism for starting and stopping between operations it is necessary to provide timing signals to ensure that the interposer magnets (*S*, Fig. 3) are energized at the correct time. This is done by means of auxiliary cams and contacts attached to the motor shaft. The sequence of operations is:—

(1) Signal arrives from computer to punch and the computer simultaneously makes available setting potentials for the interposer magnet drive thyratrons.

(2) Punch mechanism waits until appropriate time for energization of magnets and then supplies a short voltage pulse to fire any drive thyratrons which have suitable potentials on their grids. This pulse also supplies an operation complete signal to the computer.

(3) Thyratrons fire and actuate interposers.

(4) Punch action continues until tape has been perforated, at this point a second cam driven contact removes the supply potential from the thyratron anodes and thus extinguishes them.

(5) Thyratron supply is restored ready for next operation.

The very simple circuit which performs these operations is shown in Fig. 8. The first grids of thyratrons 2 to 6 are connected to the respective digit flip-flops in the machine. Conduction does not occur, however, because of an over-riding negative potential supplied to all of the second grids of the thyratrons. If punching is required, a positive potential is applied to the input to contact B and next time this closes this potential overcomes the bias and causes the appropriate thyratrons to fire. The closure of B also supplies the operation complete pulse via the anode of thyratron I whose first grid is permanently earthed. When punch penetration is complete contact A opens and extinguishes the thyratrons by removing their anode supply. A closes again before the next opportunity for a punch signal to pass through B.

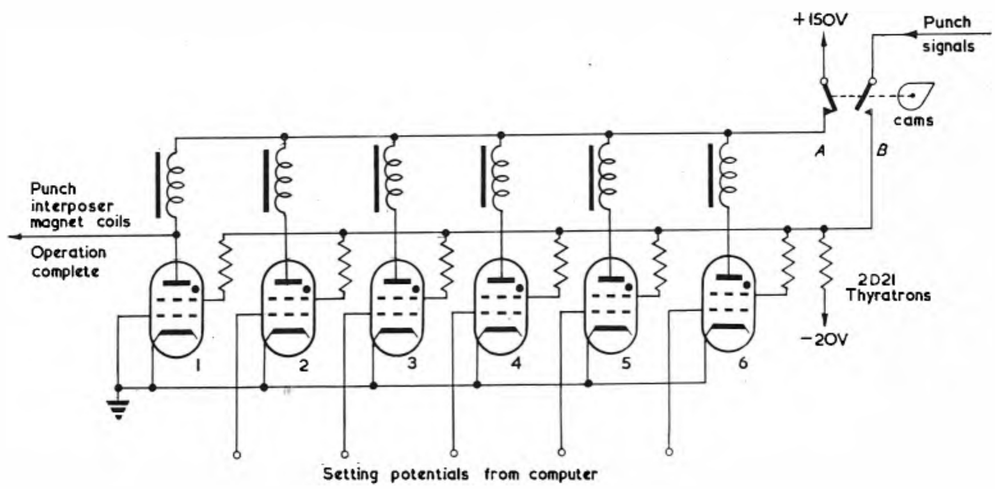


Fig. 8. Punch control circuit

Tape Preparation and Checking

The punch just described has proved to be easily adapted to hand tape preparation. The input is now taken from a set of Siemens keystrips which have multiple "make" contacts available on each key. Since these contacts can handle appreciable power the thyratrons are no longer necessary and the keys are connected directly to the interposer magnets. The circuit is shown in Fig. 9. The depression of any key closes the associated contact set and in this way selects the appropriate magnet coils. No action occurs, however, until the cam driven contact, B, on the punch, closes. Current then flows through the selected magnet coils and also through the coil of a Siemens high speed relay, H_1. The contact of H_1 closes and this locks both H_1 and the magnet coils on to the power source despite the opening of B. When punching is complete a second cam driven contact, A_1, closes and thus allows the high speed relay, H_2, to operate. The contact of H_2 changes over, locks H_2 in the on position and removes the current source from the magnet coils. The circuit is now disabled until H_1 and H_2 are released by the removal of the operator's finger from the push-button.

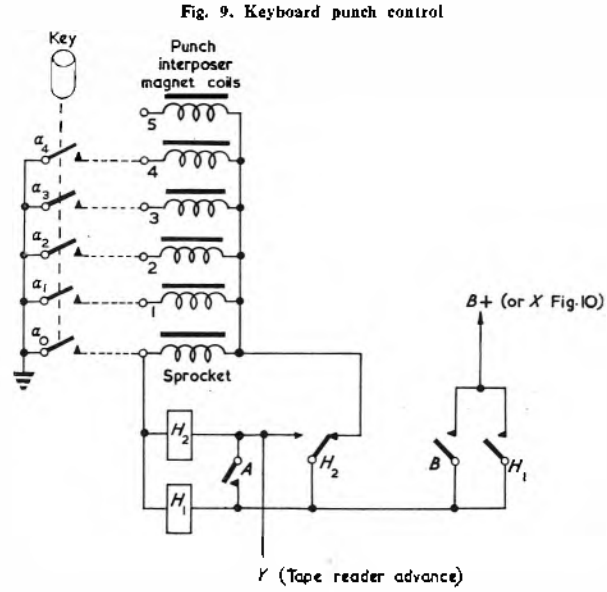
Tape checking is performed by a combination of reader, punch and keyboard. A tape, prepared by one operator, is placed in the reader. A second operator goes through the motions of preparing the same tape on the keyboard. If the character signalled by the key is the same as that under the reader the punch reproduces the character on a "correct" tape, if there is a discrepancy the operator does one of two things:—

(a) If the character which he is holding down is correct, he over-rides the inhibiting signal and records his character on tape.

(b) If his depression is incorrect, he releases his key and depresses the correct one.

The virtue of this system lies in the fact that operator accuracy can be recorded. Over-riding adds unity into a 'faulty tape' counter, releasing a key without punching or over-riding adds unity into a 'faulty key signal' counter.

Fig. 9. Keyboard punch control



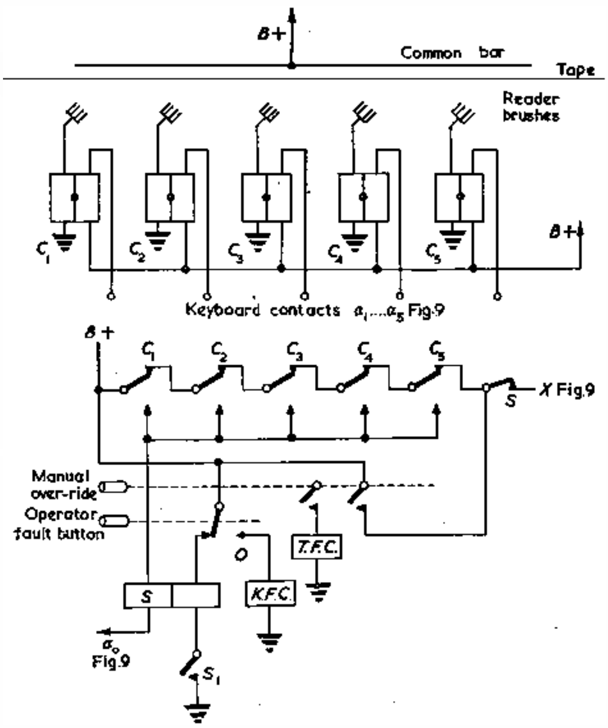


Fig. 10. Tape editing control system

The circuits for performing these operations are shown in Fig. 10. The contacts of the tape reader are connected to the respective left-hand coils of five high speed relays $C_1 \ldots C_5$. The magnetic coil inputs of the punch (and hence the keyboard outputs) are arranged to earth the right-hand coils of these relays. The relay coils are connected in opposition so that, only if both coils have identical inputs does the relay stay in the off position. The off contacts of $C_1 \ldots C_5$ are connected in series placed in the supply line, X, of the punch circuit of Fig. 9.

On depressing a key only if tape and key character agree will punching occur. If no punching occurs, and the depressed key is correct, the over-riding switch can be depressed to cause the keyboard contents to be punched. Closure of the over-riding switch automatically adds unity to the tape fault counter (t.f.c.).

The end of the tape punching cycle sends an impulse to the tape feed solenoid via Y on Fig. 9.

The second possible fault arises when the checker depresses the wrong key. In this event the coincidence system $C_1 \ldots$ C_5 maintains a connexion between the supply voltage, a slow relay (P.O. 3000) S and the feed hole energizing contact in Fig. 9. The relay, S, goes on and a second coil and make contact S_1 ensure that it remains on independently of the key depression. At the same time a break contact, S_2, in series with the coincidence chain, makes it impossible to activate the punch by a mere correction of the key depression. Before correction is possible an operator fault button must be depressed, this breaks the supply to S, via O, and transfers it to the on contact thus adding unity to the contents of a key fault counter (k.f.c).

Finally it is sometimes required to reproduce tapes. This is done by connecting a tape reader directly to the punch via a special set of cam driven contacts which alternately apply current to the selector magnet coils via the holes in the tape and their associated sensing brushes, and apply current to the tape reader advance solenoid. No additional equipment is required.

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A New Post Office Cable to the Channel Islands

A new Post Office submarine cable has recently been laid to the Channel Islands and is now in operation. The new cable which doubles the circuit capacity to the Islands also provides a more direct route to London.

Laying began at the St. Helier end and the cable ship H.M.T.S. 'Ariel' made two trips to lay the full length of cable. Ten submerged repeaters, spaced at about 13 nautical miles, amplify the signals in both directions. They are housed in steel cylinders similar to those used in the Newfoundland-Canada section of the Transatlantic cable. The route of the new underwater link is from Tuckton, near Bournemouth, to St. Helier and is about 130 nautical miles in length.

The two existing cables which will continue to be used each provides 60 circuits; the new one carries 120 over a completely alternative route. The old cables run from a point on the mainland near Dartmouth to Fort Doyle (Guernsey). Three repeaters were introduced into each of these cables in 1952. Two cables then extend the service between Saints Bay (Guernsey) and Plemont (Jersey).

The new submarine cable is coaxial with Polythene insulation 0·62in in diameter; the inner conductor is solid copper 0·16in in diameter. The outer conductor over the Polythene insulation consists of 6 copper tapes applied helically with an overall copper binding tape. The shore ends and land sections have additional layers of Polythene insulation and an outer lead sheath. The main cable is armoured with 12, 2 s.w.g. steel armour wires. The shore ends have an additional layer of armour wires for extra mechanical protection.

The repeaters are energized by d.c. fed over the centre conductor from the terminal stations and are housed in cylindrical steel housings. Special terminal equipment is installed in the repeater stations at Tuckton and St. Helier; power units at each end provide closely regulated constant current. In the Tuckton to St. Helier direction 120 telephone channels are transmitted in the frequency range 60 to 552kc/s and in the reverse direction 672 to 1164kc/s. Pilot frequencies 4kc/s from the edge of each band are transmitted all the time over the system to provide continuous monitoring and control of performance. Equipment at Tuckton will enable the gain of each repeater to be measured without interfering with traffic.

At Tuckton the 120 telephone circuits will be reduced to 10, twelve-circuit carrier groups in the frequence range 60 to 108kc/s, which will be extended into the inland carrier network. Equipment at St. Helier repeater station will reduce circuits to audio frequencies which will be fed to the Jersey trunk exchange.

Repeaters and cables were manufactured by Standard Telephones and Cables Ltd., and repeater housings by Submarine Cables Ltd.

A VERSATILE STIMULATOR

By R. H. Kay*, M.A., D.Phil., A.Inst.P., C. G. Phillips*, D.M., M.R.C.P. and R. H. Teal*

A versatile stimulator for neurophysiological research is described consisting of three basic units:—

(1) a Delay Unit, driven by the time-base waveform of the final oscilloscope display, which provides a single or a pair of pulses to trigger the units (2) or (3). The triggers, locked to the time-base, can be delayed independently and set repeatedly to any position along the X axis. They remain fixed at the same spatial positions on the c.r.t. irrespective of time-base velocity (i.e. delay is controlled by X plate potentials and not by an RC time delay);

(2) a Tetanus Unit providing gated trains of pulses to trigger unit (3) whenever energized by a pulse from unit (1). Trains can also be initiated independently of unit (1) by manual push-buttons;

(3) the Stimulator proper which provides a square pulse of controlled amplitude, duration and polarity for each trigger pulse from units (1) or (2) and also when triggered manually by a push button control. Units (1) (2) (3) are duplicated for 2 channel operation.

THERE are a variety of circuit configurations possible in the design of stimulators for neurophysiological work. One essential is ease in operation. The biological experiment is usually complex, and it is necessary to be able to achieve the required pattern of electrical stimuli with the minimum of manipulation. The present arrangement has proved versatile, yet convenient in use and, though no originality is claimed for the basic circuits, it is published in the hope that the complete design of a well tested apparatus may be useful to other physiologists.

Requirements

The experiments for which the stimulator was primarily designed require two independent channels, capable of connexion when necessary to common stimulating electrodes and of delivering rectangular current pulses either positive- or negative-going with respect to earth. A block diagram of one of the two identical channels is shown in Fig. 1.

STIMULATOR UNIT

Three current ranges are available: 10 to 100μA, 100 to 1 000μA, 1·0 to 10·0mA. The appropriate range is selected by a three-position switch. A stepped control divides each range into ten equal divisions and a further ten position switched control spans each division. A similar arrangement of coarse and fine controls determines the pulse duration in three ranges 0·1 to 1·0msec, 1·0 to 10·0msec and 10 to 100msec.

The selection of pulse duration and amplitude by switched controls permits a more rapid selection and repeatability of standard conditions than continuously variable controls.

A two position switch determines the polarity of the pulse with respect to earth.

CONTROL CIRCUITS

(1) Tetanus Unit

This unit can be made to trigger the stimulator in bursts, providing a train of stimuli of controlled p.r.f. and train duration. The repetition frequency of these triggers (5 to 500/sec) and the overall duration of the train (10msec to 10sec) are again covered by switched controls.

(2) Delay Units A and B

These are controlled by the time-base waveform of the final oscilloscope display and provide a single or a pair of trigger pulses at any desired position and separation along the oscilloscope X sweep with either pulse leading. (Switched controls determine position along the X axis in ten equal steps and a smooth control spans each step.)

* *The University Laboratory of Physiology, Oxford.*

The delay units *A* and *B* are used to release from the stimulator:—

(a) Directly, a single pulse or a pair of pulses at any position and separation along the sweep with either leading. (Routes 1 and 2, Fig. 1).

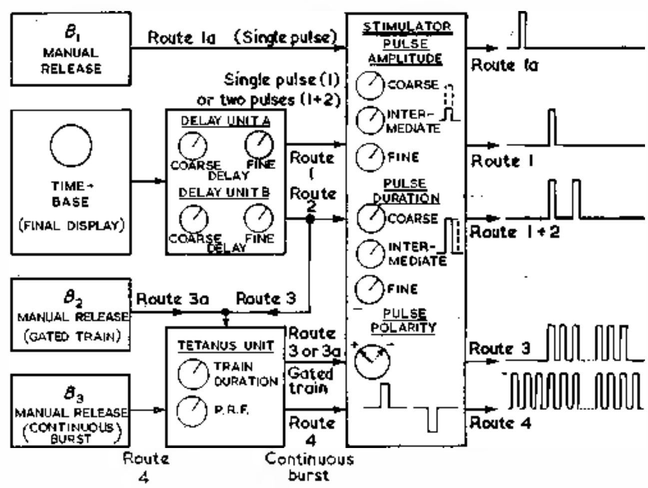

Fig. 1. One channel of the stimulator with its control units

(b) A single pulse, directly, and a train of pulses of selected p.r.f. and train duration via the tetanus unit (Routes 1 and 3, Fig. 1).

(c) Via the tetanus unit, a train of pulses of controlled p.r.f. and train duration (Route 3).

TRIGGERED OPERATION, GENERAL

With two identical channels in use, any of the functions (a) (b) (c) can be combined with similar functions (a′) (b′) (c′) on the second channel allowing a different pattern of stimuli of different amplitude, pulse length and polarity, if need be, to be combined with the first set, either via common or different stimulating electrodes.

For many purposes it is more convenient to trigger shocks or trains at chosen points on the oscilloscope X sweep (the time interval between shocks occurring during one sweep being determined by the sweep velocity), than to trigger the shocks at selected intervals of time, e.g. by some *RC* device, and then to make a separate adjustment of the sweep velocity to obtain the optimum display.

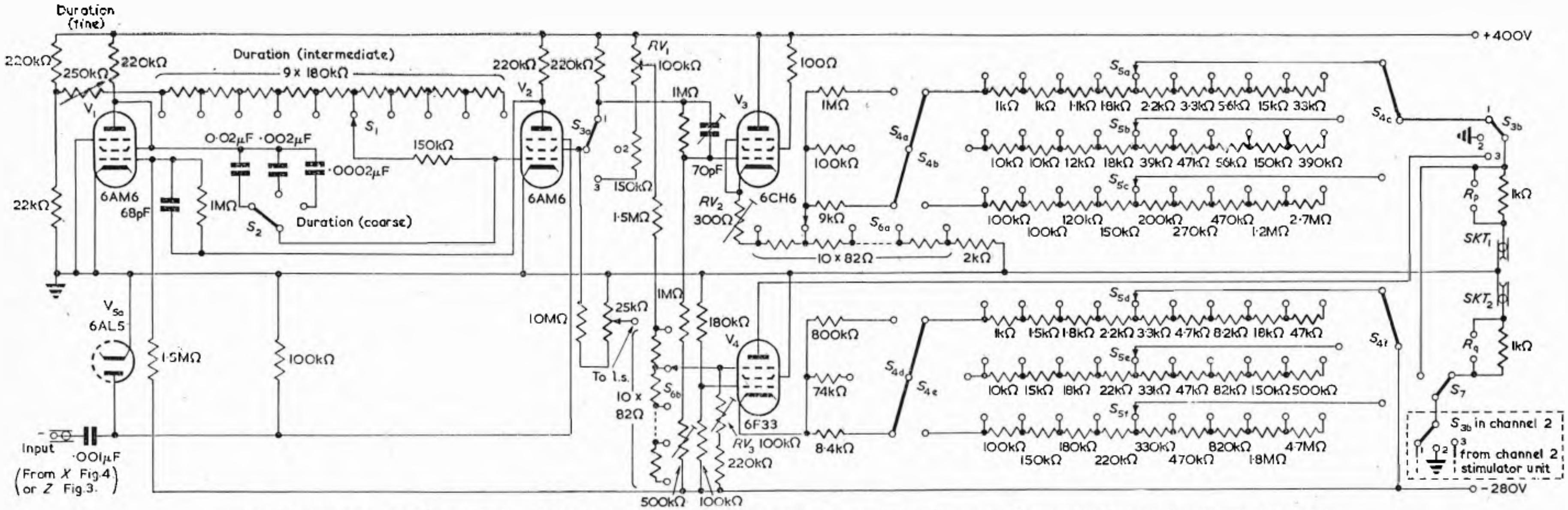

Fig. 2. Stimulator unit. *This is duplicated in the 2nd channel: S_4, S_5, S_6 are coarse, intermediate and fine amplitude controls respectively: point l.s. leads to a loudspeaker amplifier for audible monitoring of the stimulator operation*

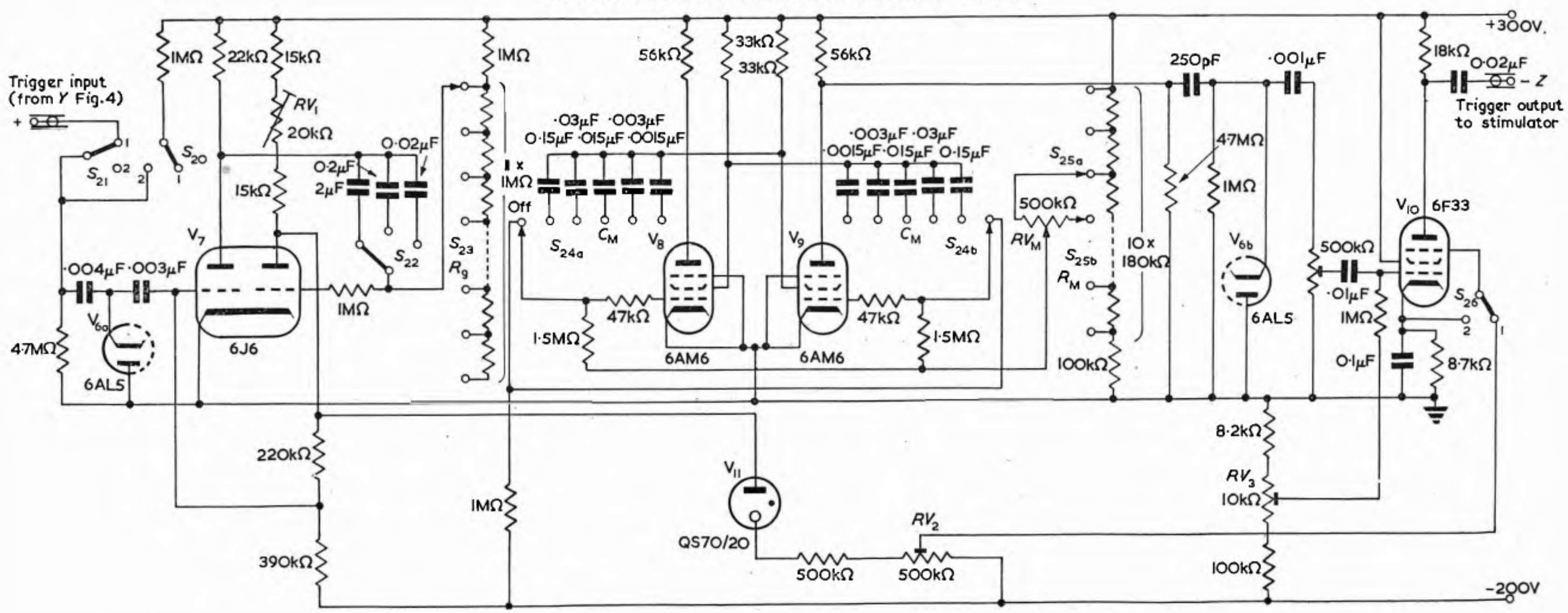

Fig. 3. Tetanus unit. *This is duplicated in the 2nd channel*

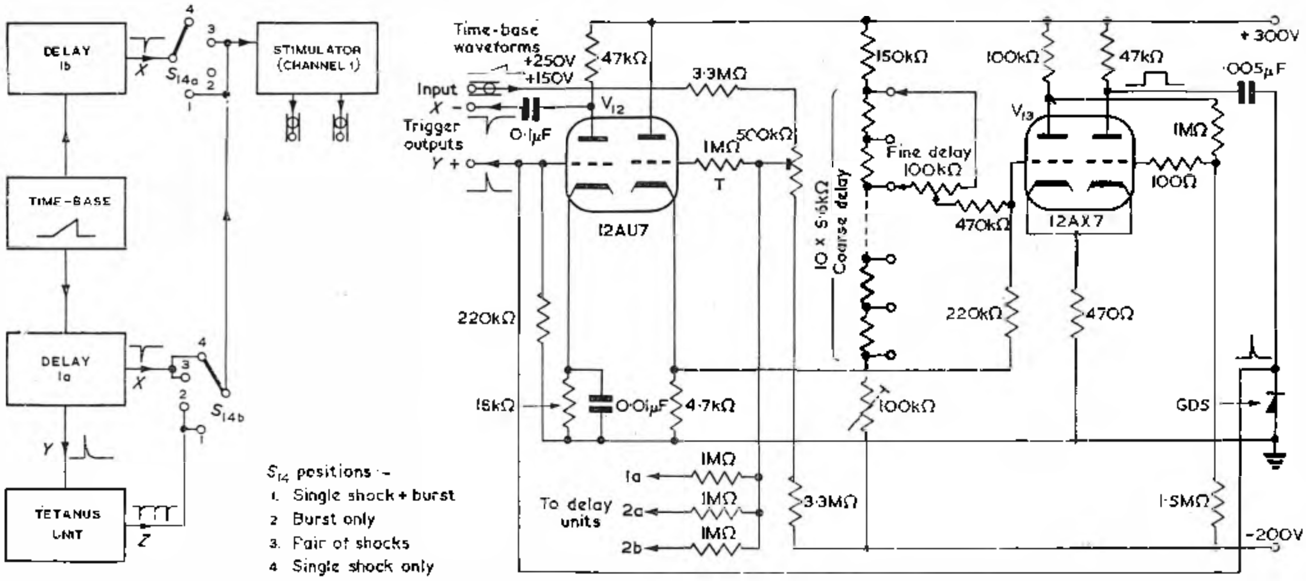

Fig. 4. Delay unit. *There are two of these in each channel. To the left is an operational diagram for the whole of one channel*

If, in an experiment with repetitive train stimulation, photographic superimposition of several sweeps had been required with the stimuli always coincident, it would have been necessary to make the first pulse of each repetitive train from the tetanus unit coincide with the instant of triggering. This facility has been needed for single or paired shock experiments only (where the necessary conditions obtain). The complication of synchronizing the tetanus p.r.f. oscillator with the triggers A and B has therefore been omitted.

Manual Operation

Three push-button switches can release from the stimulator :—

(B_1) a single pulse (route 1(a)),

(B_2) a train of pulses whose frequency and train duration are determined by the setting of the tetanus unit controls (route 3(a)),

(B_3) pulses continuing at the frequency selected in the tetanus unit but remaining 'on' for as long as the button is held down (route 4).

Circuits

Throughout, conventional pulse techniques are used (see e.g. Farley[1], and M.I.T. Staff[2]).

The Stimulator (Fig. 2)

The pulse generator 'flip-flop' (Attree[3])—valves V_1, V_2—is directly coupled to cathode-follower output valves, V_3 for positive output, V_4 for negative. Attenuators, switched by S_4, S_5, S_6 vary the output current amplitude which is monitored by R_P. The resistor R_Q similarly monitors the current from an identical second channel stimulator. S_7 directs the second channel output either to a separate electrode socket SKT_2 or mixes both outputs at SKT_1. The 'positive' and 'negative' attenuators are, in each range, fixed on a common spindle and the attenuator resistors individually matched so that an initial adjustment of RV_1, RV_2 and RV_3 ensures equality of both positive and negative outputs at all positions of the attenuator switch. S_3 determines pulse polarity and in the off position (2) short-circuits the output sockets to earth.

The Control Circuits

(1) The tetanus unit (Fig. 3)

(a) Triggered operation. With S_{21} in position 1 external triggers from the delay unit initiate the tetanus cycle. Valves V_7, V_{10}, comprise a gating circuit, opened by an external trigger pulse and closed after the $R_G C_G$ time delay. The gate allows differentiated pulses from the multi-vibrator oscillator V_8V_9 to proceed to trigger the stimulator proper. RV_1 is adjusted to arrange that the sensitivity of the flip-flop V_7 suits the amplitude of the input triggers. Variation of C_M, R_M and RV_M provides coarse, intermediate and fine control of the p.r.f. of the tetanus triggers. RV_2, RV_3 are set to bias the suppressor and control grids so that (1) the gating pulse itself produces no output; (2) the positive pulses applied to the grid are only amplified in the presence of the gating pulse on the suppressor.

(b) Manual operation. With S_{21} in position 2, the external triggers are disconnected. The push-button S_{20} is normally open (position 1) but when depressed (position 2) it initiates the tetanus cycle and with S_{26} in its normal position (1) the gate is held open by the time-constant $R_G C_G$. Alternatively, if instead S_{26} is depressed to position 2, the gate remains open until S_{26} is released again, and the triggers are allowed to pass the whole time it is depressed.

(2) Delay units A and B (Fig. 4)

The time-base waveform, direct from the positive going X plate of a Nagard DT.03 oscilloscope, is applied via a d.c. coupled cathode-follower (V_{12b}) at an amplitude and potential level suitable for controlling the delay Schmitt trigger, V_{13}. Adjustment of V_{13a} grid bias ('coarse and fine delay') determines the position along the X axis at which a trigger is initiated. The differentiated output of the Schmitt trigger can be directed, by switching, either to trigger the stimulator (output X, V_{12a}) or to trigger the tetanus unit (output Y, V_{12a}). Delay 1b exactly duplicates delay 1a.

Double Channel Operation

One complete channel is shown in the functional diagram to the left of Fig. 4. For two channel operation the whole is duplicated and the controlling time-base waveform is shared to all four delay units from point T, Fig. 4. The switching allows a varied interconnexion between the basic units of both channels. Stabilized power packs, providing +400V, 120mA; +300V, 80mA; −200V, 30mA; −280V, 20mA; are adequate to operate both channels.

Operation

One complete cycle of stimulation is usually repeated at intervals long compared with the time intervals within a given stimulus pattern, i.e. the repetition rate of the time-base is normally long compared with the time-base duration. The oscilloscope is therefore not allowed to free-run but is triggered externally. It is found convenient to trigger the oscilloscope by counting down from the 100c/s time marker pulses provided by a crystal controlled Dekatron time marker (c.f. Kay[4]).

At the 100/sec time output, there is inserted a Dekatron selector stage with a switched control to select division by 2, 5 or 10. This selector stage output provides pulses at 1/50sec, 1/20sec, 1/10sec intervals and two further Dekatrons divide these to pulses at 1/5, 1/2 or 1sec and 2sec, 5sec or 10sec intervals respectively. There is then a choice of nine rates for repeating each stimulus pattern. Overall operation in this way also ensures that the time marks at higher frequencies (100/sec, 1 000/sec, 10 000/sec) remain stationary on the tube in successive time-base sweeps. With low impedance stimulating electrodes, the stimulator is a 'constant current' device. At high impedances the stimulus current is monitored by R_P, R_Q.

The whole arrangement has proved versatile and convenient in use allowing the maximum concentration on the biological preparation with the minimum need for tedious readjustment of circuit controls during an experiment.

Two of these double channel stimulators have been made; one has worked reliably with no major fault for the last year the other, similarly, for six months.

Records of neuro-physiological experiments using the stimulator are published elsewhere[5].

Acknowledgments

The authors wish to thank Professor E. G. T. Liddell for the facilities of his laboratory and Mr. R. Dick for copying the circuit diagrams.

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Centenary of First Transatlantic Telephone Message

THIS year is the centenary of the first message to be transmitted via Transatlantic telegraph cable.

It was in August, 1858, that a communication link between the old and new worlds was first established. But whereas these earlier messages took several minutes to be hand-tapped over the cable, modern high-speed automatic techniques have now reduced this time to a few seconds.

It was not, however, until some years later—in 1866—that the first completely successful Transatlantic cable was laid. This enterprise was the culmination of a series of telegraphic developments which had taken place during the preceding years, and was attained in the face of the greatest difficulties.

As early as 1855 a network of inland telegraph lines extended throughout Britain and reached the western coasts of Ireland. Telegraph lines had been laid throughout the eastern states and provinces of America and Canada, and across Newfoundland. As the two inland telegraph systems began to stretch toward each other, there came the idea of linking them together by a Transatlantic cable.

The Atlantic Telegraph Company was formed in 1856 and it was decided to lay a cable from Valentia Island, County Kerry, to Trinity Bay, Newfoundland.

No single ship was large enough to carry and lay the 2 000-odd miles of cable necessary to cover the distance, and the task was shared by two ships, H.M.S. *Agamemnon*, and the United States frigate *Niagara*. Insufficient time was allowed for experiments and discussion, and the cable was unsuitable for laying in the deep waters of the Atlantic.

After landing the heavy shore end of cable at Valentia, on 5 August, 1857, *Niagara* began to pay out the cable as she made for the open sea. Several mishaps occurred, and frequently the signals sent from the ship to the shore were interrupted.

Eventually, in a heavy sea, the brake of the paying-out gear on board *Niagara* was applied too fiercely, the cable snapped, and the 334 miles of cable which had been laid was lost in 2 000 fathoms of water.

In June, 1858, the two ships made a second attempt. On their outward voyage, they ran into one of the severest Atlantic gales ever recorded. They were almost overwhelmed, and the cable aboard them was damaged. Work was resumed when the gale abated. A splice was made between the lengths of cable carried in each ship, and they parted company in mid-ocean. *Agamemnon*, and an escort vessel, *Valorous*, sailed eastwards, and *Niagara*, with an escort vessel, *Gorgon*, sailed westwards. The cable broke and was repaired twice, and each time the ships had to begin the work again. When 200 miles had been laid, the cable broke again near the stern of the *Agamemnon*, and the ships were forced to return to Ireland.

Another attempt was made in July, 1858, and although there were several interruptions, on 5 August the laying of the Transatlantic cable was completed successfully. It was not until a few days later, on 13 August to be exact, that the first clear message was received from Newfoundland, and on the 16th, the following message was got through from the directors in England to the directors in America:—

> "Europe and America are united by telegraph. Glory to God in the highest, on earth peace, goodwill toward men."

An exchange of greetings between Her Majesty the Queen and the President of the U.S.A. then followed.

From the start messages could only be received slowly and they were unreliable. Suddenly, however, a new and very serious fault of insulation was found to exist, which appeared to be about 300 miles from Valentia. For a few more days communication was maintained with the help of Professor Thomson's new mirror-receiving instruments; but on 1 September, 1858, signals became unintelligible. A few words were transmitted at intervals up to 20 October, when a total of 732 messages (some of them quite lengthy) had been conveyed by this cable. By this time the cable was completely unusable and the attempt at Transatlantic telegraphy was abandoned.

In 1860 attempts were set afoot to repair the cable, but were soon abandoned owing to the bad condition of the sheathing wires, the shore end only being recovered.

By 1862, interest in the project was renewed, and £265 000 was raised towards the cost of making another attempt to lay a cable between the United Kingdom and America.

Careful consideration was given to the design of the new cable, and a special ship was chartered from which to lay it. She was the 28 000 tons five-funnelled paddle steamer *Great Eastern*, designed by Brunel as the largest passenger steamer in the world.

The *Great Eastern* sailed from the Thames on 14 July, 1865, with 2 300 nautical miles of cable on board. She reached Valentia on 23 July, and began paying-out the cable, which was spliced to the shore-end laid the previous day by the S.S. *Caroline*. Between 23 to 29 July, various faults occurred in the cable, and as each was detected by the instruments in the ship, several miles of cable had to be picked up so that the fault could be eliminated.

There was no further incident until 2 August, when another fault was detected. The weather had deteriorated, and as the cable was being picked up, it chafed against the side of the ship, and broke. The end fell into 2 000 fathoms of water, and although attempts were made to raise it, the gear available was inadequate. Eventually, after ropes and grapnels had been lost, the *Great Eastern* was compelled to abandon the cable and return to England.

Preparations began for yet another attempt. During the following winter, 1 600 miles of cable of improved design were manufactured. The cable machinery on board the *Great Eastern* was strengthened and improved in the light of past experience, and proper equipment was installed for grappling the cable.

The landing of a new shore-end of cable at Valentia was completed, and the *Great Eastern*, with her escort ships, sailed on Friday, 13 July, 1866, setting a course northwards of that taken the previous year. Two weeks later, on 27 July, the expedition arrived at Trinity Bay, Newfoundland, and the S.S. *Medway* landed the shore-end. After nine years of fruitless endeavour and bitter disappointments, a cable had been laid across the Atlantic to link the old world with the new.

Resistance Potentiometers as Function Generators

By R. W. Williams*, Ph.D., and H. Marchant†, B.Sc.

The generation of functions of a single variable by means of resistance potentiometers is reviewed. Three main design approaches are described—potentiometer grading, the use of linear potentiometers in special circuits and the multi-tapping technique—and detailed examples are given in illustration of these.

RESISTANCE potentiometers are used extensively in analogue computers for function generation, and the realization of a given function often poses interesting design problems. Three main classes of function-generating potentiometer circuit are considered in the present article:—

(1) Graded potentiometers, in which the resistance card is given a profile so that the output voltage varies with the slider position in the desired manner.

(2) Linear potentiometers used in special circuits.

(3) Potentiometers with multiple tappings which are connected to external shunt resistances or voltage sources.

Discussion is limited to the generation of functions of one independent variable only. Several design examples are included in the article.

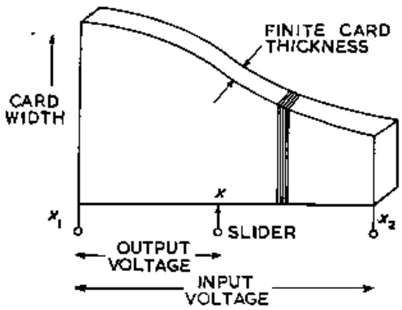

Fig. 1. Diagrammatic representation of graded potentiometer

Potentiometer Grading

It is well known[1] that the function $y = f(x)$ may, subject to certain conditions, be realized by shaping the card of a potentiometer so that its width is proportional to the derivative, dy/dx, of the function. In calculating the card profile, allowance must be made for the finite thickness of the card; in fact the effective width at any point equals the physical width plus the card thickness. In the graded potentiometer circuit depicted in Fig. 1, the independent variable is of course represented by the slider position, and the ends of the card correspond to the values x_1, x_2, respectively, of this variable. It is clear that in the simple arrangement of Fig. 1, the following limitations are imposed on the function y and its derivatives:—

(1) y must be a real, continuous, single-valued function of x: in general y' ($\equiv dy/dx$) is required to be continuous but some kinds of discontinuity in it can be accommodated.

(2) Since the potentiometer output is zero at the end $x = x_1$ of the card, $y(x_1)$ must be zero. Also, as it stands, the arrangement of Fig. 1 cannot cater for a change of sign of y.

(3) Since the card width cannot change sign, y must be monotonic in the interval $x_1 \leqslant x \leqslant x_2$. Note that y' need not be positive; this point is discussed below in connexion with limitation (2).

(4) Practical limitations arise in the manufacture and winding of cards since, in a given model of potentiometer, minimum and maximum permissible values of effective card width will exist. These limitations are summarized in the equation

$$\frac{y'_{max}}{y'_{min}} = \frac{\text{max. effective width}}{\text{min. effective width}}$$

(5) Again if the card slope (i.e. rate of change of width with length along the card) is too great, the turns of wire slip during the winding process. For positive slopes, a maximum of about 20° can usually be handled, a greater slope than this causing the turns to slip backwards. For negative slopes, a maximum of about 10° can be accommodated, a greater slope resulting in the turns slipping forward. Corresponding to these values of maximum slope, there will be maximum permitted values of the second derivative, y'', of the function. When y'' does not change sign, the maximum slope can be taken to be 20° (even if y'' is negative) since the card can be wound in the direction of increasing width.

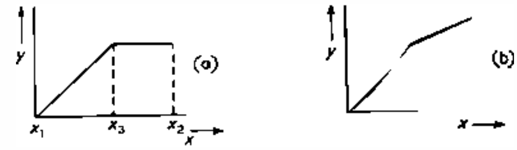

Fig. 2. Types of discontinuity in the function y

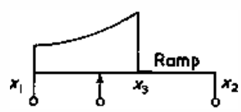

Fig. 3. Realization of function of Fig. 2(a)

Methods of Overcoming Grading Limitations

It is possible to surmount some of the limitations listed above, either by extensions of the simple circuit of Fig. 1, or by the use of approximations to the function y over a certain range of the independent variable. The following are a few illustrative examples:—

(1) Discontinuity in y'

In Fig. 2(a), y' exhibits a discontinuity corresponding to the 'corner' which occurs in y at $x = x_3$. The realization is shown in Fig. 3: a ramp of high-conductivity material is provided at one end of the potentiometer card, extending from $x = x_3$ to $x = x_2$, and is connected to the adjacent

* *English Electric Co. Ltd.*

† *Ferranti Ltd, formerly English Electric Co. Ltd.*

end of the winding. As a result, the output remains constant when the slider is in contact with the ramp, as required by Fig. 2(a) in the range $x_1 \leqslant x \leqslant x_2$. In aerodynamic computers, the sonic speed ratio as a function of height displays this type of discontinuity and the ramp solution is an effective one in this case.

A discontinuity of the type shown in Fig. 2(b) where y' changes abruptly from a non-zero value to another non-zero value can be realized provided that the resulting abrupt change in card width does not offer constructional and winding difficulties.

(2) $y(x_1)$ not zero

If in fact $y(x_1) \neq 0$, the function may be realized by including a fixed resistance r in series with the potentiometer. In Fig. 4, y increases steadily from $y(x_1)$ to $y(x_2)$ as x varies from x_1 to x_2, y' being positive throughout this range. Subject to the practical limitations of card width and slope already discussed, the function is realized by the circuit of Fig. 5. The value of r is determined from the relation

$$\frac{r}{r + R} = \frac{y(x_1)}{y(x_2)}$$

i.e.
$$r = \frac{R.y(x_1)}{y(x_2) - y(x_1)}$$

In Fig. 4, the curve of y is convex to the x axis so that $y'' > 0$. As a result, the card width is greater at the end

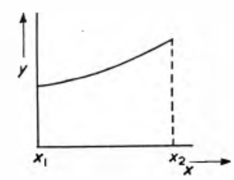

Fig. 4. Function for which $y(x_1) \neq 0$, y' being positive

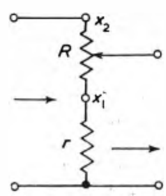

Fig. 5. Realization of function of Fig. 4

$x = x_2$. When the curve is concave, so that $y'' < 0$, the wide end of the card will be found at $x = x_1$. These simple facts are worth remembering when one is checking the installation of a graded card in a potentiometer, since the sense of rotation (i.e. whether slider rotation is clockwise or anticlockwise for x increasing) is generally settled by other considerations before the potentiometer is designed. In the case where y' is always negative, as in the function of Fig. 6, the realization is shown in Fig. 7. The value of r is determined by the relation

$$r = \frac{Ry(x_2)}{y(x_1) - y(x_2)}$$

The wide end of the card is to be found at $x = x_2$, corresponding to the concavity of the curve to the x axis. A convex curve would result in the occurrence of the narrow end at $x = x_2$.

(3) Change of sign of y

If y changes sign, as in Fig. 8, the potentiometer is energized from two appropriate voltage sources in series (in the case of a.c. operation a tapped transformer winding is very suitable—see Fig. 9) and the output of the circuit is the voltage between the potentiometer slider and the junction of the sources: if their voltages are e_1 and e_2, clearly e_2/e_1 should equal $|y(x_2)/y(x_1)|$. Alternatively, the potentiometer winding may be tapped at the point x_3 where y vanishes.

(4) y not monotonic

When y exhibits one maximum or one minimum in the given range of the independent variable, its realization is possible by means of the circuit of Fig. 10, the essential features of which are the connexion together of the ends of the potentiometer winding through a resistance α_1, and the use of a second resistance α_2 connected to the slider. For convenience, the potentiometer is taken to have a total resistance of one unit, the resistance between the slider and the bottom of the card being the fraction f. With voltage sources e_1 and e_2 connected as in the figure, it readily follows that the output voltage of e_o is given by the equation

$$e_o = \frac{e_1 \cdot \left(\frac{1}{\alpha_1 + 1 - f} + 1/f\right) + e_2/\alpha_2}{\frac{1}{\alpha_1 + 1 - f} + 1/f + 1/\alpha_2}$$

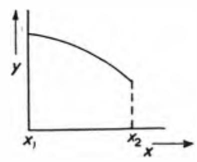

Fig. 6. Function for which $y(x_1) \neq 0$, y' being negative

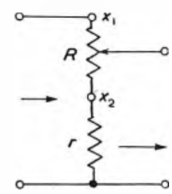

Fig. 7. Realization of function of Fig. 6

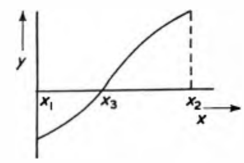

Fig. 8. Function in which y changes sign

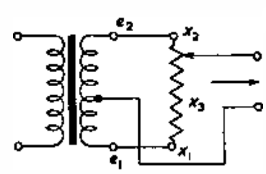

Fig. 9. Realization of function of Fig. 8

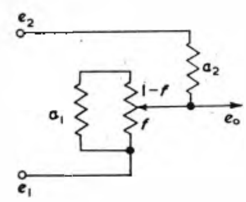

Fig. 10. Realization of function exhibiting one maximum or one minimum

This can be rewritten in the form

$$e_o = \frac{e_1 \cdot \left(\frac{\alpha_2}{\alpha_1 + 1}\right) + e_2 \cdot \frac{f}{\alpha_1 + 1} \cdot \left(1 - \frac{f}{\alpha_1 + 1}\right)}{\frac{\alpha_2}{\alpha_1 + 1} + \frac{f}{\alpha_1 + 1} \cdot \left(1 - \frac{f}{\alpha_1 + 1}\right)}$$

If $\frac{\alpha_2}{\alpha_1 + 1} = \beta$, $\frac{f}{\alpha_1 + 1} = g$, then

$$e_o = e_2 + \frac{(e_1 - e_2)\beta}{\beta + g(1 - g)}$$

It is required for y to be equal to λe_o, where λ is a scaling factor, i.e.

$$y - \lambda e_2 = \frac{\lambda(e_1 - e_2)\beta}{\beta + g(1 - g)}$$

Let $y - \lambda e_2 = 1/z$

$$\therefore \beta + g(1 - g) = \lambda(e_1 - e_2)\beta z$$

Solving for g,

$$g = \tfrac{1}{2}\left\{1 \pm \sqrt{[1 - 4\beta[\lambda(e_1 - e_2)z - 1]]}\right\}$$

and by differentiation and re-arrangement,

$$dz/dx = \left\{\frac{\mp\sqrt{[1 - 4\beta[\lambda(e_1 - e_2)z - 1]]}}{\beta\lambda(e_1 - e_2)}\right\} . dg/dx \quad \ldots . (1)$$

Now at the turning-point of the function y,

$$dz/dx = 0, \text{ since } y - \lambda e_2 = 1/z.$$

Hence, from equation (1),

$$1 - 4\beta[\lambda(e_1 - e_2)z_m - 1] = 0 \quad \ldots\ldots\ldots (2)$$

where z_m is the value of z at the turning point.

Using equation (2), equation (1) becomes

$$dg/dx = \frac{\mp\sqrt{[\beta\lambda(e_1 - e_2)]}}{2} \cdot \frac{dz/dx}{\sqrt{(z_m - z)}}$$

But $dg/dx = \dfrac{1}{f^2 + 1} . df/dx$, and one therefore needs to make the effective width proportional to

$$\frac{dz/dx}{\sqrt{(z_m - z)}}, \text{ where } z = \frac{1}{y - \lambda e_2}$$

Note that e_2 can be chosen to optimize the profile.

An example of the design of a graded potentiometer used in the circuit of Fig. 10 is given in the Appendix to this article.

(5) Card thickness and minimum width limitations

The limitations caused by finite card thickness and minimum permissible card width are well illustrated in the case of the square law function, $y = \lambda x^2$, which it is required to realize over the range $0 \leqslant x \leqslant 1$. The derivative vanishes at $x = 0$ and therefore it will be impossible to realize the function exactly over the whole range of x. However, the errors in the realization may be reduced to very small proportions if the potentiometer is constructed in the following way. The ideal card profile would be the triangle OCD of Fig. 11. The minimum effective ordinate which can be achieved in practice is AB, the maximum ordinate being CD.

Construct now a card in which the width remains constant at the minimum permitted from O to A, increasing linearly thereafter until the maximum width is attained at D, so that the card profile is OEBCD. The card is tapped at the point A and a fixed resistance of value equal to that represented by the rectangle OEBA is shunted across the points O and A. As a result, the square law will be realized exactly in the region AD (apart from the natural errors which are inherent in a potentiometer) since the effective resistance between O and A corresponds to the triangle OAB. In the region O to A, the potentiometer output follows a linear law: it is easy to show that the maximum error in the output occurs when the slider is mid-way between O and A. Expressed as a fraction of the maximum output, the maximum error is found to be

$$\frac{1}{4} . \left(\frac{\text{minimum effective width}}{\text{maximum effective width}}\right)^2$$

In the case of the Colvern CLR 8205 model of potentiometer, the card thickness is 0·047in and the minimum and maximum permitted values of physical width are 0·100in and 1·125in respectively. The output of a square law potentiometer of the kind just described, realized in this model, would show a maximum error of 0·38 per cent. A further refinement is to introduce a second tap F midway between O and A. Using fixed resistances in shunt between O and F and between F and A (see Fig. 12), the maximum error reduces to 0·1 per cent in the CLR 8205 model. There is no difficulty over the card slope since the card length OD is 8·406in, and the slope $= \tan^{-1}(1{\cdot}172/8{\cdot}406) = 8^\circ$.

If it is required to realize the square law function over the range $-1 \leqslant x \leqslant +1$, the arrangement of Fig. 13(a) may be used, which features a double square law card. Note that the ends of the potentiometer are connected together so that the sign of the output is strictly in accordance with the square law over the full range of x. If the function $x|x|$ is required, the ends of the potentiometer are fed from a balanced source (Fig. 13(b)). Some winding difficulty would be experienced with the double square law card since the slope would be doubled: this could be overcome by reducing the ordinate CD, with some loss of accuracy.

Miscellaneous Considerations

So far this article has been concerned entirely with grading problems. But the design of a graded potentiometer involves also the specification of the total resistance of the card and consideration of the resolution of the potentiometer (i.e. the inter-turn spacing). Care must be taken to see that the card profile which has been selected from considerations of grading can in fact be wound to give the desired total resistance and acceptable resolution. Where difficulty is experienced in achieving a low enough total resistance for a given resolution with nickel-chromium wire, the problem may be solved by the use of copper alloy wire such as Johnson Matthey's Mancoloy 10 whose resistivity is only a tenth of that of nickel-chromium*.

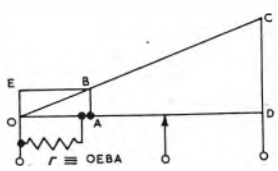

Fig. 11. Profile of square law potentiometer

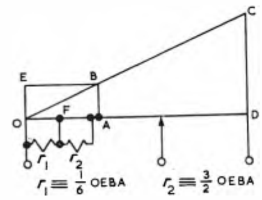

Fig. 12. Further refinement of square law potentiometer

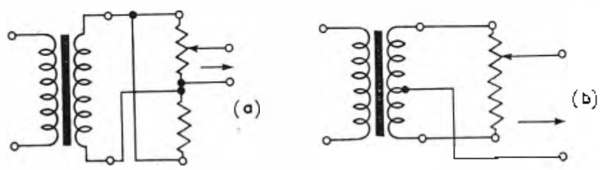

Fig. 13. (a) Realization of square law over range $-1 \leqslant x \leqslant 1$ (b) Realization of $x|x|$

It is scarcely necessary to remark that the errors resulting from the application of a known load to the output of a graded potentiometer may be eliminated in the computation of the grading.

Linear Potentiometers in Special Circuits

The connexion of a resistive load across the output of a linear potentiometer results in a departure from linearity in the output/shaft rotation characteristic. By this means it is possible to generate non-linear functions from a linear potentiometer, and several examples of this technique have been described in the literature[2,3]. The authors' intention is to present a systematic design procedure for the type of circuit shown in Fig. 14. This is simpler than the loaded potentiometer arrangement, but the methods described for synthesizing given functions can be readily adapted to the latter, and, indeed, to more general circuits.

The Circuit

The end terminals of the potentiometer are identified as T_1 and T_2 and the slider as T_0. Let the resistance between

* *There are two other techniques which help to solve grading problems, viz. wire size changes in the course of winding and variable space winding. Both are advertised features of potentiometers made by Fairchild Controls Corporation in the United States.*

T_o and T_1 be f, that between T_1 and T_2 being unity. Let T_1 be connected to a generator of zero internal impedance and e.m.f. e_1; let T_o be connected through a resistance α to a generator of zero internal impedance and e.m.f. e_2; and let e_o be the potential of T_o.

Then

$$e_o = \frac{e_1/f + e_2/\alpha}{1/f + 1/\alpha} \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

which reduces to

$$e_0 = \frac{e_1\alpha + e_2 f}{\alpha + f} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

If T_2 had been connected to the generator e_1 instead of T_1, the expression for the slider potential would have been

$$e_o = \frac{e_1\alpha + e_2 - e_1 f}{\alpha + 1 - f} = \frac{-(e_1\alpha + e_2) + e_1 f}{-(\alpha + 1) + f} \quad \ldots \quad (5)$$

Since e_1 and e_2 can have any values, positive or negative, and α can have any positive value, it follows from equations (4) and (5) that it is possible to generate any voltage e_o of the form

$$e_o = \frac{a + bf}{c + f} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where a and b can have any values, but

$$c < -1 \text{ or } > 0$$

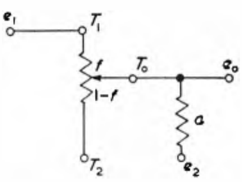

Fig. 14. Linear potentiometer circuit

This, of course, is simply the condition that the denominator of the fraction in equation (6) shall not vanish. Were this condition not necessary, it would be possible for the slider potential to become infinite, while the generator e.m.f. remained finite, which is absurd.

The Parameter Values

Suppose, now, that it is required to generate a function y of one independent variable x whose range of values is restricted to $x_1 \leqslant x \leqslant x_2$; and suppose that y is finite or zero within this range. Then x will be related to the variable f according to the equation

$$f = \frac{x - x_1}{x_2 - x_1}$$

Usually a scaling factor, λ, will be prescribed. Defining a quantity

$$y_r = \lambda e_o,$$

the problem is to generate e_o such that y_r differs from y by as little as possible. The parameters available for the synthesis of e_o are the a, b and c of equation (6). If two errors are defined:

$$\epsilon \equiv y_r - y$$
$$\epsilon' \equiv \lambda(a + bf) - y(c + f),$$

there are four principal methods of determining a, b and c. These are:

(1) Make ϵ (or ϵ') vanish at three values of f.

(2) Make $\int_0^1 \epsilon^2 df$ a minimum with respect to a, b and c.

(3) Make $\int_0^1 \epsilon'^2 df$ a minimum with respect to a, b and c.

(4) Make $y_r = y$

$$\left.\begin{aligned} dy_r/df &= dy/df \\ d^2y_r/df &= d^2y/df^2 \end{aligned}\right\} \text{ at one value of } f.$$

It should be noted that none of the methods necessarily yields a realizable result; but method (2) can be modified to ensure that the parameter values are realizable, and this solution will usually be the most satisfactory. It will now be considered in more detail.

It is more convenient to write

$$\lambda \cdot \frac{a + df}{c + f} = p + \frac{q}{r + f}, \qquad \text{where } \begin{aligned} p &= \lambda b \\ q &= \lambda(a \quad bc) \\ r &= c \end{aligned} \quad \ldots\ldots\ldots\ldots \quad (7)$$

and to minimize the error-squared integral with respect to p, q and r. From the definition of error, ϵ,

$$\int_0^1 \epsilon^2 df = p^2 + 2Hpq + Kq^2 - 2I_2 q + I_3 \quad \ldots\ldots \quad (8)$$

where $H \equiv \log \dfrac{r + 1}{r}$

$$K \equiv (1/r) - \frac{1}{r + 1}$$

$$I_1 \equiv \int_0^1 y df$$

$$I_2 \equiv \int_0^1 \frac{y}{r + f} df$$

$$I_3 \equiv \int_0^1 y^2 df$$

The condition that this shall be a minimum with respect to p, q and r does not, in general, lead to real values of these parameters. It is therefore preferable to minimize the error-squared integral with respect to p and q, and thereafter to find its least value with respect to r by searching. The values of p and q to minimize the error-squared integral are easily determined by partial differentiation with respect to p and to p in turn in equation (8), equating to zero and solving the resultant equations for p and q. The solutions are:

$$p = -\theta I_1 - \phi I_2 \quad \ldots\ldots\ldots\ldots\ldots \quad (9a)$$
$$q = -\phi I_1 + \psi I_2 \quad \ldots\ldots\ldots\ldots\ldots \quad (9b)$$

where $\theta \equiv \dfrac{\cdot K}{K - H^2}$

$$\phi \equiv \frac{H}{K - H^2}$$

$$\psi \equiv \frac{1}{K - H^2}$$

Equation (8) then reduces to

$$\int_0^1 \epsilon^2 df = \theta I_1^2 + 2\phi I_1 I_2 - \psi I_2^2 + I_3 \quad \ldots\ldots\ldots \quad (10)$$

The parameters θ, ϕ and ψ are tabulated, as functions of r, in Table 1. It is necessary to state the values to six figures at least since the net result in equation (10) is generally a small difference between large terms.

The alternative heading of the first column $-(r + 1)$, enables the table to be used for negative values of r. For example, if $r = -4$, θ is $-145{\cdot}596$, ϕ is $-502{\cdot}623$ and ψ is $+1747{\cdot}15$.

PRACTICAL CIRCUITS

It is undesirable in practice to use more generators than are really necessary. If e_1 and e_2 are of opposite sign, then the use of two generators is unavoidable; but if they have the same sign, only one generator need be used. For suppose $|e_1| > |e_2|$. Then the source e_2, connected to the terminal T_o through a resistance α, can be shown to be equivalent to a source e_1 connected to T_o through a resistance α_1, together with a resistance α_o connected between T_o and earth, where

$$\alpha_1 = (e_1/e_2)\,\alpha \quad \ldots\ldots\ldots\ldots\ldots \quad (11a)$$

$$\alpha_o = \frac{e_1\alpha}{e_1 - e_2} \quad \ldots\ldots\ldots\ldots\ldots \quad (11b)$$

This is depicted in Fig. 15. If, on the other hand, $|e_1| < |e_2|$, the source e_1 can be replaced by a resistance α_o connecting

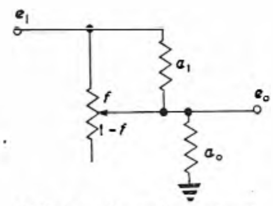

Fig. 15. Equivalent circuit when $|e_1| > |e_2|$

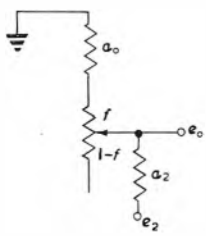

Fig. 16. Circuit when $|e_2| > |e_1|$

terminal T_1 to earth, the resistance connecting T_o to the source e_2 being altered in value to α_2, where

$$\alpha_o = (e_1/e_2)\,\alpha \quad \ldots\ldots\ldots\ldots\ldots \quad (12a)$$

$$\alpha_2 = \frac{(e_2 - e_1)\alpha}{e_2} \quad \ldots\ldots\ldots\ldots \quad (12b)$$

This is depicted in Fig. 16. (It should be noted that this circuit is not equivalent to the required basic circuit, since the output resistances of the two circuits differ).

As an example of the design technique described above, consider the realization of the function $y = x^2$ $(0 \leqslant x \leqslant 1)$.

TABLE 1
The parameters θ, ϕ and ψ

r	$-\theta$	$+\phi$	$+\psi$
$-(r+1)$	$-\theta$	$-\phi$	$+\psi$
0·10	2·72101	0·71772	0·29931
0·25	5·24840	2·63968	1·64012
0·50	10·5498	8·69263	7·91237
0·75	17·3195	19·2607	22·7319
1	25·5794	35·4605	51·1588
2	73·5927	179·036	441·556
3	145·596	502·623	1747·15
4	241·549	1078·00	4830·99
5	361·592	1977·78	10847·8
6	505·596	3273·39	21235·0
7	673·600	5037·02	37721·6
8	865·567	7340·34	62320·8
9	1081·48	10255·1	97333·1
10	1321·35	13853·2	145349·0

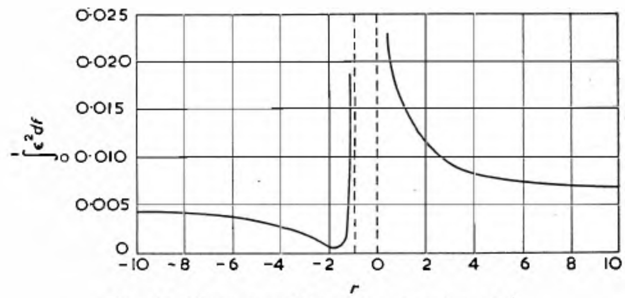

Fig. 17. Error-squared integral as function of r

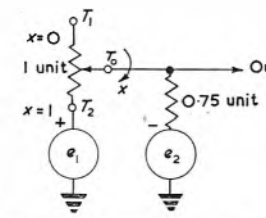

Fig. 18. Realization of square law using linear potentiometer

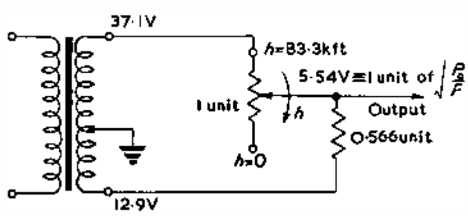

Fig. 19. Realization of $\sqrt{(P_o/P)}$

The error-squared integral is plotted as a function of the parameter r in Fig. 17; its least value occurs at $r = -1{\cdot}75$, corresponding to which $p = -0{\cdot}8689$ and $q = -1{\cdot}4189$. It follows that $\lambda a = 0{\cdot}1016$, $\lambda b = -0{\cdot}8689$ and $c = -1{\cdot}75$. The circuit required is shown in Fig. 18. The errors in the realization of the function are given in Table 2. They are expressed as a percentage of the maximum output. Greater accuracy is achievable if one is prepared to use a more elaborate circuit, the price paid for the gain in accuracy being the increased attenuation in the circuit.

A second example of the technique is afforded by the realization of the function $\sqrt{(p_o/p)}$ where p is the atmospheric pressure at a height h, p_o being its value at sea-level. The circuit is shown in Fig. 19; the potentiometer has a shaft value of 100 000ft per revolution, and its card extends over an arc of 300°. Table 3 compares the circuit output with the values of the function as derived from the standard I.C.A.N. tables, and indicates that the extremes of error are of the order of ±1 per cent. The output has been taken to be correct at $h = 80\,000$ft that is, at very nearly maximum output. The circuit of Fig. 19 was employed in an a.c. computer and the exciting voltages

TABLE 2

x	0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0
Error (per cent) ..	−5·8	−1·9	0·6	2·0	2·2	1·6	0·5	−0·8	−1·5	−1·0	2·3

TABLE 3

h, (ft × 10³)	0	10	20	30	40	50	60	70	80
$\sqrt{(Po/p)}$	1·000	1·205	1·475	1·835	2·325	2·955	3·761	4·788	6·096
CIRCUIT OUTPUT ..	0·934	1·204	1·524	1·906	2·375	2·958	3·708	4·705	6·096
ERROR (per cent)	−1·1	−0·03	+0·8	+1·2	+0·8	+0·05	−0·9	−1·3	0

were conveniently derived from a transformer winding, tapped as shown.

The Use of Tapped Potentiometers in Association with External Shunt Resistors or Voltage Sources

In this technique of function generation, a linear potentiometer is provided with several taps along its winding. These taps are connected to suitable voltage sources so that the potentiometer output attains the desired values at the slider positions corresponding to the tap locations. Between taps the output will correspond quite accurately to the value of the function obtained by linear interpolation between the function values at the taps. The voltages applied to the taps may be obtained in various ways, one of which is shown in Fig. 20. This arrangement is described by G. A. and T. M. Korn[4], who give a detailed treatment of the design of tapped potentiometers.

Other detailed accounts are those of Mayorov[5] and Shen[6] and the reader is recommended to consult these authorities. In summary, it may be said that the multiple-tapping technique is most suitable for function-generation in experimental computers built on a one-off basis. In such equipment, it is often necessary to change the shape of a function, particularly when the function is known, not in

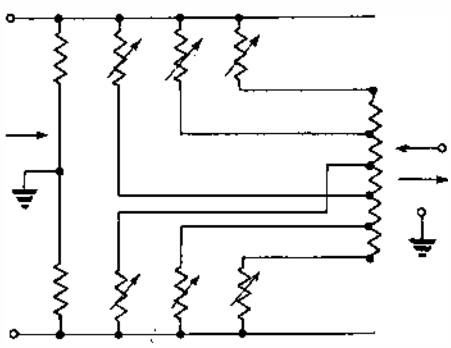

Fig. 20. Tapped potentiometer circuit

analytical form, but as the result of experimental measurements. In such cases, the realization of the function by means of a graded potentiometer might well be impracticable and in any event would be subject to manufacturing delays. On the other hand, when the quantity production of a computer is under consideration, the multiple-tapping technique would be expensive and would be likely to demand tedious setting-up operations.

The Use of Taps in Graded Potentiometers

The provision of a small number of taps is often worth consideration as a means of easing the design of a graded potentiometer. For example, in an aerodynamic computer it was necessary to realize the function $\rho/\rho_0 \, . \, a/a_0 \, . \, (1 + 1{\cdot}67 \times 10^{-6}h)$, where ρ and a are respectively the air density and speed of sound at a height of h ft, ρ_0 and a_0 being their values at sea level. Over the height range 0 to 80 000ft the function shows a decrease of about thirty-fold, and its maximum slope, which occurs at $h = 0$, is very large. The card profile, which was designed for a Colvern type 8205 potentiometer having a shaft value of 100 000ft per revolution, is shown in Fig. 21. Starting at $h = 0$ the card width is given the maximum permitted value and decreases steadily to 130°. At this point there is a discontinuity in the slope of the function corresponding to the tropopause, and the width is increased as shown. Thereafter it decreases until, at 216°, the minimum permitted width is attained. A second discontinuity is introduced here and the winding is tapped. Grading then proceeds without difficulty until the end of the card is reached at 305°. The use of an external shunt resistor connected between the tap and the end of the card offsets the effect of the width increase at 216° on the potentiometer resistance. The final circuit of the potentiometer is given in Fig. 22. The grading was computed to enable the potentiometer to feed a load of 20 times its own resistance. No constructional difficulties were encountered and the extremes of error observed were $\pm 0{\cdot}2$ per cent of maximum output over the whole range of h.

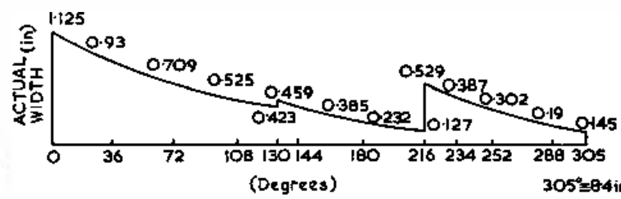

Fig. 21. Card profile for aerodynamic function

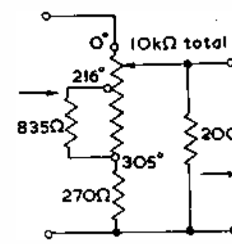

Fig. 22. Circuit of aerodynamic function potentiometer

Acknowledgments

The authors are indebted to The English Electric Company Ltd. for permission to publish this article and to Messrs. Colvern Ltd for much useful information on the art of potentiometer construction.

Appendix

An Example of the Realization of a Non-monotonic Function

It is well-known that the accurate realization of the sine or cosine function over the full range of variation of the independent variable (0-2π) using a conventional potentiometer grading is a matter of some difficulty. If the range can be confined to $0 \rightarrow \pi$ for the sine function (or $-(\pi/2) \rightarrow +(\pi/2)$ for the cosine), the difficulties are reduced appreciably and the circuit of Fig. 23 may be employed. This circuit is derived from the more general one of Fig. 10 as a result of the following considerations:

(1) The ends of the potentiometer card correspond to values of x, the independent variable, of 0 and π radians respectively and the potentiometer output is required to be proportional to $\sin x$.

(2) Since $\sin x = 0$ for $x = 0$ and $x = \pi$, the voltage source e_1 in Fig. 10 may be made zero and also α_1 may be made zero.

Using the previous notation, it follows that

$$z = \frac{1}{\sin x - \lambda e_2}$$

$$\therefore \; dz/dx = -\frac{\cos x}{(\sin x - \lambda e_2)^2}$$

The turning-point occurs when $x = \pi/2$ and therefore

$$z_m = \frac{1}{1 - \lambda e_2}$$

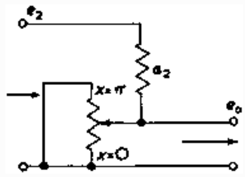

Fig. 23. Realization of sin x over range $0 < x < \pi$

In the circuit of Fig. 23, it is clear from considerations of symmetry that when $x = \pi/2$, $f = 1/2$, and it follows that

$$e_0/e_2 = \frac{1}{1 + 4\alpha_2}\ (x = \pi/2)$$

But y has been defined as λe_0, and $y = 1$ at $x = \pi/2$

$$\therefore\ \lambda e_2 = 1 + 4\alpha_2$$

Since $\alpha_1 = 0$, $\beta = \alpha_2$, and df/dx, which is proportional to the card width, is equal to dg/dx, i.e.

$$\tfrac{1}{2}\sqrt{\left(\frac{\alpha_2\lambda\,(e_1 - e_2)}{z_m - z}\right)}\ .\ dz/dx.$$

Making use of the values of z, z_m, dz/dx and λe_2 which have just been derived, it is found that the card width reduces to $\dfrac{K\ \sqrt{(1 + \sin x)}}{(1 + 4\alpha_2 - \sin x)^{3/2}}$ where K is a constant of proportionality.

The card width attains its maximum values at $x = \pi/2$, and its minimum at $x = 0$ or π. Let the ratio of maximum to minimum permitted effective card width be γ. It readily follows that

$$\gamma = \sqrt{2}\left(\frac{1 + 4\alpha_2}{4\alpha_2}\right)^{3/2}$$

which re-arranges to give

$$\alpha_2 = \tfrac{1}{4}\ .\ \frac{1}{(\gamma/\sqrt{2})^{2/3} - 1}$$

In the case of the Colvern CLR 6500 or CLR 7300 model of potentiometer, γ has the value 4·13, and the corresponding value of α_2 is found to be 0·24. The attenuation factor (ratio of maximum output voltage to input voltage) of the circuit of Fig. 23 would then be 0·51. The value of K follows from a knowledge of the minimum card width: $K = (1 + 4\alpha_2)^{3/2}\ x$ minimum width (0·131in in the models cited). Since K and α_2 are now known, the card profile can be calculated. The maximum card slope is readily derived from the formula for the card width, and is found to be just under 10° for a shaft value of 2π radians per revolution. The card as described would offer no winding difficulty: it may be remarked that a gentler grading can always be achieved at the price of increased attenuation.

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Television for Removing Radioactive Cartridges

The value of closed-circuit television for remote observation in the atomic energy field has long been recognized. The Atomic Energy Authority was among the first users of this equipment in Britain and today many television channels are at work in the Authority's establishments. It is, therefore, natural that when a need arises for inspection in areas of high gamma flux, where direct viewing is impossible, the use of television is considered. Engineers of the Authority have now designed a mechanical 'hand' with a television 'eye' for removing spent radioactive cartridges from the inside of atomic piles of the type used at Windscale. Marconi's Wireless Telegraph Company Ltd have supplied the television channel for the machine, which has been manufactured by Sir W. G. Armstrong Whitworth Aircraft Ltd, to A.E.A. designs.

The grab, television camera and light are mounted on a boom capable of rotary and lateral movement and carried on a sectional retractable column. The operation of these parts is controlled from a derrick head which houses the viewing monitor, television control unit, position indicating dials, self winding cable drums and hoist.

In the Windscale type of reactor, the uranium cartridges are discharged from the graphite moderator and, when spent, fall into a space between the discharge face and the massive concrete outer casing which acts as a biological shield. From this space, known as the discharge void, the spent cartridges are removed for disposal. However, instead of falling into the discharge void, some cartridges lodge on the arms of a burst cartridge detection scanner, or on ledges on the pile face. Some of these can be removed or dislodged with long tools inserted through inspection holes. Because the whole of the discharge face is not visible through these holes it is possible for cartridges to lodge in concealed positions. When this occurs it is important that they should be speedily detected and removed, as undetected cartridges constitute a hazard to the safe operation of the pile.

The new device will be used after each discharging to inspect the discharge void, and to remove any cartridges left inside the pile. The boom carrying the camera and grab is lowered through one of the access holes in the top of the pile and the face is systematically searched. The grab, which is situated in front of the camera, can be closed to grasp and remove any cartridge in focus.

A feature of the equipment is the provision of automatic stops to prevent the camera being damaged or lost through collision with any obstruction within the area of its operation. Because of the high degree of radiation from the pile direct viewing of the operation of the grab unit is not possible.

The television component is the new Marconi Type BD871 vidicon television channel, which has been specially designed for closed-circuit applications. The camera is cylindrical in construction and measures only 4in in diameter. It incorporates automatic sensitivity control, which compensates electronically for variations in scene illumination to present a picture of constant brightness on the monitor screen. A remote focusing attachment at the rear of the camera unit is operated from the main control position. Special provision has been made to seal the camera against the ingress of radioactive dust. The associated control unit measures 14in x 17in x 8in. A Marconi 14in industrial monitor is used to give a 625 line display.

TIME-SYMMETRIC FILTERS

(Part 1)

Methods of Simulation

By L. R. O. Storey*, M.A., Ph.D., and J. K. Grierson*, M.Sc.

Two methods are described for simulating a filter that has an impulse response which is symmetrical in time, and which extends for indefinite periods before and after the instant at which the impulse occurs. Both methods involve the use of a straightforward linear filter in conjunction with a multi-track reversible tape recorder. Experimental results are presented to show how a narrow-band filter with a time-symmetric impulse response was derived, by one of the methods, from a simple parallel-tuned circuit; the frequency response of such a filter is selective, yet has zero phase-shift at all frequencies.

In many scientific studies the experimental data are recorded as waveforms on magnetic tape. Often, in the subsequent analysis of the data, the recorded waveforms are passed through some kind of filter, to pick out a component signal that is of interest and to distinguish this from other signals or from interfering noise. If the properties of the signal and noise are known, it may be possible to specify the filter which would perform this task best. Commonly, however, the 'optimum filter' proves to be physically unrealizable, in the sense that its impulse response is expected to begin before any impulse is applied. If the desired response anticipates the impulse by a finite interval only, then the corresponding physically realizable filter may be acceptable as a substitute; this would have a response of the same shape, but delayed so as to begin on or after the instant of the impulse. But if the desired response extends infinitely into the past, such an approach fails. One case in point, which initiated the present work, was a requirement for a narrow-band filter with zero phase-shift at all frequencies. The impulse response of such a filter would be symmetrical in time, and would extend for an infinite period both before and after the instant at which the impulse occurred. Clearly, filters of this kind are not physically realizable. Nevertheless, their responses can be simulated artificially, as will now be shown.

The necessary equipment comprises a linear filter and a magnetic tape recorder. The filter is quite straightforward; the present work employed a narrow-band filter with a response similar to that of a parallel-tuned circuit. The tape recorder is a multi-track model with certain special features, as follows: firstly, the capstan drive which governs the motion of the tape is reversible; secondly, it is possible to make a recording on one track, while at the same time playing back a signal already recorded on another track, with the tape moving in either direction.

PRINCIPAL SYMBOLS

t	= Time.
τ	= Time displacement.
f	= Frequency.
f_0	= Resonant frequency.
ω_0	= Resonant pulsatance.
C	= Capacitance.
L	= Inductance.
r	= Internal resistance of inductor.
Z_0	= Characteristic impedance.
Q	= Z_0/r.
W	= Bandwidth between 3dB points.
V_{in}	= Input voltage to filter.
V_{out}	= Output voltage from filter.
I_{in}	= Input current to parallel-tuned circuit.
R_1	= Input series resistor for parallel-tuned circuit.
$u(t)$	= Impulse response of filter.
u_0	= Amplitude of impulse response of filter.
$U(t)$	= Overall impulse response.
U_0	= Amplitude of overall impulse response.
$y(f)$	= Frequency response of filter.
y_0	= Amplitude of frequency response of filter at resonance.
$Y(f)$	= Overall frequency response.
Y_0	= Amplitude of overall frequency response at resonance.

* *Defence Research Telecommunications Establishment, Canada.*

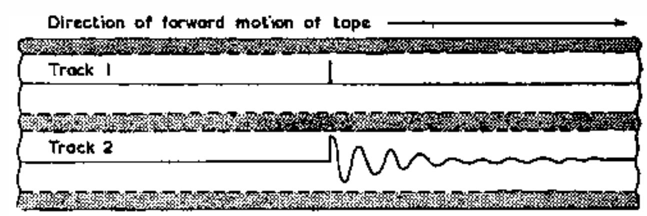

Fig. 1. State of magnetization of the tape after steps (1) and (2) of both methods for pulse input

Now the main problem is to simulate a response which anticipates the arrival of the generating impulse. The basic procedure is as follows:

(1) The signal to be analyzed is recorded on track 1, with the tape running in its normal forward direction.

(2) Then the tape is driven in reverse. The signal on track 1 is played back, passed through the filter, and the output from the filter is recorded simultaneously on track 2.

To appreciate the effect of this procedure, assume for the moment that the signal is a sharp impulse, and then consider what occurs in the second of the two steps described above. The impulse, which is recorded on track 1, arrives in due course at the playback head and appears at the output of the corresponding playback amplifier. This output is connected to the input of the filter. The impulse therefore shock-excites the filter, which then 'rings' and executes a decaying oscillation (its 'impulse response') which persists after the impulse has ceased. This oscillation is recorded on track 2. The state of magnetization of the two tracks of the tape is then as shown in Fig. 1, where the intensity of magnetization on each track is plotted vertically against distance along the tape. The direction of forward motion of the tape is from left to right, as indicated by the arrow. Thus a scale of playback time would run from right to left, for forward motion, while for reverse motion it would run from left to right.

If, therefore, the tape is now driven forward again, and the signals on both tracks are played back, the impulse response recorded on track 2 comes out backwards. The oscillation builds up steadily at first, then it stops abruptly at the moment when the impulse itself appears on track 1.

Now suppose that, instead of an impulse, some arbitrary signal is recorded on track 1. The very same argument applies to each of the elementary impulses into which such a signal can be resolved. Hence, when the recordings are finally played back, the relation between the signals which emerge from tracks 1 and 2 is the same as if the latter had been derived from the former by passing it through a filter that has an impulse response which is the time-reverse of the response of the filter actually used.

Thus the procedure has simulated a physically unrealizable filter, and the results can be described in filter terminology. Let the signal to be analyzed be $g(t)$, and let the impulse response of the actual filter be $u(t)$. If the signal were simply passed straight through the filter, the output $h(t)$ would be given by the convolution integral

$$h(t) = \int_{-\infty}^{\infty} g(t - \tau)\, u(\tau)\, d\tau \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$= g(t) : u(t) \qquad \text{, say} \quad \ldots\ldots\ldots \quad (2)$$

From here on, this integral will be signified by a colon, as in equation (2).

Similarly, then, the relation between the signal output from track 1 and the output from track 2 on playback can be represented by an overall impulse response $U(t)$. Provisionally, to make things simple, the recorder itself may be assumed to introduce no attenuation or phase-shift, so that if the filter had been omitted, and the signal had been transferred simply from the one track to the other, then identical outputs would have been received from the two tracks on playback. In this case the relation between the overall impulse response and the direct response of the filter is just

$$U(t) = u(-t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Another way to describe the performance of a filter is in terms of its frequency response $y(f)$, which is related to the impulse response by the Fourier transform

$$y(f) = \int_{-\infty}^{\infty} u(t) \exp(-2\pi j f t)\, dt \quad \ldots\ldots (4)$$

$$= \text{F.T. of } u(t), \qquad \text{say} \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

In the same way, the results of the above procedure can be characterized by an overall frequency response $Y(f)$, which is given by

$$Y(f) = \text{F.T. of } u(-t)$$

$$= y(-f)$$

$$= y^*(f) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where the asterisk denotes the complex conjugate. Equation (6) follows from the previous line, because $u(t)$ is a wholly real function. Thus the amplitudes of the overall frequency response are the same as those of the response of the original filter, but the phases are reversed.

It must be emphasized that these overall responses refer to the relationship between two signals that emerge from the system simultaneously during the final playback, one of which is a reproduction of the original signal. When the responses are defined in this way, rather than in terms of the relationship between the final output from the system and the original signal itself, it becomes unnecessary to include a representation of the long and arbitrary period of time between the original process of recording and the final playback, though it is, of course, only through the elapse of this period that 'unrealizable' responses can be simulated. It must be granted also that the simulated impulse response does not, strictly speaking, extend infinitely into the past, but is limited either by the duration of the above period, or by the finite length of the magnetic tape. However, since either limit can be increased indefinitely, and can be made much greater than the effective duration of the impulse response of any simple filter, this qualification is not significant in practice.

Now although the overall impulse response obtained in this way does indeed begin before the impulse, it does not meet the requirement for symmetry in time. However, two methods are available through which the procedure may be extended to provide the desired time-symmetric response, and these are now described†.

Method 1

The first method for simulating a time-symmetric filter requires a recorder with three tracks. The first two steps in the procedure are those described above, and the rest are as follows:

(3) The tape is driven forwards again. The signal on track 1 is played back, passed through the filter, and the output of the filter is recorded simultaneously on track 3.

(4) The tape is rewound.

(5) The tape is driven forwards once more, and the signals on all three tracks are played back. The signals that emerge from tracks 2 and 3 are added, and their sum forms the desired output.

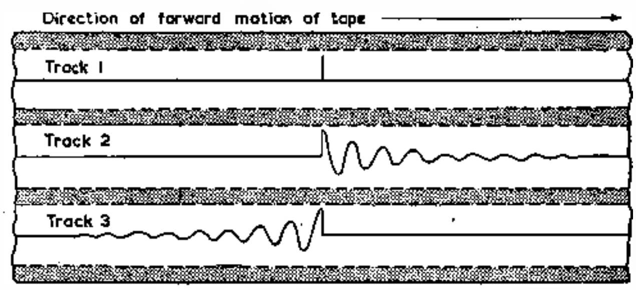

Fig. 2. State of magnetization of the tape after step (4) of method 1, for pulse input

If the signal recorded on track 1 had been an impulse, the final state of magnetization of the three tracks would be that shown in Fig. 2. The impulse response of the filter is recorded backwards on track 2, and forwards on track 3. The overall impulse response is the sum of the two, and is evidently symmetrical in time:

$$U(t) = u(t) + u(-t) \quad \ldots\ldots\ldots\ldots \quad (7)$$

The overall frequency response is therefore

$$Y(f) = y(f) + y^*(f)$$

$$= 2\,R\{y(f)\} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

where the symbol R signifies the extraction of the real part.

Method 2

The second method requires a recorder with two tracks only. The first two steps are again the same, and the remaining step is as follows:

(3) The tape is driven forwards again, and the signals on both tracks are played back. The signal that emerges from track 2 is passed through the filter once more, and the desired output is obtained.

The whole operation is equivalent to passing the signal through two filters in succession, the first with an impulse

† For the sake of succinctness, filters that have impulse responses that are symmetrical in time will be referred to as 'time-symmetric filters' from here on. Earlier work on the simulation of time-symmetric filters with the aid of a magnetic tape recorder has been carried out by Smith and Licklider[1], by Lytle[2], and by Bogert[3]. The technique employed by these authors is method 2 of the present article. Another account of the present work, more detailed in some respects, has been given previously by Grierson[4].

response $u(-t)$ and second with a response $u(t)$. The overall impulse response is thus the convolution of the two:

$$U(t) = u(t) : u(-t) \quad \ldots\ldots\ldots\ldots\ldots (9)$$

This function is evidently time-symmetric; in fact, apart from the absence of a normalizing factor, it is the autocorrelation function of $u(t)$. Its peak value occurs at $t = 0$, and is given by:

$$U(0) = \int_{-\infty}^{\infty} [u(t)]^2\, dt \quad \ldots\ldots\ldots\ldots (10)$$

The corresponding overall frequency response is the product of the two individual frequency responses, viz:

$$\begin{aligned} Y(f) &= y(f)\, y^*(f) \\ &= |y(f)|^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (11) \end{aligned}$$

The Condition for Equivalence

If the frequency response of the filter has a certain form, then either method leads to the same overall response. To ascertain the type of filter for which the two methods are equivalent, consider the fact that any complex number z may be written in the form

$$z = 1/(\alpha + \mathrm{j}\,\beta)$$

in which case the real part is given by

$$R\{z\} = \alpha/(\alpha^2 + \beta^2)$$

and the square of the modulus by

$$|z|^2 = 1/\alpha^2 + \beta^2)$$

Clearly the real part is equal to the square of the modulus if $\alpha = 1$. Thus, if the filter has a frequency response of the form

$$y(f) = \frac{y(f_0)}{1 + \mathrm{j}\,\beta(f)} \quad \ldots\ldots\ldots\ldots\ldots (12)$$

where

(a) $\beta(f)$ is a real function of frequency.

(b) f_0 is a frequency at which $\beta = 0$.

(c) $y(f_0)$ is a real constant.

then the overall frequency response is

$$Y(f) = \frac{Y(f_0)}{1 + \beta^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

where

$$Y(f_0) = \begin{Bmatrix} 2y(f_0) & \text{for Method 1.} \\ [y(f_0]^2 & \text{for Method 2.} \end{Bmatrix} \quad \ldots (14)$$

Thus the two responses are the same, apart from a constant factor.

Now consider the overall impulse responses. For method 1 the response is given in equation (7), while for method 2 it is given in equation (9). These two overall impulse responses must be expected to have the same shape, since their Fourier transforms—the frequency responses—are the same. However, close examination reveals a slight complication in one particular case which happens to be of interest: this is the case where $u(t)$—the impulse response of the original filter—contains a step discontinuity at $t = 0$. The shape of this discontinuity must be specified with care if the two overall impulse responses are to agree.

Following the accepted notation[5], let the symbol $u(0+)$ represent the limit of $u(t)$ as t tends to zero from positive values, and let $u(0-)$ be the corresponding limit as zero is approached from negative values; evidently $u(0-) = 0$, since $u(t)$ is the response of a realizable filter, and must therefor be equal to zero for all $t < 0$. At the actual point $t = 0$, $u(t)$ is now required to take the value.

$$\begin{aligned} u(0) &= 1/2\ \{u(0+) + u(0-)\} \\ &= 1/2\, u(0+) \quad \ldots\ldots\ldots\ldots\ldots\ldots (15) \end{aligned}$$

This result may be achieved by suitable definition of the unit impulse which evokes the response $u(t)$ from the filter. The unit impulse is usually defined, by a limiting process, from a pulse that has some simple analytic form (e.g., Gaussian); it is defined as the limit of the pulse when its width tends to zero and its height to infinity, while its area, or 'strength', remains constant and equal to unity. Clearly equation (15) can be made to hold by specifying that the pulse must also be symmetrical and centred on the time $t = 0$. Then, at this time, just half the impulse has arrived, and $u(t)$ has risen to half the value that it finally attains when the complete impulse has passed.

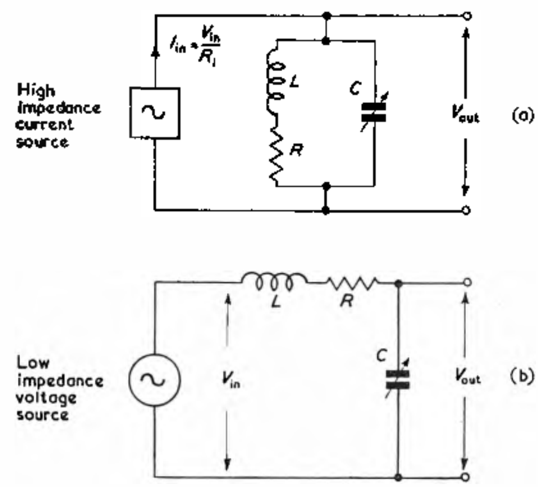

Fig. 3. Notation for two types of narrow-band filter
(a) The parallel-tuned circuit
(b) The series-tuned circuit

To define $u(t)$ in this way ensures that, when it is added to its time-reverse $u(-t)$ in method 1, no discontinuity occurs at $t = 0$. The overall impulse responses then have the same shape for both methods, and can be written in the general form

$$U(t) = \frac{U(0)}{u(0+)}\{u(t) + u(-t)\} \quad \ldots\ldots (16)$$

where

$$U(0) = \begin{Bmatrix} u(0+) & \text{for Method 1} \\ \int_{-\infty}^{\infty} [u(t)]^2\, dt & \text{for Method 2} \end{Bmatrix} \quad \ldots\ldots (17)$$

The relation between the coefficients $U(0)$ and $Y(f_0)$ is given by the Fourier transform

$$U(0) = 2Y(f_0)\int_{0}^{\infty} \frac{df}{1 + \beta^2} \quad \ldots\ldots\ldots\ldots (18)$$

The Parallel-Tuned Circuit

One example of a filter which satisfies the above condition for equivalence is the parallel-tuned circuit driven with current from a high-impedance source (Fig. 3(a)). This type of filter was used in the present work. If the Q-factor of the circuit is much greater than unity, as will be assumed throughout this article, then the relationship between output voltage and input current is approximately

$$V_{out}/I_{in} = \frac{QZ_0}{1 + jQx} \qquad \ldots\ldots\ldots\ldots \quad (19)$$

where

$$x = \omega/\omega_0 - \omega_0/\omega = f/f_0 - f_0/f$$

$$\simeq 2\,\frac{f - f_0}{f_0} \quad \text{when } |x| \ll 1$$

$$\omega_0 = 2\pi f_0 = (LC)^{-1/2}$$

$$Z_0 = (L/C)^{1/2}$$

$$Q = Z_0/r$$

Of these various parameters, ω_0 is the resonant pulsatance, f_0 is the resonant frequency, and Z_0 is the characteristic impedance.

In discussing the behaviour of the filter it is convenient to arrange the input, as well as the output, to be in the form of a voltage. The frequency response can then be defined as the ratio of the output and input voltages, which is dimensionless. Let it be supposed, therefore, that the current drive for the parallel-tuned circuit is supplied by an input voltage V_{in}, through a resistor R_1 which is much greater than the resonant impedance (QZ_0) of the circuit. Then, approximately

$$I_{in} = V_{in}/R_1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

and the frequency response of the filter is

$$y(f) = V_{out}/V_{in} = \frac{y_0}{1 + jQx} \qquad (21)$$

where the amplitude at resonance is given by

$$y_0 = y(f_0) = QZ_0/R_1 \qquad \ldots\ldots\ldots\ldots \quad (22)$$

Setting $\beta = Qx$, this response becomes of the form of equation (12), and meets the attached conditions. Thus the overall frequency response, derived from it by either method, is given by equation (13).

$$Y(f) = \frac{Y_0}{1 + Q^2x^2} \qquad \ldots\ldots\ldots\ldots\ldots \quad (23)$$

where, from equation (14), the resonant amplitude is

$$Y_0 = Y(f_0) = \begin{Bmatrix} 2\,QZ_0/R_1 \text{ for Method 1} \\ [QZ_0/R_1]^2 \text{ for Method 2} \end{Bmatrix} \quad \ldots\ldots \quad (24)$$

This overall response is compared in Fig. 4 with the frequency response of the original filter; the amplitudes of both responses have been normalized to unity at resonance. The two vertical bars on the horizontal axis mark the frequencies at which $Qx = \pm 1$; here the response of the tuned circuit is reduced by 3dB below its resonant value, while the overall response is reduced by 6dB. The bandwidth W of the tuned circuit, measured as the difference between the frequencies of these '3dB points', is given by the approximate expression

$$W = f_0/Q \qquad (Q \gg 1) \qquad \ldots\ldots\ldots\ldots \quad (25)$$

As for the impulse responses, that of the filter itself is the familiar damped oscillation

$$u(t) = \begin{Bmatrix} 0 & (t < 0) \\ 1/2\,u_0 & (t = 0) \\ u_0 \exp(-\pi Wt)\operatorname{Cos}(2\pi f_0 t) & (t > 0) \end{Bmatrix} \ldots\ldots (26)$$

where the amplitude of the response (that is to say, the peak amplitude of the envelope of the oscillation) is given by

$$u_0 = \omega_0 Z_0/R_1 = 2\pi f_0 Z_0/R_1 \qquad \ldots\ldots\ldots \quad (27)$$

and is related to the amplitude of the frequency response of the filter at resonance by the expression

$$u_0 = 2\pi W y_0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

The overall impulse response is proportional to the sum of the impulse response of the filter and its time-reverse (equation 16), and thus consists of a cosine oscillation which decays exponentially in both directions from the instant $t = 0$:

$$U(t) = \frac{U_0}{u_0}\left\{u(t) + u(-t)\right\} \qquad \ldots\ldots\ldots\ldots \quad (29)$$

$$= U_0 \exp(-\pi W|t|)\operatorname{Cos}(2\pi f_0 t) \qquad (30)$$

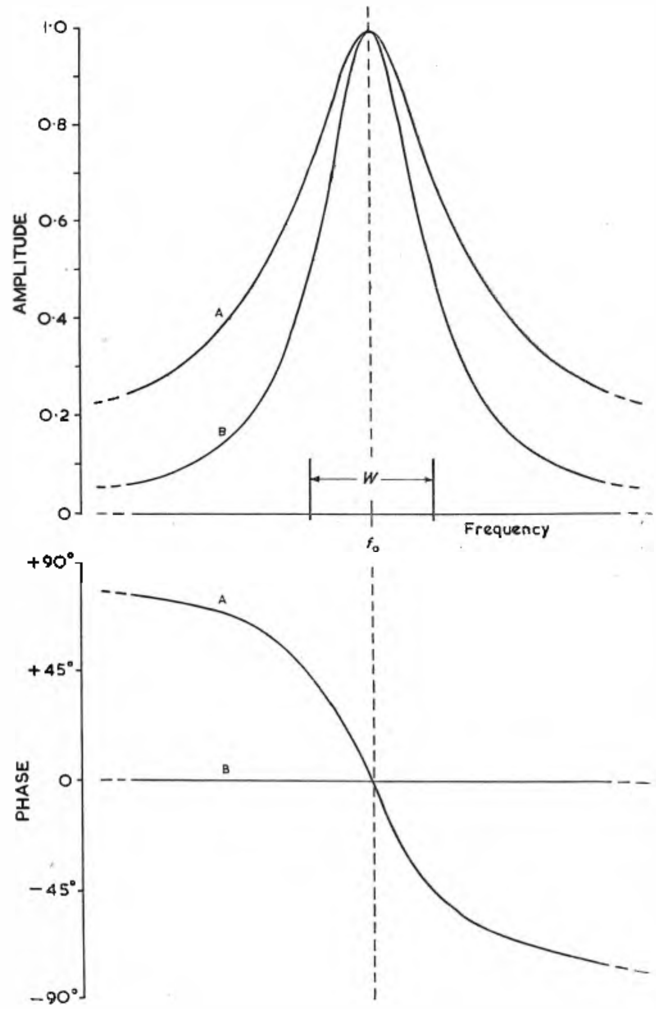

Fig. 4. Theoretical frequency response. Curve A. Parallel-tuned circuit. Curve B. Time-symmetric filter

where the amplitude is given by

$$U_0 = \begin{Bmatrix} 2\pi f_0 Z_0/R_1 & \text{for Method 1} \\ \pi f_0 Q(Z_0/R_1)^2 & \text{for Method 2} \end{Bmatrix} \quad \ldots\ldots \quad (31)$$

The relation between U_0 and Y_0 is given by equation (18) as

$$U_0 = \pi W Y_0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (32)$$

Comparison of the Two Methods

The methods may be compared from two standpoints, the theoretical and the practical.

In theory, method 1 appears the more flexible, since by this method it is possible to realize any reasonable form of symmetrical impulse response, while there are definite restrictions on the type of symmetrical response that can be simulated by method 2. These restrictions stem from the fact that the overall response derived by this method is an autocorrelation function (equation (9), for not all symmetrical functions are possible autocorrelation functions. Doob[6] has listed the properties that a function must possess, in addition to symmetry, to qualify as an autocorrelation function. The main properties are that its value at $t = 0$ must be positive and greater in magnitude than its values at all other times, and that its Fourier transform may not have negative values (c.f. equation (11)). These restrictions limit the types of response that can be realized by method 2. In contrast, method 1 is not so limited; it could, for instance, be used to simulate time-symmetric filters having impulse responses with minima at $t = 0$, or frequency responses with negative values.

In the present work the desired response was of a type that could be realized equally well by either method, so the choice between the two was made on practical grounds. Here method 2 seems to be slightly the better, though there are several factors to be considered. Firstly, it is somewhat faster; its procedure involves only three distinct steps, against five for the other. Secondly, it is less disturbed by the spurious noise and hum that may arise within the tape recorder, since the final response is taken from the output of the filter, instead of, as in method 1, directly from the playback amplifier. Thirdly, the equipment is simpler, since the recorder need have only two tracks instead of three. Indeed, the procedure of method 2 could be performed with a pair of straightforward non-reversible single-track recorders, if the direction of tape motion was reversed manually by interchanging the supply and take-up reels; this was the approach followed in the work published previously[1, 2, 3]. However, when the same waveform needs to be analyzed repeatedly with different filters, this approach is ruled out as too slow.

The final point to be considered is how the two methods are affected by the response of the recorder itself. So far this has been taken as perfect, which is to assume that a signal is unaltered and transferred from one track to another by simultaneous playback and re-recording. This assumption is unrealistic, since the playback and recording amplifiers may not have level frequency responses and certainly will introduce phase-shifts. Even if, as is usually the case, their combined response is equalized in amplitude over the working frequency range, the accompanying phase-shift cannot be eliminated. The question, then, is how this instrumental phase-shift affects the overall responses obtained by the two methods.

The phase-shift incurred when a signal is transferred from one track to another is the sum of phase-shifts in the playback and the recording amplifiers, and is a function of frequency: let it be called $\theta(f)$. If the signal is transferred while the tape runs in reverse, and the tape is then run forward and the outputs from the two tracks are compared, this phase-shift will clearly appear as $-\theta(f)$. Bearing this in mind, it is easy to show that the phase-shift modifies the overall frequency responses as follows: for method 1.

$$Y(f) = 2\cos\theta(f) R\left\{y(f)\right\} - 2\sin\theta(f)\, I\left\{y(f)\right\} \quad \ldots . (33)$$

where the symbol I denotes the imaginary part of the function: for method 2,

$$Y(f) = \exp\left[-j\,\theta(f)\right]\, |y(f)|^2 \quad \ldots\ldots (34)$$

Evidently both responses are modified, but the modification is more serious for method 1, because the amplitude as well as the phase is altered. In method 2 the amplitude is unaltered, but the phase is shifted by an amount $-\theta(f)$. However, this phase-shift could be compensated for by an external network, because its complement is just the phase characteristic of the recorder, and is therefore realizable. Alternatively, the compensation could be effected by using a recorder with three tracks, and then changing the later steps of the method as follows:

(3) The tape is driven forwards again. The filtered signal on track 2 is played back, passed through the filter once more, and the output of the filter is recorded simultaneously on track 3.

(4) The tape is rewound.

(5) The tape is driven forwards again, and the signals on tracks 1 and 3 played back. The latter forms the desired output.

The extra operation of re-recording while the tape runs forward introduces the complementary phase-shift, at the price, however, of losing the advantages of method 2 in speed and simplicity.

In the present experimental work, narrow-band filters were always used. In general, their responses to arbitary waveforms consisted of quasi-sinusoidal oscillations modulated by relatively slowly-varying envelopes. The interest happened to lie only in the shape of these envelopes, and not in the phase of the oscillations within them. Here method 2 was quite satisfactory, even when used without compensation for instrumental phase-shifts, so the practical advantages of this method led to its adoption.

Equipment

The present experiments were performed at audio frequencies. A narrow-band filter and a special tape recorder were used, details of which now follow.

The filter consists of a negative-feedback amplifier of the 'virtual earth' type, with a bridged-T null network in the feedback loop. The frequency response is similar to that of a parallel-tuned circuit. The resonant frequency is variable from 500c/s to 5kc/s, as is the Q-factor from 10 to 300, both continuously. This filter has been described more fully elsewhere[7].

The tape recorder was designed by the Ampex Corporation of Redwood City, California, and was constructed by modifying standard equipment of their manufacture. It is reversible, and provides four recording tracks on a tape $\frac{1}{2}$ in. wide. The first track is used for the waveform which is to be analyzed. The second track records the output from the filter, the third is used for the timing pulses, and the fourth track contains a 'speed lock' signal. This last consists of an 18kc/s carrier modulated by a 60c/s sine-wave from a stable oscillator, and it is recorded on the tape at the same time as is the original waveform. On playback the phase of the 60c/s modulation from the tape is compared continuously with that of the sine-wave from the oscillator, and the difference is made to actuate a servo system which varies the speed of the motor so as to keep the two in step. The servo operates with the tape running in either direction, and holds the mean speed very steady; moreover, even if the whole tape becomes slightly stretched, the servo readjusts the speed so that all the recorded frequencies are reproduced at their original values. If the tape is stretched unevenly, however, the servo, which has a time-constant of about one second, can compensate only partially for the resulting fluctuations in playback speed. The residual fluctuations produce a spurious and random time-displacement of the reproduced signal, which corresponds to a random phase-modulation that has an amplitude proportional to frequency. Evidently this effect must set an upper limit to the frequencies at which the above techniques are usable, but the position of this limit has not yet been investigated.

To minimize the effect of uneven tape stretching on the phase relations between signals recorded on different tracks, the same set of heads is used both for recording and for playing back.

Results

To test the predictions of the theory, a cathode-ray oscillogram of the overall impulse response of the system was recorded on continuously moving film. The filter was adjusted to have a Q-factor of about 35, and a resonant frequency of about 500c/s. The impulse response of the filter alone is shown in Fig. 5(a); the slight imperfection of the first half-cycle of oscillation is due to the finite width of the exciting pulse, and to the limited h.f. response of the feedback amplifier in the filter. Fig. 5(b) shows the overall impulse response derived from this filter by method 2: it has the

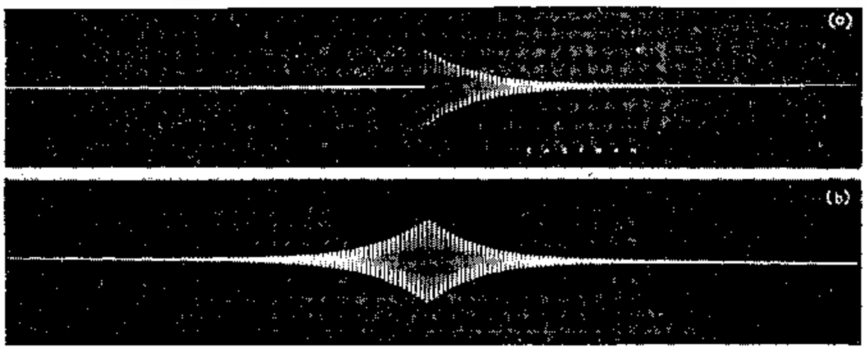

Fig. 5. Measured impulse response
(a) Response of parallel-tuned circuit alone
(b) Overall response for method (2)

expected form of an oscillation bounded by an envelope that consists of a symmetrical pair of exponentials. The peak of the envelope does not quite coincide with a peak of the oscillation, and while this may be due in part to the imperfection of the impulse response, it was, to be expected in any case, because no attempt was made to compensate for the phase-shift in the recorder.

Conclusions

Two methods have been described for simulating filters with symmetrical impulse responses, and one method has been applied experimentally at audio frequencies to realize a narrow-band filter of this type. Part 2 of this article will describe its application to the analysis of gliding tones.

It is felt that the techniques may have applications in other physical problems, wherever there is a need to smooth or filter recorded data without introducing systematic displacements in time.

While this article has been concerned only with time-symmetric filters, similar procedures could clearly be devised for simulating other kinds of physically unrealizable filter, having antisymmetrical or asymmetrical impulse responses. One such application is described in the appendix.

APPENDIX

THE SERIES-TUNED CIRCUIT

The response of the series-tuned circuit (Fig. 3(b)) to applied voltages is much the same as that of the parallel-tuned circuit to applied currents, when the Q-factors are high, so it is interesting to consider whether the former would have served the present purpose equally well. The frequency response of the series-tuned circuit is

$$y(f) = \frac{-\mathrm{j}\, y_0}{1 + \mathrm{j}\, Qx} \qquad \ldots\ldots\ldots\ldots \quad (35)$$

where the amplitude at reasonance is given by

$$y_0 = |\, y(f_0)\,| = Q \qquad \ldots\ldots\ldots \quad (36)$$

This response is of the form of equation (12) but, since $y(f)$ is not wholly real at resonance, it fails to satisfy the conditions for equivalence, so that methods 1 and 2 no longer yield the same overall response. Method 2 still leads to the desired response, viz.

$$Y(f) = \frac{Y_0}{1 + Q^2 x^2} \qquad \text{(c.f. equation (23)}$$

where the resonant amplitude is now

$$Y_0 = Q^2 \qquad \ldots\ldots\ldots\ldots \quad (37)$$

but in method 1 the result is

$$Y(f) = 2R\left\{y(f)\right\} = \frac{-\,2\,Q^2 x}{1 + Q^2 x^2} \qquad \ldots\ldots\ldots \quad (38)$$

This response is zero at the resonant frequency, and exhibits a maximum on either side of resonance; it is positive in sign at frequencies below resonance and negative above. So far no use has been found for this type of filter.

The difference between the results obtained with series and parallel circuits in method 1 may be understood by comparing their impulse responses. For the series-tuned circuit

$$U(t) = \begin{Bmatrix} 0 & (t < 0) \\ U_0 \exp(-\pi W t)\, \mathrm{Sin}\,(2\pi f_0 t) & (t \geqslant 0) \end{Bmatrix} \qquad (39)$$

where the amplitude is given by

$$U_0 = \omega_0 = 2\pi f_0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (40)$$

$$= 2\pi W y_0, \text{ as before.} \qquad .. \quad \text{(c.f. equation (28)}$$

This response also is a damped oscillation, with the same rate of decay as in the parallel-tuned case, but now the oscillation is a sine instead of a cosine wave. Thus there is no step discontinuity in the response itself at $t = 0$, though there is a discontinuity in its slope. However, when two such responses are placed back-to-back they do not join together smoothly; the discontinuity in slope remains present, and this, clearly, is the reason why method 1 yields a different result from that obtained by method 2.

The remedy is clear also: the impulse response will join up smoothly to its time-reverse if the two are subtracted instead of added. Suppose that, in step (5) of method 1, the output from track 2 is subtracted from that on track 3, then the overall response will be

$$U(t) = u(t) - u(-t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (41)$$

$$= \frac{U_0}{u_0}\left\{u(t) - u(-t)\right\} \qquad \ldots\ldots\ldots\ldots\ldots \quad (42)$$

$$= U_0 \exp\left(-\pi W\,|t|\right) \mathrm{Sin}\,(2\pi f_0 t) \qquad \ldots\ldots (43)$$

where the amplitude is given by

$$U_0 = u_0 = 2\pi f_0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (44)$$

The corresponding overall frequency response is

$$Y(f) = 2jI\{y(f)\} \quad \ldots\ldots\ldots\ldots\ldots(45)$$

$$= \frac{-jY_0}{1 + Q^2 x^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (46)$$

where the resonant amplitude is

$$Y_0 = |\,Y(f_0)\,| = 2Q \quad \ldots\ldots\ldots\ldots (47)$$

The relation between the coefficients U_0 and Y_0 remains the same, viz:—

$$U_0 = \pi\, W Y_0 \ldots\ldots \text{ (c.f. equation (32)}$$

On comparing these overall responses with those for the parallel-tuned case, where the outputs from the two tracks are added (equation 29), it appears that the envelopes of the impulse responses, and also the amplitudes of the frequency responses, are the same, but there is 90° difference in phase between the two sets of oscillations. In the present application, this phase-difference would not matter.

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(To be continued)

A Four-Pole Analysis for Transistors

By B. J. Alcock, Ph.D., A.Inst.P.

An algebraically convenient analysis for four pole networks is presented, based upon determinant techniques; it is applied to transistor circuits and introduces two new comprehensive parameters for the transistor.

THE article is concerned with the development of a convenient analytical method for the analysis of four pole networks, including transistor circuits when the transistor is operated in the quasi-linear region. An analysis of this type was felt to be desirable mainly due to the fact that the developed equivalent circuit methods for transistors, some of which appear to have arisen due to the early association of transistors with valves and the attempt to create 'valve type' circuits to describe them, result in algebraic expressions which are unwieldy when written without approximation, and do not readily show the effect upon circuit conditions of varying one particular element external to the transistor[1,2,3,4]. Some existing four terminal network techniques, when developed in a purely general manner without reference to transistor circuits, neglect the fact that the external resistance in the common lead, for example in the base lead of a transistor using the emitter as the input and collector as the output terminal, is an important variable external to the transistor. The effect is that this element becomes 'tied up' within the four circuit parameters of the four pole network[5,6]. The method developed here presents the equations in a form such that all elements external to the transistors are explicitly expressed, and their effect upon the circuit conditions is readily seen. Also the method is entirely based upon one algebraic expression which is easily memorized as it has definite form.

The Basis of the Method

The transistor may be considered as a four pole element with two poles common. Thus if it exhibits voltage and current relationships which are linear to a sufficient approximation over a finite range, one can write the incremental equations for operation in this range in the usual form.

$$V_1 = r_{11}I_1 + r_{12}I_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$V_2 = r_{21}I_1 + r_{22}I_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

These equations may be represented in circuit form as shown in Fig. 1.

The two generators r_{12} and r_{21} are considered ideal, i.e., zero field and armature impedance, and constant speed; the labels r_{12} and r_{21} are the transfer constants 'generated volts per excitation ampere' having the dimension ohms.

The manipulation of a four pole network of this type is conveniently carried out using determinant techniques.

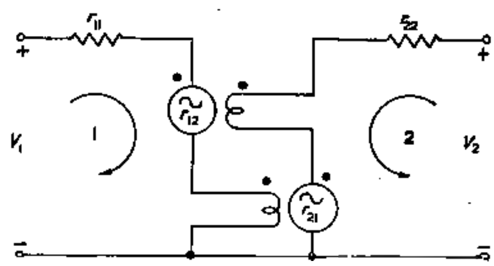

Fig. 1. General four-pole network

Some definitions of notation are required and are as follows[7,8].

$\bar{R}_{xy}$ = The total value of an element in a determinant.

r_{xy}, R_{xy}, R_x = A particular part of a determinant element.

Thus

$$\begin{vmatrix} \bar{R}_{11}, & \bar{R}_{12}, \\ \bar{R}_{21}, & \bar{R}_{22} \end{vmatrix} \equiv \begin{vmatrix} R_x + R_y, & R_z + R_a \\ R_b + R_c, & R_d + R_e \end{vmatrix}$$

D = The general circuit determinant.

D^x = D in which that part of an element R_x has been put equal to zero.

Thus if

$$D = \begin{vmatrix} R_x + R_y, & \bar{R}_{12}, \\ \bar{R}_{21}, & \bar{R}_{22} \end{vmatrix}$$

Then

$$D^x = \begin{vmatrix} R_y & \bar{R}_{12} \\ \bar{R}_{21}, & \bar{R}_{22} \end{vmatrix}$$

D_{pq} = The co-factor (signed minor) of the element $\bar{R}_{pq}$ in the determinant D.

Using standard determinant methods a circuit for example consisting of three meshes may be represented by a third order determinant as shown below.

$$D = \begin{vmatrix} \mathbf{R}_{11}, & \mathbf{R}_{12}, & \mathbf{R}_{13} \\ \mathbf{R}_{21}, & \mathbf{R}_{22}, & \mathbf{R}_{23} \\ \mathbf{R}_{31}, & \mathbf{R}_{32}, & \mathbf{R}_{33} \end{vmatrix}$$

The elements can be evaluated from the following definition.

$\mathbf{R}_{xy}$ is the ratio of the voltage developed in mesh x per unit current in mesh y when all other meshes are open-circuited, i.e. all other currents are zero*;

To solve the network for a particular voltage or current the relationship

$$E_p/I_q = D/D_{pq} \quad \ldots\ldots\ldots\ldots\ldots\ (3)$$

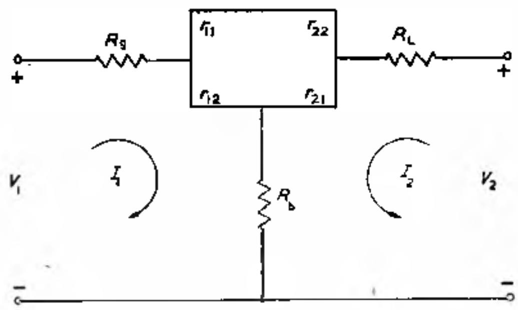

Fig. 2. General transistor circuit

is used, where E_p is the e.m.f. in mesh p, all other e.m.f.'s having been reduced to zero, and I_q is the resulting current in mesh q.

A transistor circuit in general form is shown in Fig. 2 in which the box may represent the transistor in any orientation provided the appropriate four pole parameters are used.

The general circuit determinant is given by

$$D = \begin{vmatrix} \mathbf{R}_{11}, & \mathbf{R}_{12} \\ \mathbf{R}_{21}, & \mathbf{R}_{22} \end{vmatrix}$$

where

$$\mathbf{R}_{11} = R_g + r_{11} + R_B \quad \ldots\ldots\ldots\ (4)$$

$$\mathbf{R}_{12} = R_B + r_{12} \quad \ldots\ldots\ldots\ (5)$$

$$\mathbf{R}_{21} = R_B + r_{21} \quad \ldots\ldots\ldots\ (6)$$

$$\mathbf{R}_{22} = R_B + R_L + r_{22} \quad \ldots\ldots\ldots\ (7)$$

It can be shown (see Appendix 1) that the expression for the determinant D may be written as

$$D = D_T + R_B s_T + R_L(r_{11} + R_B) + R_g(r_{22} + R_B) + R_g R_L \quad \ldots\ (8)$$

where

$$D_T = \begin{vmatrix} r_{11}, & r_{12} \\ r_{21}, & r_{22} \end{vmatrix} \quad \ldots\ldots\ldots\ (9)$$

which is the short-circuit determinant for the transistor alone and a comprehensive transistor parameter, and where

$$s_T = (r_{11} + r_{22}) - (r_{12} + r_{21}) \quad \ldots\ldots\ (10)$$

which is another comprehensive transistor parameter.

Throughout the analysis small r's and s_T will be used to denote the general parameters of the box, and R and S_T, R' and S'_T, and S'' and S_T'' will denote the parameters for grounded base, grounded emitter, and grounded collector configurations respectively, D_T being the same for all three. The relationships between R, R', and R'' parameters are given below, and numerical examples will be found in Appendix 2.

$$R_{11}' = R_{11} \qquad R_{11}'' = R_{22}$$

$$R_{12}' = R_{11} - R_{12} \qquad R_{12}'' = R_{22} - R_{21}$$

$$R_{21}' = R_{11} - R_{21} \qquad R_{21}'' = R_{22} - R_{12}$$

$$R_{22}' = S_T \qquad R_{22}'' = S_T$$

$$S_T' = 2R_{21} - R_{22} \qquad S_T'' = 2R_{12} - R_{11}$$

Thus equation (8), upon which the entire analysis is built, is perfectly general and the analysis can be used for any transistor configuration and the appropriate numerical parameters inserted. In the following examples the transistor is therefore shown as a box and small r's used for its parameters.

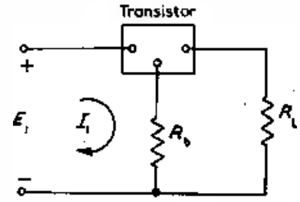

Fig. 3. Circuit for calculating Z_{in}

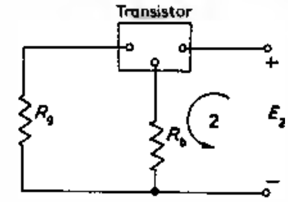

Fig. 4. Circuit for calculating Z_{out}

The Use of Method

The analysis is carried out using equations (3) and (8) and Fig. 2 as the basis, the particular variation being shown in the figure in each section. It will be seen that provided equation (8) is known, all expressions may be written down by inspection.

(a) The Input Impedance Z_{in} (Fig. 3)

R_g is zero

therefore

$$E_1/I_1 = D^g D_{11}^g$$

$$= \frac{D_T + R_B s_T + R_L(r_{11} + R_B)}{R_L + r_{22} + R_B} \quad \ldots\ldots\ (11)$$

(b) The Output Impedance Z_{out} (Fig. 4)

R_L is zero

therefore

$$E_2/I_2 = D^L/D_{22}^L$$

$$= \frac{D_T + R_B s_T + R_g(r_{22} + R_B)}{R_g + r_{11} + R_B} \quad \ldots\ldots\ (12)$$

(c) The Voltage Gain G_v (Fig. 5)

$$G_v = (V_{out}/E_1) = I_2 R_L/E_1$$

$$= R_L D_{12}^g / D^g$$

$$= \frac{-R_L(r_{21} + R_B)}{D_T + R_B s_T + R_L(r_{11} + R_B)} \quad \ldots\ldots\ (13)$$

(b) The Current Gain G_i (Fig. 6)

$$G_i = (I_2/I_1)_{E_2=0}$$

* *The elements* $\mathbf{R}_{11}$, $\mathbf{R}_{22}$ *and* $\mathbf{R}_{33}$ *being of course the total impedance in mesh 1, 2, and 3 respectively.*

The inclusion of the condition $E_2 = 0$, is necessary to obviate a possible ambiguity concerning which mesh current is the cause, and which is the effect. For instance the term I_2/I_1 may be expanded in two different ways.

$$I_2/I_1 = (I_2/E_1)\,.\,(E_1/I_1) = (D_{12}/D)\,.\,(D/D_{11}) = D_{12}/D_{11} \quad \ldots\ldots\ldots\ldots (14)$$

Also

$$I_2/I_1 = (I_2/E_2)\,.\,(E_2/I_1) = (D_{22}/D)\,.\,(D/D_{21}) = D_{22}/D_{21} \quad \ldots\ldots\ldots\ldots (15)$$

Equation (14) shows that mesh 1 is not closed and thus represents the forward current gain. Similarly equation (15) represents the backward current gain.

Using equation (14)

$$G_1 = (I_2/I_1)_{E_2=0} = D_{12}/D_{11}$$
$$= \frac{-(r_{21}+R_B)}{R_L + r_{22} + R_B} \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

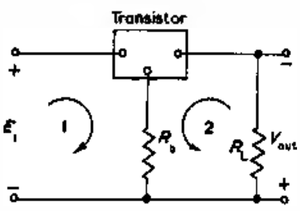

Fig. 5. Circuit for calculating G_v

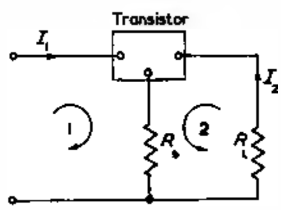

Fig. 6. Circuit for calculating G_i

(e) Power Gain G_p

For unmatched input and output conditions the power gain is usually expressed in the form

$$G_p = I_2^2 R_L / I_1^2 R_{in}$$

Therefore

$$G_p = (D_{12}^g/D_{11}^g)^2\,.\,R_L D_{11}^g/D^g$$
$$= R_L \frac{(D_{12}^g)^2}{D^g\,.\,D_{11}^g}$$
$$= \frac{R_L(r_{21}+R_B)^2}{\left\{D_T + R_B s_T + R_L(r_{11}+R_B)\right\}(r_{22}+R_B+R_L)} \quad \ldots\ldots (17)$$

For matched circuits, however, in which the source and load impedances are made equal to the appropriate image impedances the power gain can be found as follows:

$$R_L = \sqrt{[(D^{gL}/D_{22}^{gL})\,(r_{22}+R_B)]}$$
$$= \sqrt{\left[(D_T + R_B s_T)\frac{(r_{22}+R_B)}{(r_{11}+R_B)}\right]} \quad \ldots\ldots\ldots\ldots (18)$$

and $R_{in} = R_{source}$.

$$= \sqrt{[(D^{gL}/D_{11}^{gL})\,(r_{11}+R_B)]}$$
$$= \sqrt{\left[(D_T + R_B s_T)\frac{(r_{11}+R_B)}{(r_{22}+R_B)}\right]} \quad \ldots\ldots\ldots\ldots (19)$$

Therefore

$$G_p = (D_{12}^g/D_{11}^g)^2 \frac{(r_{22}+R_B)}{(r_{11}+R_B)}$$
$$= \frac{(r_{21}+R_B)^2}{\left\{\sqrt{[(r_{22}+R_B)(r_{11}+R_B)]} + \sqrt{[(D_T+R_B s_T)]}\right\}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

A useful point to note is that, from equations (18) and (19)

$$\frac{R_{source}}{R_{load}} = \frac{(r_{11}+R_B)}{(r_{22}+R_B)}$$

under fully matched conditions.

Appendix 1

$$D = \begin{vmatrix} \mathcal{R}_{11}, & \mathcal{R}_{12} \\ \mathcal{R}_{21}, & \mathcal{R}_{22} \end{vmatrix}$$

where

$$\mathcal{R}_{11} = R_g + r_{11} + R_B$$
$$\mathcal{R}_{12} = R_B + r_{12}$$
$$\mathcal{R}_{21} = R_B + r_{21}$$
$$\mathcal{R}_{22} = R_L + r_{22} + R_B$$

Now

$$D = D^g + R_g D_{11}$$
$$= D^{gL} + R_L D_{22}^g + R_g D_{11}^L + R_g R_L D_{11,22}$$
$$= D^{gL} + R_L(r_{11}+R_B) + R_g(r_{22}+R_B) + R_g R_L.$$

(It can be shown that for a determinant of order n, $D_{11,22}, \ldots, nn$, is equal to unity, therefore in this case $D_{11,22} = 1$).

Now

$$D^{gL} = \begin{vmatrix} r_{11}+R_B, & r_{12}+R_B \\ r_{21}+R_B, & r_{22}+R_B \end{vmatrix}$$
$$= \begin{vmatrix} r_{11}, & r_{12} \\ r_{21}, & r_{22} \end{vmatrix} + R_B(r_{11} + r_{22} - r_{12} - r_{21})$$
$$= D_T + R_B s_T.$$

Therefore

$$D = D_T + R_B s_T + R_L(r_{11}+R_B) + R_g(r_{22}+R_B) + R_g R_L$$

Appendix 2

	Grounded Base (R)	Grounded Emitter (R')	Grounded Collector (R'')
	Mullard Type OC70		
	Ω	Ω	Ω
r_{11}	800	800	1·5M
r_{12}	750	50	50k
r_{21}	1·45M	−1·45M	1·5M
r_{22}	1·5M	50k	50k
s_T	50k	1·5M	800
D_T	110M	110M	110M
	Mullard Type OC71		
r_{11}	600	600	500k
r_{12}	594	6	10k
r_{21}	490k	−490k	500k
r_{22}	500k	10k	10k
s_T	10k	500k	600
D_T	9M	9M	9M

Note

The above derived values are approximate, but the errors are less than 2 per cent. It can be seen that as expected D_T is a constant for all configurations. This is often a useful check upon transformations of this kind.

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An Amplitude/Frequency Response Display Using a Ratio Method

(Part 2)

By H. L. Mansford*, B.Sc. (Eng.), A.C.G.I., A.M.I.E.E.,
K. M. I. Khan†, B.Sc. (Eng.), A.M.I.E.E. and D. T. A. Margetts‡

The Display

PART 1 of this article described how a sweep frequency signal generator or wobulator may be used to explore the amplitude/frequency characteristics of a wideband amplifier. It was shown that errors due to amplitude variations (with frequency) at the source, could be balanced out by employing a circuit which developed a signal representing the logarithm of the ratio of output and input amplitudes. It was of the form:

$$y = a \log E_o/E_1$$

where y is a potential controlling the height of the c.r.t. spot on the screen.

E_1 is proportional to the amplitude of the signal input to the unit under test.

E_o is proportional to the amplitude of the signal output from the unit under test.

a is a controlled variable factor, which is used to give the desired sensitivity.

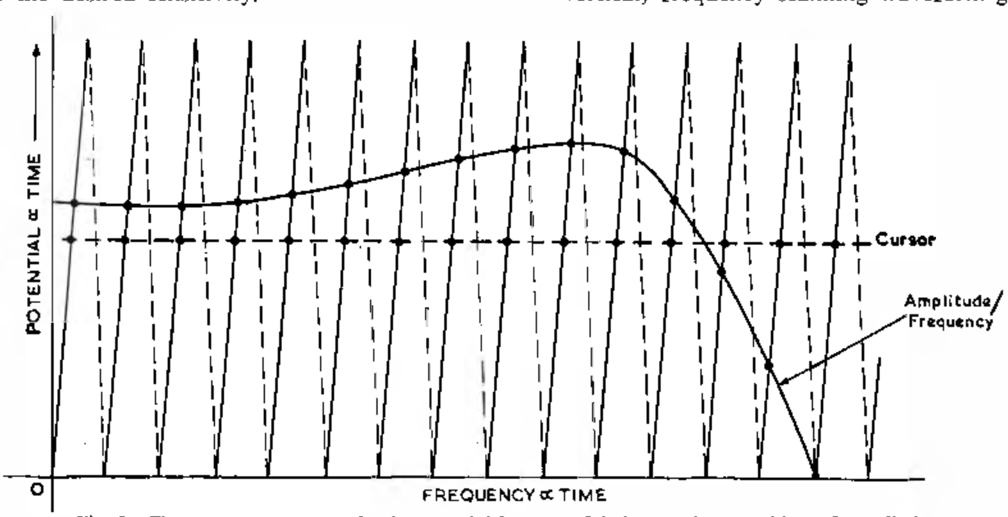


Fig. 9. The c.r.t. screen raster showing spot brightness modulation to give a multi-waveform display

The preferred type of cathode-ray tube display, by relying on a television type raster with spot brightness modulation to convey the information, opens the way for the simultaneous presentation of a large number of independent variables, all referred to a 50c/s repetitive base line.

Accordingly, a domestic type television receiver is modified by turning the magnetic deflexion coils through 90° in order to show a raster with lines vertical, and the spot travelling upwards. Brightness modulation from 0·5μsec pulses gives spots to trace the 'picture' of the curve or reference cursor, as depicted in Fig. 9.

As no attempt is made to synchronize the frequency of the line deflexion with that of the frame, the train of spots forming each line or curve is seen to drift; this may be considered unpleasant or distracting, but it gives the advantage of tracing all points on a curve, in addition to that of avoiding circuit complication.

The X axis (frame frequency) scanning circuits may be operated in synchronism with the 50c/s supply mains, and as the swept signal generator also has its sweep repetition rate synchronized with the mains, the X axis control becomes a function of the swept frequencies (50kc/s to 10Mc/s or more).

Turning to the block schematic circuit diagram of Fig. 10, box:

(1) represents the receiver frame (formerly vertical, now horizontal) frequency scanning waveform generator, with a 50c/s mains synchronizing input signal via a phase shifting circuit to cover 1/2 cycle continuously.

(2) represents the c.r.t. with a raster of vertical lines, only visible when brightness modulation is supplied from (8).

(3) represents the receiver line (formerly horizontal, now vertical) frequency scanning waveform generator, with no synchronization at all. From (3), a trigger pulse is taken to the ancillary circuits built as a separate unit in which:

(4) is a Miller integrator type of sawtooth generator, designed to start a positive going sawtooth at the finish of each narrow trigger pulse.

(5) is a clamp circuit which takes the a.c. coupled sawtooth waveform from (4) and uses the trigger pulse to control the start of the outgoing sawtooth signal from a d.c. potential level dependent upon the input control signal, $y = a \log E_o/E_1$.

(6) is a bistable flip-flop circuit, which is always re-set by the trigger pulses, and which flops when the sawtooth input potential rises to a fixed d.c. level—it does this in a time dependent upon the d.c. starting potential for the sawtooth. The pulse signal from (6) is therefore timed by the d.c. input control from the finish of the trigger pulse. Fig. 11 makes this clear.

* *Bell Punch Co., Ltd.*
† *E.M.I. College of Electronics, both formerly with E.M.I. Electronics Ltd.*
‡ *E.M.I. Electronics Ltd.*

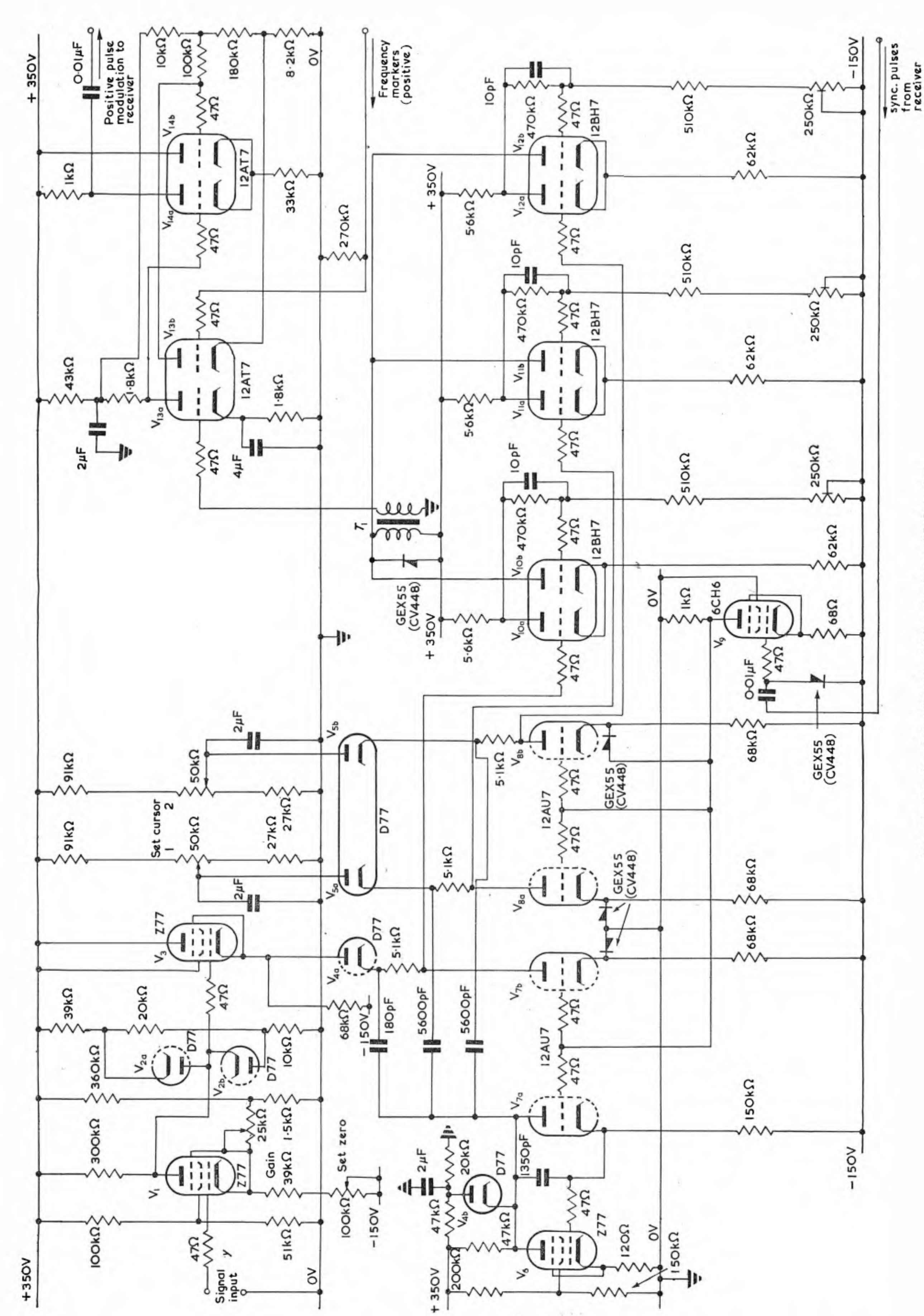


Fig. 12. Details of the Fig. 10 additions to the modified receiver

(7) represents circuits to re-form the pulses by amplification and gating, for a positive going output to (8). This can, however, be suppressed by a control potential, recurring as a short pulse at frame frequency, which gives a narrow vertical shading on all the displayed curves. This is the frequency marker. It is generated when a near zero beat frequency is derived from a diode and low-pass filter, as the swept signal frequency crosses the fixed frequency from a calibrated source.

Full advantage should be taken of the ability to display

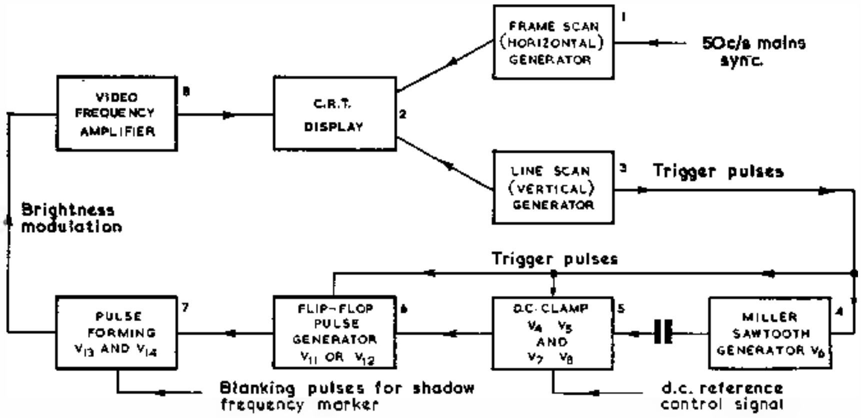


Fig. 10. A block schematic of circuit additions to the modified television receiver
V numbers refer to Fig. 12 valves

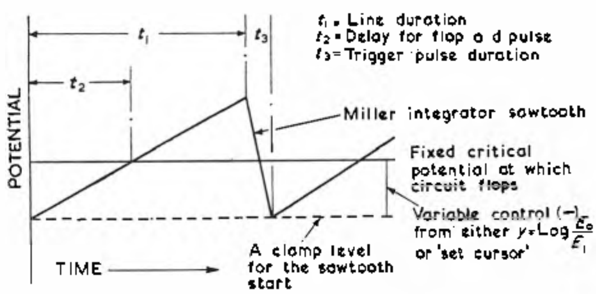


Fig. 11. Strobing circuit potentials for the Fig. 9 display

a family of curves simultaneously. In addition to the amplitude/frequency ratio curve ($y = a \log E_o/E_i$), there may also be any number of horizontal cursor lines. The cursor control potentiometers are not calibrated because it is more convincing to calibrate the spacing between pairs of cursor lines by comparison with the vertical shift on the main curve. This is controlled by the calibrated insertion loss. Also, accurate measurements may be made from the curve by a null method, using the calibrated insertion loss in the test channel to return each chosen point on the main curve to a zero signal level cursor line.

If a simultaneous presentation of a group delay characteristic curve be needed, this may also be added, together with its set of reference cursors.

The practical circuit diagram shown in Fig. 12 (p. 596) is designed for one main curve and two reference cursors, but it may readily be extended.

V_6 is a Miller integrator sawtooth generator. The cycle controlling the circuit potential changes may conveniently be taken as starting from the trigger pulse period, when the negative input pulse has cut off current in V_9 to leave V_{7a} grid at chassis potential. V_{7a} is almost without grid bias because its cathode potential is held not only by current flowing in its 'tail' resistor, but also by V_8 grid current. Consequently V_{7a} anode current value is high enough to discharge quickly the V_6 anode-grid coupling capacitor, leaving diode V_{4b} to hold V_6 anode potential constant until the end of the trigger pulse period, when V_9 current is turned on to drop the potential at V_{7a} grid.

During this trigger pulse period V_6 is also passing its maximum current, which assists V_{7a} to discharge the coupling capacitor. After the trigger pulse, with negative bias on its grid, V_{7a} cathode load current is transferred to the Miller capacitor, because V_5 anode load current exceeds that flowing to V_{7a} cathode load via the coupling capacitor. V_6 regulates its own grid bias to by-pass this excess current, and so provides for a constant current in the capacitor and a steadily rising anode potential.

Valves V_{7b}, V_{8a}, and V_{8b} have their anode currents switched in the same way as V_{7a}. Each has a crystal diode to hold its cathode potential to that of the chassis when the valve anode current flow ceases. Their respective anode circuits are supplied with the sawtooth waveform by a.c. couplings from V_6 anode circuit. During the trigger pulse conducting period each draws anode current from conducting V_{4a}, V_{5a} and V_{5b}; so that after the trigger pulse, when V_6 anode sawtooth waveform starts its positive excursion, the V_7 and V_8 currents are also switched off and their anode potentials follow the sawtooth waveform, each having started its run-up at a d.c. potential fixed by its respective diode.

V_{4a} diode gives the negative going d.c. control for the main curve because V_1, which has its gain adjustable to suit the sensitivity or decibel range required, takes the d.c. coupled logarithmic ratio signal input and inverts it before feeding it to the diode via cathode-follower V_3. V_2 diodes restrict the V_3 grid swing, maintaining it within safe limits.

Valves V_{10}, V_{11}, and V_{12} comprise three similar flip-flop circuits (d.c. coupled, each with two stable states). Each gives a flip into the re-set condition when the trigger pulse returns the grid sawtooth waveform to its negative tip. The 'b' sections of the three valves have approximately equal grid potentials, although minor differences are unimportant so long as each is fixed until the rising sawtooth potential on the opposite grid switches current to the other triode to give a flop and an output pulse. In this way, the timing of this pulse is determined by the sawtooth plus d.c. control potential.

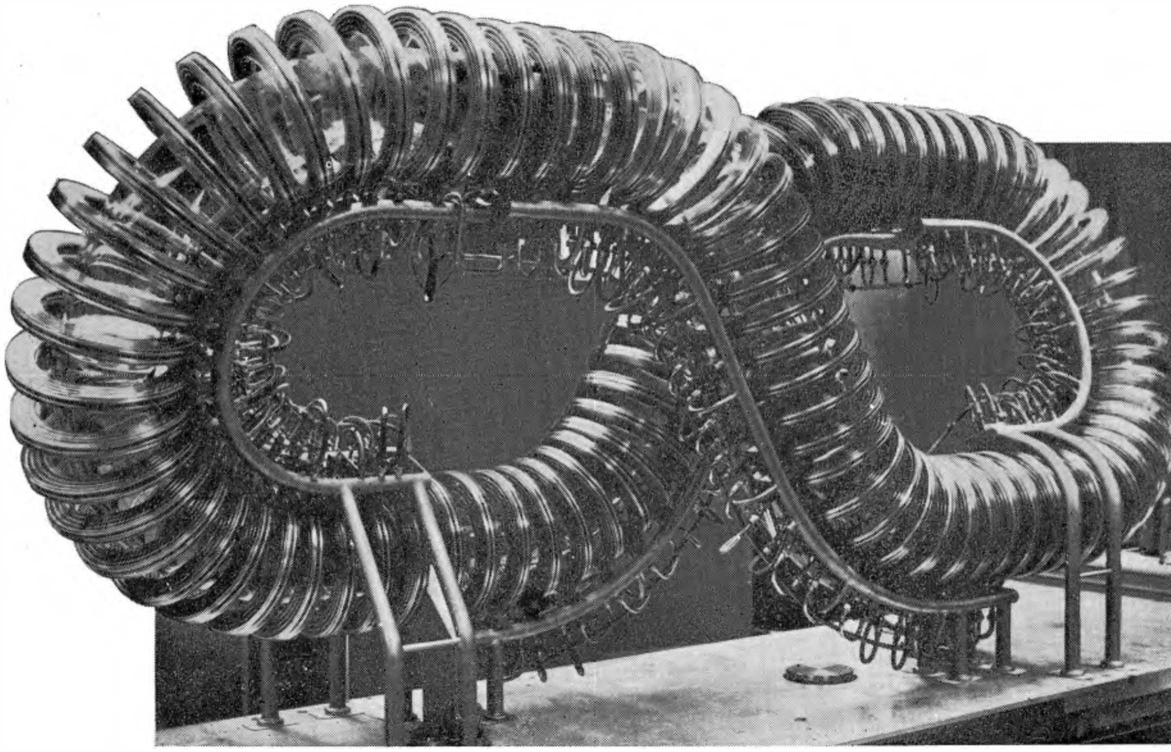
The pulse transformer T_1, common to all the anode circuits, has a Ferroxcube core with a 1mH shunt primary inductance. It carries the major part of the sum of the three anode currents because its impedance is much lower than the forward resistance of the shunt crystal diode. The current starts each line period at its maximum value, which is then decreased in steps as each circuit triggers to produce a positive going pulse in both primary and secondary windings, with the shunt diode to give damping for any overshoot on the return swing. A 1:1 transformer turns ratio serves well.

Valve V_{13a}, amplifies the positive tips of this signal pulse and its negative anode pulses are gated and reversed again by V_{11a} to form the positive output pulses.

V_{13b} controls the brightening pulse inhibitor circuit for the generation of the shadow frequency marker.

Acknowledgments

In conclusion, the author wishes to thank the management of E.M.I. Electronics Ltd for permission to publish this article, and Mr. G. S. P. Scantlebury, together with other members of the laboratory staff for their advice.



FUSION RESEARCH AT GENEVA

U.S.A. Thermonuclear Experiments exhibited at the International Conference on the Peaceful Uses of Atomic Energy

THE first comprehensive disclosure of methods used by British and U.S.A. scientists for the generation of controlled thermonuclear reactions was given[1] in Jan. 1958.

The range and type of such experiments demonstrated in Geneva this year shows that a considerable amount of scientific effort is being expended in the U.S.A. in an attempt to solve this problem. Their exhibits covered a considerable portion of this international exhibition.

Principles

The basic ideas behind these experiments have been described earlier in *Electronic Engineering*[2]. Briefly, the high temperatures required for thermonuclear fusion of the lighter elements (hydrogen and deuterium) are obtained by passing a large electric current through the gas. This current sets up a discharge in the gas (something like that in a neon sign) and produces an intense magnetic field round the column of hot gas. This magnetic field 'pinches' the gas so that it moves inwards away from the walls of the vessel in which it is contained.

One form of apparatus used in this work is a 'torus', i.e., a ring-shaped tube like the inner tube of a motor tyre.

Early torus experiments showed that when the hot gas was pinched it tended to 'wriggle' and touch the walls of the tube. For several years this problem was studied and results obtained by 1954 showed that, while the gas still 'wriggled', very high temperatures could be obtained by using high electrical currents and metal tubes of large diameter.

In 1954 design began of a large apparatus, in the U.K., which subsequently became known as ZETA (Zero Energy Thermonuclear Assembly). This was intended to reach currents of 100 000A, and it was believed that temperatures could be obtained just sufficient to give rise to detectable thermonuclear reactions. By mid-1956 the use of magnetic coils wrapped round the outside of the tube appeared to offer a promising method of counteracting the 'wriggle' and ZETA was modified to incorporate this improvement (Fig. 1).

ZETA began operation in August, 1957, and has worked more successfully than was expected. Current pulses up to 230 000A have been passed through the gas for periods up to 5msec and ion temperatures of from 1 to 5 million degrees have been indicated.

Similar results were obtained at about the same time by a similar equipment, known as the 'Perhapsatron' at Los Alamos Laboratory in the U.S.A., and details of these machines were released simultaneously in the copy of *Nature* for January 25 1958.

Several other quite new devices are now being used as research tools to collect information on the nature of the thermonuclear fusion reaction and many of the major pieces of research equipment from the four main centres of fusion research in the U.S.A. were installed and operating in this exhibition.

Many paths of approach to obtaining a confined hot plasma are being attempted.

The Devices

Some start with a cold gas in a containing magnetic field and then heat the gas by electrical discharges as well as by 'magnetic squeezing' (Stellarator). Others utilize the electrical

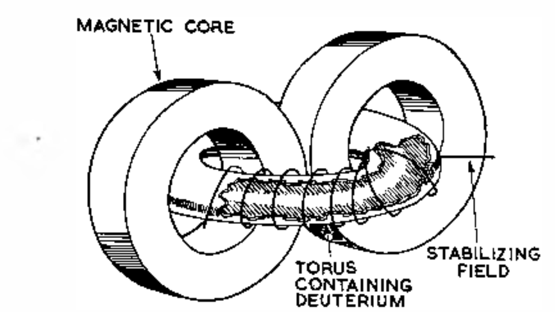


Fig. 1. Principle of ZETA: currents up to 200 000A circulate in a closed torus

discharge to produce both heat and the confining magnetic field (Pinch). Still others start with individual ions made energetic in an accelerating device and then trapped in a magnetic field, either by rapidly raising the field strength (Mirror Machine) or by the breakup of a larger ion group (that is, a molecule) by an electric arc (DCX).

The fusion research programmes represented in this exhibit are centred at four sites: Princeton University in the north-east America, Oak Ridge National Laboratory in the south-east, Los Alamos Scientific Laboratory in the south-west, and the University of California Radiation Laboratory in the far west.

The Princeton University research emphasis is on the Stellarator machines in which external currents produce a twisted magnetic field in a closed, endless tube of either the figure-8 or the racetrack form. The confining magnetic fields also possess shear, to give greater stability. The plasma is initially heated by ohmic heating and finally brought to thermonuclear temperature by magnetic pumping. Reduction of plasma impurities is achieved by scraping a layer from the surface of the confined plasma.

Both the Pinch and the Magnetic-mirror machines are being developed at the University of California Radiation Laboratory. In both cases magnetic compression of the plasma provides heating to reach thermonuclear temperature.

Also at UCRL theoretical study has been given to a different type of device, which utilizes an axially symmetric circulating beam of extremely high speed electrons to establish the confining field and to heat the plasma.

At the Oak Ridge National Laboratory a novel method of injecting and trapping a high-energy ion beam inside a magnetic mirror has been developed. The energy of the trapped beam is such that no further heating is required. Theoretically, impurities can be removed by 'burn-out' of neutral atoms as the plasma is being formed.

The Los-Alamos Scientific Laboratory places major emphasis on Pinch machines in both the toroidal and linear shape. These devices achieve high temperature by magnetic compression of the plasma. Los Alamos also pursues other approaches: a mirror machine that utilizes a fast-rising axial magnetic field, both for containment and heating, and a mirror machine in which electric fields provide heating and containment.

The Stellarator

Basically, the Stellerator is a device for confining ionized gas, or plasma, by means of an externally-produced magnetic field, in an endless, closed container. The magnetic field is generated by large electric currents, which flow in copper wires encircling the ionized gas. For equilibrium confinement the magnetic field must be twisted. This twist can be produced either by using a figure-8-shaped container or by adding extra currents of a special sort to a circular or racetrack-shaped container.

The Stellarator exhibits emphasized four aspects of the controlled-fusion problem; confinement of ionized gas, the stability of this confinement, heating of the confined gas, and control of impurities that would cool the heated gas.

The first exhibit was in the figure-8 shape (photograph, page 598). It does not contain plasma, but rather shows a few representative magnetic-field lines illuminated by means of streams of high-speed electrons. The glass vacuum chamber is surrounded by a series of copper coils. These coils carry electric current to produce a magnetic field throughout the vacuum chamber. A representative magnetic-field line, followed around the figure-8, does not return on itself but is rotated to a new position. On each successive transit it is again rotated. The rotation or twist is necessary for plasma confinement.

A field configuration possessing this rotational-transform property is capable of equilibrium confinement of plasma. X-rays produced by electrons of 2MeV energy have been observed from research Stellarators with an axial electric field

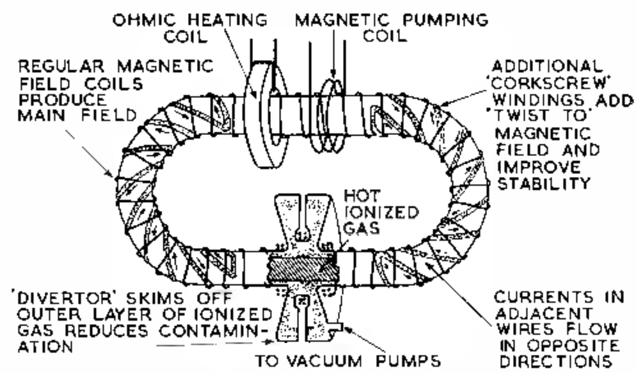
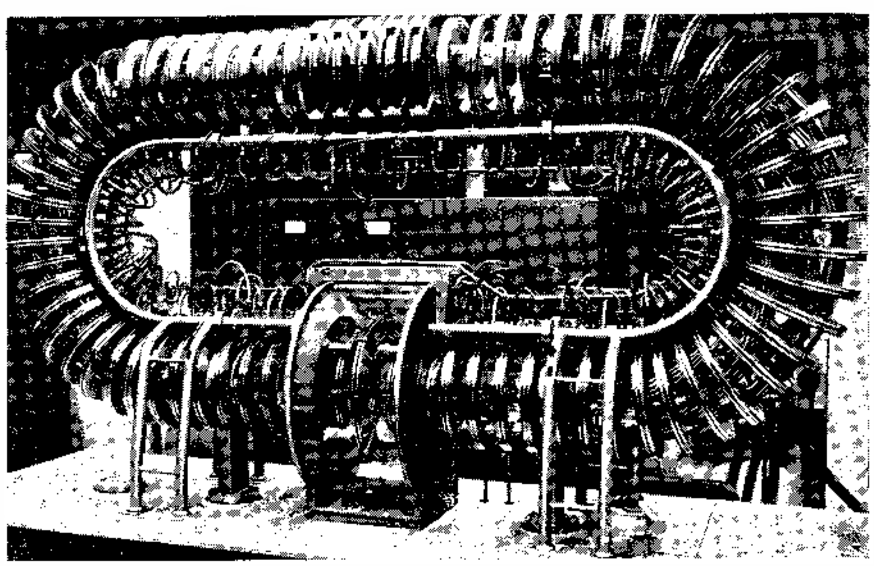


Fig. 2(a) Schematic diagram of more complex, racetrack-shaped Stellarator using corkscrew windings, instead of figure-8 shape, to twist the magnetic field. The divertor is an important Stellarator component for controlling composition of the gas

(b) A demonstration model which shows the magnetic field pattern of a 'racetrack' shaped Stellarator using 'corkscrew fields'



of 50V per turn, indicating excellent single-particle confinement.

The second demonstration model (Fig. 2) was in the racetrack shape. It has a glass vacuum chamber and magnetic field coils, like the first. In addition, there are six conductors, each consisting of four wires, which are wound diagonally around portions of the tube. Current in these corkscrew windings, flowing in opposite directions in adjacent groups of wires, produces a twist in the magnetic-field lines so that the overall figure-8 shape is not needed. The amount of twist produced by these corkscrew currents increases toward the wall. The criss-crossing of the field lines tends to stabilize the plasma and keep it from leaking out of the 'magnetic bottle.'

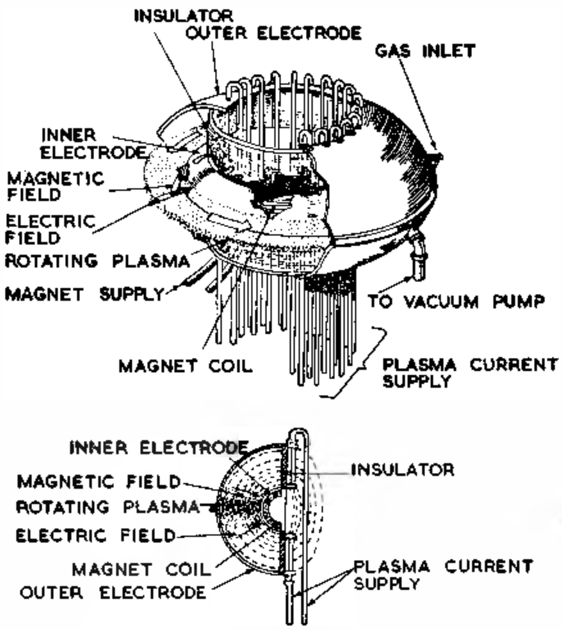


Fig. 3. Rotating plasma device

Rotating Plasma Device

In this device (Fig. 3) the plasma is caused to rotate at very high speed by momentarily passing a pulse of current through it perpendicular to a magnetic field. The ionized gas held together by the magnetic field acts as the armature and fly-wheel of a motor generator. The energy stored in rotation may be observed as a large current pulse when a short-circuit is placed across the terminals.

The plasma is at first swept into the confining region by the combined action of pinch effect and centrifugal force and then afterwards held there against the magnetic field by the centrifugal force from the rotation and the magnetic mirror effect. The purpose of this experiment is fourfold :

(1) To develop and exploit the concept of centrifugal containment of a rotating plasma.

(2) To develop new methods of heating a plasma by converting rotational energy into thermal energy.

(3) To develop the device as a hydromagnetic capacitor.

(4) To develop the device into a fusion reactor.

Tubular Pinch and High Current Switch

An infinite sheet of plasma has neutral stability, whereas an ordinary pinch is highly unstable unless magnetic fields produced by external coils are included in the plasma. The tubular-pinch device produces an approximation of the infinite plasma sheet.

A tube of plasma is supported between concentric cylindrical conductors by magnetic fields created by the current flowing in the plasma and the return conductors (Fig. 4). In the model which was shown, neutrons are produced when a current of more than 1×10^6A is passed through deuterium. It has not yet been possible to determine the temperature of the plasma with certainty; a value of 3 million degrees is suggested by theory.

A high-current switch is incorporated in this device and operates at pulse currents over 2×10^6A and a supply voltage up to 30kV. It is particularly suited to loads of the fast-pinch type used here. It has an inductance at high currents of the order of 2×10^{-9}H and can be triggered electronically in approximately 10^{-7}sec with a jitter time of less than 10^{-8}sec.

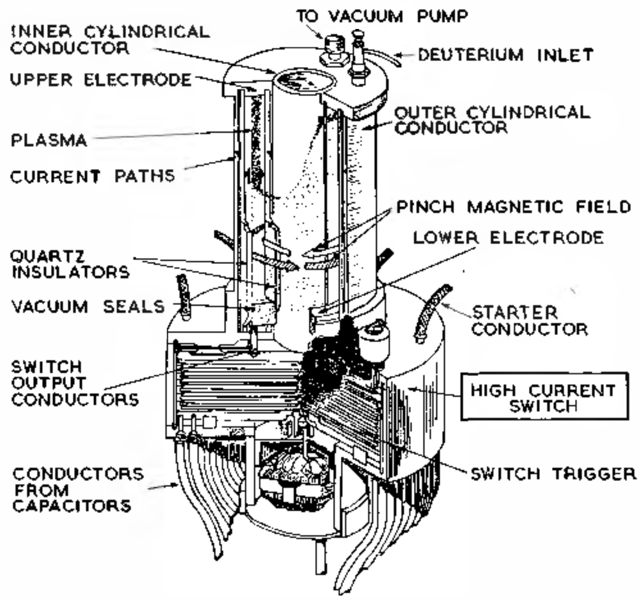


Fig. 4. Tubular pinch device

The switch consists of a series of closely spaced metal disks that divide the total applied voltage into steps of approximately 4kV. The spaces between the disks are continuously evacuated to approximately 5 microns of air pressure. Each disk is supported and insulated by a tyre-shaped fluorocarbon plastic ring which also serves as a vacuum seal when the disks are pressed firmly together. The disk assembly is contained in a close-fitting pressurized drum which also forms a grounded low-inductance current return. Triggering is accomplished by a high-voltage-induced spark at the cathode so that ionization of the low-pressure gas is set up by an electron shower through the offset-hole region. Having the holes offset prevents ions from being accelerated to more than the inter-disk voltage ; this enables the switch to 'stand off' high-voltage direct current.

Linear Pinch Exhibit

This exhibit was a stabilized pinch tube (Fig. 5). A deuterium or helium discharge, lasting 10μsec is formed between the two end electrodes of the tube. By means of a fast electronic viewer, the development of the discharge can be studied.

The pinch column is stabilized partly by means of a longitudinal magnetic field and partly by various screen cylinders external to the glass tube. Whether the pinch column remains stable during the discharge depends very much on the strength of the longitudinal field and on the size and shape of the external screen cylinder. If the longitudinal

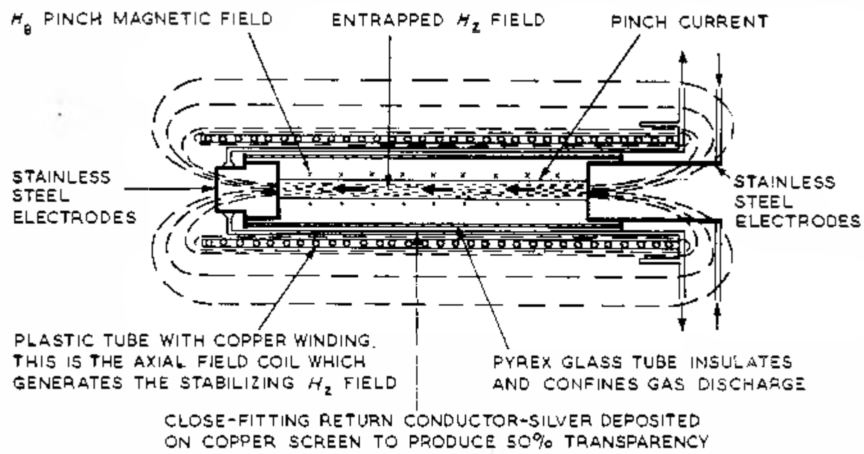


Fig. 5. Stabilized pinch tube

field is made strong and the external screen solid and close-fitting, the fast viewer indicates a stable discharge. Under improper conditions, a corkscrew-like instability develops and destroys the pinch.

Temperatures of about 250 000 degrees are obtained in this apparatus. Cooling the discharge by contact with electrodes must be avoided in any attempt to go to higher temperatures. Such contact can be avoided in a toroidal pinch tube, where the pinch current is induced as in a transformer.

Neutron yields of about 100 000 per shot have been produced with this tube, but most experimental evidence indicates that the discharge temperature is well below the thermonuclear threshold of several million degrees.

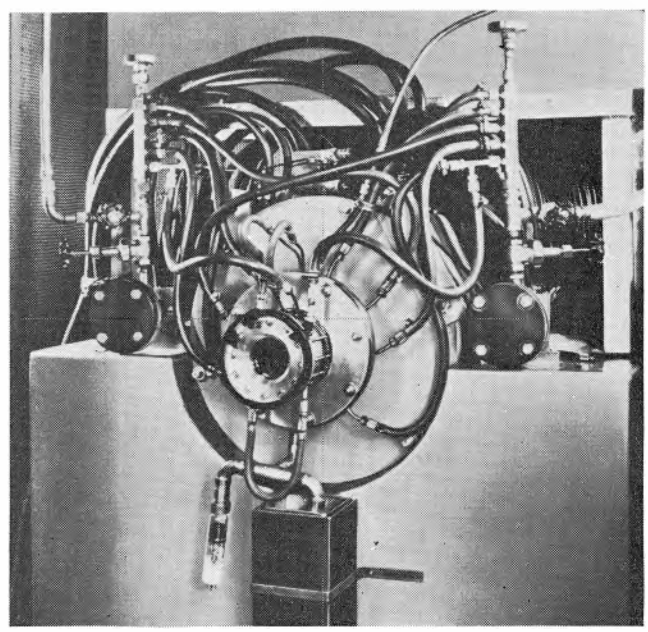


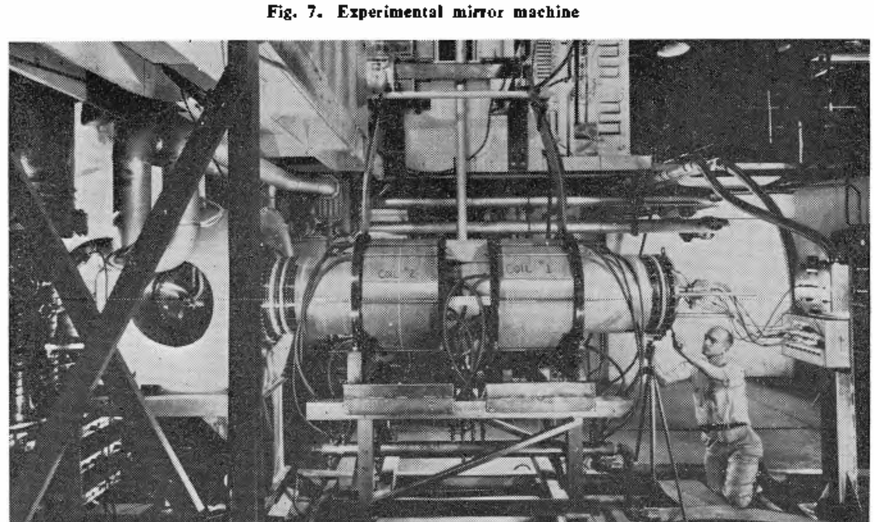
Fig. 6. Ion magnetron

Ion Magnetron

It has long been known that charged particles can be confined in a definite volume by means of superimposed axially symmetric electric and magnetic fields. The first practical device using this principle was, of course, the diode magnetron. This utilized a radial electric field superimposed upon an axial magnetic field to form an electron-trapping region. In order to provide axial confinement as well as radial confinement, it is necessary to provide an increased magnetic field or a reduced radial electric field near the ends of the device.

The ion-magnetron experiment represents an attempt to apply the diode magnetron principle to the confinement of ions as well as electrons.

Fig. 7. Experimental mirror machine



The device consists of a long metal tube surrounded by a coil to produce an axial magnetic field, with a central conductor disposed along the axis of symmetry. The central conductor, or rod, is charged electrically positive with respect to the wall. The region between the rod and the tube wall is evacuated to a pressure such that the ion mean free path is large compared to the radial dimension of the device.

When magnetic and electric fields of suitable intensities are applied an electron-rich sheath forms around the centre rod. The electrons are accelerated by the force produced on a charged particle by crossed electric and magnetic fields. Ions produced by the electron discharge are accelerated radially outward by the electric field. If the magnetic field is sufficiently intense, the ions cannot reach the wall and are returned to the central region. Increased magnetic field near the ends of the tube prevents the ions from escaping axially. The region beyond the electron-rich sheath becomes ionized and heated by collisions resulting from the motion of ions through the residual gas (Fig. 6).

Magnetic-mirror Machine

The magnetic-mirror machine is a containment device using externally applied magnetic fields, which may either vary in time or be steady in time or a combination of both, depending on the type of experiment to be performed. The magnetic mirror consists of regions of increased magnetic field strength which reflect charged particles of either sign.

This display demonstrates the path that a beam of high-energy ions would have in a magnetic-mirror field. In the region between the mirrors the ions travel in helical (spiral) trajectories about magnetic lines of force. As the ions penetrate into the strong field region near the end, their forward motion is impeded and the trajectory becomes practically circular as the ions are reflected from the mirrors.

Ions contained in this way make many thousands of traversals, all the while gaining energy as the magnetic-field strength is increasing (Fig. 7).

A cloud of ionized gas always moves along the same bundle of magnetic flux lines. The bundle of magnetic flux lines contracts as one proceeds from a region of low magnetic field to one of high magnetic field. Therefore, the ionized gas which is forced from the weak field in the large diameter system to the strong field in the small diameter system will be compressed to fit into the small system without touching the walls.

The final energy of an individual particle of the ionized gas will be increased if the ionized gas starts in a very weak magnetic field and is finally contained in a very strong magnetic field. The transfer technique makes it possible to use a final field several thousand times greater than the initial magnetic field without the problems involved in establishing a magnetic field of 100kG in a volume of several thousand litres.

DCX (Direct Current Experiment)

This experiment takes place inside a metal enclosure 3 metres long and 1·5 metres wide and high. Through a side window is seen a glowing ring 20cm in diameter. Electrically charged particles (deuterons) are travelling in this ring at the speed of 4 000 000km/h. Inside the enclosure are coils which produce a strong magnetic field. It is the invisible force of this field, and not the metal walls, which holds the electrically charged deuterons inside. Vacuum pumps are used to remove air to a pressure of 10^{-7}mm of mercury.

A large number of fast particles are shot inward from an ion source at the top of the enclosure. These particles are molecular ions composed of two deuterons and one electron. A bright arc, about 2cm in diameter, runs through the length of the enclosure. When the beam of molecular ions passes through the arc, the molecular ions are broken up into single deuterons. These lighter deuterons circle well inside the walls of the enclosure without hitting any physical obstruction.

This thermonuclear experiment has all the necessary features for producing fusion reactions at a modest rate. It is believed that continued development of these same basic ideas will lead to a device in which fusion reaction occurs much more frequently.

The Perhapsatron

This device has been previously described in the literature and the actual experimental machine was installed and working at Geneva (Fig. 8). The Perhapsatron is a ring-shaped electrical discharge device consisting of an aluminium torus and a fused-quartz liner containing deuterium gas. The system operates as an ion-cored pulse transformer, with the gas discharge forming the secondary, and the aluminium torus the primary of the transformer. A capacitor bank having a maximum energy storage capacity of 90 000 joules is discharged through the aluminium primary and generates a damped oscillatory gas current rising to more than 300 000A with a 50μsec period. A solenoid winding around the torus develops an axial magnetic field variable from zero to 5 000G. The combination of this axial magnetic field and the proximity of the aluminium primary to the discharge channel contributes toward suppression of instabilities as with the U.K., ZETA machine.

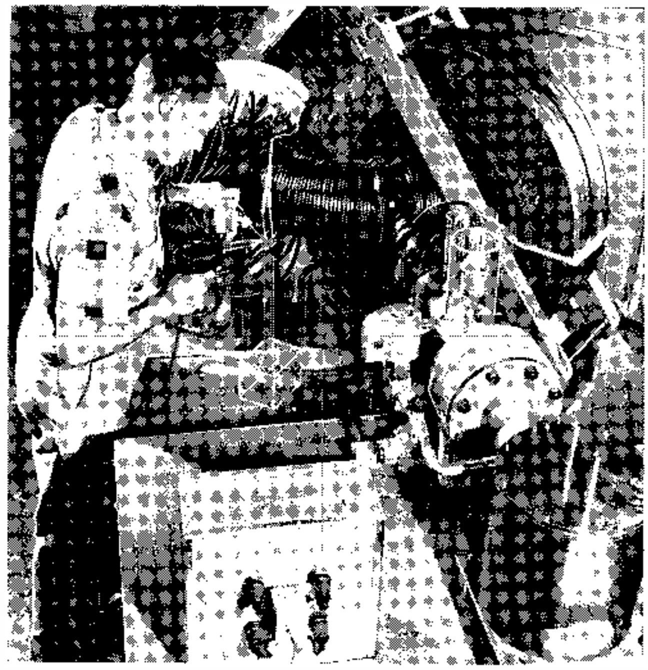


Fig. 8. A voltage measuring device being attached to the Perhapsatron S-4 toroidal pinch experiment

This machine is designed for observations on the behaviour of high temperature plasmas in the presence of electric and magnetic fields. Magnetic-field probes have been used to determine the current and the electric and magnetic-field distributions within the discharge. The probe measurements have also yielded information on the stability of the discharge and on the diffusion of plasma pressure and plasma fields during the current cycle. The neutron yield from fusion reactions in the system has been studied in detail to determine the number of reactions, their distribution in time and energy, and the region of their generation. Additional measurements on radiation from the device in the microwave, visible light, and X-ray regions have also been made.

Plasma Acceleration Machine

This exhibit consists of a demonstration of the acceleration of a jet of plasma into vacuum.

The plasma is produced from a burst of deuterium gas which is admitted to one end of the system by a quick-acting mechanical valve.

The burst of gas travels down the tube through a single-turn shock-driving coil surrounding the tube. A capacitor is discharged through the coil producing a shock wave which serves

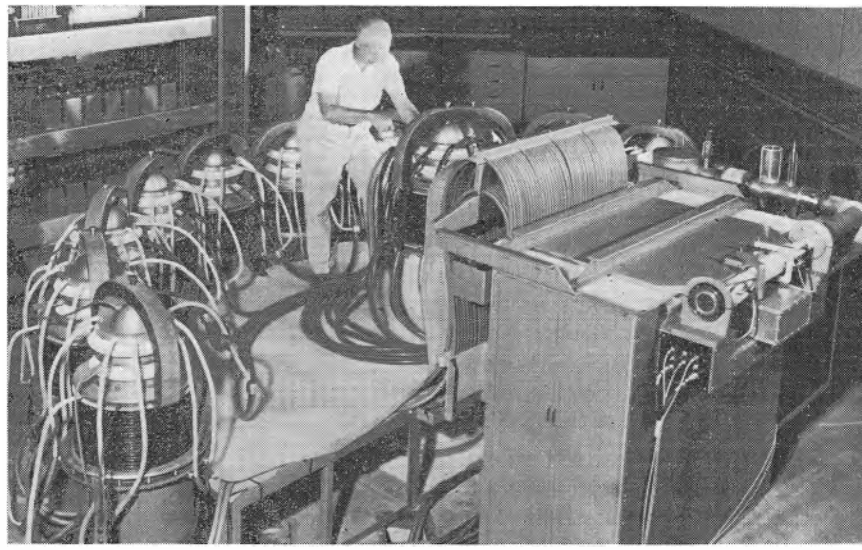


Fig. 10. Making final adjustments on Scylla

to preheat and ionize the gas. The ionized gas now passes into a solenoid (the piston coil) wound around the glass tube. The piston coil is loaded with a shunt capacitor at each turn so as to form an artificial delay line with a transmission velocity of about 10^7cm/sec. A magnetic piston of rather high intensity is thereby produced which moves in the piston coil at delay-line velocity, sweeping up the plasma ahead of it and driving it out the end of the coil into a drift tube. The drift tube section, approximately 2 metres long, is surrounded by a solenoid designed to produce an axial magnetic field of 2 to 3kG. Plasma driven into this drift space is guided and held off the walls by the magnetic field so that it forms a long jet. At the far end of the drift tube the plasma jet strikes a ballistic pendulum whose motion measures the momentum carried by the moving plasma. The motion of the pendulum is projected on a screen.

Photomultiplier telescopes are arranged to observe the light emitted by the plasma at various positions along the drift tube. The photomultiplier currents are displayed on a four-beam oscilloscope where they can be photographed at will. A measure of the speed of the plasma jet can be derived from these oscilloscope records.

A photograph of this machine is shown in Fig. 9.

Scylla

It has been known for centuries that the compression of a gas raises its temperature. In like manner, a plasma may be heated by compression. To achieve the high temperature required for a thermonuclear reaction to take place, the compression of a deuterium plasma must occur very rapidly without an appreciable influx of impurities from the walls of the containing vessel. These requirements have led to the use of a rapidly rising magnetic field for exerting the necessary pressure on the conductive plasma.

In the experimental arrangement named Scylla, a rapidly oscillating axial magnetic compression field is produced by current through a single-turn coil of special shape surrounding a tube containing deuterium gas at reduced pressure (Fig. 10). During the first half-cycle the gas is transformed into hot plasma by electrical breakdown induced by the changing magnetic field. In the next half-cycle the hot plasma so produced is compressed to still higher temperatures. Bursts of neutrons are observed during the time of the second and later peak compressions. The neutrons may be evidence of extremely high temperatures in the plasma.

Two television screens with explanatory panels formed a part of the exhibit, and showed the operating characteristics of the machine.

The Columbus Experiments

These use straight tubes and are used to study the pinch effect under high-power conditions. A transmission line consisting of two circular flat copper sheets 4·2m in diameter spaced 1·25cm apart, connects twenty-five 0·85μF, 100kV capacitors through a central spark gap to the discharge vessel. This geometry minimizes the external inductance and hence permits higher voltages to be impressed on the discharge.

The ceramic discharge tubes used range from 10 to 20cm in diameter and from 30 to 60cm in length.

Fig. 9. Adjusting the ballistic pendulum of the Plasma Acceleration Machine

The dynamics of the pinch, as inferred from voltage and current oscillograms, have been studied under varying conditions. Neutrons produced by discharges in deuterium gas at 0·2mm of mercury pressure (6×10^8 neutrons per burst) have been extensively studied over the voltage range of 40 to 70kV.

The mechanism of neutron production is at present obscure and cannot be explained either in terms of a simple thermonuclear reaction or in terms of reactions between stationary deuterons and deuterons accelerated in the electric field.

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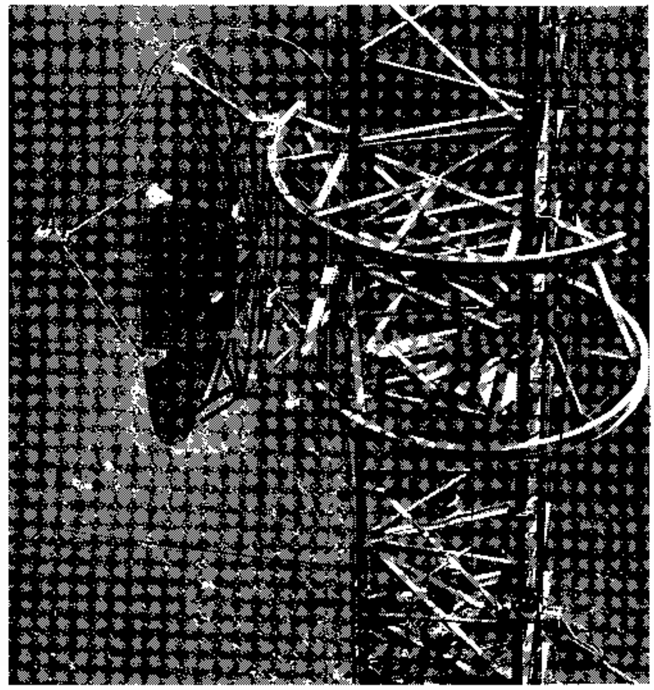
The I.T.A. Station in the Isle of Wight



Post Office dish on the I.T.A. mast at Chillerton Down

THE Independent Television Authority's transmitting station at Chillerton Down in the Isle of Wight came into service on 30 August on a vision frequency of 201·25Mc/s (Channel 11). It is the seventh transmitting station to be built by the I.T.A., who claim that 80 per cent of the population are now in the service areas of the Authority.

The complete transmitting equipment for this station has been supplied by Marconi's Wireless Telegraph Co. Ltd., and it embodies a number of new and interesting technical features. The vision transmitters are the first of an entirely new type and represent an important step forward in engineering practice. A considerable reduction has been made in the number of valves used; this has permitted a particularly clean, straightforward layout and the incorporation of a simple, yet thoroughly effective, cooling system. The need for under-floor ducting to carry the cooling air stream for the transmitter has been dispensed with, the cooling arrangements being such that this type of transmitter can be installed on any flat floor surface, with installation time reduced to the minimum. The heated air from around the valves is extracted and discharged to augment the room heating if and when occasion demands. The design of these new transmitters is such that they are very simple to operate and to maintain.

The aerial is a twin-eight stack array (used in the present instance as a sixteen-stack) mounted on a 750ft triangular mast some 550ft above sea level. The radiation pattern is directional in character with a minimum of back-radiation southwards. The aerial gain is of the order of 16dB in the forward direction over an arc of 180°. It is the intention of the Independent Television Authority to use one pair of vision and sound transmitters as 'main' with the other pair as 'standby', so that the aerial, fed by a vision output of 4kW (and allowing for feeder losses) provides a vision e.r.p. of approximately 100kW over this arc.

A further feature of interest in connexion with the aerial is the use of a new type of feeder for conveying the power from the transmitter to the aerial. To counteract the effects of expansion and contraction on such a long run of feeder line, a complex system of expansion joints has hitherto had to be employed. On the Chillerton Down feeder, however, these have been dispensed with; instead, the cable is supported flexibly by means of runners and springs so that expansion can take place without any significant stress along the length of the run.

For Southern Television Ltd, the programme constructors for the area, Marconi's have supplied the sound equipment and the Master Control Switching at their Studio Centre.

Post Office Link

The programme will be carried to the I.T.A. Transmitter at Chillerton Down over a link provided and operated by the Post Office. This link is in two parts. One will carry the I.T.A. national network programme from London to the Southern Television Plaza Studio at Southampton. The other will carry the network programme, locally provided programmes and advertising material inserted at the Plaza Studio, to the I.T.A. transmitter at Chillerton Down.

The link will be some 125 miles in length, most of which will be provided by microwave radio relays. Short connexions between Rowridge and Chillerton Down, and between Southampton Telephone Exchange and the Plaza Studio, will employ coaxial cables. Television signals will be transmitted by radio from the Museum Telephone Exchange in London to Rowridge, I.O.W. A new 30ft aerial has been erected on the roof of the Southampton Telephone Exchange for the radio link to Chillerton Down.

The London to Southampton system comprises:—

(1) A two-hop microwave radio-relay link, of 83 miles length, operating in the 4 000Mc/s band and installed on the existing route from Museum Telephone Exchange, London via a repeater station at Golden Pot, near Alton, Hampshire, to the receiving terminal situated in the BBC television broadcasting station at Rowridge, Isle of Wight.

(2) A video link of 3½ miles length on coaxial cable from Rowridge to the I.T.A. station at Chillerton Down.

(3) A single-hop microwave radio-relay link, of 18 miles length, operating in the 2 000Mc/s band, from the I.T.A. station at Chillerton Down to the Post Office Telephone Exchange at Southampton.

(4) A video link of 1½ miles length on coaxial cable from the Southampton Telephone Exchange to the Plaza Studio.

The Southampton to Chillerton Down system comprises:—

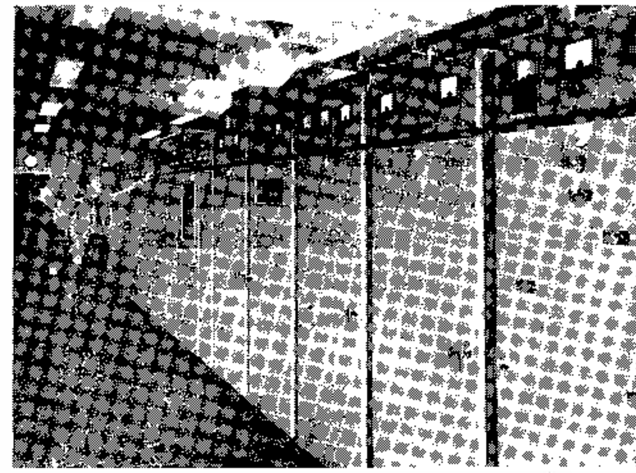
(1) A video link of 1½ miles length on coaxial cable from the Plaza Studio to Southampton Telephone Exchange.

(2) A single-hop 2 000Mc/s microwave radio-relay link, of 18 miles length, from Southampton Exchange to Chillerton Down.

To guard against interruption of television signals by equipment failures during programme time, the equipment, with the exception of aerials, is duplicated throughout to provide two independent signal paths.

The 4 000Mc/s radio equipment serving the Museum–Golden Pot–Rowridge link was designed, manufactured and installed by the Radio Experimental Branch of the Post Office Engineering Department. At each transmitter the video signal is arranged to frequency-modulate an intermediate frequency carrier of 60Mc/s which in turn phase-modulates a travelling-wave valve driven by a 4 000Mc/s carrier. A second travelling-wave valve further amplifies the microwave signal to produce an output power of about 1W. At each terminal receiver the microwave signal is translated to the 60Mc/s intermediate frequency range by means of a crystal mixer. Amplification at this frequency is followed by demodulation to recover the video signal. At each repeater similar techniques are used except that the intermediate frequency signal, instead of being demodulated, is amplified and caused to re-modulate the travelling-wave valve. The frequency of the microwave carrier driving this valve differs by 72Mc/s from that incoming to the repeater. Waveguide branching filters are used for combining the outputs of the transmitters and repeaters with those of the radio link provided on this route for the BBC. The inputs of the receivers and repeaters are combined in similar fashion. This enables the use of common aerials and aerial feeders for the I.T.A. and BBC links. The aerials are paraboloid dishes each of 10ft diameter and with waveguide feeders. The aerial at Museum Exchange is 70ft above roof level, at Golden Pot 200 to 300ft above ground, at Rowridge 70ft up the BBC mast.

The 2 000Mc/s radio equipment serving the links between Chillerton Down and Southampton was provided and installed by the General Electric Co. Ltd, Coventry, under Post Office contract. At each transmitter the video signal is arranged to frequency-modulate a 70Mc/s intermediate frequency carrier which is amplified and then translated to 2 000Mc/s by means of a triode valve mixer. Amplification



Part of the transmitter room

at this frequency is by use of triode valves in two stages to produce an output power of about 2W. At each receiver the signal is translated to the 70Mc/s intermediate frequency range by means of a crystal mixer; and, after amplification, is demodulated to obtain the video signal. Coaxial-type branching filters are used for combining the transmitter outputs at each station. The receiver inputs are combined in similar fashion. At each station two coaxial aerial feeders are used; the one serving the transmitters and the other the receivers. The 12ft diameter paraboloid dish acts as a common aerial for transmitting and receiving. The feeders enter the launching units which illuminate the paraboloids so that the radio signals being sent and received at a station have orthogonal polarization, thus avoiding interference between transmitters and receivers. The aerial at Southampton Exchange is 30ft above roof level and that at Chillerton Down is 160ft up the I.T.A. mast.

Harbour Radar for The Port of London

The first harbour radar for the projected Thames Navigation Service will be a Decca Harbour Radar Type 33, for which a contract has recently been placed by the Port of London Authority. This new radar station, a variation of the type being fitted by Decca at Liverpool, Hamburg and Southampton, will be one of the most advanced in the world.

The Decca harbour radar type 33 is a high definition, X-band equipment using an aerial of 6ft span. For reliability and to ensure continuous operation during periods of routine maintenance there are two separate transmitters and receivers with remotely controlled changeover switching arrangements. The 15in diameter display is of the fixed coil type.

The Port of London Authority are building new harbour offices adjacent to the Royal Terrace Pier on the south bank of the Thames at Gravesend. The building is designed round the 'operations room' which will be an integrated port operating centre, collecting, sorting and providing to ships navigational information covering the whole river from The Nore to London Bridge. The scanner of the first radar will be mounted on the roof of the building and the display will provide in the operations room a detailed picture of the situation in Gravesend Reach over some five miles of river.

The operations room is designed so that, as a result of experience, further radar stations can be set up both above and below Gravesend, feeding additional displays. Eventually, if the demand necessitates, the entire river from the seaward limit of the port up to the Royal Docks will be shown on eight radar displays at one central position.

The choice of Gravesend for the first radar station means that the most critical section of the river will be the first to derive benefits from the integrated operation and economic use of facilities which such equipments make possible. Through this area pass an average of 80 ships each way every 24 hours of the year. In addition, Gravesend is the port control point where Customs and Port Health Authorities grant pratique and where sea and river pilots change over. The channel is 1 000ft wide and, in addition, there are two entrances to Tilbury Docks, tug stations, ferries, the Tilbury Landing Stage and numerous other harbour activities. Ships also use the reach as an anchorage and it has become essential for the Port Authority to take steps to prevent undue congestion of shipping in this area during periods of low visibility.

The harbour radar will provide a comprehensive, up-to-date picture of all this activity, showing the exact position and movement of every ship in the reach. By displaying this information in the new information centre, the staff, pilots and other river users will be able to assist in the efficient operation of the port under all conditions.

Experience of harbour radar at a number of important ports throughout the world has demonstrated clearly, both to shipowners and port authorities, that these systems, in conjunction with the recently standardized marine v.h.f. communication frequencies, offer great advantages and economies both of time and money. The Thames Navigation Service, now being implemented in its preliminary stage, will eventually be a most ambitious harbour radar system and will provide London with the most up-to-date and efficient service for the benefit of the mariner—not exceeded at any other port in the world.

A Drip Rate Recorder for Intravenous Solutions

By A. W Melville*, A.M.I.E.E., and J. B. Cornwall*, Grad. I.E.E.

An instrument is described which will record continuously the repetition rate of recurring pulses with the range of 5 to 80 pulses per minute.

The response time for a sudden rate change corresponds to 3 pulse periods irrespective of rate and it will therefore indicate a changing rate with much greater accuracy than a conventional resistance capacitance integrator. The calibration is satisfactorily linear.

IN an initial study of the relationship between the drip rate of intravenous pitocen and the rate of contraction and tone of the uterus, carried out at the National Women's Hospital, Greenlane West, Auckland, it was necessary continuously to record drip rate over the range of 5 to 80 drips per minute.

The simplest form of pick-up, consisting of electrodes sealed into a drip chamber, provides a short duration pulse for each drop. The pulse width may be expanded by employing a suitable triggered circuit, but even if the resultant waveform is a symmetrical square wave the time-constant CR, of a simple integrating network must be $10T$,

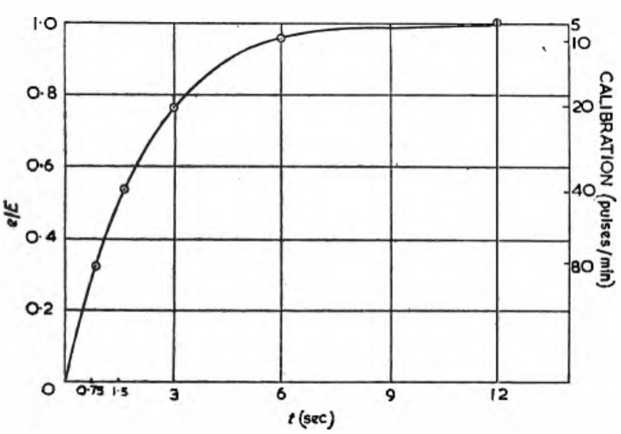


Fig. 1. Calibration curve
Plot of $e/E = 1 - \varepsilon^{-t/RC}$ *for* $t = 0$ *to 12sec*
$C = 4\mu F$
$R = 0{\cdot}5M\Omega$

where T is the period of each cycle, if the variation in the output of the integrator is not to exceed 10 per cent[1]. Thus at the minimum rate of five drops per minute the time-constant CR would be 120sec and this would result in an intolerably slow response to rapid rate changes.

To overcome this, a simple circuit has been developed which records effectively the pulse periods and is calibrated in pulse rate. If a capacitor is allowed to charge through a resistor from a constant voltage source for the period between consecutive pulses, and the final charge reached during each period recorded, the record can be calibrated as pulse rate.

In such a charging circuit the instantaneous voltage, e, across the capacitor C, when expressed as a fraction of the applied voltage E, is given by:

$$e/E = 1 - e^{-t/RC} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

and Fig. 1 illustrates the plot of e/E for $t = 0$ to 12sec, $R = 0{\cdot}5\text{M}\Omega$ and $C = 4\mu\text{F}$. The projection of specific points on this curve, corresponding to the periods of pulse rates of 5, 10, 20, 40 and 80, on to the voltage co-ordinate illustrates the relationship between e/E and pulse rate when this system is used.

This calibration is seen to be the superimposition of a reciprocal and exponential curve which results in a scale which is satisfactorily open and approximately linear even with the pulse rate ratio of 16:1.

The basic switching circuit is shown in Fig. 2.

The reception of a pulse operates the relay contacts shown as B_1, A_2 and B_2 in the following sequence:

B_1 opens, A_2 closes, A_2 opens, B_2 closes, B_2 opens, B_1

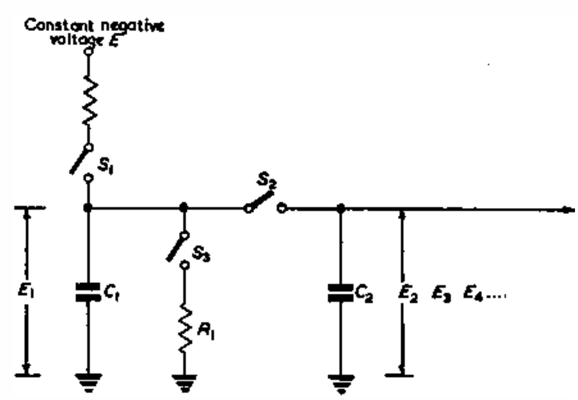


Fig. 2. The basic switching circuit

closes. Thus the charge received by C_1 during the period between pulses is distributed between C_1 and C_2 by A_2 when the next pulse is received, the source of voltage being removed at B_1. The parallel connexion is then broken at A_2 so that C_1 may be discharged at B_2 and then reconnected to the voltage source at B_1. C_2 retains its charge between pulses, and the voltage on C_2 is recorded by a simple valve-voltmeter.

If the initial charge on C_2 is zero, and the relay operation is at a constant rate the conditions are:

Charge given to C_1 between pulses $= C_1E_1$

When this charge is distributed $C_1E_1 = (C_1 + C_2)\,E_2$

$$\text{or } E_2 = \frac{C_1E_1}{C_1+C_2} \quad \ldots \quad (2)$$

where E_1 is the voltage on C_1 initially
and E_2 is the voltage on C_1 and C_2 in parallel
and is the voltage retained by C_2.

* *Department of Scientific and Industrial Research, New Zealand.*

When the second pulse is received the total charge $= C_1E_1 + C_2E_2$ and when this is distributed

$$C_1E_1 + C_2E_2 = E_3 (C_1 + C_2) \tag{3}$$

$$\text{or } E_3 = \frac{C_1E_1 + C_2E_2}{C_1 + C_2}$$

where E_3 is the voltage retained by C_2 after the reception of the second pulse.

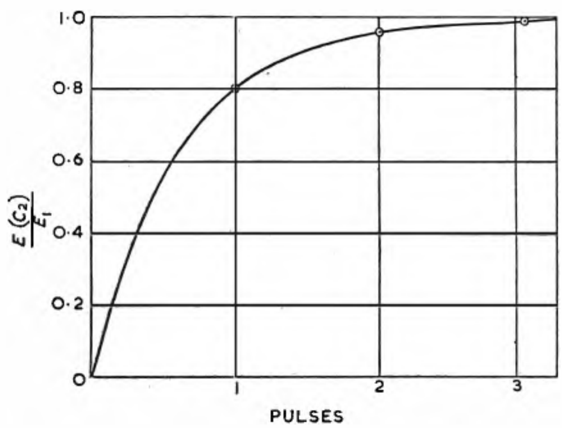


Fig. 3. Voltage plotted against number of pulses

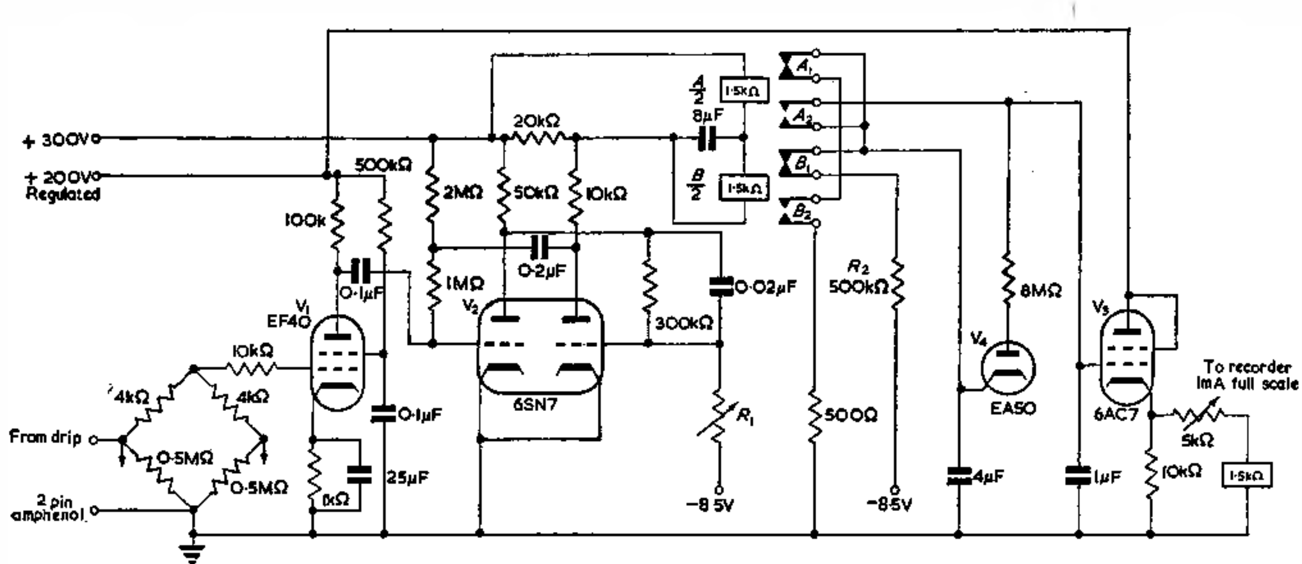


Fig. 4. Drip rate recorder circuit

Similarly E_4, E_5, ... may be determined.

If $C_1 = 4\mu$F and $C_2 = 1\mu$F and E_2, E_3, E_4 ...... are plotted against constant rate pulses with the initial voltage on C_2 zero, the curve shown in Fig. 3 is produced.

From this it is seen that the voltage will have reached 0·99 of its final value when three pulses have been received and this is true regardless of the actual pulse rate, the magnitude of the change, and whether the change is positive or negative.

Description of Complete Instrument (Fig. 4)

Platinum electrodes, sealed into a Murphy drip, are connected in parallel with one arm of a Wheatstone bridge which is balanced when the electrodes are dry. The bridge is energized at 6·3V, 50c/s. This system is used so as to limit the maximum voltage that can appear between either electrode and earth under fault conditions. The 6·3V winding is isolated from the transformer primary by an earthed electrostatic shield for the same reason. A drop provides a momentary shunt resistance of the order of 30kΩ. The resultant unbalance signal from the bridge consists of a few cycles at mains frequency with an amplitude of approximately 2·5V r.m.s. This signal is amplified by V_1 and operates the trigger circuit of V_2. When V_{2b} conducts relays *A* and *B* operate almost simultaneously, but when conduction ceases, the de-energizing of relay *B* is delayed by a shunt capacitor so as to obtain the required sequence of contact operation. If the switching cycle is interrupted the recorder will continue to indicate the pulse rate at the moment of interruption.

The diode V_4 and the 8MΩ series resistor are therefore included to ensure that the recorder returns to zero if the pulse rate becomes zero. When this occurs the voltage E_1 on capacitor C_1 approaches the negative supply voltage, the diode V_4 conducts, the voltage on C_2 approaches the voltage on C_1 and the recorder reads zero. The setting of the recorder zero, which corresponds to cut off in V_3, is controlled by adjustment of the 8·5V supply which is derived from a voltage regulator type 85A2 and suitable voltage divider. Small calibrating adjustments are made by varying the 5kΩ resistor in series with the recorder. Major changes in the range may be made by alteration of the values of R_2, C_2, and the negative supply voltage as required.

A 0 to 1mA Esterline Angus Recorder with a coil resistance of 1·2kΩ has been used, but any recording milliameter having similar characteristics may be substituted.

If the mains regulation is poor a constant voltage transformer should be used.

REFERENCE

1. PUCKLE, O. S., Time Bases, p. 178 (Chapman & Hall).

Response of a Capacitance-Resistance Divider
to the Step-Function, Exponential-Function and Ramp-Function

By S. Turk*

The capacitance-resistance divider response is considered for three input waveforms. The results are represented analytically and graphically.

THE capacitance-resistance divider is an important element in a great number of electronic circuits. The waveforms on the divider output depend not only on the waveforms on its input, but also on the time-constants of its branches. In this article the response of the divider as a function of these time-constants will be considered for the following input waveforms:

(1) Step function
(2) Exponential function
(3) Ramp function

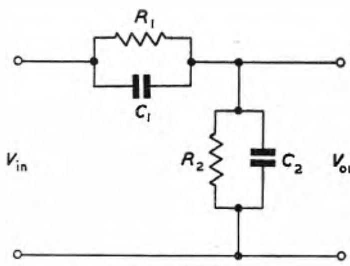


Fig. 1. The circuit analysed

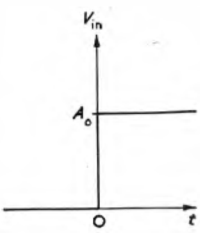


Fig. 2. Step function
$V_{in} = A_o V(t)$
$V(t) = 0 \quad t < 0$
$V(t) = 1 \quad t \geqslant 0$

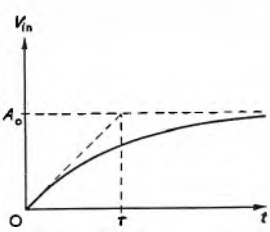


Fig. 3. Exponential function
$V_{in} = A_o\left(1-e^{-t/\tau}\right)$

The circuit of Fig. 1 is described by the differential equation

$$V_{out}/R_2 + C_2(dV_{out}/dt) + \frac{V_{out}-V_{in}}{R_1} + C_1\frac{d(V_{out}-V_{in})}{dt} = 0$$

If the capacitors C_1 and C_2 are initially uncharged, the Laplace transform of this equation is

$$\{1/R_1 + 1/R_2 + p(C_1+C_2)\}\mathcal{L}V_{out} = [(1/R_1)+pC_1]\mathcal{L}V_{in}$$

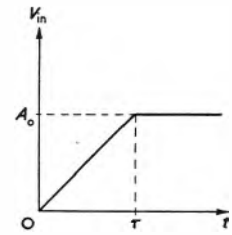
whence

$$\mathcal{L}V_{out} = \frac{k(\theta_1 p + 1)}{[(1-k)\theta_2 + \theta_1]p + 1}\mathcal{L}V_{in}$$

or

$$\mathcal{L}V_{out} = \frac{k[ap + (1/v)]}{p + (1/v)}\mathcal{L}V_{in} \quad \ldots\ldots\ldots\ldots (1)$$

Fig. 4. Ramp function
$f(t) = 0 \quad t < 0$
$f(t) = A_o(t/\tau) \quad 0 < t \leqslant \tau$
$f(t) = A_o \quad t > \tau$



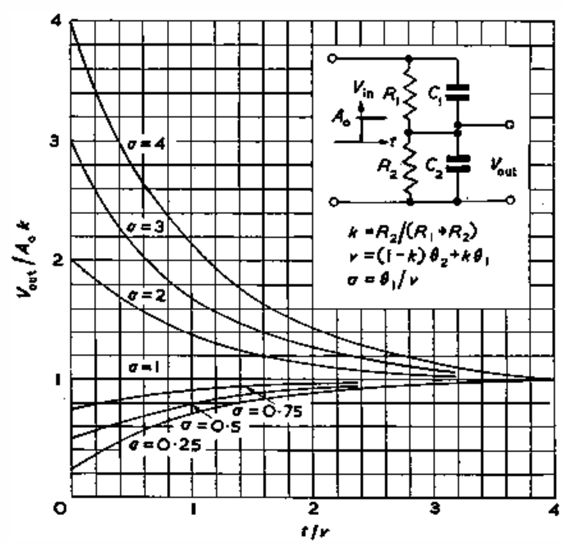


Fig. 5. Response of the divider to the step function as a function of t/v for different values of a

where

$$\theta_1 = R_1C_1 \qquad \theta_1/v = a \qquad k = \frac{R_2}{R_1+R_2}$$
$$\theta_2 = R_2C_2$$

$$v = (1-k)\theta_2 + k\theta_1 = \frac{R_1 \,.\, R_2}{R_1+R_2}(C_1+C_2)$$

The quantity v is the natural time-constant of the divider represented as the time-constant of the parallel combination R_1, R_2, C_1 and C_2.

The calculation of the output waveform for each of the three different input waveforms follows:

* Institute "Rudjer Boskovic," Zagreb.

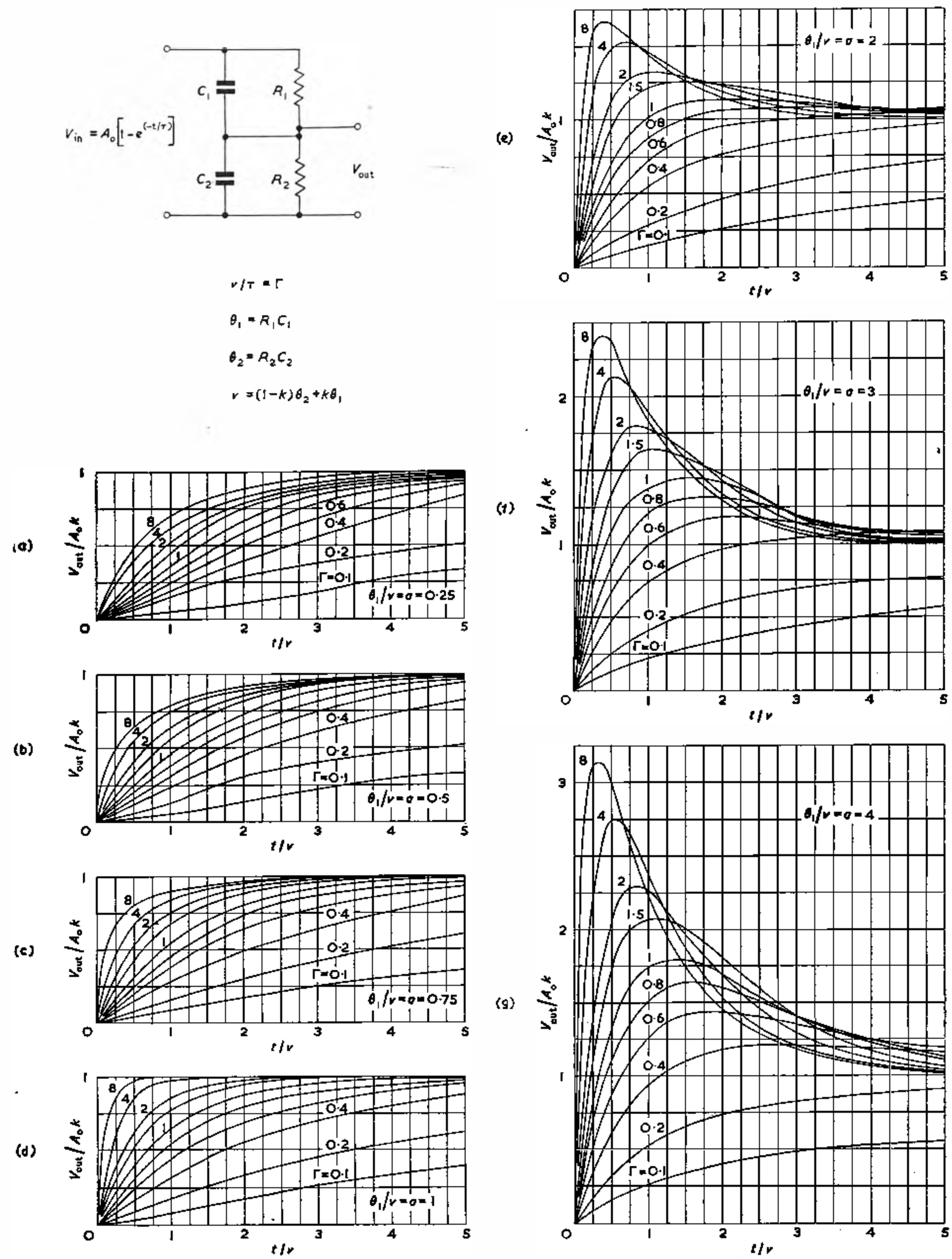


Fig. 6. Response of the divider to the exponential function as a function of t/v for different values of a and Γ

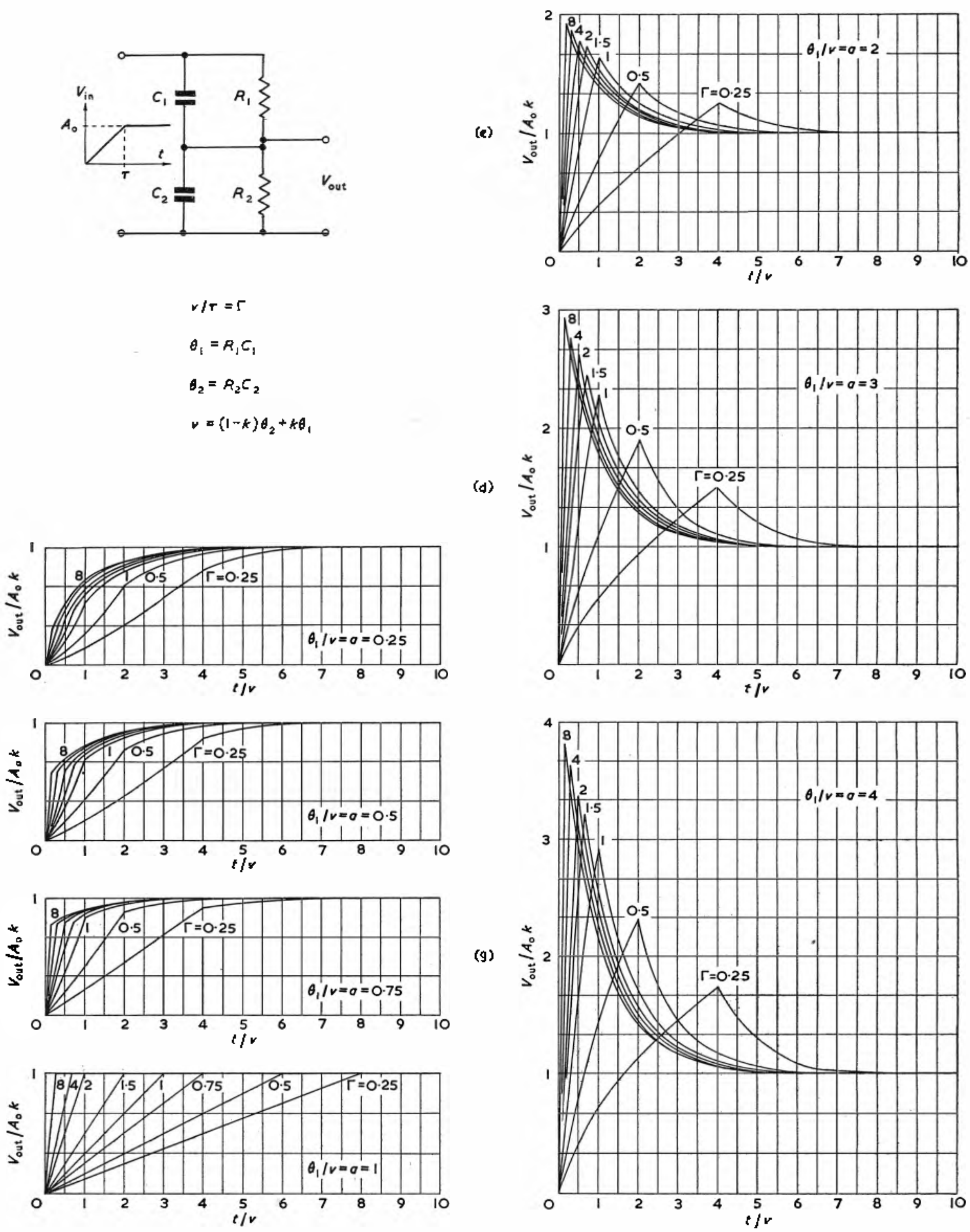


Fig. 7. Response of the divider to the ramp function of t/v for different values of a and Γ

(1) Step Function Response

The input waveform is of the shape shown in Fig. 2 and is given by

$$V_{in} = A_0 V(t)$$

Its Laplace transform is

$$\mathcal{L}\, V_{in} = (A_0/p)$$

By inserting this expression into equation (1) one obtains

$$\mathcal{L}\, V_{out}/A_0 k = \frac{ap + (1/v)}{[p + (1/v)]p} \quad \ldots\ldots\ldots\ (2)$$

The application of Heaviside's expansion theorem gives the solution

$$V_{out}/A_0 k = 1 - (1 - a)\, e^{-(t/v)} \quad \ldots\ldots\ (3)$$

The graph of the $V_{out}/A_0 k$ for different values of the parameter a is shown in Fig. (5).

(2) Exponential Function Response (Fig. 3)

The analytical form of the input waveform is

$$V_{in} = A_0 (1 - e^{-(t/\tau)})$$

and the corresponding transform is

$$\mathcal{L}\, V_{in} = \frac{A_0 (1/\tau)}{p[p + (1/\tau)]}$$

Introducing this into equation (1)

$$\mathcal{L}\, (V_{out}/A_0 k) = \frac{1/\tau\, [ap + (1/v)]}{p[p + (1/v)]\, [p + (1/\tau)]} \ldots\ldots\ (4)$$

The use of the expansion theorem gives

$$V_{out}/A_0 k = 1 + \frac{1 - a\Gamma}{\Gamma - 1}\exp(-\Gamma\, t/v) - \frac{\Gamma(1 - a)}{\Gamma - 1} e^{-(t/v)} \quad \ldots\ldots\ldots\ldots\ (5)$$

with $\Gamma = v/\tau$.

The graph of equation (5) is drawn in Fig. 6 for different values of the parameters a and Γ.

(3) Ramp Function Response

The transform of the ramp function shown in Fig. 4 is

$$\mathcal{L}\, V_{in} = A_0 \frac{1 - e^{-p\tau}}{p^2 \tau}$$

and equation (1) then becomes

$$\mathcal{L}\, (V_{out}/A_0 k) = \frac{[ap + (1/v)]\, (1 - e^{-p\tau})}{[p + (1/v)]\, p^2 . \tau} \quad \ldots\ldots\ (6)$$

The expansion theorem gives

$$\begin{aligned} V_{out}/A_0 k = \Gamma \Big\{ & [t/v - (1 - a)(1 - e^{-(t/v)})] - \\ & - [(t/v - 1/\Gamma) - (1-a)\, (1 - \exp - (t/v - 1/\Gamma))] \\ & V\, (t/v - 1/\Gamma) \Big\} \quad \ldots\ldots\ldots\ (7) \end{aligned}$$

with

$$\Gamma = v/\tau \quad V(t/v - 1/\Gamma) \begin{cases} = 0 & t/v < 1/\Gamma \\ = 1 & t/v > 1/\Gamma \end{cases}$$

In Fig. 7 equation (7) is shown graphically for different values of the parameters a and Γ.

Acknowledgment

The author wishes to express his thanks to Mr. B. Vidjak for preparing the figures and helping in numerical calculations.

A New Casting Process

In the 'Mercast' process of precision investment casting frozen mercury is used as the pattern material which enables castings of better quality and greater intricacy to be produced than those from wax or plastic patterns.

The sole operating licensee of the Mercast Process outside the U.S.A. is Sankey-Telcon Limited, a company owned jointly by Guest, Keen and Nettlefolds Ltd and The Telegraph Construction and Maintenance Company Ltd.

Mercury as the pattern material has the following advantages:—

(1) Solid/liquid expansion is small and, therefore, thin shell moulds can be employed without fear of cracking the shell.

(2) It readily welds to itself under light pressure so that accurate and intricate patterns can be produced by abutting or "booking" simple component patterns together in a precision jig. This characteristic also enables cores to be positioned in sites inaccessible in other techniques.

(3) Its high density and good wetting characteristics permit perfect reproduction of minute detail.

The zircon base refractory material, free from all moisture combined or absorbed, together with the mercury pattern enables a shell mould to be produced which, after firing, is strong, stable and inert to most alloys. The shell mould versus the block mould produced by other investment techniques, permits preferred metallurgical practice to be employed during casting. Freedom from porosity, shrinkage cavities and blow holes, development of controlled grain size and consistency of dimensions, are all achieved. The particle size of the zircon base refractory investment material is selected in relation to the metal being cast and enables fine surface finish of the casting to be attained.

The shell moulds enable chills to be used allowing directional solidification to be induced, even in those cases where rapid changes in cross section occur. The strength of the thin shell mould is sufficient to withstand the most severe mechanical shock associated with casting by suction, vibration, inversion, centrifugal or vacuum casting methods.

Because of the unique operations involved in the Mercast process, specific design requirements, unobtainable by other techniques, can now be met. When a part is considered as a casting, it is usually unwise to follow the design of the fabricated part in detail. In fabrication, it is necessary to incorporate flanges, junction planes, bosses, etc., which become unnecessary when the part is cast as an integral unit and indeed, may become an embarrassment in the casting operation.

It is impossible to specify general tolerance levels as each part must be considered on its own merits.

In particular, more accurate castings with better surface finish, more complex castings and castings with very good mechanical properties can now be produced readily.

A general guide to tolerances obtainable is $\pm$ ·003in/in for most alloys. Somewhat closer tolerances are obtainable for aluminium alloys. This tolerance does not increase proportionately with length, e.g. castings with a linear length of 9in can be held to a tolerance of $\pm$ 0·018in. Concentricity and flatness is another superior characteristic of Mercastings. With regard to surface finish aluminium alloys have a cast finish of 30 to 40μin r.m.s., copper alloys 50 to 60μin r.m.s. and of high alloy content 50 to 100μin r.m.s.

Mechanical properties attained by the Mercast process are better than those normally obtained by other casting techniques. Indeed in the U.S.A. castings are in current production with an ultimate tensile strength in excess of that obtainable from forged components.

Many types of waveguides including tight bends, horns, etc., for such equipment are being regularly manufactured. Both E and H plane bends with integrally cast flanges are produced in S and X bands. These are cast either in aluminium alloy LM.8, which is the best available compromise between machinability and castability, or in gunmetal.

Tolerances consistently maintained are $\pm$ ·002in on the 0·9in and 0·4in dimensions and $\pm$ ·004in on the 1in and 3in dimensions. Surface finish is maintained at 25 to 35μin r.m.s.

As flanges are cast on, the only finishing necessary is the machining of the flange faces including choke grooves and the drilling of fixing holes. Complex horns containing transfer sections have proved to be particularly suitable for the process, as they are very difficult to produce by fabrication techniques in aluminium alloys.

Short News Items

An International Convention on Transistors and Associated Semi-Conductor Devices will be held at the Institution of Electrical Engineers from 25-29 May next. This Convention will be the most comprehensive ever held on this subject, covering design, manufacture, materials, basic theory, characteristics, measurements, applications and equivalent circuits. The submission of papers for consideration for inclusion in the Convention is now invited; manuscripts should be sent in triplicate as soon as possible and in any case not later than 30 November, to the Secretary, The Institution of Electrical Engineers, Savoy Place, London, W.C.2. Registration forms and further particulars of the Convention may also be obtained from this address.

Huddersfield College of Technology are holding a series of ten post-advanced lectures on "Electronic Computers" commencing on 7 October. The fee is £1 10s. and the entry qualification Higher National Certificate in Electrical Engineering, or equivalent. The series ends on 9 December. Further information may be obtained from the Head of the Department of Electrical Engineering, Huddersfield College of Technology, Huddersfield, Yorkshire.

An International Congress on Automation organized by the Instituto de Electricidad y Automatica, and presided over by Mr. J. A. Suanzes, President of the Instituto Nacional de Industria, will be held in Madrid from 13-18 October. This congress is sponsored by the Consejo Superior de Investigaciones Cientificas, the Instituto Nacional de Industria, and various Spanish and foreign industrial firms, among which the American firm Remington Rand has granted the most substantial financial aid. Further information may be obtained from Professor J. G. Santesmases, President of the Organizing Committee, Instituto de Electricidad y Automatica, Facultad de Ciencias, Ciudad Universitaria, Madrid.

An Electronics for Industry Exhibition will be held at the Bennett Hall, Y.M.C.A., Snow Hill, Birmingham, 4, on 21-22 October. The exhibition is organized by Hawnt & Co Ltd of 59 Moor Street, Birmingham, 4, and further information may be obtained from this address. Among the exhibitors will be Advance Components Ltd, Belling Lee, Boulton Paul Aircraft Ltd, Cossor Instruments Ltd, Dawe Instruments Ltd, Isotope Developments Ltd, London Instrument Co Ltd, Nagard Ltd and Rank Cintel Ltd.

International Aeradio Ltd are to open an Air Traffic Control Training School at their premises at Hayes Road, Southall, Middlesex, this month. The object is to provide training in all aspects of Air Traffic Control, including radar. The first course will be a primary course in Approach and Aerodrome Control and is designed for students who have already attained a general standard of education and who have a basic knowledge of aviation. The Company's intake of potential Air Traffic Control Officers is normally limited to former pilots and navigators, who, possessing the basic knowledge for the job, can be instructed on the detailed aspects of Air Traffic Control. While this school is primarily designed for the Company's own staff a number of places are also available to private individuals and outside organizations who might be interested in taking advantage of it.

The Royal Society announces that among the grants by the Paul Instrument Fund Committee which have been approved is £2 000 to Professor J. D. McGee, professor of instrument technology, Imperial College of Science and Technology, London, to enable him to construct a television system for X-ray image intensification. The Paul Instrument Fund Committee, composed of representatives of the Royal Society, the Physical Society, the Institute of Physics and the Institution of Electrical Engineers, was set up in 1945 "to receive applications from British subjects who are research workers in Great Britain for grants for the design, construction and maintenance of novel, unusual or much improved types of physical instruments and apparatus for investigations in pure or applied physical science".

Elliott-Automation Ltd have entered into arrangements with Consolidated Electrodynamics Corporation of Pasadena, California, under which the Elliott-Automation Group will manufacture a wide range of analytical and control instruments of Consolidated design. These will be sold largely to the oil, chemical, coal by-products, gas and other industries. For some time Elliott-Automation have been active in the field of 'quality control instrumentation' in which Consolidated claim to lead in the United States. Co-operation with them is an important step in broadening very substantially the range of equipment Elliott-Automation will be able to offer.

Major H. S. Prince has retired from the Inspectorate of Electrical and Mechanical Equipment at Bickley and has joined the Cossor Group of Companies as Commercial Consultant, and the boards of Cossor Communications Co Ltd, and Cossor Instruments Ltd.

The British Ambassador to Sweden, Sir Robert Hankey, is to open the Exhibition of British Radio and Electronic Components which is to be held in the Ostermans Marmorhallen, Stockholm, from 29 September to 3 October. Thirty-two manufacturers are taking part in the exhibition which is expected to show a very representative cross-section of British manufacture.

The Postmaster General has appointed Mr. O. W. Humphreys, C.B.E., as Chairman of the Advisory Committee on wireless interference from ignition apparatus. The Committee was appointed under section 9 of the Wireless Telegraph Act, 1949. Mr. Humphreys succeeds Sir Stanley Angwin, K.C.M.G., K.B.E., D.S.O., M.C.

Sunvic Controls Ltd have recently opened a training school to instruct customers' operators and maintenance staff in the use of their pneumatic and electronic control instruments. This school is at their Harlow, Essex, factory. Duration and content of the course is flexible, depending upon the degree of technical detail required by students, but it will not generally exceed one week.

The Belgian Atomic Energy Authority has ordered a high-speed Mercury electronic digital computer manufactured by Ferranti Ltd. The Belgian order represents the seventh European Atomic Centre to standardize on this computer. The other Atomic Centres to order the computer are: Geneva, Paris, Oslo, Stockholm and the U.K. Centres at Harwell and Risley. Most of the atomic energy and nuclear engineering calculations done at these Centres during the next few years will be carried out on this British computer. A total of 15 Mercury computers has been sold, of which five are for export. Price of the machine is about £100 000.

B & K Laboratories announce the acquisition of additional premises at Tilney Street, Park Lane, London, W.1. As well as representative displays and demonstrations from overseas principals, the new headquarters will provide cinema features on instrument applications. The building will also house an extensive library compiled from worldwide sources. The work of order processing, servicing, shipping, etc., will continue to be effected from Union Street, S.E.1 (Hop 4567) but sales enquiries will now receive attention from 4 Tilney Street, Park Lane, London, W.1 (Grosvenor 4567).

Erratum. In the article, 'A High Speed Rotary Switch and Some Applications' by M. Lowenberg, which appeared in the September issue, ". . . speeds of up to 200 rev/min" on page 524 should read ". . . speeds of up to 200 rev/sec."

Notes from ——— NORTH AMERICA

I.R.E. News

The Fifth Annual National Meeting of the Professional Group on Nuclear Science will be held at San Mateo, California on 6 and 7 November.

The two-day conference will comprise four sessions as follows:

(1) Electronics for Particle Accelerators
(2) Electronics for Controlled Fusion Research.
(3) Reactor Instrumentation
(4) Nuclear Radiation—Effects, Detection and Measurements

The technical papers to be presented will cover applications of electronics to the problems of nuclear detection, measurement and control.

The 1959 Western Joint Computer Conference will be held at the Fairmount Hotel, San Francisco from 3 to 5 March.

Joint sponsors of the conference are the Institute of Radio Engineers, the American Institute of Electrical Engineers and the Association for Computing Machinery.

The three-day conference, following the pattern of successful meetings alternating between San Francisco and Los Angeles during the past five years, will draw an attendance of more than 1 200.

The theme set for the programme is 'New Horizons with Computer Technology'.

The Eleventh Annual Conference on Electrical Techniques in Medicine and Biology will be held in Minneapolis, Minnesota, from 19 to 21 November at the Nicollet Hotel. It is sponsored by the Institute of Radio Engineers, the American Institute of Electrical Engineers, and the Instrument Society of America through their Joint Executive Committee on Medicine and Biology.

This year the conference has adopted the policy of having a principal theme for the entire meeting. The theme for this year will be Biology and Computers. This theme is of special current interest because of the many new avenues of research and development in medicine and biology which have been opened up through the increasing availability of electronic computers and computer techniques. Of less widely realized but perhaps greater importance is the possibility of greatly improving the performance, efficiency, and compactness as well as greatly extending the scope of electronic computers through utilization of knowledge regarding the computer-like systems that reside in animals and plants.

One special session will examine the possibilities of applying electronic computers to the theoretical and clinical problems of electrocardiography. This field has enjoyed a sudden increase in interest since it has been realized that machine analysis and possibly even partial electrocardiographic diagnosis of heart disease may become a reality in the near future. They will also examine the many ways in which the physician may be aided in making his diagnosis rapidly and accurately through the use of electronic computers.

Another special session will be devoted to computer ideas as applied to electroencephalography, popularly called brain wave analysis. There are numerous scientific hints at the moment that through examining the electric field within the brain and on the surface of the head, much can be learned regarding the processes of the brain, both normal and abnormal. Several different means for analysing this data are already being planned and tested and will be compared and discussed at this meeting.

Telephone User Research

Bell Telephone Laboratories have recently brought into use a new equipment to help in predicting the desires of future telephone users.

Known as 'Sibyl' it is a computer-like machine and laboratory which can simulate a variety of future communication devices and systems and permit them to be tested without the expense of building special equipment for one-time use. It also will provide objective data on how telephone users would respond to a new service.

Sibyl is essentially a laboratory for studying the human factor aspects of future communication devices and services through the use of simulation. Simulation may be defined as the technique of providing a human with specific machine experience by any means short of building the final machine itself. In general, it is desired to collect information concerning the performance of the user without disturbing him or his environment in any manner.

In normal usage, Sibyl is connected to intercept telephone lines between the telephone equipment under test and the local Bell Laboratories PBX while preserving privacy of the actual conversations. It is digital in operation and is composed mostly of electromechanical switching elements constructed in small modular units. Interconnexion between these units is accomplished by extensive patch cords, which permit extreme flexibility of operation. Consoles for observation and manual control are interconnected in a similar fashion.

Tone-multiplex and d.c. signalling are used between the main machine and the remote terminal equipment. For example, in testing a push-button telephone, equipment would be located inconspicuously near the telephone for converting the push-button signals into tone signals corresponding to the number on the push-button. These tone signals would be transmitted to Sibyl where they would be converted into conventional dial pulses and forwarded to the local exchange. Thus, the local exchange equipment would not detect that any unusual equipment was being tested, but Sibyl would have obtained and recorded the desired information from the equipment under test. Such information could typically include time required to dial, dialing errors, number and duration of calls, and the like.

Readout of collected data may be through a combination of direct-writing recorders, magnetic-tape recorders, paper tape punches, electric typewriters or tabulating card punches. Statistical analyses of punched cards are done by a high-speed electronic computer. Visual displays, such as strip charts, may also be employed for immediate recognition of the information being collected.

Capacity of the present system is approximately twenty input channels with two complete data processing and recording channels. These can be increased as the need for additional channels arises.

Sibyl permits study of a new telephone device either intensively in a laboratory with close observation and control, or in a more realistic manner in the normal environment of the test user.

Digital Voltmeter

An all-electronic digital voltmeter with no stepping switches is announced by Electronic Associates Incorporated of New Jersey. It is designed to provide a rapid digital read-out of analogue voltages with extreme accuracy. It is a self-contained unit with its own power supply and reference voltages and was designed for use as a general purpose instrument in data handling systems and similar applications. Through the extensive use of printed circuit wiring and transistors all components including power supplies have been incorporated in a package that occupies a minimum of space.

A high brilliance projection read-out is used to display the four digit reading, decimal point, and sign. The large numerals are visible at distances up to 50ft with up to 70° of access in all directions. Three range scales are provided from 0 to 10, 10 to 100, and 100 to 1 000. Accuracy is 0·01 per cent of full scale on all three ranges. Both positive and negative inputs can be read by the digital voltmeter and the input sign is automatically displayed on the front panel.

Range selection is available either through manual or automatic means. Model 26·070 provides manual adjustment of range by means of a front panel selection switch. Model 26·044 provides automatic adjustment of range by means of internal circuits. In both models decimal location appears in the front panel display.

The speed of the instrument is indicated by an average of 5msec per reading. Where there is a change of polarity or range with the automatic range selection model and additional 3msec to 9msec is required before the first correct reading is displayed.

LETTERS TO THE EDITOR

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

Multivibrators With Wide Mark-to-Space Ratio

DEAR SIR,—The cathode-coupled multivibrator circuit still appears to be surprisingly little known although it has many advantages over the more usual arrangement. It was described some while ago in a book called *The Elements of Pulse Circuitry* by F. J. Farley and was originally due to G. G. Scarrott. Both these workers used thermionic valves, but all the basic principles remain the same when crystal valves are substituted for thermionic ones and there is no need for the reader to be worried by the fact that the figures accompanying this letter show transistors and their appropriate component values. The circuit details for use with thermionic valves can easily be worked out when the principle of operation is understood.

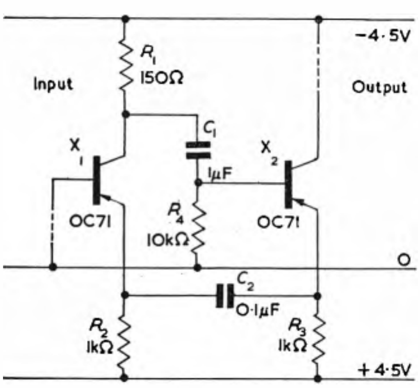


Fig. 1. A typical transistor multivibrator

Fig. 1 shows a typical circuit. The load resistance R_1 together with the couplings provided by C_1 and C_2 makes a feedback loop of adequate gain to ensure that X_1 and X_2 can never stably conduct simultaneously. R_2 and R_3 are two 'long-tail' resistors which carry constant currents to the emitters of X_1 and X_2 respectively. Due to the feedback from R_1 the combined currents from R_2 and R_3 will at any moment be switched to flow in one only of the valves while the other will be cut-off. (The value of R_1 and any load connected to X_2 are made such that even this combined current does not cause bottoming to occur in either X_1 or X_2. The time-constant of C_1 and R_4 is made negligibly long and thus the capacitor C_2 controls the relaxation time in each of the two states.

The advantages of this arrangement are that the square-waves it generates have fast edges for both the rise and fall, the speed is well defined and free from jitter, there is no possibility of oscillation failing to start, and there are free electrodes available both for injecting trigger pulses at the input and for arranging pulse-forming networks at the output. Last, but not least, there is the possibility of obtaining mark-to-space ratios other than 1 : 1 by altering the relative values of R_2 and R_3.

In the circuit of Fig. 1, R_2 is made 4·7kΩ while R_3 is reduced to 470Ω, then X_2 must conduct for ten times longer than X_1 although the transitions remain as sharp as ever. Both the marks and spaces remain free from jitter as they are now being timed by C_2 in conjunction with the different resistors R_2 and R_3. If, however, R_2 is made larger than this, the circuit as drawn will fail to work. The state where X_1 and X_2 conduct together becomes stable due to the

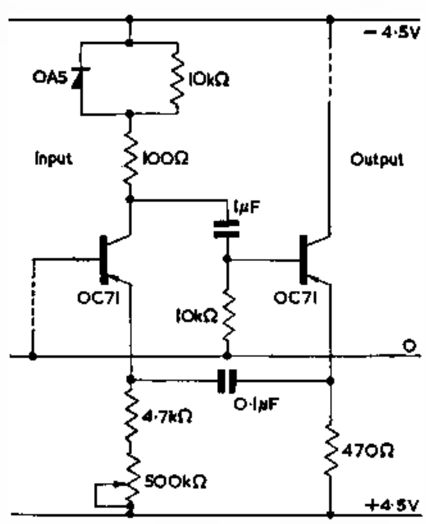


Fig. 2. Incorporation of low impedance diode

poor mutual conductance of X_1 at low current values making R_1 no longer large enough to give instability. It is not sufficient merely to increase R_1 however, as too much voltage will then be made at the normal working current; the solution is to make R_1 non-linear.

There are many ways of doing this and that shown in Fig. 2 is a simple one that works well. A low-impedance diode is used to by-pass the greater part of the load resistance during the time when relatively heavy current is passing. The circuit shown will give a continuously variable mark-to-space ratio from 1 : 10 to at least 1 : 1000 having a constant mark width of about 15µsec. Clearly it could be modified to give wider marks or more powerful outputs in the usual way.

Yours faithfully,
K. C. JOHNSON
Ferranti Ltd., Manchester.

White Noise Testing

DEAR SIR,—I was interested to read the article by Mr. J. F. Golding on page 349 of your May issue. The formula which Mr. Golding quotes for the Conversion Factor R which has to be employed when expressing the measured results in terms of signal-to-noise ratio rather than noise power ratio has been, I think, quoted from Reference 1. As author of the Post Office Radio Report referred to, may I be permitted to point out that a typographical error in this Report has been perpetuated in the present article? The expression should, of course, read:—

$$R = (10 \log (A/4) - p) \text{ dB.}$$

The cut-off frequency of the low-pass filter which is used when 120 channels are to be simulated is given as 522kc/s. This should be 552kc/s, in order to conform to standard frequency allocations on telephony systems.

As Post Office Radio Reports are not generally available to the public, it may be helpful to point out that the information in this Report has already been included with other, later, material, in an article written by Mr. R. W. White and myself, and published in the Post Office Electrical Engineers Journal, Vol. 48, Part 3, October, 1955.

Yours faithfully,
J. S. WHYTE
Post Office Engineering Department, Research Station,
London, N.W.2.

The Author Replies:

DEAR SIR,—With regard to Mr. J. S. Whyte's letter concerning my article on the White Noise Method of Measuring Crosstalk, I must agree with him on both points.

The expression to which he refers was indeed taken directly from Post Office Radio Report No. 2339.

The second point is the result of a typographical error which passed unnoticed and for which I must apologize.

Yours faithfully,
J. F. GOLDING
Marconi Instruments Ltd.,
St. Albans, Herts.

A Feedback Electrometer Amplifier

DEAR SIR,—Mr. D. Allenden's interesting article in the January 1958 issue calls for some comment, as anything on so controversial a subject must.

(1) The figure 10mV equivalent input drift for 1 per cent change in (input valve) heater voltage varies very widely with the type of valve used and its operating conditions, and should be treated as a rough approximation only. In their paper, Brown and Kandiah suggested ±10mV for a balanced input stage.

(2) Balanced stages can reduce drift by much more than 'a factor of 5 or so'—with careful design, 30 times is reliably possible without selection of

valves other than elimination of gross mis-matching.

(3) Stabilization of electrometer valve heater supplies has been used very widely in commercial practice, certainly since 1947, and in some cases very thoroughly; for example, in a pH-meter by W. G. Pye (1950) where input valve heater voltage is stable within ±0·2 per cent for any normal variations in mains voltage or frequency.

(4) The performance of the author's circuit could be improved by using neon tubes of higher implicit stability, such as the 85A2 or QS-83/3, and by pre-protecting them against wide mains variations, either by a coarse stabilizer circuit in front or by a bridge arrangement.

Yours faithfully,
G. I. HITCHCOX
Electronic Development & Applications Co., Ltd.,
Wellington, New Zealand.

The Author Replies:

DEAR SIR,—In answer to the points raised in Mr. Hitchcox's letter:—

(1) While the quoted figure of 10mV per 1 per cent heater-voltage variation is approximate and subject to some variation, it is nevertheless a well-established one for oxide-coated uni-potential cathodes run under space-charge-limited conditions and at low anode currents, conditions which apply in almost all low-level d.c. amplifier stages. Valley and Wallman[1] have confirmed this by tests on numbers of valves of various types and the fact that almost any pair of valves even of different types will give a significant degree of compensation surely indicates that there is no wide deviation from the average figure. Kandiah and Brown's figure of 10mV for a balanced stage is an overall figure including all sources of variation.

(2) Balanced stages can reduce drift by much more than a factor of 5: this was mentioned in my article, during the discussion of the intermediate stage circuits. However, as Martin[2] confirms, 5 times is the best figure that can be guaranteed with unselected valves and no provision for adjustment—both desirable features as far as reliability of performance is concerned. Adjustable compensation techniques permit factors of the order of 100 to be realized, though the long-term stability of such adjustments and the range of voltage variations against which they are able to compensate often leave much to be desired. I should certainly be very interested to hear of a design procedure which allows a factor of 30 to be realized without any adjustment. A feature of balanced stages which is often not mentioned is the fact that uncorrelated variations are increased by a factor of 2 relative to a single-ended stage.

(3) My reference to stabilized heater supplies was meant to refer to heater stabilization to a degree which renders balanced stages unnecessary: the example given by Mr. Hitchcox would presumably come into this category, but I do not think that stabilization of this order has been widely used until the practice developed of running nuclear amplifier heaters in series from a stabilized h.t. line. The advent of power transistors, of course, now makes heater stabilization a practical and economical proposition.

(4) I agree that better stabilizer tubes would improve the performance as would pre-stabilization—but the desired performance was realizable without such measures. One of the main features of my amplifier is that its performance is realized with circuits of extreme simplicity and reliability.

Yours faithfully,
D. ALLENDEN
Electronics Services Group,
Associated Electrical Industries Ltd.,
Research Laboratory.

REFERENCES

1. VALLEY, G. E., WALLMAN, H. Vacuum Tube Amplifiers. (McGraw-Hill, 1948).
2. MARTIN, D. J. R. Direct-Coupled Amplifiers. *Radio and Electronic Engng. 34*, 458 (1957).

Multivibrator Circuits

DEAR SIR,—In an article in your June issue Mr. A. E. Jackets dealt very fully with the problem of obtaining sharp waveforms at the collectors of a transistor multivibrator circuit.

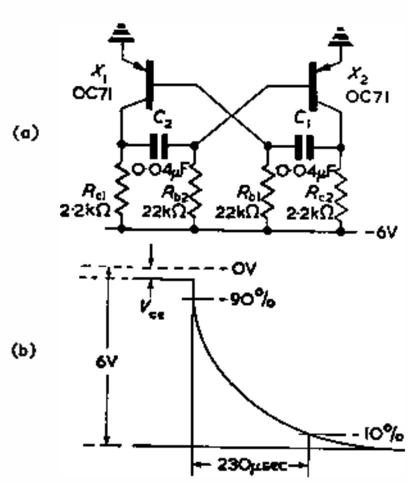


Fig. 1. A typical multivibrator and associated waveform

An alternative technique for obtaining sharp square waves, and one which has been in use in these laboratories for some time, makes use of the impedance transforming property of the common collector (or emitter-follower) transistor. A multivibrator circuit in which this property is used is shown in Fig. 2(a). When X_1 is cut off the emitter-follower X_3 completes a low impedance discharge path through the timing capacitor C_2 and the emitter-base diode of X_2, thus enabling C_2 to be discharged in a fraction of the time taken in a conventional multivibrator in which discharge takes place through the emitter-base diode of X_2 and R_{C1}, which results in a waveform with a very sluggish falling edge at the collector of X_1.

For the purpose of comparison, a typical multivibrator (Fig. 1(a)) running at a frequency of 840c/s was built and the time taken for the voltage at one of the collectors to fall from 90 per cent to 10 per cent of full amplitude measured and found to be 230μsec. Modification of this same circuit to the form shown in Fig. 2(a) resulted in a greatly improved collector voltage waveform with a fall time of 24μsec.

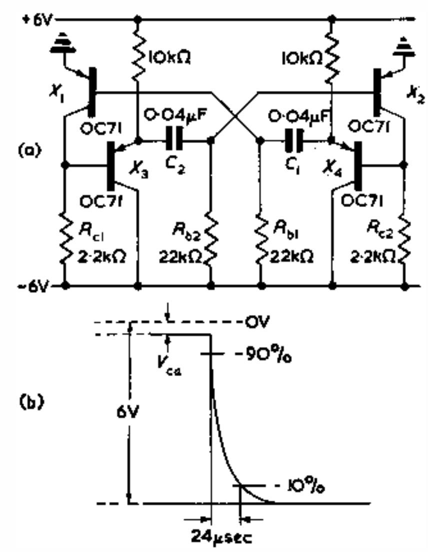


Fig. 2. Modification of Fig. 1

While open to criticism on economic grounds, the circuit of Fig. 2(a) has the merit of providing sharp square waves from both collectors of a transistor multivibrator. In a one shot multivibrator which uses only one extra transistor, this criticism is less valid and, using this type of circuit, it has been found possible to generate reasonably square waveforms with a duration of greater than 2 seconds.

Yours faithfully,
N. L. LEECE
Ferranti Ltd.,
Wythenshawe.

The Author Replies:

DEAR SIR,—I would like to thank Mr. Leece for mentioning his interesting modification to multivibrator circuits. There are, I am sure, a number of applications in which the improvement obtained justifies the extra components employed.

Another method of improving the collector waveform was described by Mr. Armstrong in a letter to the Editor of ELECTRONIC ENGINEERING in May 1957; this has the advantage that no additional transistors are required.

Yours faithfully,
A. E. JACKETS
Research Laboratories of
The General Electric Co. Ltd.,
Wembley.

BOOK REVIEWS

Faisceaux Hertziens et Systèmes de Modulation

(Radio Waves and Modulation Systems)

By L. J. Libois. 512 pp. 204 figs. Demy 8vo. Editions. Chiron, Paris. 1958. Price Fr.6.200.

THE author is an engineer specializing in multi-channel radio links at the National Centre for Telecommunication Studies near Paris. The book deals with the fundamental problems in the design of line-of-sight radio links for multi-channel telephony, telegraphy and television, describing in particular the various systems of modulation. Tropospheric scatter communication is specifically excluded, but readers are directed towards suitable information on this subject.

The chapters on modulation which form the middle two-thirds of the book are sandwiched between introductory chapters on the history of radio links, with a statement of the system performance requirements and the distribution of frequency channels recommended by CCITT, and final chapters on propagation, fading, diversity and signal-to-noise ratio. It will depend upon the outlook of the reader whether the mathematical centre or the more practical outer parts of the sandwich are of greater value.

The introductory and concluding parts of the book present the fundamental considerations for the design of multichannel radio systems in a very clear way which the system-planning engineer will find of value. The chapter on propagation places proper stress on the way in which it can influence the performance of radio links; the sections on signal-to-noise ratio and the general design of equipment are also well presented. The problem of transmitting television pictures over links is discussed in relation to the parameters of the French monochrome system.

The central part of the book is devoted to types of modulation for multi-channel links. After a theoretical discussion of basic information theory and modulation principles, frequency and pulse modulation are dealt with. Problems are considered in a fundamental algebraic way, and more space could have been devoted to practical considerations. The reader could be assumed capable of calculating how a variable reactance can modulate the resonant frequency of a tuned circuit without the basic calculation on pages 131-2. This space could well be devoted to more practical details of reactance tube modulators. The circuit diagrams would be improved if values of components were given for a particular design.

The different forms of pulse modulation are described, including pulse-code modulation systems. The section on delta-modulation forms an excellent introduction to the subject.

The material is well arranged and illustrated, with some mathematical derivations transferred to appendices at the ends of chapters. After Chapter II, appendices on definitions of terms and some distortion measuring methods are also included. At the end of each chapter is a reference section, a useful number of papers in English being included.

This book will be of value to a specialist in radio-link work who is able to use a mathematical approach to produce answers adaptable to engineering requirements.

G. L. GRISDALE

Pulse and Time Base Generators

By D. A. Levell. 175 pp. 60 figs. Demy 8vo. Sir Isaac Pitman & Sons Ltd. 1958. Price 25s.

THIS book is divided into eight chapters as follows:

Introductory, Linear Circuits, Non-Linear Circuits, Pulse Modulators, Trigger Circuits, Negative Transconductive Trigger Circuits, Electromagnetic Time Bases and Transistor Circuits. The book deals with passive and active networks both linear and non-linear, including clippers and restorers. Line and valve pulse generators, soft and hard valve trigger circuits and many types of time base and amplifier are discussed together with methods of synchronization. The book ends with a discussion on transistors and their behaviour and a description of some transistor equivalents of existing valve circuits.

The circuit diagrams could be clearer with terminals properly indicated instead of using, often minute, arrows sometimes placed right "inside" the circuit. The use of the symbol "i" to mean both "input" and "instantaneous current" may prove misleading even when, in the former case, it is used as a subscript. The addition of component values and valve types in a far higher proportion of the circuits would be helpful to experts in other fields who wish to construct apparatus for their experiments.

The book is, perhaps, rather too condensed to meet fully the needs of students but this could be remedied in a second edition. It would also add to its value as a reference book, if the symbols used in each mathematical exposition could be defined. This would mean some repetition but would save time.

The book is excellent and the author is to be congratulated upon it. It will prove very valuable and can be highly recommended.

O. S. PUCKLE

Circuit Analysis of Transmission Lines

By J. L. Stewart. 186 pp. 72 figs. Medium 8vo. John Wiley and Sons Inc., New York. Chapman and Hall Ltd., London. 1958. Price 44s.

THE object of the author of this new book on transmission lines is to provide a text more suited to present-day engineering than those already available. Many of these, the author observes, are out of date and others "display an uncontrolled obsession for qualitative graphical explanations". The treatment of transmission lines in undergraduate courses should, the author holds, be postponed until the student has acquired a good foundation in the steady-state and transient analysis of networks. He asserts that the subject of wave-filters properly belongs to discrete-parameter network theory and, together with considerations of characteristic impedance and skin effect, should not be attached to that of transmission lines. The author believes also that "Devices and concepts such as repeaters, hybrid coils, specialized graphical procedures, and so forth, are easily picked up on the job; the luxury of teaching such topics is not justified if it means limiting more basic analytic material".

From this enlightened point of view, the book begins the study of transmission lines with the transient state. The fundamental differential equations are established by the infinitesimal line-segment approach and transient waves along non-dissipative and low-dissipative lines are discussed in the first three chapters. The remaining six chapters are concerned with the sinusoidal steady-state. The concept of steady-state is introduced in the fourth chapter and the following chapter deals with standing-waves, transmission efficiency, and impedance matching. The use of the line as a resonator is considered in the sixth chapter; transmission cavities and cavity coupling are also included in the discussion. Discrete parameter analogues of the transmission lines are treated in the next chapter which deals also with power lines and circle diagrams. The eighth chapter is devoted to measurements and standing-wave ratio and the final chapter introduces the Smith chart. The discussion of the Smith chart is left until the end of the book, the author explains, to force the student to be "analytic in his thinking. Students using a book in which the Smith chart is discussed at the outset tend to display some laziness by substituting dogmatic chart manipulation for solid analysis effort".

The book reflects the new trend in network theory and complements the author's *Circuit Theory and Design* which was published two years ago and was an attempt to present the modern approach to passive and active network design. Both books can be recommended with confidence to anyone studying electronic engineering privately but it is doubtful if they will be suitable as course books in technical colleges in this country.

S. R. DEARDS

Fernwirktechnik II (Telecontrol Engineering II)

Edited by J. Wosnik. 85 pp. Crown 4to. Friedr. Vieweg & Sohn, Braunschweig. 1958. Price paper bound DM 14.

THIS is a verbatim report on the papers read at a symposium held in Cologne in June 1957. The first volume dealing with the same subject appeared in 1957. The scope of the symposium appears from a list of the various contributions. The following papers were presented after the opening address of the Chairman:

H. J. Zetzmann, Tasks of telecontrol engineering in flight traffic; *P. Rother*, Traffic control in large cities by centrally controlled traffic signal installations; *H. Nibier*, Telecontrol engineering for the current supply of the German Federal Railways; *W. Lindrum*, Phase angle measuring instruments for railway track circuits; *J. Herrmann*, Telecontrol by radio in lignite mining; *E. Mambrini*, Telecontrol and automatic section protection for a surface mining railway; *G. Rehschuh*, Telecontrol engineering for the interlocking installations of mining railways; *H. Groeger*, Regulation of the water level of a flow equalizer by telecontrol; *G. Becker*, Telecommunication and telecontrol engineering in the network control of interconnected networks; *de Quervain*, The control network of the Swiss electricity works; *W. P. Venzke*, Novel circuit diagrams for load dispatcher posts; *G. August*, Telemetering in interconnected networks; *H. Wilireit*, Selective telemetering according to the impulse-encoding-method; *K. Bartels*, Telecontrol and remote supervision of communication plant; *W. Peinke*, Elements of telecontrol engineering in the chemical industry; *F. Steiner*, Transmission of quantities by binary systems and its significance for telecontrol engineering.

The first of the contributions contains a short bibliography, the second a brief discussion and the last a list of suppliers of encoding devices. All the contributions are adequately illustrated with halftones and line drawings. The text is mainly descriptive and stresses mostly the practical aspects. The chairman expressed the hope that later on a more theoretical treatment of the subject matter will be possible.

R. NEUMANN

Research for Industry 1956-57

159 pp. Demy 8vo. Her Majesty's Stationery Office for Department of Scientific and Industrial Research. 1958. Price 7s. 6d.

THIS publication is a summary of the work done by the industrial co-operative research associations grant-aided by D.S.I.R. There are now thirty-nine associations in the Government scheme, together with seven research councils on the same pattern, serving industries as diverse as baking, printing, hosiery and marine turbines.

Previously this summary of work has been included in the annual report of D.S.I.R., but in future it will be published separately for each calendar year.

Microwave Transmission Design Data

By Theodore Moreno. 248 pp. 50 figs. Demy 8vo. Dover Publications, New York. Constable & Co. Ltd., London, 1958. Price 12s.

THE purpose of this volume is to provide a reference handbook for radio engineers whose work is related to microwave systems or components. The subject matter deals with microwave transmission lines and associated components. This book is based on a Sperry publication of 1944. The new volume has been almost completely rewritten and considerable new material has been added. Four complete new chapters have been added, those dealing with transmission line theory and flexible cables.

Electrical Who's Who 1958-59

531 pp. Demy 8vo. 5th Edition. Demy 8vo. Electrical Review Publications Ltd. 1958. Price 27s. 6d.

THE Electrical Who's Who was introduced in 1950 and it has now become a recognized guide to people in the electrical profession and industry. This latest edition contains about 8 000 entries, covering men and women in all branches —electricity supply, electrical manufacturing, contracting, consulting, research, transport, mining and trade associations. Electrical engineers in the Post Office, the Admiralty, the Ministry of Supply and other Government Departments are also included. Brief biographies give particulars of the education and training, and previous positions held by those concerned. These are supplemented by an index to the entries, classified under the names of their companies or other organizations, thus making it easy to ascertain the names of the principals of a particular concern and from there refer to the bibliographical entries.

High Fidelity: A Bibliography of Sound Reproduction

Compiled by K. J. Spencer. 325 pp. Demy 8vo. Iota Services Ltd. 1958. Price 30s.

THIS work of approximately 2 600 entries represents the field of published information and research on high quality sound reproduction, from the subject's inception up to and including June 1957. K. J. Spencer has scanned the world literature on this subject, including all the important research and institutional publications. This bibliography will prove of invaluable assistance to all who wish to be able to consult, quickly and easily, what has been published on high fidelity, from definitions to installation and maintenance.

A Beginner's Guide to Television

By F. J. Camm. 128 pp. 60 figs. Demy 8vo. George Newnes Ltd. 1958. Price 7s. 6d.

THIS book is written in non-technical language which the very beginner can understand. The reader is taken by easy stages through every aspect of television transmission and reception.

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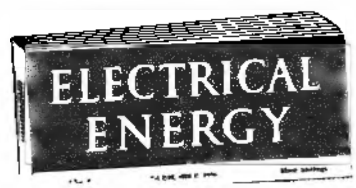

For the Advancement of Electrical Science

ELECTRICAL ENERGY is a monthly technical journal for electrical engineers having a scientific turn of mind. Its articles are designed to bridge the gulf between research and the practical application of the knowledge so gained to industry. Bringing up-to-date information about new theories, methods and materials, it is of inestimable value to electrical designers.

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THE S.B.A.C. EXHIBITION

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

RAPID PROCESSING PHOTOGRAPHIC PROJECTOR

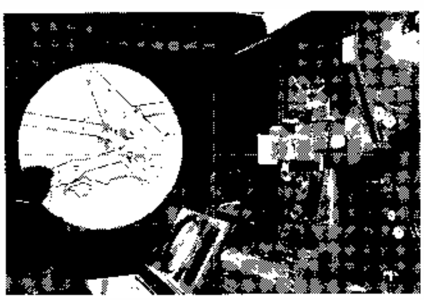
(Illustrated below)

Kelvin and Hughes Ltd, New North Road, Barkingside, Essex

DESIGNED in conjunction with the Ministry of Supply, this equipment facilitates for the first time, in production form, the large scale presentation of photographically recorded and processed sequential events as they appear on a cathode-ray tube. A 35mm film can be processed and projected with the minimum of delay on to a screen of suitable size according to the intensity of the illumination required.

A positive or negative image is available to suit personal preference or to conform to the admissible levels of ambient light.

Although the equipment has been generally used with conventional cathode-



ray tubes, it is equally suitable for recording the fast read-out from a Charactron shaped beam tube or other similar device. The cathode-ray tube presentation may be for example a p.p.i. radar display on a long persistence tube, or any other form of presentation, such as a data processing display or other instantaneous picture.

The wide potentialities of the apparatus have been investigated by Kelvin and Hughes Ltd and valuable experience has been gained in many civil applications embracing air and marine traffic control and, linked to electronic computing equipment, in industrial and research projects.

Completely self-contained and fully automatic, the apparatus takes 1 000ft reels of film which at a normal film speed of 4 exposures per minute, gives it a continuous operating period of approximately 24 hours. Integral reservoirs permit the replenishment of chemicals without stopping the machine. The minimum time between photographing and projecting is 6sec.

EE 2751 *for further details*

LONG RANGE SURVEILLANCE RADAR

Decca Radar Ltd, Albert Embankment, London, S.E.11

THE long range civil surveillance radar type D.A.S.R.I. which has been recently introduced, was specially developed for terminal use where high speed, high altitude, civil aircraft are being operated. With coverage extending above 40 000ft and to ranges well in excess of 100 miles, the D.A.S.R.I. is one of the most advanced equipment of its type developed for civil use. Operating in the 10cm band, this single equipment not only provides long and close coverage, from the radar horizon to well above the present limit of aircraft operating heights, but also has a high rotation rate and a narrow beamwidth, providing a radar picture suitable for controlling aircraft precisely and accurately even at long range.

Modern techniques such as variable polarization to eliminate weather echoes and air target indication to suppress permanent ground echoes are built into this radar. The use of separate transmitters feeding double reflector, back to back aerial array, is another interesting feature in design and it is this technique which allows the high performance to be extended from a comparatively small radar station.

EE 2752 *for further details*

MULTI-CHANNEL RECORDER

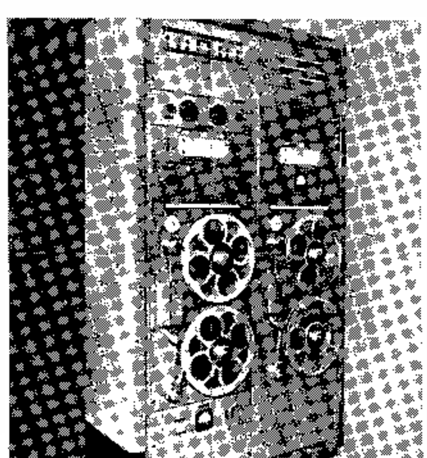
(Illustrated below)

Thermionic Products Ltd, Hythe, Southampton

THIS equipment is designed to operate for long periods with a minimum of attention and to record up to 14 separate channels simultaneously on a tape 0·7in wide.

A number of versions of this equipment is available of which the Mark XII is typical. This two bay installation consists of a master record bay in which is incorporated playback facilities and a subsidiary record bay. It is designed to record for 16 hours without attention and when it is necessary to use the playback facilities the subsidiary record bay automatically takes over to give an uninterrupted recording. Special features of this equipment are:—

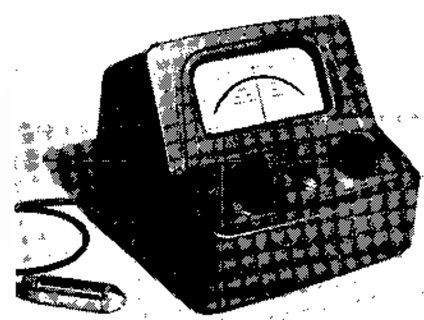
(a) Automatic restart in which provision is made for restarting the equipment if there is a mains power failure. On the resumption of the supply the equipment automatically restarts and the fact that there has been a power failure indicated on the power supply unit, so that the timing device can be adjusted to the correct time.



(b) Four wire input. The record facilities in this unit are provided with dual inputs with independent gain controls, and the input impedance can be adjusted within the range of 10Ω to 100kΩ, balanced or unbalanced. This facility gives impedance control of, for instance, a transmit and a receive channel using the same frequency.

(c) A limiting amplifier has been designed for this equipment which enables signals varying up to 30dB level to be adequately recorded.

EE 2753 *for further details*



ELECTRONIC COMPARATOR

(Illustrated above)

Southern Instruments Ltd, Frimley Road, Camberley, Surrey

THE Magna-gage is an electronic comparator of high magnification and accuracy. It consists of two parts: a probe unit which is brought into contact with the work, and an amplifier unit which displays the magnified movement. Displacement of the probe tip causes minute electrical changes which are transmitted to the amplifier unit; these changes are amplified and made to move a pointer over a scale.

By mounting the probe on a suitable stand, comparator measurements can be made to an accuracy of ·00001in (·00025mm).

By mounting the probe on a machine, work size can be controlled to the same limit. Electrical outputs are available for operating other devices.

EE 2754 *for further details*

MACHINE TOOL CONTROL

Ekco Electronics Ltd, Southend-on-Sea, Essex

THE Ekco type E117 machine tool control which utilizes a punched card information storage system, is a relatively simple equipment which provides accurate automatic co-ordinate setting of machine tools and can be fitted to existing as well as new machines.

It can automatically reset a 10turn/in lead screw to $\pm 1/500^{th}$ of a single turn representing 0·0002in linear movement of the work table; as the final approach is uni-directional the effects of backlash are avoided. Gearing is employed in the system to suit lead screws of 4, 5, 6, 8 or 10 turn/in and metric screws can be provided for to order.

The equipment normally comprises a combined control unit with a separate traverse unit for each lead screw. It was demonstrated with a single control unit, calibrated for circular measure, operating a circular table. The newly developed punched-card information storage system allows information for up to 23 holes to be contained on one card, enabling the system to be programmed for sequential operation of the machine until all operations with a particular drill have been completed.

As the equipment uses no electronic valves and comprises mainly resistors and relay circuits, its maintenance is within the province of the works electrical engineer and requires little special training.

EE 2755 *for further details*

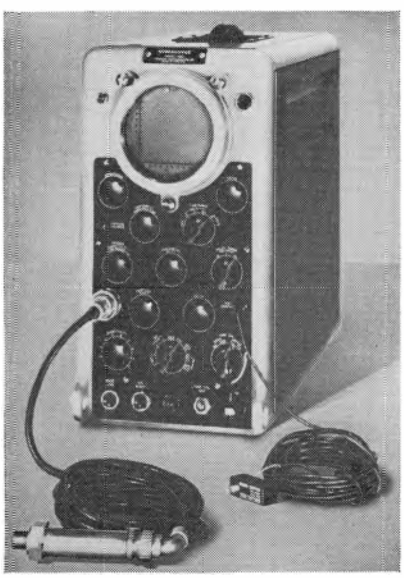
PRESSURE DISPLAY AND ANALYSIS EQUIPMENT

(Illustrated below)

Cossor Instruments Ltd, Cossor House, Highbury Grove, London, N.5

THE model 1063 Hydraudyne is a small, portable instrument for the display and measurement of pressure conditions in all hydraulic and pneumatic systems. It provides, graphically, an accurate means of ascertaining the exact static pressure in a reservoir or conduit and will display variations therefrom of any rate-of-change from zero. It consists of an oscillograph unit with a long-persistence cathode-ray tube having a built-in d.c. amplifier and a time-base with delay facilities. A single pressure transducer covers the range 0 to 8 000lb/in² and a 35mm camera and motor drive unit are fitted for recording purposes.

A time scale, by which calibration of pressure phenomena may be carried out, has been arranged by brightness-modulation of the trace producing a series of stationary dots spaced by intervals of 0·2, 0·02, 0·002, 0·0002sec. The speed of the scan may be set over wide limits and X (horizontal) amplifier allows continuous variation of spot velocity between the fixed points in the range. A microswitch with 20ft of cable is provided so that an electrical trigger pulse to fire the time-base may be initiated.



EE 2756 *for further details*

FUEL CONTENTS GAUGE

Firth Cleveland Instruments Ltd., Treforest, Glamorganshire

THE increasingly critical fuel loading demands of the armed services and civil airline operators for ultimate performance has resulted in two immediate applications of the 'Pacitran' systems: A fuel contents gauge, and, latterly, a liquid oxygen gauge. Both are small transistorized servo-driven devices of light-weight design giving high accuracy and reliability.

The operation of all 'Pacitran' gauges is based upon the established principle of the electrical capacitance change which results when a pair of electrodes, comprising the tank unit, are immersed in the fluid to be gauged. This change is indicated on a scale normally calibrated in mass units showing, directly, the weight of fuel loaded. In the case of aircraft fuel, calibration in terms of mass is dependent upon the fuel density, and the fuel dielectric constant: these factors vary widely with variations in temperature and the source of the fuel. In the 'Pacitran' gauges, compensation for these factors is achieved by means of a force balance float device which comprises a density corrector and a continuously immersed sensing unit which detects changes in the dielectric constant of the fuel.

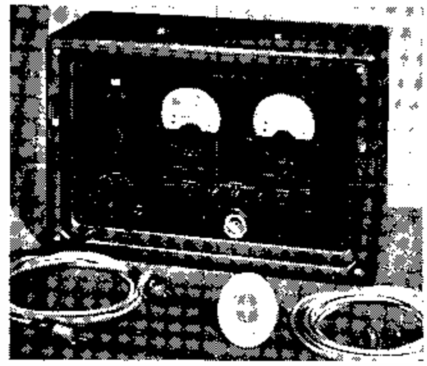
Final correction and measurement is effected by the indicator which is in the form of an instrument case having a 2⅜in or 3¼in S.A.E. bezel. This contains a self-balancing double bridge circuit having the elements described which vary as functions of fuel density, fuel dielectric constant and fuel level. An error signal derived from the bridge circuit is amplified by a three-stage silicon transistor amplifier and is used to drive a low torque re-balancing potentiometer via a split phase servo motor and reduction gear box. Hysteresis damping is incorporated to give the instrument a 'dead beat' effect.

EE 2757 *for further details*

VIBRATION METER

(Illustrated above right)

The Wayne Kerr Laboratories Ltd, Roebuck Road, Chessington, Surrey



DISTANCES and vibration amplitudes from 50μin to 0·5in can be measured accurately in the frequency band 1c/s to 10kc/s. Variation in the magnitude of either quantity, within the operating range of the instrument, does not affect the accuracy of measurement of the other.

A non-contacting probe, connected to a 50kc/s oscillator and suitable amplifying equipment, is brought into proximity with the object under test. The capacitance so formed is interpreted in terms of distance and peak-to-peak vibration. The two quantities are displayed on direct-reading meters.

Probes are available to give full-scale deflexions for both distance and vibration of 0·001in, 0·01in and 0·5in but a switch is provided on the instrument to increase the vibration sensitivity, relative to that for distance, by a factor of five. The accuracy is 2 per cent of full-scale deflexion and the discrimination better than 0·5 per cent. An output is available from both meter circuits for feeding to recording equipment, alarm or servo-control systems. Facilities are provided for the connexion of an oscilloscope to the amplified probe signal, permitting qualitative and quantitative analysis of vibration.

The equipment finds application where safety considerations make it necessary to have the indicating instruments remote from the machinery and the probe. It is particularly suited to the measurement of vibration where direct physical contact is not possible, and for measuring the dilation and eccentricity of rotating parts.

EE 2758 *for further details*

PORTABLE TRANSDUCER TEST SET

Boulton Paul Aircraft Ltd, Wolverhampton

THE 'Pendeford Multimeter' is a portable self-contained instrument for the measurement of physical quantities. It is simple to operate and very versatile. Direct measurement of displacement, force, load or pressure can be obtained by plugging in the appropriate transducer. Direct readings of strain can be made by connecting the instrument to strain gauges suitably attached to the specimen under test. The instrument also provides an electrical output for control or recording purposes.

The salient feature of the instrument is simplicity of control and for normal operation only the 'range control' is used, the full-scale reading of the instrument being 100, 25, 10, 2·5, 1·0 or 0·25, representing inches $\times 10^{-3}$ or other units, e.g., strain in lb/in² or load in lb, depending on the type of transducer in use.

The other controls are so arranged that they cannot be accidentally moved, and for most applications will only require to be adjusted when initially selecting the measurement required.

A wide range of transducers is available for use with this instrument.

EE 2759 *for further details*

PRECISION POTENTIOMETER

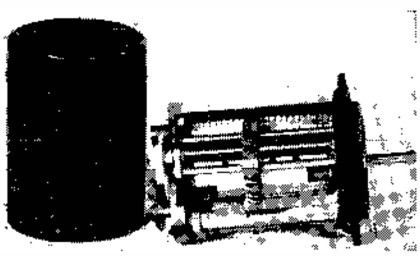
(*Illustrated below*)

The Sperry Gyroscope Co. Ltd, Great West Road, Brentford, Middlesex

THIS component provides a compact means of achieving precise voltage division proportional to the angular position of a shaft.

Fed with a constant voltage, it could give a signal proportional to shaft rotation in an analogue computer. It could be geared to a dial or counter and used in a manual or self balancing potentiometer or bridge circuit. It provides a useful combination of compactness and precision.

The rotating mandrel is helically wound with 50 turns of silver palladium wire specially tested for uniformity. The gold alloy wiper is spring loaded radially towards the wire on the mandrel. All contacts are tarnish free. It is carried along the mandrel on slides by a lead screw geared to the mandrel and parallel to its axis. The slides and lead screw are



mounted on a balanced frame pivoted about the axis of the mandrel and spring loaded against a cam which advances the wiper along the wire by a few degrees. The initial shape of the cam is that required to compensate for the load on the potentiometer as specified by the customer. Adjustments are made on test to correct for manufacturing errors including non-uniformity of the wire. The standard cam is for a load of 250kΩ and zero input impedance, but other combinations can be corrected by suitable cams. For use in bridge circuits, an initially straight cam can be provided to correct for manufacturing errors only.

The linear accuracy is 0·008 per cent, the rating 0·5W and the potentiometer resistance 1kΩ or less.

EE 2760 *for further details*

SELF-LOCKING CONNECTORS

Belling and Lee Ltd, Great Cambridge Road, Enfield, Middlesex

THIS range of 'Interlock' self-locking connectors provides a reliable connexion that assures uninterrupted circuits with no possibility of accidental disconnexion. The connexion is 'locked-in' until purposely released and this is effected by a simple thumb and index finger movement.

Plugs have two separate contact surfaces, one of which is always making contact. A coil spring presses the Interlock contact head against the mating socket which eliminates uncertain friction and contact fatigue.

The locking action is positive and reliable even under vibration or impact conditions. There are no catches or separate locking parts as the contacts themselves form the locking mechanism. Contact resistance is low and stays constant throughout plug life, due to the spring pressure.

The flexibility of these components makes them of particular use for printed circuit or terminal strip applications.

Current capacity is 5A and plugs are Nylon insulated.

EE 2761 *for further details*

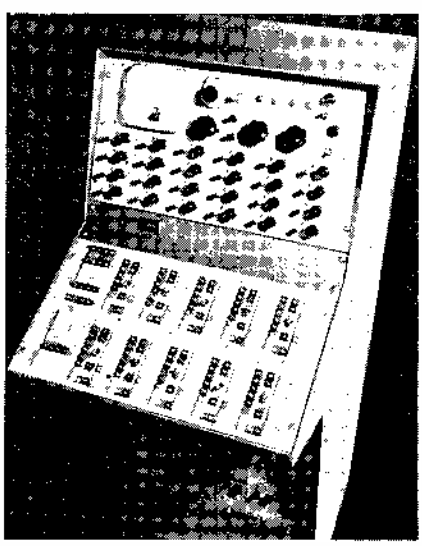
ANALOGUE COMPUTER

(*Illustrated below*)

The Solartron Electronic Group Ltd, Thames Ditton, Surrey

THE 'Minispace' analogue computer is a completely self-contained unit, comprising ten drift-corrected d.c. amplifiers, with all input and feedback components, potentiometers, control panel, patching panel, and power supplies. Non-linear elements are incorporated, and expansion facilities are provided.

Each amplifier can be used for summing, sign reversing, integration or simulation of a transfer function over a wide range. Therefore any problem requiring up to ten such operations can be solved or simulated on the computer—for example: two simultaneous second or third order differential equations; one equation of fourth or fifth order; network analysis; resonant circuits with variable damping; critical damping; servo systems with multiple loops, damping terms, end stops etc; coupled mass-spring-friction systems; viscous damping etc. All computing elements are permanently wired, connexions to them being made on the patching panel. The amplifiers are individually committed to sum or integrated by switches on the patching panel. Each amplifier position has associated with it four summing inputs (two × 1 and two × 10 gain) and either 1μF or 0·1μF (0·5 per cent tolerance) polystyrene capacitors for integration. All fixed input and feedback resistors are wirewound and of 0·1 per cent tolerance. Also provided are twenty wirewound 10-turn helical potentiometers for non-integral transfers, initial conditions and transfer functions of the form $1/1+pT$.



More complex series-parallel feedback networks are easily introduced by removal of link plugs on the patching panel. In addition, four earth-free potentiometers and four diodes are provided for simulation of non-linear functions such as dead zone, limiting, or backlash.

Used in conjunction with the Solartron servo multiplier TJ725 which can be used as a multiplier, resolver, or non-linear function generator, many more complex problems can be tackled.

EE 2762 *for further details*

ELECTRONIC VELOCITY ANALYSER

(*Illustrated below*)

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

THE 'Electronic Velocity Analyser' ('EVA'), has been produced to meet the demand by Trials Staffs of Service establishments and proving grounds for a portable equipment capable of accurate measurement of weapon velocity performance over the whole range of air-to-air,

surface-to-air and surface-to-surface devices. 'EVA' not only fully meets all these onerous requirements but can also be used to measure the speeds of aircraft and road vehicles. In particular, performance on aircraft take-off and touch-down can be accurately assessed or checked. Car and brake manufacturers can likewise record in precise detail the performance of their products under all conditions.

'EVA' operates in the X-band; the basic equipment covers the 2 to 80 mile/h (3 to 115ft/sec) bracket and by the addition of stable oscillators working (for example) up to the 50kc/s region and an amplifier detector chassis the equipment can then check speeds up to 3 000ft/sec. Even higher speeds can be checked if required.

The equipment can be easily and quickly set up and will give satisfactory performances even on projectiles presenting an effective radar reflector area of only one-third of a square metre.

Range performance requirements naturally depend on the particular application—for vehicle testing, for example, ranges of up to a few hundred yards are sufficient, while for rockets and guided missiles much greater ranges are required. By careful choice of design parameters the equipment can be adjusted to suit particular requirements.

A typical version, with a 50mW output and 20° (horizontal) and 6° (vertical) beamwidths, has a range of approximately 250ft against a projectile target with an effective radar reflecting surface 1/3m². A superheterodyne receiver has been incorporated to bring this range up to 1 000ft. Other versions with greater transmitter powers give ranges which are commensurately greater (from three to nine miles can be achieved).

The speeds are recorded on moving Teledeltos paper and give a graphical representation against calibration pips every one-tenth second. 'EVA' will record instantaneous changes in velocity which are often undetectable by other means. Additional recording arms can be fitted if desired.

EE 2763 *for further details*

SEALED NICKEL-CADMIUM CELLS

Burndept Ltd, Erith, Kent

THE 'Burndept/Vidor' sealed nickel cadmium cell is a minute version of the rugged, dependable metal encased rechargeable cell which for many years has been familiar to electrical and electronic engineers. The electro-chemical principles of the 'Burndept/Vidor' cell are substantially the same, but are made available in a miniaturized construction, which combines the advantages of an accumulator with those of a leakproof dry cell.

Because these cells are completely sealed, the only maintenance required is the supply of the necessary charging current, and even here a very great deal of latitude is possible. Provided certain values are not exceeded the charging current can be kept flowing indefinitely if need be without damage being caused.

At present two sizes of cell are available —a 225mAH type, and a smaller 50mAH type. Besides single cells, packs of assembled batteries can also be produced as required.

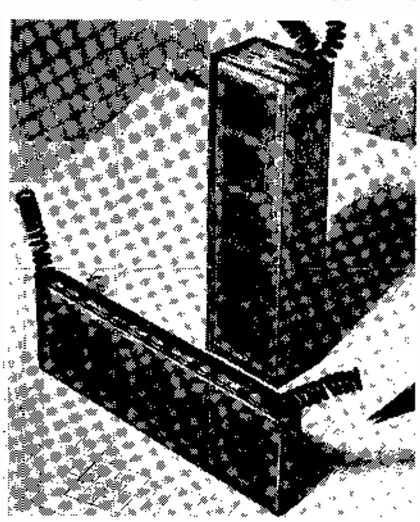
EE 2764 *for further details*

RESIN SEALED ACCUMULATORS

(*Illustrated below*)

Venner Ltd, Kingston By-Pass, New Malden, Surrey

THE lightweight silver-zinc accumulators, type HT 125 are completely sealed in resin and have been produced to meet the need for a light rechargeable battery of any desired voltage capable of providing power in a wide range of applications, most particularly for guided missiles. These batteries, which are hermetically sealed, can be formed to fit into odd shaped spaces. No topping up or maintenance is required. The HT 125 cell has a nominal capacity of 0·125Ah being suitable for discharge over a range of currents from 10 to 500mA.



EE 2765 *for further details*

VIBRATION SWEEP OSCILLATOR

Dawe Instruments Ltd, 99-101 Uxbridge Road, Ealing, London, W.5

THE type 444 vibration sweep oscillator fulfils the need for a low distortion resistance-capacitance tuned oscillator covering the range 5c/s to 5kc/s, in a single range. The oscillator provides constant output and the frequency scale calibration is truly logarithmic. The frequency sweep control is driven by a self-contained motor arranged to give various sweep rates between any desired frequency limits.

The equipment is designed to drive a power amplifier and moving-coil generator for vibration testing as required in component and equipment specifications.

Essentially the circuit consists of a frequency controlling bridge feeding a balanced push-pull amplifier with a cathode-follower output.

The frequency controlling network consists of a modified form of Wein bridge. With no connexion to earth at any point of the bridge the calibration is extremely stable since any leakage or stray capacitance at the output does not shunt the individual bridge arms.

The resistive arms of the bridge have been replaced by complex resistance-capacitance networks. These extend the constant phase shift frequency range over a ratio of 1000:1 with a 10:1 capacitance ratio of the tuning capacitor. The tuning capacitor has a fully rotating shaft and has been specially designed to provide a truly logarithmic scale calibration.

A motor drive and gearbox provide six frequency sweep rates between 0·2 and 10 octaves/min and adjustable limit switches are arranged so that the frequency can be swept through any part of the range.

The signal from the bridge is fed into the balanced push-pull amplifier which is directly coupled to the cathode-follower stage. Negative feedback is applied from the cathodes of the output stage to the grids of the amplifier valves. A thermally sensitive resistance element is incorporated in the resistive arms of the bridge to stabilize the amplitude of oscillation at a level within the linear range of the balanced amplifier. This, together with the large amount of negative feedback at harmonic frequencies, ensures a very pure sine wave output.

Within the overall negative feedback loop a controlled amount of positive feedback is applied over the output stage alone, to reduce its output impedance virtually to zero. The output terminals are fed from a balanced isolating transformer, the secondaries of which are padded to increase the source impedance up to the rated 600Ω. The instrument can thus work into any value of load resistor with negligible reaction on the oscillator circuit.

An output of up to 100mW into 600Ω, is available at the output terminals. The output level is continuously variable from maximum to zero.

The instrument is mains operated and arranged for 19in relay rack mounting.

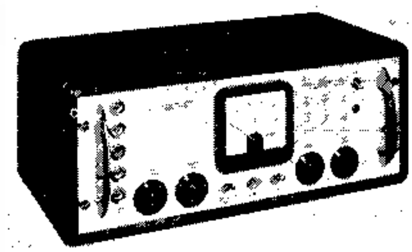
EE 2766 *for further details*

VIBRATION CONTROL AMPLIFIER

(*Illustrated below*)

Goodmans Industries Ltd, Axiom Works, Wembley, Middlesex

DESIGNED to complete the Goodmans vibration system, the control amplifier model E.501 is capable of controlling vibration amplitude, acceleration, or velocity to a level, which can be pre-set, or programmed from the external source. The unit consists of a special input stage, a head amplifier, a metering circuit an error detector stage, a compressing amplifier and a cathode-follower. An error of



25dB can be compressed to about 4dB under suitable circumstances. The amplified and rectified output from a suitable vibration pick-up is compared with a predetermined direct voltage, to derive a signal indicative of the error of the vibration level from the desired value. The error signal controls the compressing amplifier, to which an external sine wave oscillator supplies alternating input thus giving a sine wave signal of frequency determined by the oscillator setting, but of such amplitude that it will produce the correct level of vibration (after passing through a power amplifier if necessary). The working frequency range is from 20c/s to 10kc/s, but response can be obtained beyond these limits.

Input sockets are provided for five signal sources, which can be switch selected at the input of the special cathode-follower; for c.ystal accelerometers of sensitivity from 10to20mV/$g$themeter sensitivity adjustment can be set for full scale values of 10g and 50g respectively on the two ranges provided.

The special design of the input cathode-follower enables crystal accelerometers to be used with cable lengths up to 100ft without disadvantageous results. A coaxial socket is fitted which provides an output from the cathode-follower stage and is suitable for connecting directly to any conventional cathode-ray oscilloscope without additional impedance conversion.

An oscillator input signal of 150mV r.m.s. is suitable and a maximum output of 4V r.m.s. can be provided by the amplifier.

At an output level of 1V the total harmonic distortion is less than 2 per cent.

EE 2767 *for further details*

Meetings this Month

THE BRITISH INSTITUTION OF RADIO ENGINEERS

Date: 29 October. Time: 6.30 p.m.
Held at: The London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1.
Lecture: Computers and Ferro-electric Storage.
By: M. Prutton.

South Western Section

Date: 2 October. Time: 7 p.m.
Held at: The School of Management Studies, Unity Street, Bristol, 1.
Address by Rear Admiral Sir Philip Clarke, K.B.E., C.B., D.S.O. (Past President).
Followed by Lecture: Scope and Applications of the Modern Digital Computer.
By: A. D. Booth.

South Wales Section

Date: 15 October. Time: 6.30 p.m.
Held at: Cardiff College of Advanced Technology.
Lecture: Principles of Transistor Circuitry.
By: B. R. A. Bettridge.

South Midlands Section

Date: 3 October. Time: 7 p.m.
Held at: North Gloucestershire Technical College, Cheltenham.
Lecture: Nuclear Instrumentation.
By: J. Thomas.
Date: 31 October Time: 7 p.m.
Held at: The Winter Gardens, Malvern.
Lecture: Thermal Design.
By: E. N. Shaw.

Scottish Section

Date: 23 October. Time: 7 p.m.
Held at: The Institution of Engineers and Shipbuilders, 39 Elmbank Crescent, Glasgow.
Lecture: Flight Evaluation of Airborne Electronic Equipment.
By: H. G. Hinkley.
Date: 24 October. Time: 7 p.m.
Held at: Department of Natural Philosophy, Edinburgh University.
Repeat of above lecture.

Merseyside Section

Date: 15 October. Time: 7 p.m.
Held at: The University Club, Liverpool.
Lecture: The Manufacture of High Frequency Surface Barrier Transistors.
By: P. A. Charman.

North Western Section

Date: 2 October. Time: 6.30 p.m.
Held at: Reynolds Hall, College of Technology, Sackville Street, Manchester, 1.
Lecture: Television Studio Techniques.
By: J. Chen.

North Eastern Section

Date: 8 October. Time: 6 p.m.
Held at: The Institution of Mining and Mechanical Engineers, Neville Hall, Westgate Road, Newcastle-on-Tyne.
Lecture: Electronic Control Systems for Large Astronomical Telescopes.
By: G. H. Hickling and I. Paul.

West Midlands Section

Date: 8 October. Time: 7.15 p.m.
Held at: The Wolverhampton and Staffordshire College of Technology, Wulfruna Street, Wolverhampton.
Lecture: An Introduction to Colour Television.
By: T. Jacobs.

THE INSTITUTION OF ELECTRICAL ENGINEERS

All London meetings, unless otherwise stated, will be held at the Institution, commencing at 5.30 p.m.

Ordinary Meeting

Date: 9 October.
Inaugural Address as President.
By: S. E. Goodall.

Informal Meeting

Date: 13 October.
Discussion: The Rationalization of the Avenues of Higher Education.
Opened by: The President.

Measurement and Control Section

Date: 14 October.
Chairman's Address: The Scope of the Measurement and Control Section.
By: J. K. Webb.
Date: 28 October.
Discussion: Electronic Control of Machine Tools.
Opened by: D. T. N. Williamson.

Radio and Telecommunication Section

Date: 22 October.
Chairman's Address: Random Thoughts of a Propagation Engineer.
By: G. Millington.
Date: 27 October.
Lecture: Rating of Speech Links and Performance of Telephone Networks.
and: Assessment of Speech Communication Links.
By: J. Swaffield and D. L. Richards.

East Midland Centre

Date: 7 October. Time: 6 p.m.
Held at: Loughborough College.
Chairman's Address and Annual General Meeting.

East Anglian Sub-Centre

Date: 6 October. Time: 6.30 p.m.
Held at: The Technical College, Cambridge.
Chairman's Address.
Date: 20 October. Time: 6.30 p.m.
Held at: The Crown and Anchor Hotel, Ipswich.
Lecture: High Quality Sound Reproduction.
By: J. Moir.

Mersey and North Wales Centre

Date: 6 October. Time: 6.30 p.m.
Held at: The Royal Institution, Colquitt Street, Liverpool.
Chairman's Address.
Date: 20 October. (Time and place as above.)
Discussion: Electronic Control of Machine Tools.
Opened by: D. T. N. Williamson.
Date: 27 October. Time: 6.30 p.m.
Held at: Chester Town Hall.
Lecture: Recent Developments in X-Ray and Electron Microscopy with some Applications to Radio and Electronics.
By: W. C. Nixon and C. W. Oatley.

North-Eastern Centre

Date: 13 October. Time: 6.15 p.m.
Held at: The Neville Hall, Westgate Road, Newcastle-on-Tyne.
Chairman's Address.
Date: 27 October.
(Time and place as above.)
Lecture: Operational Experience at Calder Hall.
By: K. L. Stretch.

North-Eastern Radio and Measurement Group

Date: 20 October. Time: 6.15 p.m.
Held at: King's College, Newcastle-on-Tyne.
Chairman's Address.

North Midlands Centre

Date: 7 October. Time: 6.30 p.m.
Held at: C.E.G.B. Offices, Leeds.
Chairman's Address.

Sheffield Sub-Centre

Date: 15 October. Time: 6.30 p.m.
Held at: The Grand Hotel, Sheffield.
Chairman's Address: The Origin and Growth of Electronics.
By: F. A. Benson.
Date: 20 October. Time: 6.45 p.m.
Held at: The Angel Hotel, Grigg.
Repeat of above Address.

North-Western Centre

Date: 7 October. Time: 6.30 p.m.
Held at: The Engineers' Club, 17 Albert Square, Manchester.
Chairman's Address.

North-Western Measurement and Control Group

Date: 28 October. Time: 6.15 p.m.
Held at: The Engineers' Club, Albert Square, Manchester.
Chairman's Address: Digital Computing Machines.
By: T. Kilburn.

North-Western Radio and Telecommunication Group

Date: 8 October. Time: 6.45 p.m.
Held at: The Engineers' Club, Albert Square, Manchester.
Chairman's Address.

North Lancashire Sub-Centre

Date: 8 October. Time: 7.15 p.m.
Held at: The North Western Electricity Board Demonstration Theatre, Friargate, Preston.
Chairman's Address.

South-East Scotland Sub-Centre

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

South-West Scotland Sub-Centre

Date: 15 October. Time: 7 p.m.
Held at: The Institution of Engineers and Shipbuilders, 39 Elmbank Crescent, Glasgow, C.2.
Centre Chairman's Address.

South Midland Centre

Date: 7 October. Time: 6 p.m.
Held at: The Grand Hotel, Birmingham.
Chairman's Address, Annual General Meeting and Conversazione. (Admission by ticket.)
Date: 13 October. Time: 7.30 p.m.
Held at: Malvern Winter Gardens.
Lecture: Radio Observations on Artificial Satellites.
By: J. A. Ratcliffe.

South Midland Radio and Measurement Group

Date: 27 October. Time: 6 p.m.
Held at: The James Watt Memorial Institute, Birmingham.
Informal Lecture: Sceptre Design and Experiment.
By: R. F. Hemmings.

North Staffordshire Sub-Centre

Date: 10 October. Time: 7 p.m.
Held at: Duncan Hall, Stone.
Chairman's Address: Electrical Engineers and Electronics.
By: R. W. Palmer.

Rugby Sub-Centre

Date: 8 October. Time: 6.30 p.m.
Held at: Rugby College of Technology and Arts.
Chairman's Address.
Date: 22 October. (Time and place as above.)
Lecture: The Atomic Clock.
By: L. Essen.

Southern Centre

Date: 1 October. Time: 6.30 p.m.
Held at: C.E.G.B. Offices, 111 High Street, Portsmouth.
Chairman's Address.
Date: 22 October. Time: 6.30 p.m.
Held at: Brighton Technical College.
Lecture: Operational Experience at Calder Hall.
By: K. L. Stretch.
Date: 31 October. Time: 6.30 p.m.
Held at: South Dorset Technical College, Weymouth.
Lecture: Three Weeks in the U.S.S.R.
By: Sir Josiah Eccles.

Western Centre

Date: 13 October. Time: 6 p.m.
Held at: Electricity House, Carlton Avenue, Bristol.
Chairman's Address.

Western Supply Group

Date: 20 October. Time: 6 p.m.
Held at: The S.W.E.B. Demonstration Theatre, Electricity House, Colston Avenue, Bristol 1.
Chairman's Address.

Western Utilization Group

Date: 27 October. Time: 6 p.m.
Held at: The South Wales Institute of Engineers, Park Place, Cardiff.
Section Chairman's Address.

South-Western Sub-Centre

Date: 16 October. Time: 3 p.m.
Held at: S.W.E.B. Showrooms, New George Street, Plymouth.
Chairman's Address.

West Wales (Swansea) Sub-Centre

Date: 9 October. Time: 6 p.m.
Held at: The Conference Room, S.W.E.B. Showrooms, The Kingsway, Swansea.

Oxford District

Date: 8 October. Time: 7 p.m.
Held at: The Demonstration Room, Southern Electricity Board, 37 George Street, Oxford.
Lecture: Rockets and Satellites.
By: R. L. F. Boyd.

THE PHYSICAL SOCIETY

Acoustics Group

Date: 10 October. Time: 5.30 p.m.
Held at: Imperial College, South Kensington, London, S.W.7.
Lecture: Vibrations and their Measurement.
By: A. J. King.

THE SOCIETY OF INSTRUMENT TECHNOLOGY

All London meetings, unless otherwise mentioned, will be held at Manson House, Portland Place, London, W.1, commencing at 6 p.m.
Date: 9 October.
Lecture: Aircraft Flight Simulators.
By: A. E. Cutler.
Date: 20 October.
Lecture: A Simple Data Read-Out System.
By: G. P. Tonkin and J. B. Bownas.
Date: 28 October.
Lecture: Basic Measurements of Time and Frequency.
By: L. Essen.

THE TELEVISION SOCIETY

Date: 2 October. Time: 7 p.m.
Head at: The Cinematograph Exhibitors' Association, 164 Shaftesbury Avenue, London, W.C.2.
Lecture: Printed Circuit Techniques Applied to a Television Tuner.
By: P. C. Ganderton.
Date: 24 October. (Time and place as above.)
Lecture: The Present Position of Amateur Television.
By: J. Royle.