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The Institution of Post Office Electrical Engineers.

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A Paper read before the London Centre of the Institution on 6th December, 1949, and at other Centres during the Session

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1. INTRODUCTION

In recent years, it has been found convenient to use electronic technique in the solution of a number of the telegraph problems which have been presented to the Research Branch. It is thought that some of the items of equipment which have been developed may be of interest, not merely to telegraph engineers, on account of the special facilities provided, but also to a wider circle of members of the Institution, as examples of the ways in which electronic switching methods may sometimes be applied with advantage even in apparatus for low-frequency telecommunication.

The items which will be described have been selected for their technical interest from this point of view and not for their importance to general progress in the telegraph art. It must also be emphasized that the dates at which the various developments took place are spread over the last six years, and that most of the basic electronic circuit units used in building up the designs are not novel.

2. BASIC CIRCUIT UNITS

For the benefit of those not familiar with the use of electronic devices as switches, some of the basic circuit units will first be briefly described. For more detailed treatments, reference should be made to other works. Many of these circuits are analogous to various types of electromechanical relay circuits, but have the merit that the operations may be much more precisely designed and transit speeds are far higher. It must be observed, however, in drawing comparisons between electronic and electromechanical relay circuits, that often, though not always, one valve is equivalent to a relay with only one pair of contacts ; in some cases an equivalent to a chain of contacts may be provided up to the number of electrodes to which control potentials may be applied. The process of synthesizing a complete operational circuit from these elements is very similar to that familiar to relay circuit engineers.

2.1 Limiting Amplifier

In Fig. 1 (*a*) is shown a pentode valve connected as a d.c. amplifier. Fig. 1 (*b*) shows the anode volts-anode current characteristics of the valve, and also the load line corresponding to the anode load R_A, and to an H.T. voltage E_B. The anode current and anode potential corresponding to any particular grid voltage are then given by the point of intersection of the load line with the curve appropriate to the grid voltage. Thus when a very large negative potential is applied to the grid, the anode current is zero and the anode potential is E_B. As the negative grid potential is reduced, the anode current rises and the anode potential falls, until, when $E_G = -2$, the anode potential is E′. It will be observed, however, that any further change of grid potential in a positive direction produces no further change of anode current or potential, since in this region the characteristics coincide. It follows that, no matter what the grid potential, the anode potential cannot fall below E′. The anode of a valve operated in this way is said to " bottom." It will be evident that the grid potential at which bottoming occurs becomes more negative as the anode load resistance is increased. It is usually desirable to make the anode load resistance high enough to ensure that this grid potential is negative with respect to the cathode in order that bottoming occurs before grid current commences to flow.

If a voltage having the waveform shown in Fig. 1 (*c*) is applied at " a," the waveform of the anode potential is as shown in Fig. 1 (*d*). The excursion of the anode potential (E_B to E′) remains constant for all inputs greater than the effective grid base, but as can be seen from Figs. 1 (*c*) and 1 (*d*), the transit time is controlled by the input waveform.

Such a circuit, in itself, may be compared with a non-polarized relay. The principle of anode bottoming is used in most of the circuit units described.

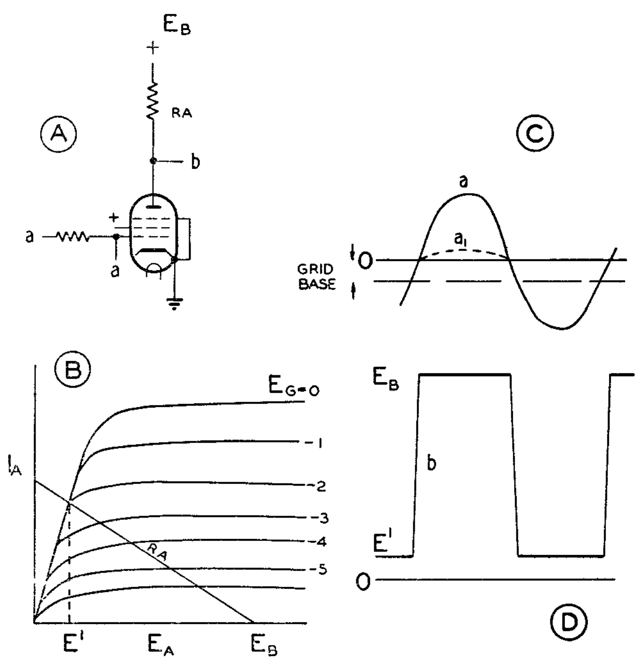


FIG. 1.—LIMITING AMPLIFIER.

2.2 Two-position Triggers

The transit time of the limiting amplifier resulting from the input waveform may be practically eliminated by the use of positive feed-back ; the transit time of the output waveform will then be dependent upon only the stray capacitances in the circuit. Suitable circuits are shown in Figs. **2** (*a*) and (*b*). In Fig. **2** (*a*) the feed-back is provided via R1, R2, and in Fig. **2** (*b*) by the common cathode resistor RK. By employing suitable values of feed-back, an effectively negative input grid base can be produced as indicated in Fig. **2** (*c*) (i.e., the input/output characteristic exhibits hysteresis). This results in the mode of operation indicated in Fig **2** (*d*) where it will be observed that the output does not change until the input has passed the zero line and attained one of the operating values, the transit taking place very rapidly. The output is the same for either of the two input waveforms shown.

The detailed operation of Fig. **2** (*a*) is as follows. Suppose that V2 is conducting. The anode potential of V2 will drop to a few volts above earth. The grid of V1 is connected to the junction of the resistors R1 and R2 which form a potentiometer between the anode of V2 and the very negative bias supply. The grid of V1 is therefore negative with respect to its cathode and the anode current of V1 is cut off. The anode potential of V1 is in consequence highly positive, approaching the H.T. supply potential. The values of R1 and R2 are such that the grid of V2, which is connected to the potentiometer between the anode of V1 and the negative supply, is positive with respect to its cathode, so that V2 remains conducting. The trigger is thus stable in this condition.

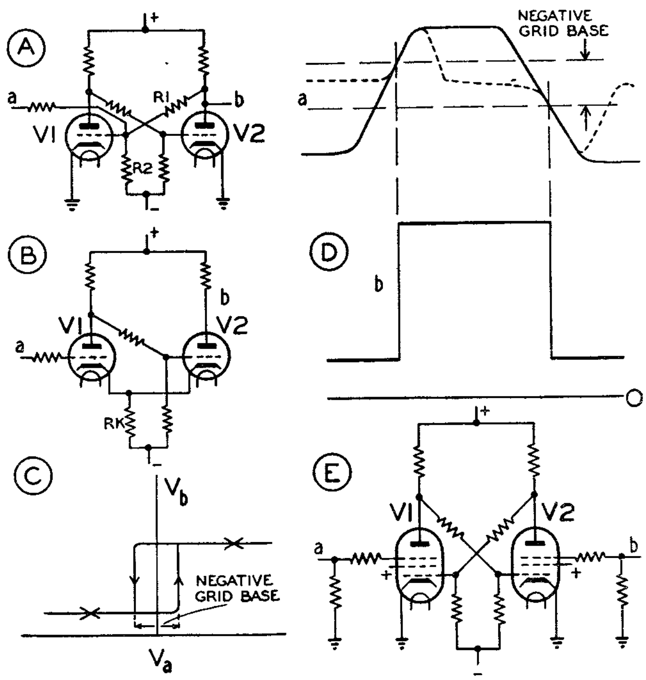


FIG. 2.—TWO-POSITION TRIGGERS.

Suppose now that anode current is initiated in V1 by applying a positive potential at " a " (i.e., to the grid of V1). The anode potential of V1 will fall to a few volts above earth, the grid of V2 will therefore become negative with respect to its cathode ; V2 will cease to conduct, its anode potential will rise nearly to the H.T. supply potential, and the positive potential which was applied at " a " will be reinforced by a positive potential applied to the grid of V1 from the potentiometer R1R2 to which it is connected. By applying a negative potential at " a," the original condition (V2 conducting and V1 cut off) can be restored. With no input, the circuit will remain in the condition to which it was last operated, with one valve conducting and the other cut off.

The triggering of these two circuits may be initiated by either positive or negative-going waveforms, but it is often desirable to employ a circuit which is operable only by negative pulses. The circuit of Fig. **2** (*e*) employs pentodes in which the triggering pulses are applied to the suppressor grids. Positive pulses will not affect the condition of the valves, but the application of a negative pulse to the valve which is conducting will cause the circuit to reverse its condition and remain so until a negative pulse is applied to the other valve. If pulses are applied simultaneously to both inputs, the circuit will finally be left in the condition corresponding to the input pulse of longer duration.

The circuits of Figs. **2** (*a*) and (*b*) may be compared to a neutral polarized relay and that of Fig. **2** (*e*) to a two-coil latching relay.

2.3 Pulse Triggers

Basically the pulse trigger circuit may be considered to be that of a two-position trigger with one of the d.c. intervalve couplings replaced by an a.c. coupling as shown in Fig. **3** (*a*). This circuit has one stable

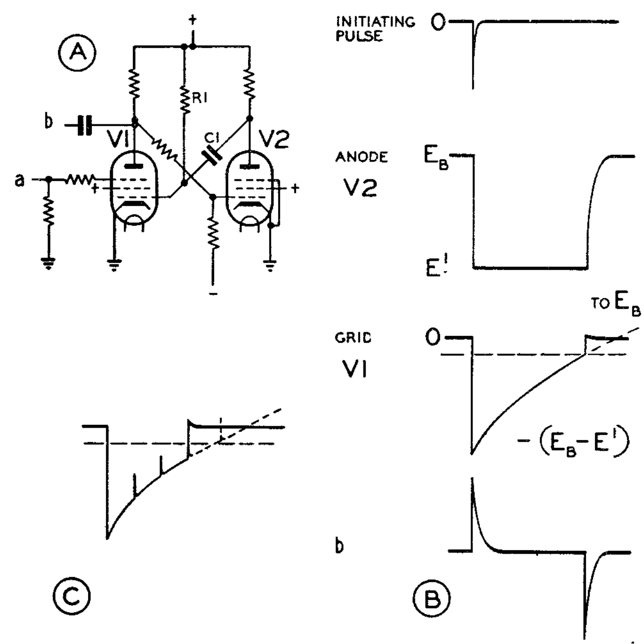


FIG. 3.—PULSE TRIGGER.

(the unoperated) condition and one quasi-stable (the operated) condition, the period of which is determined by the time constant of the a.c. coupling. The circuit is triggered by the application of a negative pulse to the suppressor grid of V1 which reduces the anode current, causing the anode potential, and with it the grid potential of V2, to rise. As soon as the grid potential of V2 rises above cut-off, the positive feed-back is completed, V1 then becoming cut off at its control grid and the grid of V2 rapidly becoming more positive, so that the anode of V2 bottoms. The fall in potential of the anode of V2 is transferred via C1 to the grid of V1, which was originally held at earth potential by grid conduction. This cuts off the anode current of V1 even though the negative pulse applied to its suppressor grid has terminated. The circuit remains in this condition until C1 is discharged sufficiently for V1 to conduct again, then the positive feed-back rapidly restores the original stable condition with V1 conducting and V2 cut off. The connection of the grid of V1 via R1 to H.T. instead of to earth minimises the effect of variation in grid base of V1 and of variation in H.T. voltage upon the period of the circuit. If the bottoming potential of V2 and the grid base of V1 are very small compared with E_B, the relaxation period of the circuit $\doteqdot$ 0.69CR. Waveforms at various points are indicated in Fig. **3** (*b*). It will be observed from the last two waveforms that this circuit may be used to provide a negative pulse delayed by the circuit period from an initial negative pulse. The action of this circuit can also be initiated by the application of a positive pulse to the grid of V2.

It is sometimes desired to make the relaxation period of a pulse trigger a precise multiple of that of some other train of pulses. If the circuit of Fig. **3** (*a*) is considered with a train of negative pulses, whose common interval is slightly less than a third of the natural period of the trigger, applied to the suppressor grid of V1 and also applied at a suitable amplitude to the suppressor grid of V2, the circuit will be triggered in the normal manner by the first of a series ; the subsequent pulses, amplified and inverted by V2, will appear at the grid of V1, superposed on the normal exponential waveform (Fig. **3** (*c*)). The second and third pulses of the series will have no effect upon the recovery of the trigger, but the fourth will cause the grid potential to rise above cut-off before it would normally do so, and initiate the recovery action. This method of synchronisation is satisfactory for ratios of up to about five.

There are several other forms of pulse trigger, but the one described has proved the most suitable in the equipment described in this paper.

2.4 Multivibrator

The multivibrator may be considered as an extension of the last circuit with the d.c. coupling replaced by a second a.c. coupling, as shown in Fig. **4** (*a*), and so having no stable condition. If the anode of V1 is considered to have just bottomed, the grid of V2 will stand at a negative potential, cutting off V2 until C1 discharges through R1 sufficiently to permit V2 to conduct again, when positive feed-back ensues, causing the potential of the grid of V2 to rise rapidly until grid current holds the grid at approximately earth potential. This causes V2 to bottom and the grid of V1 to become negative through the coupling capacitor C2. V1 is thus cut off until C2 discharges via R2 sufficiently for conduction to recur when the anode of V1 will bottom again to re-initiate the whole cycle. The grid and anode waveforms are shown in Fig. **4**. The period of the complete cycle is proportional to the sum of the time constants C1R1 and C2R2.

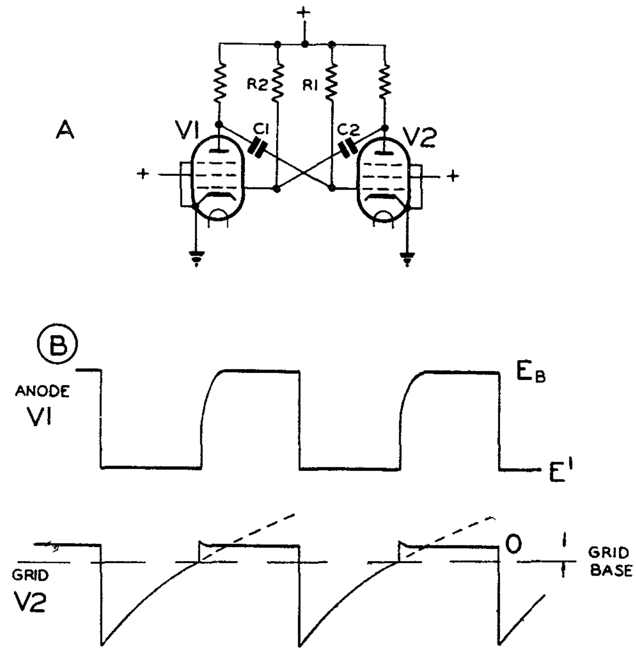


FIG. 4.—MULTIVIBRATOR.

In certain applications, e.g., for producing a train of timing impulses commencing at an arbitrary zero, a multivibrator comprising pentodes may be used as a start-stop oscillator. The circuit can be held quiescent by applying a large negative bias to the suppressor grid of one of the valves to prevent the flow of anode current, and when the bias is removed, the circuit is permitted to oscillate in its natural manner. There is no sensible difference between the first and subsequent cycles.

2.5 Counting Circuits

2.5.1 *Scale-of-two or Binary Counter*

This circuit is yet another modification of the two-position trigger. It has two stable positions and is changed from one to the other by successive input pulses. In the circuit of Fig. **5** (*a*) it will be seen

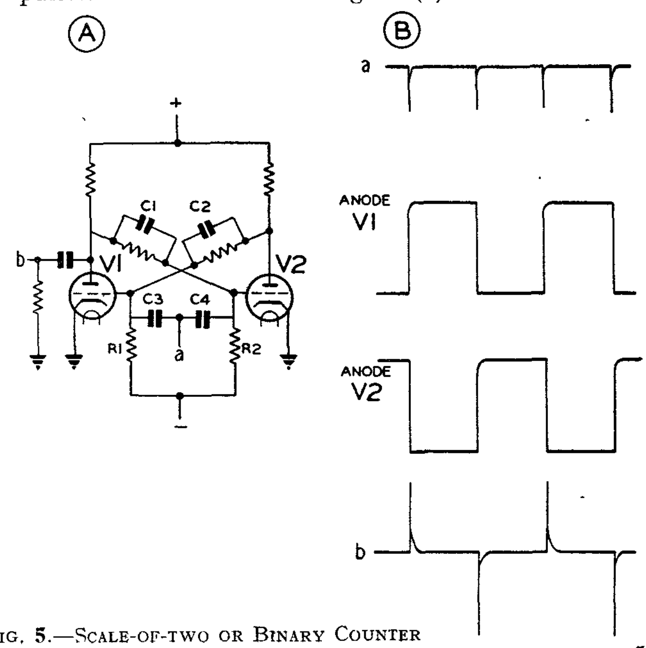


FIG. 5.—SCALE-OF-TWO OR BINARY COUNTER

that the intervalve couplings are augmented by the capacitors C1, C2. The time constants of these capacitors and their associated resistors are larger than that of the input capacitors C3 and C4 combined with R1 and R2. Considering the initial state to be that of V1 conducting, V2 cut off, the application of a negative pulse at " a " will result in V1 being cut off and the grid of V2 being made more negative, but V1 being cut off results in the anode potential becoming more positive. This potential change is communicated to the grid of V2, so that on the decay of the initiating pulse, the grid of V2 starts at a higher potential than that of V2. Hence V2 commences to conduct first and then the fall in anode potential is communicated to the grid of V1 to hold it cut off. The valves are therefore left in the condition V2 conducting, V1 cut off. The next input pulse reverses the process. Fig. **5** (*b*) indicates schematically the time relation between the input pulses and the anode conditions. If an output from " b " is selected, it will be observed that there is one negative pulse for every second input pulse. These pulses may be used to drive further similar circuits ; the positive pulses, with correct circuit proportions, will not operate the circuit, as they would have to overcome the negative bias on the cut off valve before any change in condition could occur. Since one of these circuits will count pulses in twos, it is obvious that n circuits in cascade will count groups up to 2^n. Considering two in cascade and noting the non-conducting valves, the cycle will be 1,3 ; 2,3 ; 1,4 ; 2,4.

2.5.2 *Ring Counters*

Another form of counter circuit is shown in Fig. **6**, this particular example counting in threes. The anode of each valve has a d.c. coupling to the grids of each of the other valves in such a way that the circuit is in equilibrium when two valves are conducting and one non-conducting. Each valve has also an a.c. coupling between its anode and the grid of the next valve in the chain. The input is a series of positive pulses from a low impedance source. Considering V1 to be initially non-conducting, the pulse applied via C1 causes it to conduct and the fall in anode potential is transferred to V2 via C4, this overcoming the effect of the positive pulse via C2, so that V2 becomes cut off. The d.c. couplings maintain equilibrium in the new condition until a second input pulse transfers the non-conducting condition to V3 and then a third pulse to V1 again. Such circuits are quite satisfactory up to five stages, but each increase in the number of stages makes an increased demand on the accuracy and stability of components.

2.6 Gates or Coincidence Circuits

Two forms of gate (there are others) will be described, one for operation by positive waveforms and one by negative waveforms. The former is shown in Fig. **7** (*a*) and is a pentode with both the suppressor and control grids biased to cut-off. Both have positive-going waveforms applied to them as indicated and it is obvious that anode current will flow only when pulses at the two inputs coincide. This arrangement is equivalent to two contacts in series.

When the waveforms are negative-going, a different method must be employed as shown in Fig. **7** (*b*). This comprises pentodes with a common anode load of such a value that the anode bottoms when one valve conducts. This means that the anode potential cannot rise substantially unless the input waveforms are coincident.

It will be observed that in passing through the gate, the pulse waveform is inverted and in some cases may have to be reinverted for further use by means of another valve.

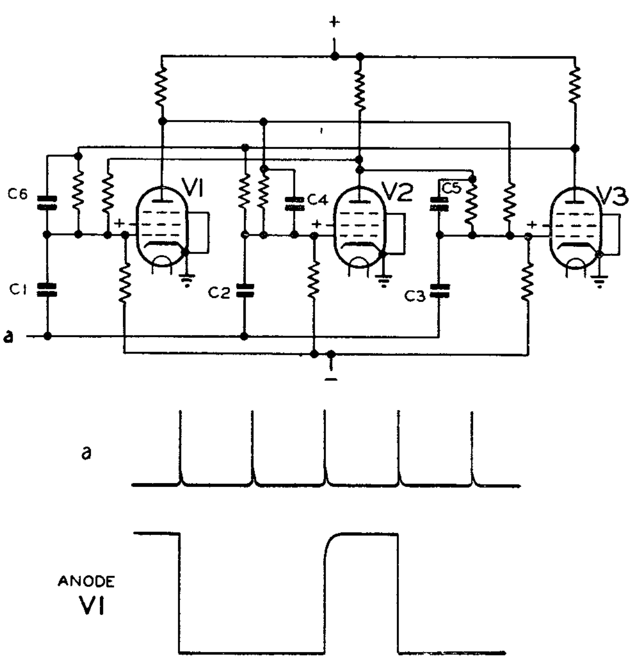


FIG. 6.—RING COUNTER.

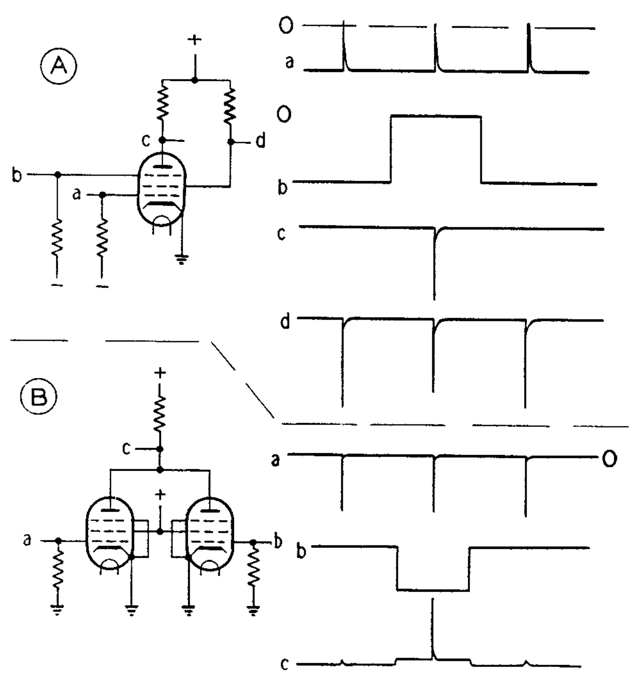


FIG. 7.—GATES OR COINCIDENCE CIRCUITS.

2.7 Circuits Using Gas-filled Valves

So far, the elementary circuits described have employed thermionic hard valves, but the gas (usually neon, argon, or helium)-filled valve, has advantages in certain applications. Both hot and cold cathode valves have similar properties in that, generally, once conduction is initiated it can only be suppressed by the reduction of the anode potential below a critical value for sufficient time for the valve to become deionised. This limits the field of application.

Hot cathode valves may be used in the operation of external electromagnetic devices where the property of delivering comparatively heavy currents with a small internal potential drop is valuable, but in other situations they seldom offer any advantage over vacuum valves and usually require more heater power. On the other hand, the cold cathode valve is attractive because it requires no heater power and it is sometimes economical to re-arrange circuitry to permit its use.

The cold cathode diode is familiar to everyone as the neon lamp ; it has the property that no conduction occurs until the critical anode potential is exceeded and then the potential drops to a value which is sensibly constant over a range of current.

The cold cathode triode has a third electrode, the primer, which is situated close to the cathode and which will initiate conduction with a lower potential than the anode, and if the anode potential is above the normal running potential, anode conduction will ensue, the potential falling to the running value. With a particular type of cold cathode triode, for example, anode conduction does not commence (in the absence of a positive potential on the primer) unless the anode potential exceeds about + 150 volts, and once conduction has started, the anode potential drops to the running voltage of about 75 volts. If, however, an anode potential between + 75 and + 150 volts is applied, anode conduction can be initiated by raising the primer to about + 70 volts, and will then continue even though the positive potential is removed from the primer. To restore the valve to the non-conducting state, the anode potential must be reduced below the running value for a period of, in most present types, not less than about 4—5 mS, and this places a limit on the repetition rate of operation.

The main applications of cold cathode valves are in code storage devices and counters. The storage use is obvious, as conduction can be initiated by an input pulse of short duration and persists after the end of the pulse. Two examples of circuits using cold cathode valves will be given.

A scale-of-two counter circuit is shown in Fig. **8** and operates as follows: Assume V1 to be conducting and V2 non-conducting. The application of a positive pulse at " a " will cause V2 to conduct and hence the cathode potential to rise. This potential change is communicated via the capacitor C to the cathode of V1 which is already standing at a positive potential, so that the anode to cathode potential of V1 is reduced below the running value and conduction suppressed. The next input pulse reverses the conditions. A possible disadvantage of this type of counter is that if, by mischance, one valve fails to extinguish, the counter becomes permanently locked up with both valves conducting.

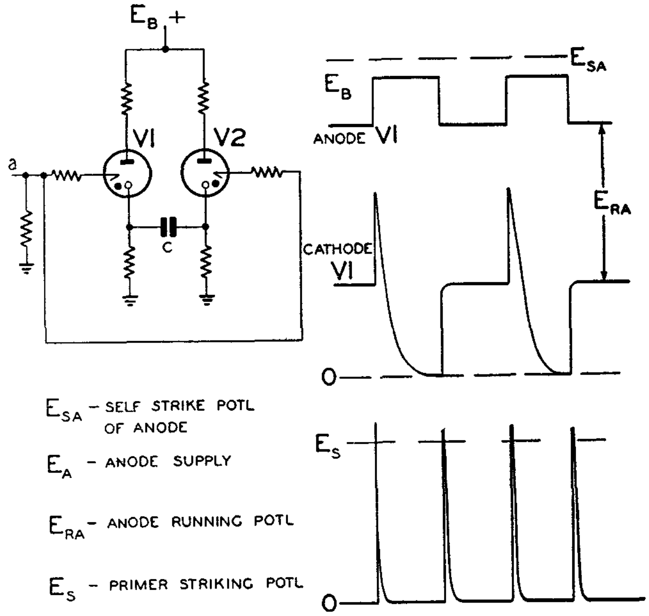


FIG. 8.—BINARY COUNTER USING GAS-FILLED VALVES.

In Fig. **9** is shown a cumulative chain counter circuit. Positive pulses are applied at " a," but their amplitude is less than the striking voltage of the priming electrodes. The primer of V1 has a positive bias so that the superposition of the pulse initiates conduction. The resultant potential rise across R1 provides the positive bias to enable V2 to be primed by the next pulse and so on down the chain. After a counting sequence the circuit must be reset by reducing the common anode supply potential so that conduction ceases and the valves deionise.

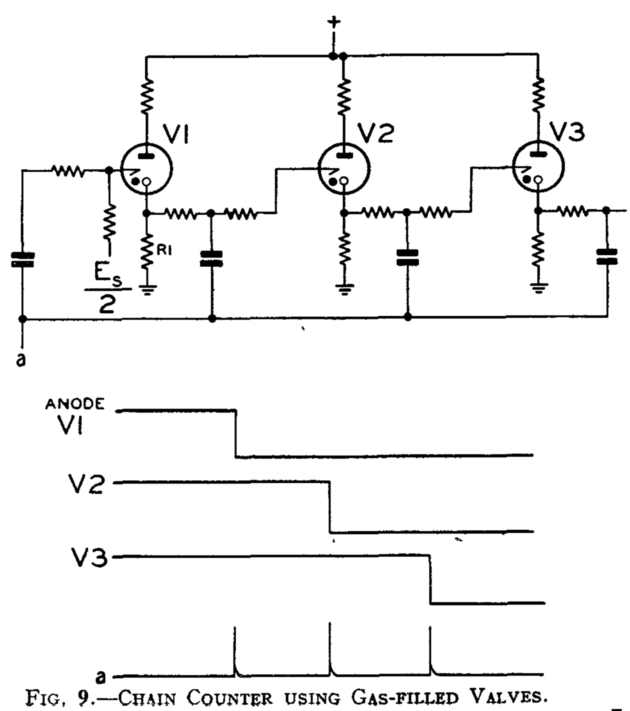


FIG. 9.—CHAIN COUNTER USING GAS-FILLED VALVES.

2.8 Translators

These translate from character indication to the corresponding telegraph code combination and vice versa.

2.8.1 *Coders*

There are several possible forms of coder, usually comprising resistance networks, rectifiers or valves, connected so that there are separate inputs for each character to be coded and outputs corresponding to each code element. In the simple example shown in Fig. **10**, a three-element binary code is assumed, giving eight possible character combinations. Each character input is connected to the required element outputs through cold-cathode diodes. Supposing the character B to be represented by element output potentials + + 0, the application of a suitable voltage at B strikes the tubes connecting it to outputs 1 and 2. The operating voltage is chosen so that the output on, say, 1 is insufficient to cause the valves connected to, say, C to strike in series and produce an output on 3. This type of coder has the advantage over the resistor and rectifier types that only two values of output are possible, + and zero. In the others the difference between selected and unselected outputs decreases as the number of elements in the code increases.

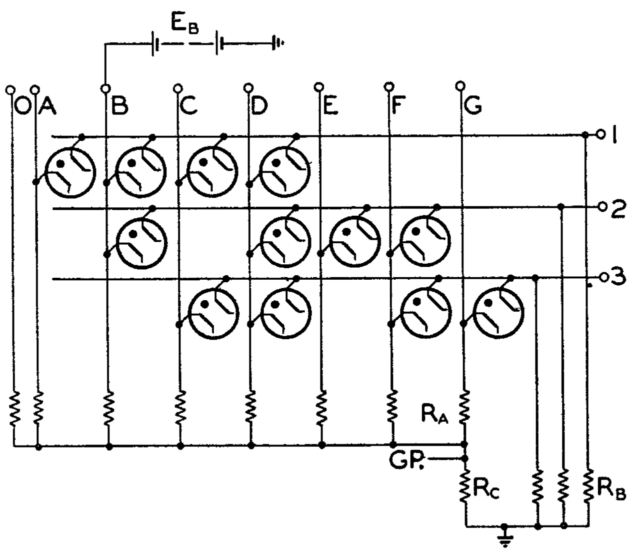


Fig. **10**.—3-Unit Coder.

2.8.2 *Decoders*

Again, resistor or rectifier networks can be employed and a 3-unit decoder network is shown in Fig. **11**. The element inputs are shown as contacts, but, of course, they can be fed from valves. There are four values of output, 1, 2/3, 1/3, 0 of the input voltage and if the system is extended to n elements, the intervals between outputs become 1/n. This shortcoming can be minimised by combining the inputs in pairs through a similar network and operating trigger devices. The outputs from these may then be com-

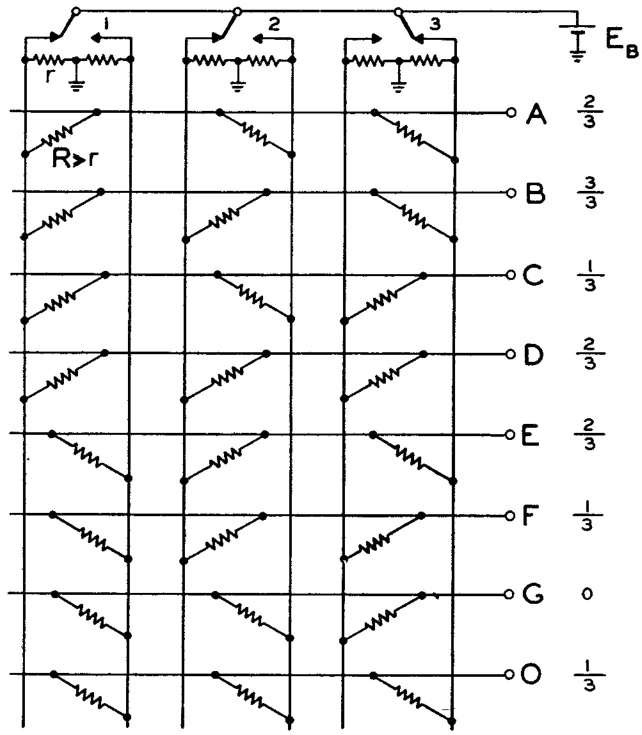


Fig. **11**.—3-Unit Decoder.

bined to arrive finally at the full number of outputs. In this way the discrimination ratio between wanted and unwanted outputs becomes 2/1 at each stage.

2.9 Distributors

The conversion of code indications from a static group into a time sequence of signals and vice versa is a common requirement in a telegraph system. Two distributors, one transmitting and one receiving, will be briefly described. The techniques employed in these examples are different, but this is only to illustrate the variety of circuitry which may be used to achieve a similar end.

The circuit of Fig. **12** comprises two scale-of-two counters in cascade which control four gates with a common output. The counter is operated by a series of impulses with a repetition frequency corresponding to the transmission speed and the control grids of the gate valves are connected to pairs of the anodes in the counter so that they are biased to cut-off except in one condition of the counter for each gate. The grid potentials are indicated by waveforms 1, 2, 3, 4. This means that the gate valves will be permitted to conduct in sequence, each for a unit time interval, but the output into the common anode load during each interval is controlled by the presence or absence of a negative bias on the suppressor grid. The output corresponding to the input condition shown is indicated by waveform b.

Fig. **13** shows a receiving distributor employing a cold cathode counter described earlier. A train of timing pulses at the transmission speed and phased to occur at the nominal mid-instants of the incoming signal elements operate the counter. V1, V2, V3, conducting in sequence, produce pulses at the primers of V4, V5, V6 in turn. These pulses are added to the incoming signal at each primer, so that if the potential of the signal plus timing pulse exceeds the priming potential, the valve conducts. Thus the condition of the line at the instant of each timing pulse in the sequence is registered in terms of conducting and non-conducting valves.

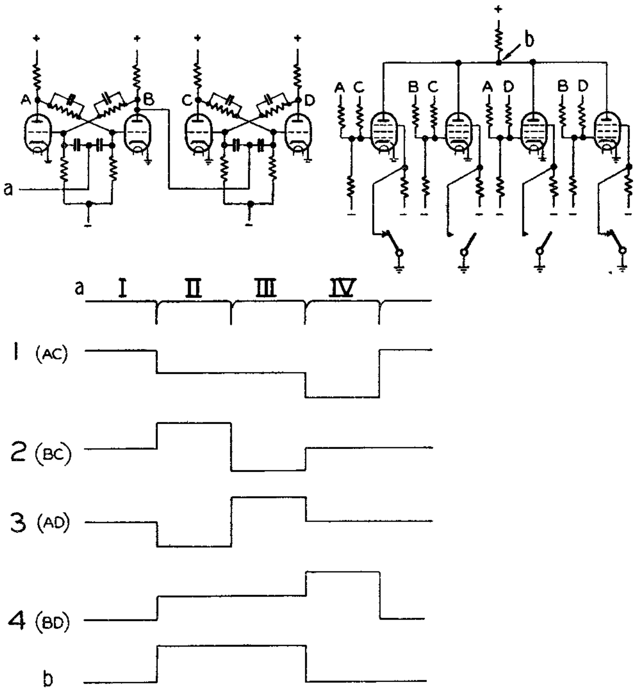


Fig. 12.—Distributor (Transmitter).

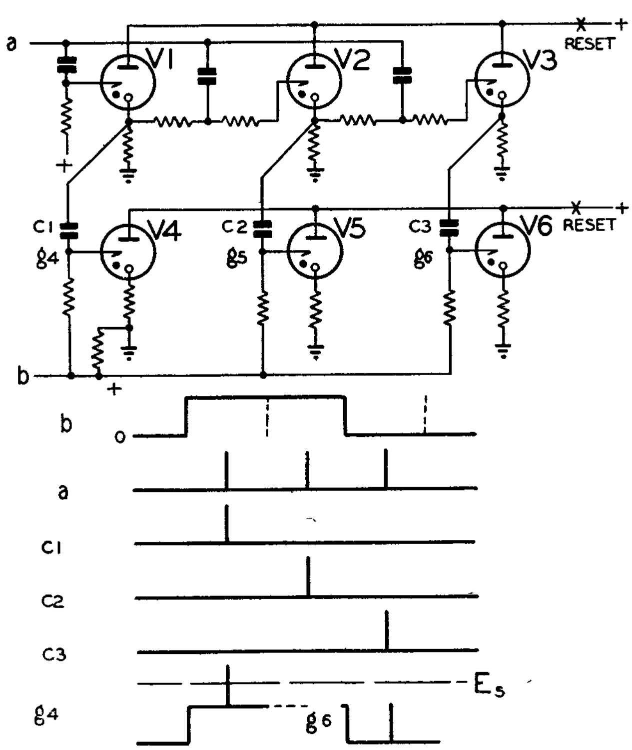


Fig. 13.—Distributor (Receiver).

3. START-STOP TELEGRAPH DISTORTION MEASURING SET

In teleprinter transmission each character signal comprises seven elements in binary code and transitions from the one line condition to the other (instants of modulation) should, ideally, follow the commencement of the start element at multiples of the unit element period. The measurement of the departures of the instants of modulation from the ideal is important in the maintenance of equipment. Instruments of the type to be described are being installed at the test desks at telegraph switching centres.

A cathode ray oscilloscope is used with time base circuits, the operation of which is initiated by the reception of the start element of a character. The primary time-base period is made equal to the nominal time of a unit signal element (20 mS for a telegraph speed of 50 bauds) and the cathode ray traverse is repeated for each possible signal transition during the reception of a character (i.e., six traverses). The occurrence of a signal transition causes the beam to be intensified to produce a bright spot on the C.R.T. screen. To permit observation of the distortion of the individual instants of modulation in a character, the six traces may be mutually displaced by a suitable vertical deflection circuit so that the trace forms a column of six lines. Fig. **14** (*a*) shows a typical display produced by a distorted character. The repetition rate of the time base is controlled by an oscillator which is started when the start element of each character is received and stopped when the correct number of beam traverses has occurred. To facilitate reading of the distortion of the instants of modulation,

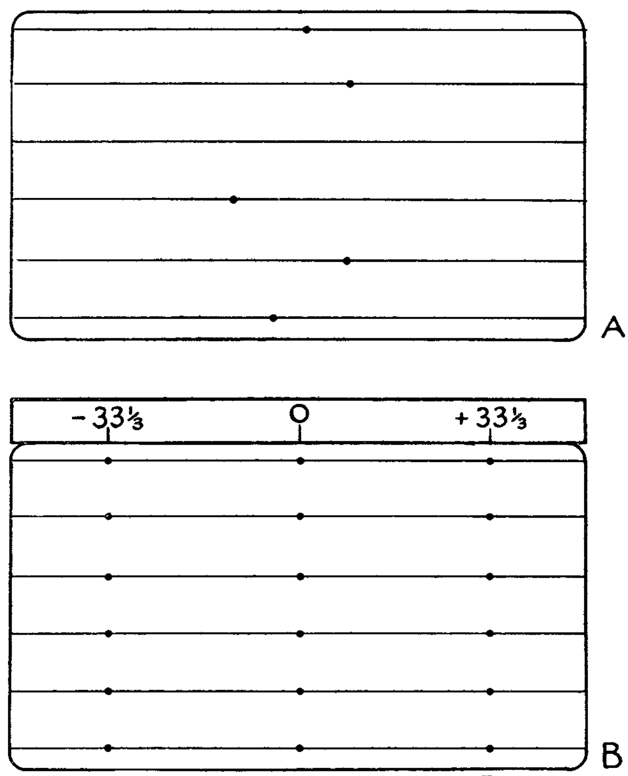


Fig. 14.—Electronic Start-Stop Telegraph Distortion Measuring Set (Oscilloscope Displays).

which may be either advanced or retarded with respect to their nominal positions, the commencement of the cycle is delayed by half a unit period so that undistorted signals are indicated at the centre of each traverse. Transit time and bounce of transmitting contact units can be displayed ; the trace is deflected vertically to indicate the break and make of the tongue with the side contacts.

The use of a rectilinear, as opposed to a circular, beam-sweep entails the provision of means of calibration to ensure that a linear measurement of the horizontal traverse against a fixed scale represents accurately a time interval. This is provided by making the frequency of the time base controlling oscillator six times that of the time base so that signal indications which are accurately 0, + 33⅓% and − 33⅓% relative to perfect signals can be used to mark the trace. By manipulation of the horizontal shift and gain controls these markers may be positioned to agree with corresponding points on the fixed scale, as shown in Fig. **14** (*b*).

The speed of continuous signals may be compared with that of the time base, by eliminating the start-stop action. A calibrated frequency control enables speed error to be measured. Provision is also made for checking the oscillator frequency against an external standard.

A sectionalised circuit diagram is shown in Fig. **15**. The schematic waveforms are shown with times stated in milliseconds after the commencement of the start signal. The line circuit acts as a limiting and squaring amplifier and the commencement of the start signal produces a negative pulse to operate the control circuit and its guard. This permits the multivibrator to oscillate, and pulses from the frequency divider are passed by the gate, which is opened by the control guard circuit, to the X time base. This time base is of the conventional type, using a pentode as a constant current source to charge a capacitor, which is reset by the pulses at 20 mS intervals, commencing at 10 mS. Pulses from the X time base are fed to the Y time base which is a nearly similar circuit, but the charging valve conducts only when a pulse is fed in, so that a staircase waveform is generated by the intermittent charging of the capacitor. After the sixth pulse has passed through, the gate is closed by the control guard circuit, which also removes the guard from the control circuit so that it can be reset by the next pulse (at 130 mS, i.e., 6½ units) from the frequency divider. The restoration of the control circuit closes down the multivibrator. The pulses produced by the incoming signals on the line circuit are amplified and applied to the modulator grid of the C.R.T. When the connection for the measurement of transit time is made, pulses derived in the line circuit at the instants when the tongue leaves or meets a side contact are injected into the Y-amplifier circuit.

A more detailed description of this instrument has since been published in the P.O.E.E.J., Vol. 43, Pt. 1, April, 1950.

4. TELEGRAPH DISTORTION MONITOR

This device was developed primarily for use on radio-telegraph circuits ; its function is to monitor continuously the grade of telegraph service on a channel carrying live traffic. Trials of a monitor on two-tone telegraph channels operating over a trans-Atlantic radio link showed that the need for a change of wavelength could regularly be predicted about twenty minutes before the error rate on the receiving teleprinter became appreciable.

In any system of telegraphy, no train of undistorted signals will contain any period of either mark or space polarity having a time duration less than that of the unit signal element. When the signals are distorted, however, a proportion of those pulses (either mark or space) which are nominally one unit in length will be shortened. The rate of occurrence of pulses so shortened has been found to give a fair indication of the grade of service on the channel, and the function of the monitor is to provide a continuous check of this rate. The amount of shortening which must be suffered by a pulse before it is " counted " can be preset on a dial. The period over which counting takes place, and the number of shortened pulses above which an alarm is given, are also preselected. Checking the distortion of only single-element pulses greatly simplifies the design of the apparatus, and renders it suitable for any type of telegraph code.

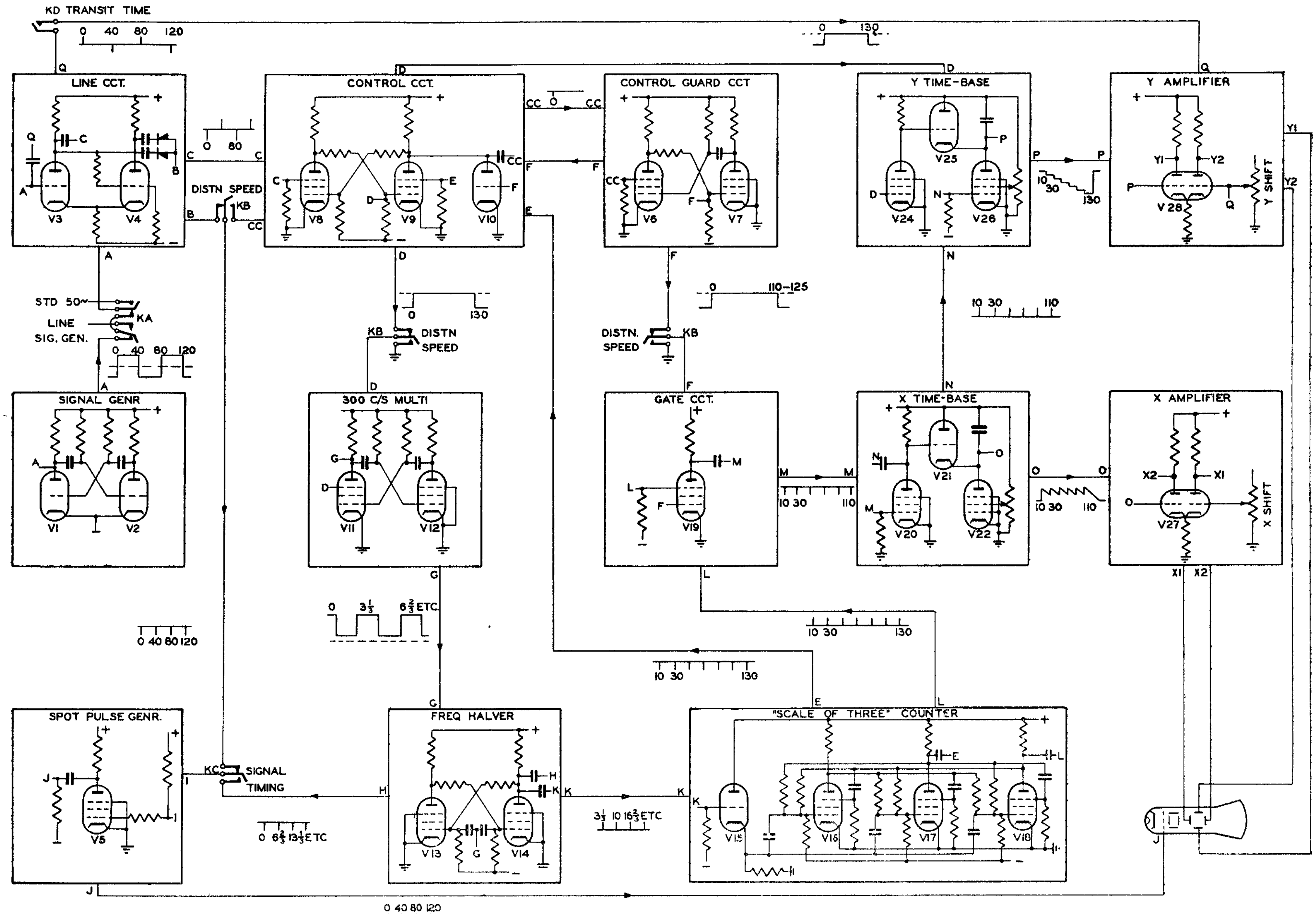
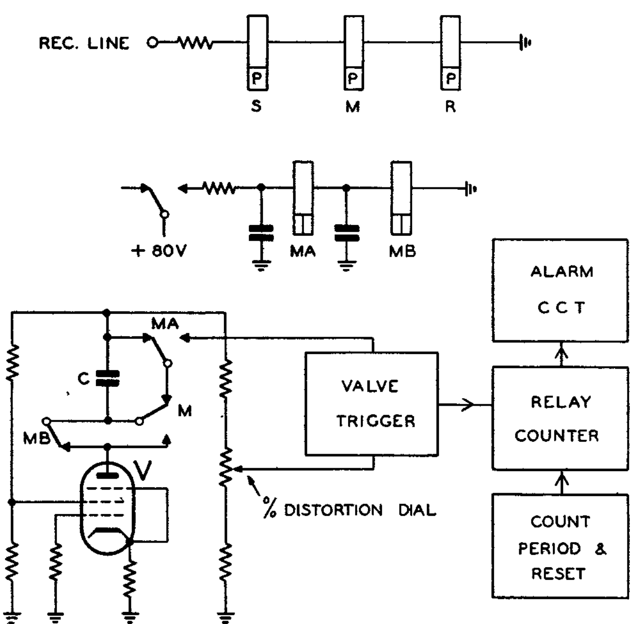


Fig. 15.—Electronic Start-Stop Telegraph Distortion Measuring Set (Sectionalized Circuit Diagram).

Fig. **16** shows the principle of the method of measuring pulse lengths. At the commencement of a " mark " pulse, the capacitor C is charged in series with the pentode at constant current. At the conclusion of the pulse, the voltage of the capacitor is compared with a standard voltage derived from a potentiometer. If the pulse is of less than the preset duration, the capacitor voltage is less than the standard voltage and a valve trigger operates, which in turn operates a counting train. The preset duration is controlled by varying the standard voltage. Fig. **16** shows only the components for measuring " mark " pulses, and the monitor contains a second pentode, capacitor and pair of auxiliary relays for " space " pulses, connected to the same trigger and counter. A synchronous clock motor, running from the a.c. mains, controls the period of counting, after which the counter is automatically reset.

There is also provision for continuous counting of the distorted pulses. For this purpose, the counter is replaced by a subscriber's type meter which can be read at the beginning and end of the period of observation. Since, however, distorted pulses may be occurring, for short periods, at a rate equal to 50 per second, a divider circuit is interposed before the meter, so that the meter records on every fourth pulse. Two lamps indicate in binary scale the intermediate steps between multiples of 4.

Although the monitor was developed primarily as an instrument to assist in the operation of working circuits, it has also been found useful as a research tool. For this purpose, continuous counting is of much more value than the resetting counter and alarm, and on the model demonstrated, the latter facility has been omitted.



NOTE: RELAY CONTACTS SHOWN FOR 'SPACE' ON LINE

FIG. 16.—DISTORTION MONITOR.

5. 7½-UNIT START-STOP REGENERATIVE REPEATER

This instrument will be only briefly described since a full description has already appeared in the P.O.E.E.J. (January, 1949). Its function is to receive teleprinter signals which may be distorted and to retransmit them with no distortion, i.e., with all the instants of modulation in a character in correct time relation to the beginning of the start signal. While it may be used at the receiving end of a telegraph circuit, its more valuable application is at the junction of two links of a circuit consisting of two or more links in series, when it serves to correct the signals before the cumulative distortion has so mutilated the signals that no apparatus, electronic or mechanical, could determine the characters transmitted.

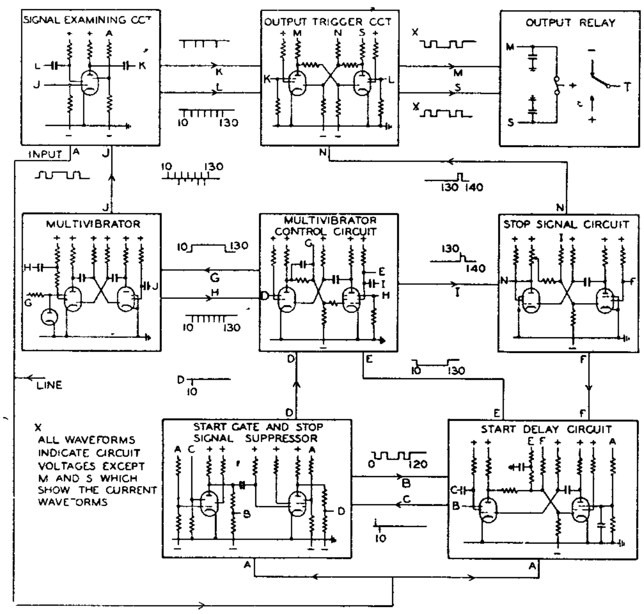


FIG. 17.—REGENERATIVE REPEATER.

Referring to Fig. **17**, the signal examining circuit, under the control of the multivibrator, examines the polarity of the incoming line at the theoretical mid-instants of each element of a character, and determines accordingly the condition of the two-position output trigger circuit and consequently that of the output relay. Thus the retransmitted character is identical with the received character, but with the distortion eliminated, and commencing 10 milliseconds later than the commencement of the received character.

The remaining blocks in the diagram fulfil the following functions:

(1) To hold the multivibrator inoperative until a start signal is received.

(2) To start the multivibrator 10 milliseconds after the commencement of a received signal.

(3) To reject as spurious any start signal shorter than 10 milliseconds.

(4) To insert a stop signal of the correct (mark) polarity after the fifth code element, irrespective of the receiving line polarity at the time.

(5) To suppress the automatic insertion of the stop signal if all the code elements have been of space polarity.

Functions (3) and (4) were added to improve operation on radio links subject to severe distortion. Function (5) permits a long period of continuous space, required for signalling purposes in switched telegraph systems, to be transmitted through the repeater.

In this circuit, some of the valves perform more than one of the elementary functions described in section 2. This makes the circuit more difficult to follow, but effects a considerable reduction in the number of valves and therefore in the power consumption of the repeater. All the valves are miniature pentodes of the same type, including the diode, which is a pentode diode-connected.

Use is made of a polarised telegraph relay at the output in order to make the repeater universal in application. To provide an electronic output circuit of sufficiently low impedance and high current capacity to give the same performance as a relay in all practical circuit connections would require large valves. For a repeater designed to transmit, for example, only into voice frequency telegraph channels, a simple electronic output circuit could readily be provided.

6. ELECTRONIC TELEPRINTER

This laboratory experimental model is one of several designs which were produced in the course of a general investigation of the possible advantages to be derived from replacing some of the mechanical parts of a teleprinter by electronic equivalents. In this design, the translation from character to 5-unit code in the transmitter and vice versa in the receiver, is mechanical, and the distributors and auxiliary functions involved in transmitting and receiving the code signals in time sequence are electronic. For ease of construction, the transmitting and receiving mechanical units are separate in the model shown, but they could, of course, be combined and run from a common motor if there were any practical application for the scheme.

The keyboard unit has combination bars which set up the code on five contacts. A mechanical lock occurs when a key is depressed, and the locking device operates a sixth (" start ") contact, the keyboard being unlocked by an electromagnet which is energized from the electronic unit at the appropriate time. The receiving mechanical unit is the receiving part of a standard teleprinter modified to receive the code elements on five electromagnets and with certain other modifications.

The circuit of the electronic transmitter unit is shown on Fig. **18**. The timing of the signals is controlled by a multivibrator which is started by the start contact. Pulses from the multivibrator at 20 millisecond intervals are applied to a cold-cathode distributor. Valves V13 to V18 are successively struck, and as each valve strikes it applies a pulse to one of the contacts 1 to 5. If the contact in question happens to be closed (depending on the key depressed) the pulse (indicating a " space " element) reaches the output circuit at F. Simultaneously the output circuit receives at C a pulse direct from the multivibrator, tending to pull the output trigger to the " mark " condition, but if there is a pulse at F it overrides that at C and pulls the trigger to " space." After the last code element, a pulse at E operates the reset and guard circuit and extinguishes the valves of the distributor.

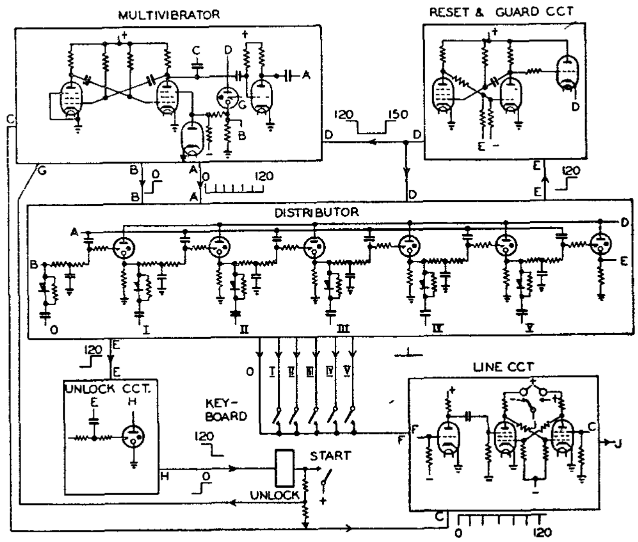


FIG. **18**.—TELEPRINTER TRANSMITTER.

The same pulse strikes a cold cathode valve which energizes the keyboard unlocking electromagnet. The reset and guard circuit also holds the multivibrator inoperative until the character period (150 milliseconds) has elapsed. Transmission of the next character cannot therefore start prematurely.

The electronic receiver circuit is shown in Fig. **19**. The received line signals are " squared " by the line circuit. The commencement of a start signal sets a

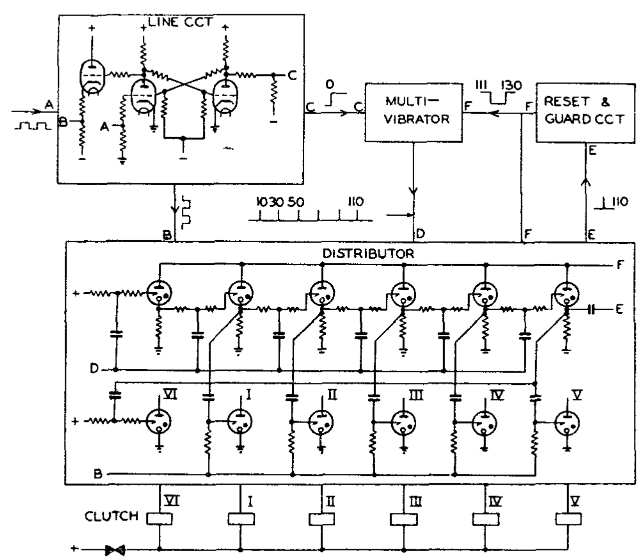


FIG. **19**.—TELEPRINTER RECEIVER.

multivibrator in operation, which controls a distributor as in the transmitter. Associated with each valve of the distributor is a register valve which receives a pulse when the particular distributor valve strikes. The control electrode of the register valve also receives at B a potential (+ve for mark and −ve for space) from the line circuit. Only if the pulse coincides with a " mark " at B does the register valve strike and operate the corresponding electromagnet. After the electromagnets have been set according to the code, a sixth storage valve operates a sixth electromagnet which releases the clutch of the printer camshaft and the transfer, translation and printing operations take place. Finally, the reset and guard circuit extinguishes the distributor cold cathode valves ready for the next character. It also holds the multivibrator inoperative until 130 milliseconds after the commencement of the start signal. This makes the receiver equivalent to a mechanical teleprinter with a receiving cycle having a period of 6½ units (the normal P.O. practice).

It should be emphasized that a minimum of modifications was made to the receiving machine to enable the principle to be demonstrated. Further alterations in detail could advantageously be made in a receiving unit designed specially for the purpose.

7. CODE CONVERTERS

These equipments have been developed for use at stations connecting networks using morse and teleprinter codes (e.g., junctions of inland teleprinter networks and submarine telegraph cables or marine radio). As the two codes are completely unrelated, conversion from one to the other necessitates decoding to character in some form and then recoding. Also, because morse is a code with characters of non-uniform length and there is no standard speed, storage of the traffic is required at some stage in the process. The most convenient form is as morse code punched in tape. Other problems arise from the fact that morse has only a single case, one code for brackets and one for combined line-feed and carriage-return when page printing is used, whilst five-unit code has two cases, two bracket codes and separate codes for line-feed and carriage-return.

7.1 Five-Unit to Morse

This equipment, shown in Fig. **20**, receives teleprinter signals from line and perforates tape in morse code. A block diagram is shown in Fig. **21**. The five-unit receiver is electronic and similar to that of the teleprinter previously described, except that the code-element register records both marks and spaces positively and also records whether the decoder is functioning in the " letters " or " figures " case. Decoding to character indication is effected in two steps by means of resistor networks as described in Section 2.8. The case and first code element, the second and third code elements, and the fourth and fifth code elements, combined in these pairs, select an outlet in each of three groups of four, these twelve outlets terminating at the primers of cold cathode valves, the outputs of which are connected through similar networks to 64 outlets. Those outlets which correspond to characters catered for by the morse perforating unit are connected to cold cathode valves. These final valves energise electromagnets which actuate the key bars of a conventional morse perforator. The selection of a character outlet also energises a clutch magnet to release the perforating mechanism. The clutch is released only for characters catered for in the mechanical coder of the perforator. If a case-shift outlet is selected, this affects only the case indicator stage in the code register.

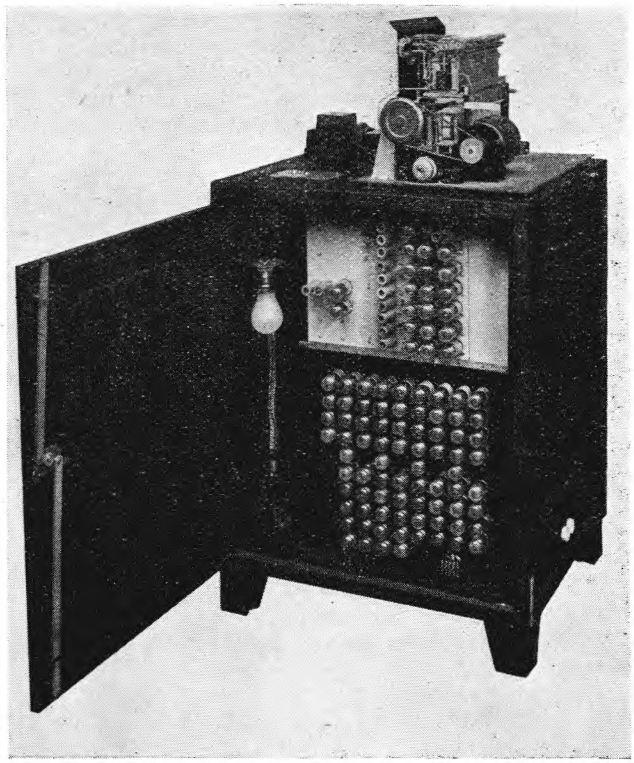


FIG. 20.—5-UNIT CODE TO MORSE CODE CONVERTER.

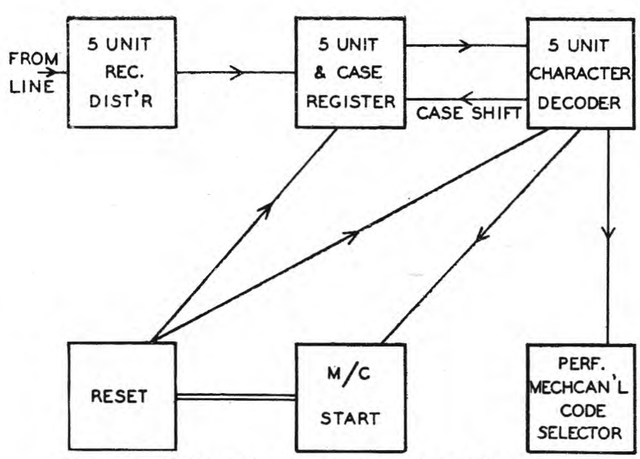


FIG. 21.—5-UNIT CODE TO MORSE CODE CONVERTER.

Part of the decoding circuit together with the code element register is shown in Fig. **22**. The operation will be more easily understood by considering a specific character, e.g., the letter Y, for which the code is MSMSM. In the code element register, the corresponding valves will be primed and positive potentials will be developed at the points L, 1M, 2S, 3M, 4S, 5M. Combination of the first pair of conditions will prime one of the valves in the group C1, so that a positive potential is produced at GLM, and combination of the other two pairs of conditions will produce positive potentials at RSM and CSM. There is only one valve in the final group which is connected directly to these three points—Y. This consequently is primed and operates the corresponding electromagnet on the perforator. The anode supply to all the final valves is taken through a common resistor across which a voltage impulse is developed to initiate the machine-start and resetting circuits.

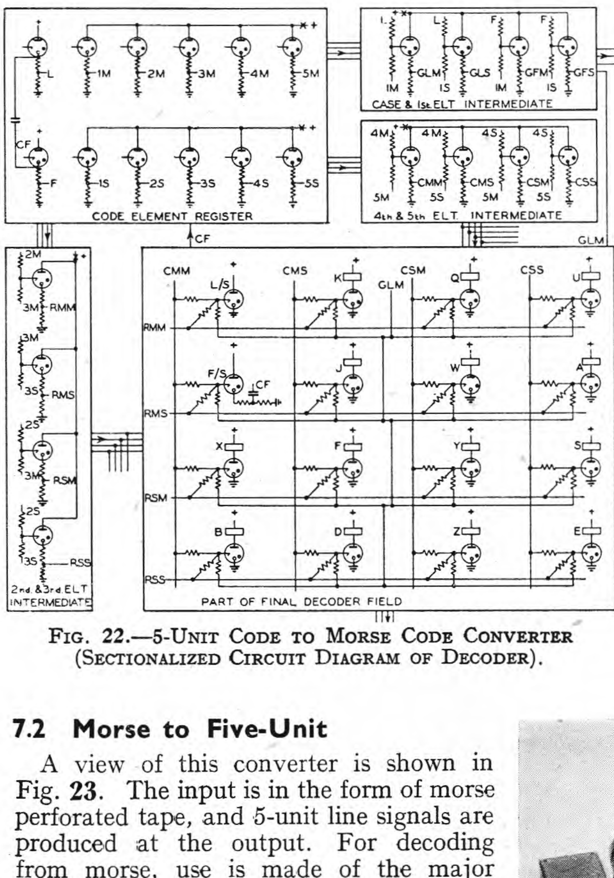


Fig. 22.—5-Unit Code to Morse Code Converter (Sectionalized Circuit Diagram of Decoder).

7.2 Morse to Five-Unit

A view of this converter is shown in Fig. **23**. The input is in the form of morse perforated tape, and 5-unit line signals are produced at the output. For decoding from morse, use is made of the major portion of the existing Creed morse printer, the type-head being replaced by a rotary switch (decoder distributor) with one outlet for each position of the type-head, and a governed motor is fitted. The recoding is done electronically and transmission is effected by a mechanical distributor coupled to the motor.

A sectionalized circuit is shown in Fig. **24** to assist the understanding of the straightforward functions. The decoder distributor outlets are connected to an electronic 5-unit coder similar to that described in Section 2.8, with certain exceptions which will be explained later. The coder is duplicated as far as necessary to cater for figures and letters, each group having a separate case-indicating outlet (L, F). When an outlet has been selected by the tape-reader, a voltage pulse is applied and the appropriate coder outputs are energised to indicate marking elements. The coder outputs strike the corresponding cold-cathode valves in the normal storage. When the previous character has been transmitted, the passage of the transmitting distributor brush over the stop-element segment operates the marker reset circuit which, in sequence, operates the normal transfer and reset circuit. This latter causes a transfer pulse to be applied to the storage stages so that the conditions stored there are transferred to the distributor marker and, at the same time, the storage valves are extinguished to await a new selection. (It will be observed that the interconnection of the storage and marker valves is similar to that in the counter in Section 2.7. The valves which are struck in the distributor marker apply a positive potential to the corresponding segments of the distributor.

When a case-change occurs, the case-shift circuit sets up the appropriate shift code in the insertion storage and operates the machine stop circuit. This causes the tape-feed to be interrupted for a character period and breaks the pulsing circuit to the decoder distributor. In addition, the gate between the marker reset and normal transfer circuit is closed so that the character requiring the case-change is retained in the normal storage until the case-shift code has been transmitted.

The facility of automatic insertion of carriage return and line feed is provided, this occurring at the first space after a predetermined number of characters. The " space " outlet from the tape reader is not connected to the normal coder, but is connected with the alternative coder in which cold cathode triodes are used instead of diodes. In this, only valves which are already primed will operate, so that the code which is set up is controlled by other circuits besides the selection of the " space " outlet. Ordinarily the " space " code is set up in the normal storage, but

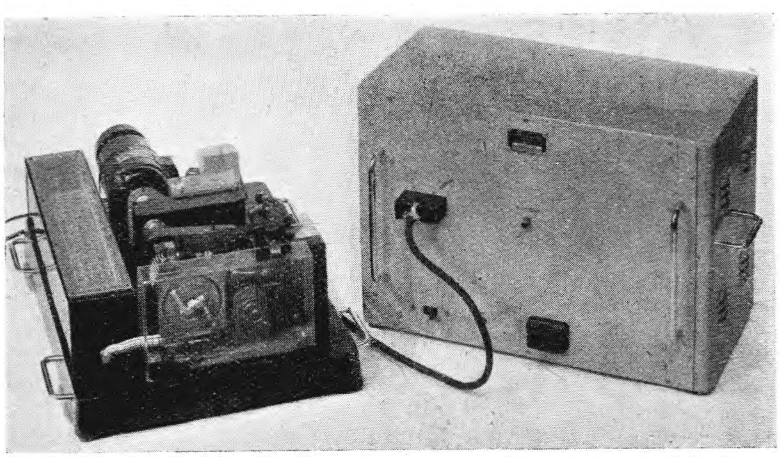


Fig. 23.—Morse Code to 5-Unit Code Converter.

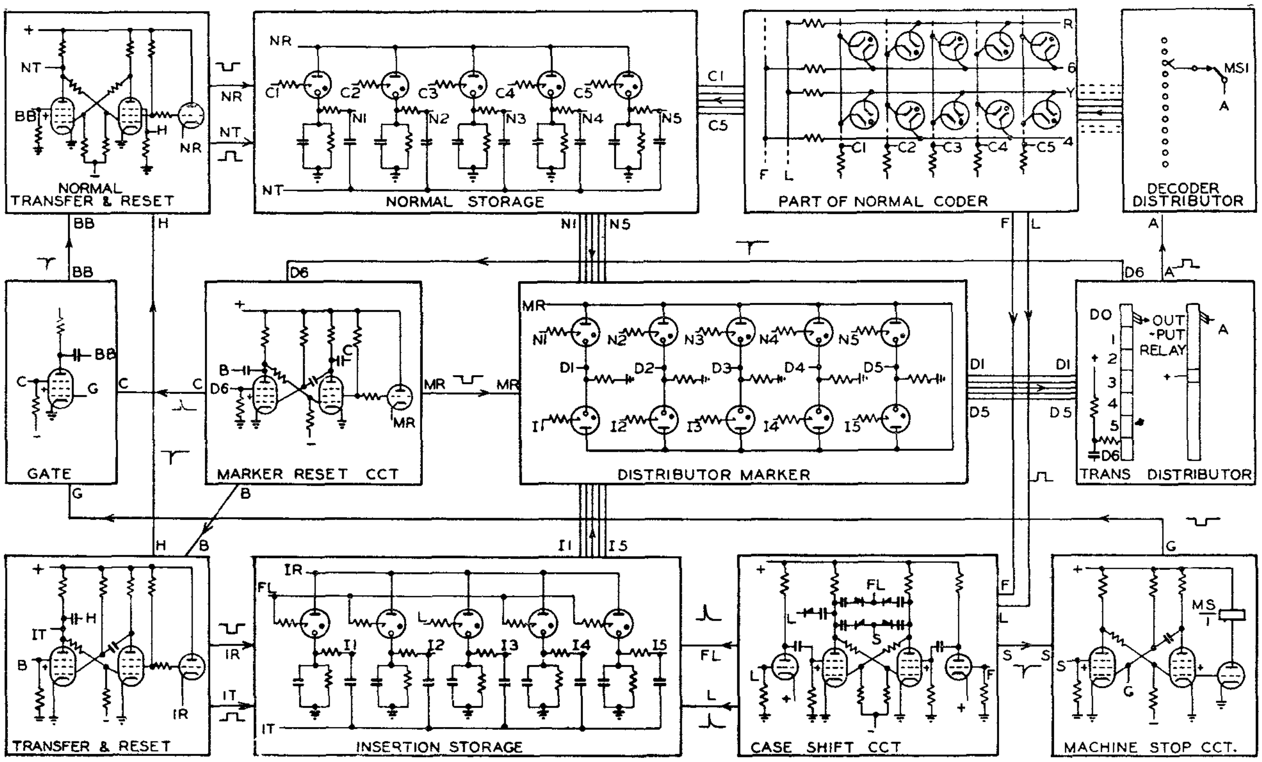


FIG. 24.—MORSE CODE TO 5-UNIT CODE CONVERTER. (SECTIONALIZED CIRCUIT DIAGRAM).

when the counter has reached its preset limit, the " space " connection is switched to set up carriage-return in the insertion storage and line-feed in the normal storage, the following action being similar to that for shift insertion. The setting up of the code resets the counter. If the morse tape contains the carriage-return code, this operates the counter to the limit immediately and the operation is initiated by the space following it. The brackets code is also dealt with in the alternative coder, the translation being switched alternately to give opening and closing brackets. A block diagram is given in Fig. 25.

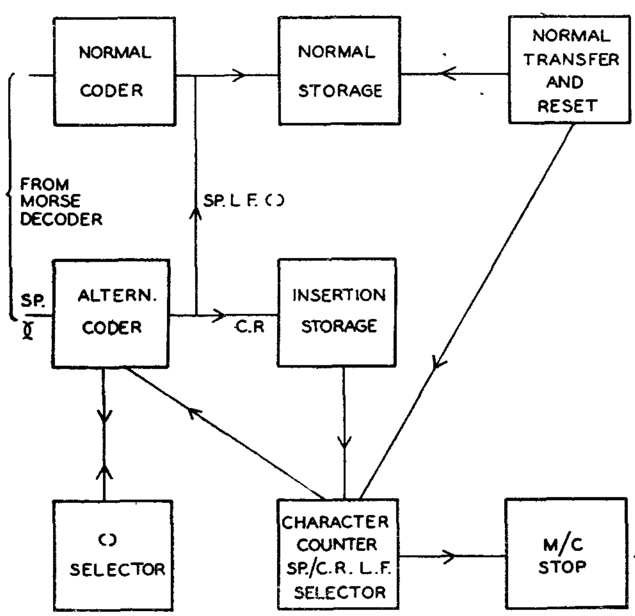


FIG. 25.—MORSE CODE TO 5-UNIT CODE CONVERTER (BRACKETS AND CHARACTER COUNTING BLOCK DIAGRAM).

8. MERITS AND DEMERITS OF ELECTRONIC DEVICES

In the design of equipment of the type considered in this paper, where the speeds involved are not very high, electronic devices are rarely indispensable, and alternative mechanical or electromechanical methods usually exist. Where alternatives are possible, there is no single answer to the question " which is the best technique? ". Each case must be decided according to the purpose and conditions of use of the apparatus, and it may sometimes be advantageous to combine techniques in the same instrument. Many factors have to be considered, such as (1) bulk, (2) weight, (3) cost, (4) reliability, (5) ease and cost of maintenance, (6) robustness, (7) power consumption. It is obvious that the relative importance of these factors, and of others in special cases, will vary with the particular problems. Space will not permit a detailed general discussion of the factors ; instead, the reasons leading to the choice of particular techniques in several of the pieces of apparatus described in the paper will be given by way of illustration. One general observation on factor (4), reliability, may however be of interest. The fault incidence of electromechanical devices, more particularly those involving contacts, depends on the number of operations performed, whereas that of electronic devices (at any rate those using thermionic valves) depends on the running time. Choice will therefore tend to favour electronic methods when the rate of use is high.

The life of cold-cathode valves, however, depends on the proportion of the time during which they are conducting, and it is usual, where possible, to design the circuit so that the valves are non-conducting in the idle condition of the device. Cold-cathode valves, therefore, combine in some respects the advantages of thermionic and mechanical devices, in that they avoid the use of contacts and also give a life and fault liability which is proportional to the amount of use and not to the time the equipment is switched on. They have the additional advantages of reduced power consumption and of easier fault location due to the fact that it is possible to see at a glance whether a valve is conducting or not. For these reasons, cold-cathode valves may be expected to find increasing application, where their characteristics permit their use.

Regenerative repeaters will often be located at intermediate stations where the other apparatus is mainly thermionic, reliability and high performance are vital, and the numbers involved are not so great that bulk and power consumption are very important. These considerations favour an electronic solution. Somewhat similar considerations apply to the distortion set.

As regards code converters, an early solution was desired, and the number of equipments required was small. Since the process involves tape reading and/or punching, part at least of the equipment must be mechanical. For tape handling, existing types of machines were therefore adopted ; use was also made of any other parts of these machines, which performed, or which could with minor modification conveniently be made to perform, some function required in the process of code conversion. The remaining functions were provided mainly by electronic means. If the demand for this type of equipment were large enough to justify the design and tooling costs, there is little doubt that the most compact and generally satisfactory long-term solution would be a fully mechanical one. On the other hand, if morse becomes displaced by either 5-unit or some other uniform character-length code, then these semi-electronic converters may have satisfied a temporary requirement in the most economical manner.

As already explained, the electronic teleprinter described is one of several designs investigated during a general study, and at the present time it does not appear that any of the designs offers great practical advantages over the fully mechanical teleprinter. Since the process starts with the depression of a key and finishes with an inked impression on paper, an appreciable part must inevitably be mechanical. This fact and the relatively small volume and weight of the additional parts involved in a fully mechanical teleprinter, make the size of the semi-electronic designs a serious drawback.

If a partly electronic teleprinter is desired, however, the particular division of functions between electronic and mechanical in the model shown has advantages. Functions requiring critical timing, i.e., the transmitting and receiving distributors, are electronic. This avoids the use of governed motors and enables somewhat lower distortion and higher receiving margin to be achieved than are possible with a mechanical teleprinter. On the other hand coding and decoding are performed mechanically. It is obvious that electronic methods similar to those in the code converters could be used, but the total number of valves and therefore the volume of the electronic equipment would be considerably increased, and in the receiver there would be the additional bulk of one electromagnet per character. The number of wires connecting electronic and mechanical units will also be much greater, being approximately equal to the number of characters. This may be important if it is desired to locate the electronic equipment at some distance from the mechanical units. Moreover, in the design shown, there are six robust and accessible contacts only on the keyboard ; with electronic coding there would be at least one contact per key, and space considerations make it difficult to use a design giving equal reliability. Furthermore, much of the greater mechanical simplicity which might otherwise result from electronic coding disappears when, as is normal, a keyboard lock is desired. When it is remembered that the keyboard and mechanical coding of the ordinary mechanical teleprinter give probably less trouble than any other parts of the machine, the reasons for retaining mechanical coding on the design will be clear.

A further consideration arises if an answer-back facility is required. With the design described, this can be of a mechanical type, operating either on the same contacts as the keyboard, or, if found more convenient, on separate contacts connected in parallel with them. With electronic coding, it is difficult to envisage other than an electronic answer-back or an electromechanical one, such as a uniselector. For the usual 20 character capacity, neither would compare favourably with the mechanical type as regards size.

There remains the factor, already mentioned, that with an electronic teleprinter lower transmitter distortion and higher receiver margin are possible than with a mechanical teleprinter. With modern types of mechanical transmitter the difference is, however, very small. On the receiving side it must be remembered that even the electronic teleprinter cannot have a margin exceeding 50%, and the maximum advantage to be gained under practical conditions is probably not greater than 10—15%. Inland telegraph circuits are normally designed so that the maximum distortion is well within the margin of a mechanical teleprinter ; although an increase in receiving margin is always worth having if it costs little, the price paid in the case under discussion appears excessive.

On radio telegraph circuits subject to noise and selective fading, an increase in receiving margin of 10—15% may give a useful reduction in error rate. Even for this application, however, the use of a regenerative repeater is, in the authors' opinion, a better solution than the adoption of a special electronic teleprinter. This has the following advantages:

(*a*) Since only one wire is required between it and the receiving teleprinter, it need not be located adjacent to the teleprinter, but can be placed at the radio terminal, where the maximum improvement will be gained from its use.

(*b*) The signals being then free of distortion, can be connected over any line circuit to any teleprinter.

Future improvements in electronic methods may increase the number of applications in which electronic devices can advantageously be applied. Already the introduction of several types of cold-cathode valve has enabled considerable reductions in power consumption to be made in some devices in which it was previously necessary to use thermionic valves. Developments in multi-electrode valves may be expected to make further reductions in power consumption and also in bulk. A detailed discussion of future possibilities is, however, beyond the scope of this paper.

9. CONCLUSIONS

It is possible that the paper would have been of greater interest to telegraph engineers if the scope had been restricted to one or two pieces of equipment, and matters of design, performance, practical application and maintenance discussed in greater detail. It was thought, however, that a more general treatment of a larger number of items would have a wider appeal. The choice has at least the merit of illustrating some of the factors which may have to be considered in determining whether electronic methods are the best solution of any particular problem.

In conclusion, the authors wish to acknowledge the efforts of all those past and present members of the Telegraph Group of the Research Branch who have played a major part in the developments described in the paper.

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