PATENT SPECIFICATION

DRAWINGS ATTACHED

866,279

Date of filing Complete Specification Aug. 16, 1957.

Application Date May 18, 1956. *No. 15494/56.*

Complete Specification Published April 26, 1961.

Index at acceptance:—Class 81(2), K.

International Classification:—A61b.

COMPLETE SPECIFICATION

Apparatus for assisting an Operator in performing a Skill

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The present invention relates to apparatus for assisting an operator in performing a skill and is concerned particularly but not exclusively with apparatus for teaching an operator to perform a skill.

In this specification a skill is intended to mean acts an operator is required to perform in response to data supplied to him. Thus the operator may be supplied with data visually and be required to perform manual operations, such as pressing buttons or turning knobs, in response thereto. A telephone operator who has to insert a plug in a given jack whenever a certain flap falls down is performing a fairly simple skill. A plant control engineer who observes a set of dials and manipulates control switches, valves, etc. in response to the indications of the dials performs a more complicated and difficult skill.

The examples given above illustrate two different types of skills. The telephone operator responds to stimuli which occur at spaced intervals in time and each time a response is made it is either right or wrong: that is the right jack is or is not selected. Thus the degree of success of the telephone operator may be largely measured by observing what proportion of his responses are correct. In connection with this same type of skill, another important quantity which may be measured is the average time taken for the operator to respond to a stimulus, and this is a particularly important measure of success when the rate at which a skill is performed is limited not by the rate at which stimuli occur, but by the rate at which the operator can deal with stimuli.

The second of the two types of skill referred to is exemplified by the plant control engineer who is supplied continuously with data. The times at which any responses are to be made are determined by the judgment of the engineer. Some of his responses are capable of being judged "wrong", as it may be known, for instance, that they will definitely lead to an undesired result, for example to an explosion. However, many responses cannot be said to be "right" or "wrong", and the engineer's degree of success can only be judged by measuring the efficiency with which he operates the plant.

Having discussed these examples of skills, certain factors which make an operator inefficient in performing a skill, or which render a training routine inefficient, will be considered.

If the operator is receiving data at too slow a rate, he is likely to become bored and attend to other irrelevant data.

If the data given indicates too precisely what responses the operator is required to make, the skill becomes too easy to perform and the operator again tends to become bored.

If the data given is too complicated or is given at too great a rate, the operator is unable to deal with it. He is then liable to become discouraged and lose interest in performing or learning the skill.

Ideally, for an operator to perform a skill efficiently, the data presented to him should always be of sufficient complexity to maintain his interest and maintain a competitive situation, but not so complex as to discourage the operator. Similarly these conditions should obtain at each stage of a learning process if is to be efficient. A tutor teaching one pupil seeks to maintain just these conditions.

Normally, however, systems which require data to be transmitted to an operator are inefficient, often because attention cannot be given to the individual. Inefficiency must then arise because individuals vary so much from one to another and vary so much from time to time.

In order to overcome such inefficiency the data needs to be "coded" in such a manner that it is optimally matched into the operator, that is, the data actually supplied to the operator has to be made such that it is adapted to the capabilities of the operator at all times. In the case of performance of a skill, as distinct from learning a skill, the data to be dealt with being externally determined without reference to the operator, what has to be "coded" is existing data. In the case of teaching a skill, the "coding" needs to be more far-reaching, and does not merely have to modify the way in which the data is presented, but also has to modify what data is presented.

In either case the aim must be to match the data into the operator continuously, even though his characteristics are always varying.

The present invention has for one of its objects to provide apparatus, which effects such a matching, and therefore enables an operator to perform or learn a skill efficiently.

The invention is based upon the realisation that any apparatus capable of effecting such a matching must comprise a device having characteristics like those of an operator, insofar as an operator is non-stationary and trainable. The operator is here called non-stationary because his characteristics cannot be represented as a set of transfer functions.

Accordingly reference will hereinafter be made to "trainable assemblages", to indicate assemblages which can be so "trained" or modified by performance characteristics of the operator that, with reference to the skill in question, they come to have characteristics related to those of the operator.

According to the present invention there is provided apparatus for assisting an operator in performing a skill, comprising a marking device adapted to be supplied with input signals representative of the responses of an operator to data supplied to him, and to generate output signals representative of the operator's degree of success in responding to the data, in at least four channels, each corresponding to a different category, each category being determined by one or more characteristics of the skill, a trainable assemblage having its input coupled to the marking device in such a manner as to have its state determined by the output signals and to generate, in dependence upon such state, from time to time or continuously, control signals suitable to control one or more parameters of the data-supplying means in such a way as to tend to increase the said degree of success to an optimum value, and to maintain the degree of success at this optimum value.

The word "marking" has been chosen to characterise the device adapted to generate output signals representative of the operator's degree of success since the device acts in a manner analogous to an instructor who marks or assesses the performance of a pupil.

The expression "trainable assemblage" as used herein is defined as an assemblage including at least four storing means storing quantities determined by signals applied to the input of the assemblage over a period of time, and whose state at any instant can be represented by a vector whose components are the quantities held at that instant by the storing means respectively.

The assemblage must comprise at least four storing means in order to make it complicated enough to assume states which have characteristics related to those of the operator. Thus there will be some pattern in the state of the assemblage related to some pattern in the responses of the operator. It is in order to enable such a related pattern to exist in the assemblage that the output signals representative of the operator's degree of success must be provided in a plurality of channels each corresponding to a category determined by one or more characteristics of the skill.

Thus in skills wherein the data supplied to the operator consists of discrete indications selected from a finite number of such indications and the operator is required to make corresponding discrete responses selected from a finite number of responses, the categories may correspond to the responses, respectively. The indications and responses from which indications and responses are selected will be called populations of indications and responses, respectively.

In skills such as those described in the preceding paragraph wherein each response may be marked in more than one marking category, the categories to which the storing means respond can be further subdivided, the total number of categoriest being the number of responses of the population of responses multiplied by the number of marking categories employed. For example, there will hereinafter be described an embodiment of the invention (referred to as a Type II coordinator) having a population of twelve discrete indications and a population of twelve corresponding responses. Each response, however, requires two switches to be pressed and the operator may make a correct or an incorrect response in two marking categories. Accordingly the marking device has twenty-four output channels, and the assemblage has twenty-four storing means, which as will be described are capacitors.

In skills, such as that of chemical plant control, where there is no finite population of indications or responses, but, where, rather, the operator determines a strategy in response to data which presents a picture of a situation, the divisions between categories have to be determined more arbitrarily. Very often some categories can be determined by imposing marking categories in the apparatus. For instance in an embodiment to be described hereinafter under the name of a Type III coordinator, four marking categories are imposed in dependence upon the spatial relationships between two spots of light on a cathode ray tube screen (one spot representing a target aircraft and the other a pursuing aircraft). Furthermore four " strategy categories " are imposed in this embodiment, in dependence on four stagtegies that the spot of light representing the escaping aircraft can adopt. This enables a total of four times four, namely sixteen, categories to be defined and the trainable assemblage in this embodiment comprises sixteen capacitors.

Having discussed the trainable assemblage and the types of categories with which its storing means may correspond, the nature of the input signals to the marking device and the nature of the marking device will be considered.

In apparatus for assisting an operator to perform a skill wherein the operator is required to make a succession of discrete responses the input signals may be pulses, which may, for example, be present only when a response is correct. Alternatively pulses may be present in one circuit when the operator makes a correct response and present in an other circuit when the operator makes an incorrect response. The marking computer may then comprise an integrating device which computes a marking variable measuring the average number of correct responses in unit time. Furthermore, as described hereinafter, for example, in connection with the embodiment of the invention under the name of the Type I coordinator, this variable may be increased by correct responses and decreased by incorrect responses and may furthermore be " compensated ", that is the amount by which it is increased by a correct response may be made dependent on how long before a limit time the response is made. Thus a variable representative of the operator's degree of success over a period of time is derived.

In cases where the operator determines a strategy, the input signals to the marking device may include a signal representing, for instance, in the case of a " pursuit " skill in which the operator tries to bring one pointer or spot of light into coincidence with another pointer or spot of light, the deviation between the two pointers or spots of light. In this case the marked computer may provide a compensated marking variable by subtracting from this signal a signal representing the expected deviation, computed for instance from the state of the trainable assemblage. In the case of chemical plant control, a compensated marking variable may be computed by subtracting a signal representing an expected rate of production from a signal representing the actual rate of production.

The input signals to the marking device need not be of the nature exemplified above, but may, for example, be derived by measuring a physiological or a psychological variable of the operator, as will be hereinafter described.

Some examples of characteristics of the data supplied to the operator which may be varied will now be considered. pointing out how they may be varied in such a manner as to increase the operator's degree of success to an optimum value.

For skills wherein the data consists of discrete indications and where, accordingly, each indication may be regarded as a selection from a finite number of possible indications, various characteristics may be varied. Fundamentally the rate at which the indications are presented may be increased as the operator increases his degree of success, but this is not sufficient by itself to achieve the desired results. Such an increase in rate could be achieved without a trainable assemblage, but it has been found that this does not lead to satisfactory results. The apparatus becomes " osillatory ", getting alternately too fast and too slow for the operator. In apparatus concerned with such skills it is for this reason that the trainable assemblage is required. The trainable assemblage is able to vary some characteristic in a " patterned " manner, that is to different degrees in the different categories.

Thus superimposed upon the average increase in the rate of presentation of the indications there may be a " patterned " increase, the operator being required to respond more quickly to indications in a category in which the operator has achieved a relatively high degree of success, than to indications in categories in which the operator has achieved a relatively low degree of success.

It will be appreciated that such an increase in rate may be described, alternatively, in terms of the determination of the positions in time of limit times before which responses to the indications must be made.

Another characteristic which may be varied is the clarity with which the indications are made. Thus the discrete nature of the indications may be blurred by displaying all the indications all the time, accentuating only the relevant indication. This may be described by saying that " ambiguity " is introduced in the indications. The ambiguity is of course " patterned ". Also, when the indications occur in a repeated sequence in a training routine, the appearance of the indication, or the time at which it becomes apparent which indication is the relevant one when ambiguity is being introduced, may be delayed, in a " patterned " manner, so that the operator has to remember the sequence in order to achieve a high degree of success.

In skills wherein each discrete indication requires a number of discrete responses, the number of responses required per indication may be increased as the operator's degree of success increases. For instance, each indication may consist of flashing up a sequence of symbols, each of which requires a corresponding key or switch to be pressed, and the length of the sequence of symbols may be progressively increased. This procedure would be appropriate in teaching a skill such as typing.

Although the procedures outlined above are adequate for making the data presented to the operator more and more difficult to deal with, they are not so well adapted to help the operator in stages in a learning process where he needs help. In the early stages of learning a skill an operator does not usually merely require the apparatus to be not too competitive, but he requires the apparatus to be actively co-operative if he is to learn the skill efficiently.

Thus "corrective information" may be added to the data in a "patterned" manner, the corrective information indicating to the operator directly which response is required. In a skill wherein the responses are made by pressing switches or keys, the corrective information may be provided by lights adjacent the switches or keys which light up when the switch or key to which they are adjacent is to be pressed. Corrective information may then be withdrawn by decreasing the intensity of these lights and causing them to light up progressively later and later, that is nearer to the limit time.

In other embodiments of the invention the operator may be provided with "anticipatory information", such embodiments being particularly useful for purposes of mental testing. The use of apparatus according to the invention for purposes of mental testing will be described hereinafter. Anticipatory information may be in the form of an indication to the operator that he is shortly to be provided with data to which he is to make a response. The anticipatory information may then be provided, for example, by means adapted to flash a warning light a short time before the data is caused to appear. Furthermore the means may be adapted to decrease the interval between the flashing of the warning light and the appearance of the data as the operator's degree of success increases.

When the data is supplied visually, anticipatory information may also be in the form of a short preview of the data to be formally supplied at a later time. The data is formally supplied at the instant of time from which the operator's response time is measured. For instance, in an embodiment of the invention wherein the data is formally supplied by illuminating a line of symbols, each of which has to be recognised by the operator and responded to appropriately, the like of symbols may be briefly illuminated a short time before they are formally illuminated, and again the length of the interval between the brief illumination and the formal illumination may be decreased as the operator's degree of success increases.

In apparatus teaching a skill wherein the operator determines a strategy, the apparatus in effect determines a strategy with which it plays against the operator. Since this strategy may be made more or less competitive or co-operative, the need for the separate provision of corrective information is decreased.

Although so far the concept of selection from a population of possible contingencies has only been used in discussing the teaching of skills wherein discrete indications are selected from a finite number of indications, the concept may in fact be universally applied. When the apparatus determines a strategy, that strategy will frequently be one of an infinite number of possible strategies. The apparatus may thus be said to select from an infinite population of possible contingencies. Likewise the operator's responses may always be regarded as a selection from a population, finite or infinite, of possible responses.

In this terminology the function of the apparatus may be described as follows. The operator is provided visually, by touch, or by other sensory paths, with data or information from a "display". In response to this information the operator performs selective operations on a population or set of responses and appropriate signals are fed to a marking device which also, in general, receives signals from the trainable assemblage and provides output signals to the assemblage. The trainable assemblage may also affect the said appropriate signals directly to effect a scaling procedure whereby the computation of a compensated marking variable is facilitated. The output signals alter the state of the trainable assemblage by varying the quantities held by its storing means. Control signals derived from the assemblage are used to effect selective operations on a population or set of possible contingencies and thereby the data "displayed" to the operator by the "display" is largely determined. However the actual representation of this data is coded, again under the control of the trainable assemblage, in order to present the data in a manner appropriate to the operator.

A scaling procedure, mentioned above, may for instance be effected, in apparatus wherein the operator makes responses by turning a knob, by providing a servo-mechanism which controls a gear-ratio in a drive between the knob and the device which the knob actuates, thereby varying the sensitivity of the actuation. The servo-mechanism is controlled by the apparatus and the sensitivity of the actuation may be increased as the operator's degree of success increases.

It will be apparent from the foregoing that embodiments of the invention may take a very wide variety of forms. Accordingly three embodiments of the invention will be described in detail, and as indicated previously these will be called a Type I coordinator, a Type II coordinator, and a Type III coordinator.

The three Types are by no means representative of all the different forms the invention may take, but they do illustrate some important distinctions between different forms of apparatus according to the invention.

One important division of types is between those, including Type I and Type II coordinators, in which the coordinator is adapted to teach a predetermined routine and adapts the rate and manner of presentation of the routine, without varying the basic routine itself, and those, including Type III coordinators in which the coordinator is adapted to teach a basic routine within which, however, it adopts a strategy, that is it "plays against the operator", adapting its strategy to suit the skill of the operator. This division of types is determined by the nature of the coordinator.

Another important division is between those types, including Type I coordinators, in which the responses which the operator is required to make are of the same nature as the instructions given to the operator, and those types, including Type II and Type III coordinators, in which the responses are of a different nature from that of the instructions.

Thus the properties of the three types of coordinator will now be summarised and briefly exemplified by reference to the embodiments to be described later.

Type I coordinators:—

(a) Operate in a fixed training routine, varying the rate and manner of presentation of the routine.

(b) Responses are of the same nature as the instructions given.

Thus in the embodiment to be described instructions are given by a plurality of lamps which light up in a fixed sequence, the operator being required to press one corresponding switch for each lamp when it lights up. Both the sequence in which the lamps light up and the correspondence between the lamps and the switches is made of a random nature, so that to perform the skill the operator has to learn the correspondence and the sequence.

Type II coordinators:—

(a) Operate in a fixed training routine, varying the rate and manner of presentation of the routine.

(b) Responses are of a different nature from that of the instructions given.

In the embodiment to be described instructions are given by a plurality of lamps which light up in a fixed sequence, the operator being required to press two switches of two groups of switches respectively for each lamp when it lights up.

Type III coordinators:—

(a) Operate in a basic routine within which they adopt a strategy.

(b) Responses are of a different nature from that of instructions given.

In the embodiment to be described instructions are given by the position of two spots of light on a cathode ray tube, the operator being required to adjust control knobs to bring one spot of light (representing a pursuing aircraft) into concidence with the other (representing a target aircraft). The coordinator adopts an "escape strategy" which makes the target aircraft sufficiently elusive to maintain the operator's interest, but not so elusive that the operator feels he has no chance of ever catching the aircraft.

This embodiment of a Type III coordinator has also been chosen because it is concerned with continuous variables, the operator achieving success as he gets the pursuing aircraft nearer the escaping aircraft, whilst the other embodiments are concerned with discrete variables, the operator achieving success as he makes more and more correct responses more and more quickly.

In modifications of both the Type I and the Type II coordinator (of which modifications no detailed embodiments are described), the said fixed training routine is made one of a plurality of routines, the coordinator being adapted to present different routines in succession, that routine in which the operator is least successful being presented most frequently.

It will be appreciated that whilst, for simplicity of description, embodiments of Type I and Type II coordinators have been described which teach arbitrary skills of no practical use, other embodiments may teach an operator to use a typewriter, a desk computing machine or a punched card keyboard for example.

The invention will now be described by way of example with reference to the accompanying drawings, in which:—

Fig. 1 is a diagrammatic representation of the exterior of the Type I coordinator, hereinbefore referred to;

Fig. 2 is a block circuit diagram of the Type I coordinator;

Fig. 3 is a diagram of two voltage waveforms illustrating the operation of the Type I coordinator:—

Fig. 4 is a circuit diagram of a uniselector bank U_1, a terminal block TB_1 and a display DS_1 shown in block form in Fig. 2;

Fig. 5 is a circuit diagram of three uniselector banks U_2, U_3 and U_4, a permutator PE_1 and a set of control relays CR_1 shown in block form in Fig. 2;

Fig. 6 is a circuit diagram of a selector SE_3 and a store ST_1 shown in block form in Fig. 2;

Fig. 7 is a circuit diagram of a terminal block TB_2 and a response board RB_1 shown in block form in Fig. 2;

Fig. 8 is a circuit diagram of a terminal block TB_3 and a display DS_2 shown in block form in Fig. 2;

Fig. 9 is a circuit diagram of a set of marking relays MR_1 shown in block form in Fig. 2;

Fig. 10 is a circuit diagram of a marking computer MC_1 shown in block form in Fig. 2;

Fig. 11 is a circuit diagram of a waveform generator WG_1 shown in block form in Fig. 2;

Fig. 12 is a circuit diagram of a uniselector control UC_1 shown in block form in Fig. 2;

Fig. 13 is a circuit diagram of a voltage reader VR_1 shown in block form in Fig. 2;

Fig. 14 is a circuit diagram of a uniselector bank U_5 and a store ST_2 shown in block form in Fig. 2;

Fig. 15 is a circuit diagram of an access controller AC_1 shown in bock form in Fig. 2;

Fig. 16 is a circuit diagram of a corrective information computer CI_1 shown in block form in Fig. 2;

Fig. 17 is a circuit diagram of a modulator MD_1 shown in block form in Fig. 2;

Fig. 18 is a block circuit diagram of the Type I coordinator showing how the circuits shown in Figs. 4 to 17 are connected together;

Fig. 19 is a diagrammatic representation of the exterior of the Type II coordinator, hereinbefore referred to;

Fig. 20 is a diagram of two voltage waveforms illustrating the operation of the Type II coordinator;

Fig. 21 is a block circuit diagram of the Type II coordinator;

Fig. 22 is a circuit diagram of a uniselector bank U_6, a terminal block TB_4 and a display DS_3 shown in block form in Fig. 21;

Fig. 23 is a circuit diagram of a uniselector bank U_7, a terminal block TB_5 and a display DS_4 shown in block form in Fig. 21;

Fig. 24 is a circuit diagram of two uniselector banks U_8 and U_9, two terminal blocks TB_6 and TB_7 and a response board RB_2 shown in block form in Fig. 21;

Fig. 25 is a circuit diagram of a set of marking relays MR_2 shown in block form in Fig. 21;

Fig. 26 is a circuit diagram of a waveform generator WG_2 shown in block form in Fig. 21;

Fig. 27 is a circuit diagram of two uniselector bank U_{12} and U_{13}, two terminal blocks TB_8 and TB_9 and a display DS_5 shown in block form in Fig. 21;

Fig. 28 is a circuit diagram of an ambiguity modulator AM_1 shown in block form in Fig. 21;

Fig. 29 is a block circuit diagram of the Type II coordinator showing the interconnections of the circuits shown in Figs. 22 to 28, two further circuits, which are in essence the same as those shown in Figs. 10 and 12 respectively and five pairs of circuits, comprising two circuits in essence the same as those shown in each of Figs. 13 to 17 (the reference numerals designating terminals in Figs. 13 to 17 having been provided with either a subscript "r" or a subscript "c" as will hereinafter be explained);

Fig. 30 is a block circuit diagram of a radar training apparatus including the Type III coordinator hereinbefore referred to;

Fig. 31 is a more detailed block circuit diagram of the Type III coordinator;

Fig. 32 is a circuit diagram of a selector SE_4 shown in block form in Fig. 31;

Fig. 33 is a circuit diagram of an access controller AC_2 shown in block form in Fig. 31;

Fig. 34 is a circuit diagram of a store ST_3 shown in block form in Fig. 31;

Fig. 35 is a circuit diagram of a set of output relays OR_1 shown in block form in Fig. 31;

Fig. 36 is a circuit diagram of a variance computer VC_1 shown in block form in Fig. 31;

Fig. 37 is a circuit diagram of a marking computer MC_3 shown in block form in Fig. 31; and

Fig. 38 is a block circuit diagram of the Type III coordinator showing the interconnections of the circuits shown in Figs. 32 to 37, a circuit constituting a row access controller AC_3 shown in block form in Fig. 31 and being in essence the same as that shown in Fig. 33, with, however, the reference numerals designating its terminals primed, and three amplifiers AA_1, AA_2 and AA_3 shown in block form in Fig. 33.

The embodiment of a Type I coordinator will now be described, firstly in broad outline, with reference to Fig. 1, as it appears to an operator whom it is training, then in more detailed functional form with reference to Figs. 2 and 3, and finally in still more detail with reference to Figs. 4 to 18.

The coordinator functions in a cyclic sequence of twelve "positions" in each of which an instruction is given to the operator and in which the operator is required to make a response to that instruction. Each position will be said to start at a certain time, to end at a later time and to be of a certain duration, which duration in general varies from position to position and varies for a given position for successive occurrences of that position. The twelve positions will be numbered consecutively p_1 to p_{12} and a general position will be indicated by the symbol p_i. Each two consecutive positions are separated from each other by a short fixed "moving-on" interval of duration u.

Referring to Fig. 1, the instructions are given to the operator by a "display" DS_1 comprising eight lamps arranged in a horizontal row and numbered k_1 to k_8 from left to right, a general lamp being given the symbol k_u.

In each position p_i one of the lamps k_u lights up. In response to this the operator is required to press a switch of a "response board" RB_1 having eight press-button switches arranged in a horizontal row and numbered s_1 to s_8 from left to right, before the end of the position p_i.

A routine for the operator to learn is set up by making connections in certain terminal boards to be described hereinafter which determine which lamp lights up in each position p_i and which switch is the correct switch to be pressed for each lamp k_u. In describing the coordination it will be assumed, merely by way of example, to set up in the following manner:—

Position in sequence	Lamp lit up
p_1	k_3
p_2	k_8
p_3	k_3
p_4	k_4
p_5	k_1
p_6	k_5
p_7	k_7
p_8	k_6
p_9	k_4
p_{10}	k_8
p_{11}	k_3
p_{12}	k_2

Lamp lit up	Switch to be pressed
k_1	s_7
k_2	s_4
k_3	s_5
k_4	s_2
k_5	s_8
k_6	s_6
k_7	s_1
k_8	s_3

It will thus be seen that, with the particular routine assumed, the following sequence of switches has to be pressed:—

$s_5 \quad s_3 \quad s_5 \quad s_2 \quad s_7 \quad s_8 \quad s_1 \quad s_6 \quad s_2 \quad s_3 \quad s_5 \quad s_4$

The function of the coordinator is to teach the operator to make the correct response for each position p_i rapidly and thus the operator may be said to learn firstly which switch of the response board RB_1 corresponds to each lamp in the display DS_1 and secondly the sequence in which the lamps in the display DS_1 light up and accordingly the sequence in which the switches of the response board RB_1 have to be pressed.

A lamp 37 indicates to the operator that he has made a correct response and a lamp 38 indicates an incorrect response.

The teaching process is effected firstly by adapting the rate at which the operator is required to make responses to the operator's ability at each stage in the learning process, increasing the rate as he becomes more successful in making correct responses. This is done by decreasing the duration of the positions p_i. However it is not done merely by decreasing the average duration of the positions. Superimposed on such an increase in the rate of operation of the machine is a "patterned increase" which may be provided in one of two ways, selected by the setting of a switch.

In one of the two ways the coordinator remains in a position for a relatively short length of time when the operator has had a relatively high degree of success in responding in that position previously. In the other of the two ways the coordinator remains in a position for a relatively short length of time when the operator has had a relatively high degree of success in responding to the lamp which lights up in that position (and may be in other positions, since some lamps light up in more than one position).

Thus the distinction between the two alternatives is that the coordinator takes account of the previous degree of success in responding, in the first case in a particular position and in the second case to a particular lamp. By "previous degree of success" is meant average success in a number of previous sequences and physically this averaging is effected by adding or taking away charge to or from a capacitor.

The distinction between the two alternatives is not fundamental. The two ways described are convenient ways of achieving the "patterned increase" and in the later stages of a learning process even the detailed operation of a coordinator will be little affected by which way is used.

The learning process is further assisted by a second "display" DS_2 having eight lamps in a horizontal row, numbered m_1 to m_8 from left to right and adjacent the switches s_1 to s_8 respectively. These light up to indicate to the operator directly which switch should be pressed, the lamp m_4 for example lighting up when the switch s_4 is to be pressed. The display DS_2 gives the operator corrective information.

However these lamps only light up slowly and not until their brilliance reaches a certain level do they assist the operator. In the initial stages of learning they are caused to reach this level fairly quickly and thus to give the operator considerable help. As progress is made they are caused to reach the level more and more slowly, corrective information thus being withdrawn until eventually the level is not reached at all before the end of each position and accordingly the operator is given no corrective information. Moreover this withdrawal of corrective information is "patterned" in the same way that the rate of increase in the rate of operation of the coordinator is "patterned".

Provision is also made whereby the lamps of the display DS_1 may be caused to light up in this manner, that is to say quickly during the initial stages of learning, and progressively less quickly as learning proceeds. Use may be made of this provision particularly in the later stages of the learning process when the operator is progressing towards the point where he knows the sequence in which the lamps light up.

Referring to Fig. 2 there is shown a functional block diagram of the Type I coordinator. Electrical connections between units of the coordinator are shown by full lines (some of which represent more than one wire) whereas control of a unit by a relay or relays in another unit is shown by a chain dotted line. A broken line is used in conventional manner to indicate that switches or uniselector arms are mechanically ganged together. A number in a circle against a full line represents the number of wires constituting that connection when the number is other than one.

The twelve positions in which the coordinator operates are controlled by a five-bank uniselector U_1, U_2, U_3, U_4, U_5 having twelve positions and being stepped on by a "uniselector control" UC_1.

The wiper of the first bank U_1 is connected through a switch SW_1 either to a transformer T_1 supplying to the wiper an unmodulated alternating voltage, or to the output of a modulator MD_1. The twelve output terminals from the bank U_1 are connected through a first terminal block TB_1 to the eight lamps of the display DS_1. Thus depending on the setting of the switch SW_1 the lamps can be caused to light up either steadily or in a manner depending on the output of the modulator MD_1, which output is a fifty cycle alternating current amplitude modulated in a manner to be described later.

A 25 volt supply is connected to the wipers of the three banks U_2, U_3 and U_4 the output terminals of which are connected through a "permutator" PE_1, which is a terminal block with provision made for altering the connections within the block by means of switches, to a set of "control relays" CR_1. This set of relays controls three "selectors", SE_1, SE_2 and SE_3, each having an input terminal and eight output terminals. For each position of the sequence the input to each selector is connected through to one of the eight output terminals of each selector respectively, the routing through the selectors being controlled by the control relays.

The input to the selector SE_1 is a 25 volt supply. The output terminals of this selector are connected through a second terminal block TB_2 to the response board RB_1 which, as shown in Fig. 1, has eight press-button switches. In each position of the sequence the operator is required to press one of these switches, whereupon an output from the response board registers upon a set of "marking relays" MR_1 firstly the fact that a response has been made and secondly whether the response is correct or incorrect, and the marking relays MR_1 are set in appropriate states. The output from the response board RB_1 registering whether the response is correct or incorrect is dependent on the input to the response board RB_1 from the terminal block TB_2. The marking relays control the two lights 37 and 38 in Fig. 1 which indicate to the operator whether his response is correct or incorrect.

The state of the marking relays MR_1 determines the state of a "marking computer" MC_1 which computes a continuously varying marking variable θ, represented by a potential, from its state at any instant. Normally θ decreases slowly, but when a correct response is made θ is increased by an amount depending on how long the response is made before the end of the position p_i in which it is made.

Thus referring to the upper part of Fig. 3, θ is shown for two consecutive positions p_i and p_{i+1}. The positions p_i and p_{i+1} begin at times t_1 and t_4 respectively and end at times t_3 and t_6 respectively. A correct response is assumed to be made in the position p_i at time t_2 and an incorrect response is assumed to be made in the position p_{i+1} at time t_5. The interval $t_3—t_2$ is of duration δt_i and the interval $t_6—t_5$ is of duration δt_{i+1}. At times other than those in the last two said intervals, θ is decreasing at a slow steady rate. In the interval $t_3—t_2$ following the correct response at time t_2, θ is caused to increase at a relative rapid rate and in the interval $t_6—t_5$ following the incorrect response at time t_5, θ is caused to decrease at a relatively rapid rate.

One output from the marking computer MC_1 (Fig. 2) is fed to a "waveform generator" WG_1 which generates a waveform V_{sm} shown in the lower part of Fig. 3. At the beginning of the position p_i the potential V_{sm} starts to rise from a constant level V_a at a rate $dV_{sm}/dt=(a+b\theta)$ where a and b are constants. The position p_i ends when the potential V_{sm} reaches a variable trigger level Vt_i. The variations in the slope of the waveform V_{sm} show the increase and decrease of the slope when θ increases and decreases by relatively large amounts respectively.

The trigger level Vt_i is determined by a "voltage reader" VR_1 (Fig. 2) connected through a single-pole two-way switch SW_2 to a "store" ST_1 when the duration of the position p_i is required to depend on the previous degree of success in responding to the lamp of the display DS_1 which lights up in that position and to a store ST_2 when the duration of the position p_i is required to depend on the previous degree of success in responding in that position.

The waveform generator WG_1 also controls through the uniselector control UC_1 the moving-on interval u, at the end of which the uniselector control UC_1 moves the uniselector on to the next position. During the moving-on interval the marking relays MR_1 are prevented from functioning.

The input to the voltage reader VR_1 at each position of the sequence is determined by the charge on a capacitor of either the first store ST_1 or the second store ST_2. The store ST_1 has eight capacitors connected to the eight output terminals of the selector SE_3 respectively the input terminal of which is connected to one fixed contact of the switch SW_2. The store ST_2 has twelve capacitors connected to the twelve output terminals of the uniselector bank U_5 respectively. The wiper of the bank U_5 is connected to the other fixed contact of the switch SW_2. The movable contact of the switch SW_2 is connected to the input to the voltage reader VR_1 and through an "access controller" AC_1, the state of which is dependent on the state of the marking relays MR_1, to an output from the marking computer MC_1.

The eight capacitors of the store ST_1 are in one-to-one correspondence with the eight lamps in the display DS_1 and thus with the switches of the response board RB_1. For convenience the capacitors will be numbered e_1 to e_8 where the capacitor e_1 corresponds to the lamp k_1, the capacitor e_2 to the lamp k_2 and in general the capacitor e_u corresponds to the lamp k_u. The charge held by each capacitor of the store ST_1 is, as will be hereinafter described arranged to be representative of the degree of success achieved by the operator in responding to the associated lamp, averaged over a number of sequences.

Assuming that the coordinator is set up as previously described, in the position p_1 the input to the voltage reader VR_1 when the store ST_1 is in use, that is when the switch SW_2 is in the position shown in Fig. 2, is determined by the capacitor e_3; in the position p_2 the input is determined by the capacitor e_8 and so on.

When a capacitor e_u holds a charge representing a high previous degree of success the trigger level Vt_i for the corresponding position p_i is low and when the capacitor e_u holds a charge representing a low degree of success the trigger level Vt_i is high.

The twelve capacitors of the store ST_2 are in one-to-one correspondence with the twelve positions p_1 to p_{12} and will be numbered f_1 to f_{12}, where the capacitor f_1 corresponds to the position p_1, the capacitor f_2 to the position p_2 and so on. The charge held by each capacitor of the store ST_2 is, as will hereinafter be described, arranged to be representative of the degree of success achieved by the operator in the corresponding position in the sequence, averaged over a number of sequences.

When the store ST_2 is in use, that is when the switch SW_2 is in the other position from that shown in Fig. 2, and a capacitor f_i holds a charge representing a high degree of success the trigger level Vt_i for the position p_i is low and when the capacitor f_i holds a charge representing a low degree of success the trigger level Vt_i is high.

Thus referring again to Fig. 3, the duration Δt_i of the position p_i depends both on the rate at which V_{sm} is increasing, which in turn depends on θ, and the height of the level Vt_i. If θ is large, and, if, for the position p_i, Vt_i is low, then Δt_i is short. When the store ST_2 is in use the level Vt_i is determined by the previous degree of success in the position p_i. When the store ST_1 is in use the level Vt_i is determined by the previous degree of success in responding to the lamp corresponding to the position p_i. Thus when the coordinator is set up as described above, in the position p_2 the level Vt_2 is determined by the previous degree of success in responding to the lamp k_8, that is the previous degree of success in positions p_2 and p_{10}.

The output from the voltage reader VR_1 is also fed to an input terminal of a "corrective information computer" CI_1 which also receives an input from the waveform generator WG_1 and provides the input to the modulator MD_1. The output of the modulator MD_1 is fed through the selector SE_2 and through a terminal block TB_3 to the second display DS_2.

The corrective information computer CI_1 adds a voltage proportional to the output from the voltage reader VR_1 to the rising waveform V_{sm} and in the modulator MD_1 the fifty-cycle output is amplitude modulated in response to these added voltages. The connections of the terminal block TB_3 are so made that in any position p_i the modulator MD_1 is connected to the lamp of the display DS_2 corresponding spatially with the switch on the response board RB_1 which has to be pressed to provide a correct reponse in that position.

The output from the corrective information computer CI_1 is a potential proportional to V_{sm} (Fig. 3) superimposed on a step of height determined by the output of the voltage reader VR_1, and proportional to the level Vt_i (Fig. 3). The output of the modulator MD_1 is an alternating current amplitude modulated in the same way and thus the lamp in the display DS_2 to which the modulator MD_1 is connected will increase in brightness during the period Δt_i. The minimum level of brightness at which the lamp actually supplies the operator with corrective information is determined by physiological and psychological factors and the corresponding level of output from the modulator will be called the level B_c.

Thus when the operator has achieved a very low previous degree of success in a position p_i (and Vt_i is thus very high) the amplitude of the output from the modulator MD_1 starts at a relatively high value, namely the height of the step derived from the voltage reader VR_1, which step is proportional to Vt_i and increases therefrom. Thus the level B_c is reached as soon as the period Δt_i starts, or very soon afterwards, and the operator rapidly receives some corrective information. If he delays his response the lamp increases in brightness until he receives a large amout of corrective information.

Conversely when the operator has achieved a high previous degree of success in a position p_i (and Vt_i is thus low) the output from the modulator MD_1 starts at a relatively low value and increases therefrom. The level B_c is only reached late in the period Δt_i and in the ultimate is not reached at all, the operator then receiving no corrective information.

The output from the modulator in the position p_i of course depends on the previous degree of success in responding to the lamp of the display DS_1 corresponding to the position p_i when the store ST_1 is connected to the voltage reader VR_1 and on the previous degree of success in the position p_i when the store ST_2 is connected to the voltage reader VR_1.

Thus at the beginning of the process of learning a skill, the value of θ is low, the trigger levels Vt_i are in general high and the output from the modulator MD_1 in general reaches the level B_c quickly in each position p_i of the sequence.

As progress is made in learning the skill, θ increases and thus the average rate at which responses are required to be made increases. Furthermore the trigger levels Vt_i decrease and the amplitude of the output from the modulator MD_1 decreases but these decreases are different for the different positions p_i. Thus the coordinator adapts itself to the "pattern of learning" of the operator and in positions p_i where he achieves a high relative degree of success gives him a relatively short period of time in which to make a response and a relatively small amount of corrective information.

The coordinator will continue to vary the variable θ, the trigger levels Vt_i and the amount of corrective information supplied to the operator until a stable state is reached where θ is high and constant (that is the slow continuous decrease of θ is just offset by the increase afforded by his correct responses), all the trigger levels are low and of the same height, and no corrective information is supplied to the operator.

Furthermore when the switch SW_1 is so set that the input to the lamps of the display DS_1 is from the modulator MD_1 the information given by the display DS_1, which information, once the correspondence between lamps of the display DS_1 to switches on the response board RB_1 has been learned, may be regarded merely as telling the operator whereabouts he is in the sequence, decreases as the skill is learned. That is the lamps of the display DS_1 only light up slowly to reach a level of brightness which gives information to the operator after the beginning of a position p_i. If this information is decreased to zero a further lamp (not shown) is provided which lights up when the coordinator is in the position p_1 and indicates the start of the sequence.

The units of the coordinator will now be described in more detail, and in this detailed description the connections of the terminal blocks TB_1, TB_2, TB_3 and of the permutator PE_1 will be shown arranged to set up the coordinator as in the example described above.

In Fig. 4 the twelve output terminals 10 of the uniselector bank U_1 are numbered p_1 to p_{12} in correspondence with the positions of the sequence. The output terminals 10 are connected to twelve input terminals 11, respectively, of the terminal block TB_1 which input terminals are connected to eight output terminals 12 of the block TB_1. The terminals 12 are connected to one terminal of the eight lamps k_1 to k_8, respectively, of the display DS_1, the other terminal of each lamp being connected to earth.

In Fig. 5 the twelve output terminals 13, 14, 15 of the uniselector banks U_2, U_3, U_4 respectively are in each case numbered p_1 to p_{12}. The output terminals 13, 14, 15 are connected in one-to-one correspondence with three sets each of twelve terminals 16, 17, 18 in the permutator P_1 respectively. The terminals 16 are connected to two terminals 19, 20, the terminals 17 to two terminals 21, 22 and the terminals 18 to two terminals 23, 24, the connections shown and the arrangement of the contacts of the relays A, B and C shown in Fig. 6 being such that the capacitors of the store ST_1 number e_1 to e_8 from left to right in Fig. 6. It will be recalled that the capacitors e_1 to e_8 correspond to the lamps k_1 to k_8 respectively. The terminals 19, 21 and 23 are connected through three ganged switches SW_3, SW_4 and SW_5 respectively to the windings of three relays A, B and C respectively (forming the control relays CR_1 of Fig. 2), the other ends of which windings are connected to a -25 volt line.

The switches SW_3, SW_4 and SW_5 can be changed over to connect the terminals 20, 22 and 24 to the relays A, B and C respectively. This enables a ready alteration to be made in the sequence in which the selectors SE_1, SE_2 and SE_3 are set and thus to alter the sequence of switches on the response board RB_1 corresponding to the sequence of lamps lit up through the uniselector bank U_1. When the switches SW_3, SW_4 and SW_5 are in the other position from that shown, the co-ordinator is of course no longer set up as in the example described above.

The three selectors SE_1 are themselves identical and in Fig. 6 the selector SE_3 is shown connected to the store ST_1. The selector SE_3 has an input terminal 27 connected to the switch SW_2 and eight output terminals 30 connected to one terminal of the eight capacitors e_1 to e_8 respectively, the other terminals of the capacitors being connected to earth. In dependence on the setting of the relays A, B and C the input terminal 27 is connected to one only of the capacitors e_1 to e_8 through sets of relay contacts A3, B5, B6, C9, C10, C11 and C12 arranged as shown. Thus when the uniselector arms are in the position shown in Fig. 5, that is the position p_5, and the switches SW_3, SW_4 and SW_5 are in the setting shown in Fig. 5, the relays A, B and C are all de-energised. The terminal 27 is then connected to capacitor e_1 corresponding to the lamp k_1 which is on in position p_5 (Fig. 4).

When the uniselector arms are in the next position p_6 the lamp k_5 is on as will be seen from Fig. 4 and the relay A is energised and the relays B and C are de-energised (Fig. 5). Thus, as will be seen from Fig. 6, the capacitor e_5 is connected to the terminal 27.

The selector SE_1 has an input terminal 25 (Fig. 2) connected to a +25 volt line, eight output terminals 28 (Fig. 7) connected to eight input terminals 31 of the terminal block TB_2 (Fig. 7) and sets of relay contacts A1, B1, B2, C1, C2, C3, C4, (not shown, as the selector SE_1 is constructionally the same as the selector SE_3) corresponding to the sets of relay contacts A3, B5, B6, C9, C10, C11 and C12 (Fig. 6).

Referring to Fig. 8, the selector SE_2 has an input terminal 26 connected to the output of the modulator MD_1 (Fig. 16), eight output terminals 29 connected to eight input terminals 35 of the terminal block TB_3 and sets of relay contacts A2, B3, B4, C5, C6, C7 and C8 (not shown, as the selector SE_2 is constructionally the same as the selector SE_3) corresponding to the sets of relay contacts A3, B5, B6, C9, C10, C11 and C12 (Fig. 6).

Thus referring to Fig. 7 the output terminals 28 of the selector SE_1 are shown connected to the input terminals 31 of the terminal block TB_2 which has eight output terminals 32 connected respectively to one set of fixed contacts of eight two-pole, one-way press-button switches, namely the switches s_1 to s_8. The connections in the permutator PE_1 and the terminal board TB_2 are such that when the lamp k_1 is lit up the 25-volt line is connected through the input terminal 25 (Fig. 2) of the selector SE_1 to the fixed contact of the switch s_7, when the lamp k_2 is lit up the connection is to the fixed contact of the switch s_4 and so on.

The set of movable contacts associated with the said one set of fixed contacts of the switches s_1 to s_8 are connected together to an output terminal 33. The other set of movable contacts of the switches s_1 to s_8 is connected to a +25 volt line and the other set of fixed contacts of the switches is connected to an output terminal 34. Thus the terminals 33 and 34 are dead when no switch is pressed. When any switch is pressed the terminal 34 is at a potential of +25 volts and when a correct switch only is pressed the terminal 33 is at a potential of +25 volts.

In Fig. 8 the output terminals 29 of the selector SE_2 are shown connected to the input terminals 35 of the terminal block TB_3, which has eight output terminals 36 connected to one terminal each of the eight lamps m_1 to m_8 constituting the display DS_2. The other terminal of each of the lamps is connected to earth. The connections in the block TB_3 are the same as those in the block TB_2. Thus when the switch s_1 is the correct one to be pressed the output of the modulator MD_1 is connected to the lamp m_1, when the switch s_2 is the correct switch to be pressed the output of the modulator MD_1 is connected to the lamp m_2, and so on.

The terminals 33 and 34 (Fig. 7) are connected to two input terminals 63 and 64 respectively of the marking relays shown in Fig. 9, these terminals being connected to one end of the windings of two relays E and F respectively. The other ends of the windings of the relays E and F are connected together to a −25 volt line, through a set of relay contacts L1 of a relay L.

A set of relay contacts N4 of a relay N (Fig. 11) is connected in series with a set of relay contacts F1 and a set of changeover relay contacts E1, between the +25 volt line and one end of the winding of each of two relays G and H, the other ends of the windings of which are connected to a −25 volt line. The said one end of the winding of the relay G is also connected through a set of relay contacts G1 and a set of relay contacts N3 (of the relay N (Fig. 11)) to the +25 volt line and the one end of the winding of the relay H is also connected through a set of relay contacts H1 and the set of relay contacts N3 to the +25 volt line.

For the duration of each interval $\triangle t_i$ (Fig. 3) the relay N (Fig. 11) is energised, as will hereinafter be described, and the sets of relay contacts N3 and N4 are closed. If a switch on the board RB_1 is pressed the relay F is energised since the terminal 64 is then at a potential of +25 volts. The set of contacts F1 is closed in consequence and either the relay G or the relay H is energised, depending on whether the switch pressed is correct or not. If the switch pressed is incorrect or not. of contacts E1 remains as shown and the relay G is energised and if correct the relay E is energised since the terminal 63 is then at a potential of +25 volts, and the set of contacts E1 changes over so that the relay H is energised. The relay F is a slow-to-make relay in order that the set of relay contacts E1 shall have time to change over before the contact F1 closes if a correct response is made.

The relays G and H are self-holding by the sets of contacts G1 and H1. Thus assuming, as before, that in the position p_i (Fig. 3) a correct response is made at time t_2, the relay H is energised and remains energised until the time t_3 when the relay N is de-energised and the sets of contacts N3 and N4 are opened. The relay H will thus remain energised during the interval δt_i.

If (as already assumed) an incorrect response is made in the position p_{i+1} at time t_5 the relay G is energised and remains energised until the time t_6, that is during the interval δt_{i+1}.

In order that only one response may be effectively made in any position of the co-ordinator, the relay L has its winding connected in series with sets of relay contacts G2 and H2 in parallel between the +25 and −25 volt lines. Whilst either of the relays G or H is energised the relay L is energised and the set of contacts L1 is open. No further inputs can then be provided to the relays E and F by pressing any of the switches of the response board RB_1.

The lamp 37 and the lamp 38 are connected in series with a set of relay contacts G3 and a set of relay contacts H3, respectively, between the +25 volt line and the −25 volt line. Thus when a correct response is made the lamp 38 lights up and when an incorrect response is made the lamp 37 lights up, indicating to the operator whether his response is correct or incorrect.

Referring now to Fig. 10, the marking computer MC_1 comprises two triodes V_1, V_2. The triode V_1 has its anode connected to a +350 volt line through a load resistor R_1 and its cathode connected to earth. The control grid of the triode V_1 is connected to earth through a resistor R_2 and a capacitor C_1 in series and directly to earth through a set of changeover relay contacts G4 when the relay G (Fig. 9) is de-energised. When the relay G is energised the grid is connected to the cathode of a triode V_2. The triode V_2 acts as a cathode follower, having its anode connected direct to the +350 line, its grid connected through a resistor R_3 to the anode of the triode V_1 and its cathode connected through two resistors R_4 and R_5 in series to a −150 volt line.

The grid of the triode V_3 is connected through a resistor R_6 and a set of changeover relay contacts H4 of the relay H to the junction of the resistors R_4 and R_5 when the relay H is de-energised and to the junction of two resistors R_7 and R_8 connected in series between earth and the −150 volt line when the relay H is energised. The grid of the triode V_3 is also connected to earth through a capacitor C_2. The triode V_3 acts as a cathode follower, its anode being connected direct to the +350 volt line and its cathode being connected to earth through a resistor R_9 and to the −150 volt line through a resistor R_{10} in parallel with two resistors R_{11} and R_{12} in series.

The variable θ is represented by the potential on the cathode of the triode V_3. With the sets of contacts G4 and H4 in the position shown, that is when no response has been made, the input to the triode V_1 is held at earth potential and the junction of the resistors R_4 and R_5 is at a steady negative potential, say E_1. The capacitor C_2, assumed to be initially charged as will appear hereinafter, discharges through the resistors R_6 and R_5 and thus the value of θ decreases. When a correct response is made the relay H is operated and the capacitor C_2 is connected through the resistor R_6 to the junction of the resistors R_7 and R_8, which junction is at a higher steady potential, say E_2, than the steady potential E_1. Thus the capacitor C_2 charges up and θ increases, relatively quickly when θ is low and relatively slowly when θ is high. This increase in θ occurs for the duration of the interval δt_i, at the end of which the relay N is energised and the relay H is de-energised.

When an incorrect response is made the relay H remains de-energised and the capacitor C_2 is connected through the resistor R_6 to the junction of the resistors R_4 and R_5, but the potential of this point is made lower than E_1 by feeding back θ through the operated contacts G_4 to the grid of the triode V_1. θ is represented by a positive potential and thus the triode V_1 is caused to conduct more and the triode V_2 to conduct less. The extent to which this occurs depends on the value of θ and an error has a greater effect when θ is high, that is when the operator has been doing well, than when θ is low, that is when the operator has been doing badly.

The cathode of the triode V_3 is also connected through a resistor R_{13} to the grid of a triode V_4. This grid is also connected through a resistor R_{14} to the junction of two resistors R_{16} and R_{17}. A variable resistor R_{15} and the resistors R_{16} and R_{17} are connected in series between earth and the −150 volt line. The cathode of the triode V_4 is connected to a variable tap on the resistor R_{16} and the anode of the triode V_4 is connected to a terminal 39. The triode V_4 acts as a variable resistance passing a relatively large current when θ is high and a relatively low current when θ is low.

Four terminals 40, 41, 42 and 43 for connection through the access controller AC_1 (shown in Fig. 14) to the store ST_1 or the store ST_2 (as indicated in the block diagram in Fig. 2) are connected respectively to a variable tap on the resistor R_4, the junction between two resistors R_{18} and R_{19} connected in series between earth and the −150 volt line, a variable tap on the resistor R_{10} and the junction of the resistors R_{11} and R_{12}. The terminal 40 is connected to the terminal 43 through a resistor R_{57}. A terminal 126 connected to the cathode of the triode V_3 is not used in this embodiment, but is used in the Type II coordinator to be described later.

The terminal 39 is connected to an input terminal 44 of the waveform generator WG_1 shown in Fig. 11, the terminal 44 being connected to the grid of a triode V_5 and through a capacitor C_3 to the cathode of the triode V_5. The triode V_5 also has its grid connected to its cathode through a resistor R_{20} in series with a set of relay contacts N1 which is open when the relay N is energised. The cathode of the triode V_5 is connected to the junction of two resistors R_{21} and R_{22} connected in series between the +350 volt line and earth. The anode of the triode V_5 is connected to the +350 volt line through a resistor R_{33} and to the grid of a triode V_6 through a resistor R_{24}. The triode V_6 functions as a cathode follower and has its anode connected direct to the +350 volt line and its cathode connected to earth through a resistor R_{25}.

The cathode of the triode V_6 is connected to an output terminal 46 for connection to the corrective information computer CI_1, and through a resistor R_{26} to the grid of a triode V_8, which together with a triode V_7, resistors R_{27}, R_{29} and R_{30} and a relay M connected together as shown constitutes a Schmitt trigger circuit of conventional type. The winding of the relay M constitutes the anode load of the triode V_8 and the resistor R_{29} is variable for controlling the backlash of the circuit. The relay M is energised when the waveform V_{sm} (Fig. 3) reaches the trigger level Vt_i.

The grid of the triode V_7 is connected to the −150 volt line through a resistor R_{31} and to a terminal 45 through a resistor R_{32}. The grid of the triode V_8 is connected to the junction of two resistors R_{33} and R_{34}, connected in series between earth and the −150 volt line, through the resistor R_{26} and a resistor R_{36} in series.

The terminal 45 is connected to a terminal 47 of the voltage reader VR_1 (Fig. 13). Thus the instants at which the Schmitt trigger circuit changes over depend upon the potential on the terminal 47 of the voltage reader VR_1, and hence on the terminal 45, and upon the potential on the cathode of the triode V_6 which latter potential in turn depends on the charge on the capacitor C_3. Thus when θ is high and the triode V_4 (Fig. 10) passes a relatively large current the capacitor C_3 charges relatively rapidly, driving the grid of the triode V_5 in a negative direction and thus causing the potential on the cathode of the triode V_6 to rise relatively rapidly.

When the potential on the grid of the triode V_7 is above the potential on the grid of the triode V_8 the triode V_7 is conducting and the triode V_8 is non-conducting and conversely. When the triode V_8 is conducting the relay M is energised. Thus during each interval $\triangle t_i$ the relay M is de-energised. Each interval $\triangle t_i$ is terminated when the potential on the grid of the triode V_8 rises to the potential of the grid of the triode V_7 and the relay M is energised.

The relay M operates a set of changeover contacts M_1 (Fig. 11) which connects one terminal of a capacitor C_4 to the +350 volt line through a resistor R_{37} when the relay M is energised and to earth through a resistor R_{38} when the relay is de-energised. The other terminal of the capacitor C_4 is connected to earth through a resistor R_{39} and to the grid of a triode V_9 through a capacitor C_5 and a rectifier X_1 in series. The grid of the triode V_9 is connected to earth through a resistor R_{40}. The triode V_9 together with a triode V_{10}, resistors R_{41}, R_{42} and R_{43}, a capacitor C_6 and the relay N connected together as shown constitutes a Kipp relay of conventional type. The winding of relay N constitutes the anode load of the triode V_{10}.

The relay M is de-energised in each interval $\triangle t_i$ and accordingly the capacitor C_4 is discharged through the resistors R_{38} and R_{39}. When the relay M is energised the capacitor C_4 is charged through the resistor R_{37} and a positive pulse is applied to the grid of the triode V_9. The triode V_9 then conducts and the triode V_{10} is rendered non-conducting for a short interval, which is the interval u in Fig. 3, and is of a duration determined by the constants of the Kipp relay. The relay N is de-energised in this interval.

The waveform V_{sm} of Fig. 3 may now be discussed in more detail. It is the potential on the grid of the triode V_8 and the trigger levers Vt_i and Vt_{i+1} are potentials on the grid of the triode V_7.

When the potential V_{sm} has risen to the level Vt_i at time t_3, the Schmitt trigger circuit changes state and the relay M is energised. The length of time $\triangle t_i$ taken for this to occur (measured from the instant when the relay N is energised and the set of relay contacts N1 closed, at which instant the waveform V_{sm} begins to rise from the level V_a) depends both on Vt_i and the rate of increase of V_{sm} which depends on θ.

When the relay M is energised, an input pulse is applied to the Kipp relay and the relay N is de-energised for a fixed interval u beginning at time t_3 and ending at time t_4. The set of relay contacts N_1 is closed during this interval and the capacitor C_3 is discharged causing the potential on the cathode of the triode V_6 to fall. The relay M is thus rapidly de-energised again.

Referring to Fig. 12 the uniselector control UC_1 is shown, comprising a uniselector coil 49 connected in series with a set of relay contacts N2 between the +25 volt line and the −25 volt line. When the relay N is de-energised, that is during the interval u the contact N2 is closed and the coil 49 is energised drawing back the ratchet (not shown) of the uniselector. When the relay N is again energised the coil 49 is de-energised and the ratchet released to step the uniselector on to the next position.

Referring to Fig. 13 which shows the voltage reader VR_1 an input terminal 50 is connected to the movable contact of the switch SW_2 (Fig. 2) and thus to either the store ST_1 or the store ST_2, and to an output terminal 51 of the access controller AC_1 (Fig. 15).

The voltage reader VR_1 comprises a triode V_{11} acting as a cathode follower, its grid being connected through a resistor R_{44} to the terminal 50, its anode direct to the +350 volt line and its cathode to earth through a resistor R_{45} and to the −150 volt line through a resistor R_{46}. The cathode of the triode V_{11} is connected to the terminal 47 already referred to through a resistor R_{47}. The capacitors of the store ST_1 or ST_2 are negatively charged, holding a relatively large negative charge when they are associated with a lamp or position in response to which there has been a high previous degree of success. The larger the negative charge, the lower the potential of the terminal 47, and hence of the terminal 45 of the waveform generator (Fig. 11), the potential on which terminal is the trigger level of the Schmitt trigger circuit.

The store ST_1 has already been described in detail. The store ST_2 is shown in Fig. 14. The wiper of the uniselector bank U_5 is connected to one terminal of the switch SW_2 as previously described. The twelve output terminals 48 of the uniselector are numbered p_1 to p_{12} corresponding to the twelve positions of the sequence and are connected to one terminal of the twelve capacitors f_1 to f_{12} respectively, the other terminals of which are connected to earth.

The charges on the capacitors of whichever store is in use are determined by the potentials on the terminals 40, 41, 42 and 43 of the marking computer (Fig. 10) and a set of resistors R_{53}, R_{54}, R_{55} and R_{56} and sets of relay contacts G5 to H5 of the access controller AC_1 (Fig. 15). The resistors R_{53} to R_{56} are connected between four terminals 53 to 56 and the sets of relay contacts as shown and the terminal 51 is connected to the resistor R_{56}. The terminals 53 to 56 are connected to the terminals 40 to 43 respectively. Thus the terminal 51 is permanently connected through the resistor R_{56} to the junction of the resistors R_{11} and R_{12} of Fig. 10. In intervals when no response has been made and in intervals δt_i following an incorrect response the terminal 51 is also connected through the sets of contacts H5 and the resistor R_{54} to the junction of the resistors R_{18} and R_{19}, and in intervals δt_i following an incorrect response also through the set of contacts G5 and the resistor R_{53} to the movable contact on the resistor R_4. In periods δt_i following a correct response in addition to the aforesaid permanent connection the terminal 51 is connected through the set of contacts H5 and the resistor R_{55} to the movable contact on the resistor R_{10}. The values of the resistor R_{53} to R_{56} and the potentials of the points to which the terminals 40 to 43 are connected are so chosen that the capacitor connected to the terminal 51 normally loses negative charge at a relatively slow rate (through the resistors R_{54} and R_{56}), loses negative charge at a relatively fast rate in intervals δt_i following an incorrect response and gains negative charge at a relatively fast rate in intervals δt_i following a correct response. The movable contacts on the resistors R_4 and R_{10} enable the effects which an incorrect and a correct response respectively have on the charge on a capacitor of the store ST_1 or ST_2 to be varied.

In Fig. 16 there is shown the corrective information computer CI_1 which has an input terminal 57 connected to the output terminal 47 of the voltage reader VR_1 (Fig. 13) and an input terminal 58 connected to the terminal 46 of the waveform generator WG_1 (Fig. 11). The potentials on these two input terminals 57 and 58 are combined in an adding network of resistors R_{57}, R_{58} and R_{59} and applied to the grid of a triode V_{12}. The triode V_{12} acts as a cathode follower and has its anode connected to the +350 volt line and its cathode connected to the −150 volt line through a resistor R_{60}. An output terminal 59 is connected to the cathode of the triode V_{12} through a resistor R_{61}. The potential on the terminal 57 is the trigger level Vt_i and the potential on the terminal 58 is the rising potential on the cathode of the triode V_6 (Fig. 11). Thus the output at the terminal 59 in each interval $\triangle t_i$ is a potential rising at a rate determined by θ from a level determined by the voltage reader VR_1 as previously described.

The output terminal 59 is connected to an input terminal 60 of the modulator MD_1 (Fig. 17). The input terminal 60 is connected to the grid of a triode V_{13} having its cathode connected to earth and its anode connected through a resistor R_{62}, the primary winding of an output transformer T_2 and the secondary winding of a mains transformer T_3 to earth. An output terminal 61 is connected through the secondary winding of the transformer T_2 to earth. Thus the current flowing through the terminal 61 is an alternating current modulated by the rising output at the terminal 59 of the corrective information computer CI_1 (Fig. 16). The terminal 61 is connected to the input terminal 26 of the selector SE_2 and to one fixed contact of the switch SW_1.

In a modification (not shown) of the coordinator both the stores ST_1 and ST_2 are used together and the voltage reader VR_1 determines a trigger level dependent on the added effects of an element of the store ST_1 and an element of the store ST_2. Thus, for example, in the position p_1 the input to the voltage reader VR_1 and thus the trigger level Vt_1 is determined by the quantities stored on the element f_1 and the element e_3.

It will be appreciated that an exact description of the way in which the system comprising the operator and the coordinator reaches a state of dynamic equilibrium is not possible. However, to conclude this description of the Type I coordinator the complete sequence of operations in the positions p_i will be described, assuming here that $p_i=p_5$.

Thus referring to Fig. 3, at time t_1 the relay N is energised. The set of contacts N2 open and the uniselector control UC_1 moves on the uniselector banks U_1 to U_5 from the position p_4 to the position p_5. The set of contacts N1 open and the waveform V_{sm} starts to rise from the level V_a at a rate dependent on the value of θ then obtaining. At the same time the sets of contacts N3 and N4 close and allow the relays of the response board RB_1 to function.

The lamp k_1 slowly lights up (the switch SW_1 being assumed to be in the setting shown in Fig. 2) and the lamp m_7 also slowly lights up, indicating directly that the switch s_7 is the correct switch to be pressed. At time t_2 the operator presses the correct switch, namely s_7 and the relays E and F are energised. The set of contacts E1 changes over and subsequently the set of contacts F1 close. Accordingly the relay H is energised. The sets of contacts H1, H2 and H3 close, holding on the relay H, energising the relay L and lighting up the lamp 38 respectively. The relay L opens the set of contacts L1 and the relays E and F cannot again be energised until H has been de-energised.

The set of contacts H4 changes over and the value of θ is caused to increase at a relatively rapid rate. Furthermore the set of contacts H5 changes over and negative charge is added to the capacitor e_1 of the store ST_1 or the capacitor f_5 of the store ST_2, depending on the setting of the switch SW_2. The trigger lever Vt_5 is determined by the potential across either the capacitor e_1 or the capacitor f_5 as the case may be and when the waveform V_{sm} reaches this level, at time t_3, the relay M is energised.

This terminates the position p_5, the relay N being de-energised. The set of contacts N1 closes, causing the waveform V_{sm} to fly back to the level V_a. The set of contacts N2 sets the uniselector control, ready to move on the banks U_1 to U_5 to the position p_6 after the interval u, at time t_4. The sets of contacts N3 and N4 open and the marking relays, including the relay H, are all de-energised.

The sequence of events is similar, *mutatis mutandis*, in the position p_6 in which an incorrect response is made at time t_5.

Turning now to the example of a Type II coordinator, Fig. 19 shows diagrammatically the lamps displayed to the operator and the press button switches to be pressed by the operator. In this embodiment the coordinator operates in a sequence of twelve positions, which will again be referred to as p_1 to p_{12}, and in each position p_i a general lamp h_u of twelve lamps h_1 to h_{12} lights up. These lamps constitute a display DS_3. At the end of each position p_i there is again a short fixed moving on interval of duration u before the start of the next position p_{i+1}.

As previously explained, in a Type II coordinator the form in which responses have to be made differs from that in which signals are given. The responses are made by pressing one of three row switches, sr_1, sr_2 and sr_3 and (not necessarily simultaneously) one of four column switches sc_1, sc_2, sc_3 and sc_4. A full response is made only when one row and one column switch has been pressed. The row and column switches together constitute a response board RB_2. Each combination of one row switch and one column switch defines one of an array of twelve translucent screens n_1 to n_{12}. These bear distinguishing symbols, which are not however shown, in order not to confuse the figure. By way of example, the switches sr_2 and sc_1 define the screen n_5. A one-to-one correspondence is set up between the twelve lamps h_1 to h_{12} and the twelve screens n_1 to n_{12}. Thus as in the description of the Type I coordinator an example of the way in which the coordinator may be set up is given in Table I and the Type II coordinator will be described as set up in this way.

TABLE I

Position in sequence	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}	p_{12}
Lamp of display DS_3 alight	h_{12}	h_{10}	h_8	h_{11}	h_2	h_9	h_7	h_4	h_1	h_5	h_3	h_6
Corresponding location	n_5	n_{12}	n_1	n_9	n_{10}	n_{11}	n_4	n_6	n_2	n_7	n_3	n_8
Row switch to be pressed	sr_2	sr_3	sr_1	sr_3	sr_3	sr_3	sr_1	sr_2	sr_1	sr_2	sr_1	sr_2
Column switch to be pressed	sc_1	sc_4	sc_1	sc_1	sc_2	sc_3	sc_4	sc_2	sc_2	sc_3	sc_3	sc_4

Corrective information is supplied to the operator by three row lamps mr_1, mr_2 and mr_3 and four column lamps mc_1, mc_2, mc_3 and mc_4 constituting a second display DS_4. A lamp 100 lights up when a correct response is made and lamp 101 when an incorrect response is made. A response is deemed incorrect when either an incorrect row or column switch is pressed or when both switches pressed are wrong.

In addition the coordinator has a third display DS_5 comprising twelve lamps mm_1 to mm_{12}, the lamp mm_1 being under the screen n_1, the lamp mm_2 under screen n_2 and so on.

In the interval u following the end of a position p_i the lamp of the display DS_5 under the screen which should have been defined by a row and a column switch for a correct response lights up. Thus the operator, in cases where he makes an incorrect response or no response, is supplied with information as to the response he should have made. This information is of course different from the corrective information supplied by the display DS_4 as it is never supplied early enough to help the operator make a correct response in the position in which the coordinator then is.

The operation of the coordinator will now be contrasted with the operation of the Type I coordinator, with reference to Fig. 20.

Again a marking variable θ normally decreases slowly, decreases relatively rapidly when an incorrect response is made (whether it be a row or a column response) until the end of the position in which the incorrect response is made and increases relatively rapidly when a completely correct response is made until the end of the position in which the completely correct response is made. Thus two consecutive positions p_i and p_{i+1} are again shown, starting at t_{10} and t_{16} respectively and ending at t_{13} and t_{19} respectively. In the position p_i a correct row response is assumed to be made at time t_{14} and a correct column response at time t_{15}. θ accordingly increases from t_{15} to t_{13}. In the position p_{i+1} an incorrect row response is assumed to be made at time t_{20} and a correct column response at time t_{21}. θ accordingly decreases relatively rapidly from t_{20} to t_{19}.

Again the duration of the positions p_i is determined by a waveform V_{sm} which rises at a rate dependent on θ to a trigger level V_t, which is, however, fixed in the Type II coordinator. Thus the increase in the rate of operation of the coordinator is a general increase as θ increases, and not a "patterned" increase as in the case with the Type I coordinator.

Because in the Type II coordinator there are two marking categories, that is a row catergory and a column category (the operator may make a correct or incorrect response in either category), it is not satisfactory to measure intervals of time corresponding to the intervals of time δt_1 (Fig. 3) from the instant at which a response is made to the end of the position in which the response is made. Accordingly in each position p_i two further instants of time are defined by two subsidiary trigger levels $Vt_{r(i)}$ and $Vt_{c(i)}$ and will be called the row limit time and the column limit time respectively. These two times are at t_{11} and t_{12} in the position p_i and at t_{17} and t_{18} in the position p_{i+1}.

These two trigger levels are determined by two stores ST_r and ST_c respectively, each comprising, as will be described, twelve capacitors storing negative charges whose magnitude is a measure of the previous degree of success averaged over a number of sequences in making a row response or a column response as the case may be, in each position p_i. Apart from the slow leakage of charge occurring from the capacitors, the charge on a row capacitor is only altered in an interval between a row response (e.g. t_{14}) and the row limit time (e.g. t_{11}), and then only if the row response is made before the said time. When an alteration in the negative charge is made, it is increased in magnitude if the response is correct and decreased in magnitude if the response is incorrect. Similar remarks, *mutatis mutandis*, apply to column responses.

Thus referring again to Fig. 20, in the position p_i no alteration is made in the charge of the row capacitor because although a correct row response is made (at time t_{14}) it is not made before the time t_{11}. The magnitude of charge on the column capacitor is increased in an interval $\delta t_{c(i)}$ beginning at time t_{15} at which a correct column response is made and ending at the column limit time t_{12}. In the position p_{i+1} the magnitude of the charge on the row capacitor is decreased in an interval $\delta t_{r(i+1)}$ following the incorrect row response at time t_{20} and the magnitude of the charge on the column capacitor is increased in an interval $\delta t_{c(i+1)}$ following the correct column response at time t_{21}.

Thus trigger levels $Vt_{r(i)}$ and $Vt_{c(i)}$ are determined by the charge on the row and column capacitors, respectively, associated with the position p_i, the levels being relatively low when the charge is of relatively great magnitude.

Furthermore the corrective information given to the operator by the display DS_5 is withdrawn in a "patterned" manner dependent on the charges on the capacitors of the two stores in a manner essentially the same as that in the Type I coordinator.

Referring now to the block circuit diagram Fig. 21, the twelve positions of the coordinator are determined by an eight bank, twelve position uniselector having banks U_6 to U_{13} controlled by a uniselector control UC_2.

The first bank U_6 feeds the display DS_3 through a terminal block TB_4 and determines which lamp of the display DS_3 lights up in each position. The intensity with which the lamp lights up and the intensity of a background illumination of all the lamps, which causes ambiguity in the instructions to the operator, are determined by an "ambiguity modulator" AM_1. When θ is high the intensity of the background illumination is made high and *vice versa*. The intensity of the selected lamp is arranged to increase from a level proportional to the average value of $Vt_{r(i)}$ and $Vt_{c(i)}$ in the position p_i. Thus as the operator progresses the coordinator gives him instructions in an increasingly ambiguous fashion. Moreover this increases in ambiguity is "patterned" in the sense used above.

The uniselector bank U_7 feeds the display DS_5 through a terminal block TB_5 and determines which lamp of this display lights up. The selected lamp lights up in the interval u after a position p_i since the wiper of the uniselector bank is connected to a source of potential through a set of relay contacts Na5 of a relay Na (Fig. 24) which is closed in the intervals u, as will be described hereinafter.

The uniselector banks U_8 and U_9 feed the response board RB_2 (constituted by the switches sr_1 to sr_3 and sc_1 to sc_4) through two terminal blocks TB_6 and TB_7 respectively. The output from the response board RB_2 is fed to a set of marking relays MR_2 which controls the state of a marking computer MC_2, which is in essence the same as that described for the Type I coordinator, and which computes the variable θ from its state.

One output from the marking computer goes to a waveform ganerator WG_2 generating the waveform V_{sm} (Fig. 20) and controls the rate of rise of the waveform V_{sm} in each position p_i. The waveform generator controls the uniselector control UC_2 in the same way as the generator WG_1 controls UC_1 in the type I coordinator.

Another output from the marking computer is fed through an access controller AC_r and the uniselector bank U_{10} to the store ST_r and through an access controller AC_c and the uniselector bank U_{11} to the store ST_c. The access controllers AC_r and AC_c are in essence the same as the access controller AC_1 of the Type I coordinator, but the state of the access controller AC_r is determined by two relays of the marking relays MR_2 one of which, as will hereinafter be described, is energised in any interval $\delta t_{r(i)}$ in the position p_i, which of the relays is energised depending on whether the interval $\delta t_{r(i)}$ is initiated by a correct or an incorrect response. Likewise the state of the access controller AC_c is determined by two relays of the marking relays MR_2, one of which, as will hereinafter be described, is energised in any interval $\delta t_{c(i)}$ in the position p_i.

Two voltage readers VR_r and VR_c are in essence the same as the voltage reader VR_1 of the Type I coordinator and have their inputs connected to the stores ST_r and ST_c respectively through the uniselector banks U_{12} and U_{13} respectively. The outputs from the voltage readers VR_r and VR_c are the trigger levels $Vt_{r(i)}$ and $Vt_{c(i)}$ respectively and are fed to the waveform generator WG_2, to the ambiguity modulator AM_1 and to a corrective information computer CI_r and a corrective information computer CI_c respectively.

The corrective information computers CI_r and CI_c are in essence the same as the corrective information computer CI_1 of the Type I coordinator and add the trigger levels $Vt_{r(i)}$ and $Vt_{c(i)}$ respectively (obtained from the voltage readers VR_r and VR_c respectively) to the wave form V_{sm} obtained from the waveform generator WG_2. The outputs from the corrective information computers CI_r and CI_c are fed to a modulator MD_r and a modulator MD_c respectively. The modulators MD_r and MD_c are in essence the same as the modulator MD_1 of the Type I coordinator and their outputs are fed to the display DS_5 through the uniselector banks U_{12} and U_{13}

respectively and terminal boards TB_8 and TB_9 respectively.

The display DS_5 is also controlled by two relays of the waveform generator WG_2 which allows the row lamps mr_1 to mr_3 to light up only after the row limit time and the column lamps mc_1 to mc_4 to light up only after the column limit time.

The ambiguity modulator AM_1 is connected to the outputs of the voltage readers VR_c and VR_r and to outputs of the marking computer MC_2 and the waveform generator WG_2, and controls the lamps of the display DS_3 in the manner hereinbefore described, in response to the input signals thus obtained.

Considering now the detailed construction of the coordinator and referring first to Fig. 22, twelve output terminals 102 of the uniselector bank U_6 are connected respectively to twelve input terminals 103 of the terminal block TB_4. The twelve lamps h_1 to h_{12} of the display DS_3 are connected in series with twelve resistors R_{70} to R_{81} respectively between earth and a terminal 104. Twelve output terminals 105 of the terminal block TB_4 are connected to the junctions respectively of the lamps h_1 to h_{12} and the resistors R_{70} to R_{81}.

When a potential is applied to the terminal 104 (from the ambiguity modulator AM_1—Fig. 28), all the lamps h_1 to h_{12} light up with a background illumination. A suitable potential applied to the wiper of the blank U_6 (from the ambiguity modulator AM_1) causes one lamp to light up with a greater intensity than the others, this lamp indicating the response which is to be made. As will be seen, the connections in the terminal block TB_4 are such that in each position p_i the lamp h_u which lights up with a greater brightness is that shown in Table I. In the position shown, namely p_5, this lamp is h_2.

Referring to Fig. 23, the wiper of the uniselector bank U_7 is connected through the set of relay contacts N*a*5 to the +25 volt line. The twelve outputs 106 of the bank U_7 are connected to twelve input terminals 107 respectively of the terminal block TB_5, twelve output terminals 108 of which are connected to one terminal of the twelve lamps mm_1 to mm_{12} respectively of the display DS_5. The other terminals of these lamps are connected to earth.

It will be seen that for the duration of an interval u following a position p_i, whilst the set of relay contacts N*a*5 is closed, the lamp of the display DS_5 which is under the screen n_u corresponding to the position p_i lights up (Table I). Thus following the position p_5 the lamp mm_{10} lights up. In this connection it will be appreciated that, as in the Type I coordinator the uniselector steps on from a position p_i to a position p_{i+1} at the beginning of the position p_{i+1}.

Referring now to Fig. 24 the same principle is used to energise the switches of the response board RB_2 as is used in the Type I coordinator, although a " permutator ", a set of " control relays " and a " selector " are not used, the upper half of each of the row switches sr_1 to sr_3 being connected to the +25 volt line through the uniselector bank U_8 and the terminal block TB_6 and the upper half of each of the column switches sc_1 to sc_4 being connected to the +25 volt line through the uniselector bank U_9 and the terminal block TB_7. The response board RB_2 has four output terminals 109, 110, 111 and 112. As will be seen from the diagram these terminals are energised under the following conditions: terminal 109 when any row switch is pressed, terminal 110, when a correct row switch is pressed, through the uniselector U_8, terminal 111, when any column switch is pressed, and terminal 112, when a correct column switch is pressed, through the uniselector U_9.

The terminals 109, 110, 111 and 112 are connected to four input terminals 113, 114, 115 and 116 respectively of the marking relays MR_2 shown in Fig. 25. As will be seen from this figure a set of row relays Er, Fr, Gr, Hr and Lr and a set of column relays Ec, Fc, Gc, Hc and Lc both in essence duplicate and function in like manner to the set of relays E, F, G, H and L of the Type I coordinator (Fig. 9). Thus the relay Gr is energised through the sets of contacts Na2, Fr1 and Er1 in an interval beginning with an incorrect row response in the position p_i and ending with the end of the position p_i. Likewise the relay Hr is energised through the same sets of contacts Na2, Fr1 and Er1 in an interval beginning with a correct row response in the position p_i and ending with the end of the position p_i. However the lamp 100 indicating a correct response (corresponding to the lamp 37 in Fig. 9) is connected in series with sets of relay contacts Hr4 and Hc4 and is alight only in an interval beginning with the later response of both a correct row response and a correct column response and ending with the end of the position in which the responses are made. A relay J in parallel with the lamp 100 is energised in such an interval and operates a set of changeover contacts in the marking computer MC_2 as will be described hereinafter. Furthermore the lamp 101 indicating an incorrect response (corresponding to the lamp 38 in Fig. 9) is connected in series with sets of relay contacts Gr4 and Gc4 in parallel and is alight in an interval beginning with either an incorrect row response or an incorrect column response and ending with the end of the position in which the response is made. A relay K in parallel with the lamp 101 is energised in such an interval and operates a set of changeover contacts in the marking computer MC_2 to be described hereinafter.

Two further row relays are provided, namely a relay Pr having its winding connected in series with two sets of relay contacts Gr3 and Sr1 and a relay Qr having its winding connected in series with a set of relay contacts Hr3 and the set of relay contacts Sr1. The set of relay contacts Sr1 are of a relay Sr of the waveform generator shown in Fig. 26 and are closed at the beginning of a position p_i and remain closed until the row limit time is reached as will be hereinafter described. Accordingly in a position p_i the relay Pr is energised for the duration of an interval beginning with an incorrect row response made before the row limit time is reached and ending with the row limit time and the relay Qr is energised for an interval beginning with a correct row response made before the row limit time is reached and ending with the row limit time.

Two relays Qc and Pc and sets of relay contacts Sc1, Gc3 and Hc3 act for column responses in the same way as the relays Qr and Pr and the sets of contacts Sr1, Gr3 and Hr3 act for row responses. The sets of contacts Sc1 are of a relay Sc, again in the waveform generator WG_2. The relays Pr and Qr control the state of the access controller AC_r and the relays Pc and Qc control the state of the access controller AC_c.

The circuit diagram of the marking computer MC_2 is not drawn separately as it is the same as Fig. 10 except that the set of relay contacts G4 are now a set of relay contacts of the relay K shown in Fig. 25, and will be referred to as K1 and the set of relay contacts H4 are now a set of relay contacts of the relay J, and will be referred to as J1. The variable θ (Fig. 20) is again the potential on the cathode of the triode V3 (Fig. 10). The output terminal 39 is connected to an input terminal 117 of the waveform generator WG_2 (Fig. 26) corresponding to the input terminal 44 of the generator WG_1 of Fig. 11.

In the waveform generator WG_2 triodes V_{14}, V_{15}, V_{16}, V_{17}, V_{18} and V_{19}, relays Ma and Na, sets of relay contacts Ma1 and Na1 and associated resistors R_{82} to R_{103}, capacitors C_7 to C_{10} and rectifier X2 correspond respectively to the triodes V_5, V_6, V_7, V_8, V_9 and V_{10}, the relays M and N, the sets of relay contacts M1 and N1 and the associated resistors, capacitors and rectifier of the waveform generator WG_1, with the one difference (apart from any in component values) that the terminal 45 (Fig. 11) is now connected to the +350 volt line. Thus the trigger level of the Schmitt trigger circuit comprising triodes V_{16} and V_{17} is fixed and is the trigger level V_1 shown in Fig. 20. The waveform V_{sm} in Fig. 20 is the potential on the grid of the triode V_{17}. The relay Na is, like the relay N, energised during the intervals u. An output terminal 118 for connection to the corrective information computers CI_r and CI_c is connected to the cathode of the triode V_{15}.

The waveform generator WG_2 also comprises two further Schmitt trigger circuits similar to that comprising the triodes V_7 and V_8 in Fig. 11. The first of these comprises triodes V_{20} and V_{21}, resistors R_{104}, R_{105} and R_{106} and the relay Sr connected together as shown. The control grid of the triode V_{20} is connected to the −150 volt line through a resistor R_{107} and to a terminal 119 through a resistor R_{108}. The control grid of the triode V_{21} is connected to the cathode of the triode V_{15} through a resistor R_{109} and to the junction of two resistors R_{110} and R_{111} connected between earth and the −150 volt line through a resistor R_{112}.

Thus the relay Sr is energised in a position p_i when the waveform V_{sm} reaches the potential on the grid of the triode V_{20}, which is arranged, as will be hereinafter described, to be the trigger level $Vt_{r(i)}$, and remains energised until very shortly after the end of the position p_i, when owing to the closing of the set of contacts Na1, and the consequent discharge of the capacitor C_7 which leads to the fall in the potential on the cathode of the triode V_{15}, the relay is de-energised.

The second of the further Schmitt trigger circuits comprises triodes V_{22} and V_{23}, resistors R_{113} to R_{121}, the relay Sc and a terminal 120 which components correspond exactly to the triodes V_{20} and V_{21}, resistors R_{104} to R_{112}, the relay Sr and the terminal 119. The relay Sc is energised in a position p_i when the waveform V_{sm} reaches the potential on the grid of the triode V_{22}, which is arranged, as will hereinafter be described, to be the trigger level $Vt_{c(i)}$ and remains energised until very shortly after the end of the position p_i. The uniselector control UC_2 is the same as the uniselector control UC_1 (Fig. 12) except that the set of relay contacts N2 is now a set of the relay Na and is named Na2.

The trigger levels $Vt_{r(i)}$ and $Vt_{c(i)}$ are determined by the potentials on the terminals 119 and 120 respectively which potentials are provided by the voltage readers VR_r and VR_c respectively. Each of these is the same as the voltage reader VR_1 shown in Fig. 13, but for convenience the terminals 47 and 50 will be given subscripts r and c according to whether they belong to the reader VR_r or the reader VR_c. This same convention will be adopted for the access controllers AC_r and AC_c, the corrective information computers CI_r and CI_c and the modulators MD_r and MD_c all of which are in essence the same as the access controller AC_1 of Fig. 15, the corrective information computer CI_1 of Fig. 16 or the modulator MD_1 of Fig. 17 as the case may be.

The stores ST_r and ST_c are in essence the same as the store ST_2 of Fig. 14. The terminals 40, 41, 42 and 43 of the marking computer MC_2 of Fig. 10 are connected to the four terminals 53_r, 54_r, 55_r and 56_r respectively of the access controller AC_r of Fig. 15 and to the four terminals 53_c, 54_c, 55_c and 56_c respectively of the access controller AC_c of Fig. 15.

In the access controller AC_r the sets of relay contacts G_5 and H_5 in Fig. 15 become sets of relay contacts Pr1 and Qr1 respectively, and in the access controller AC_c the sets of contacts G5 and H5 become sets of contacts Pc1 and Qc1 respectively.

The terminals 51_r and 51_c of the access controllers AC_r and AC_c respectively are connected to the wipers of the uniselector banks U_{10} and U_{11} respectively and to the terminals 50_r and 50_c of the voltage readers VR_r and VR_c respectively.

The terminal 118 of the waveform generator WG_2 is connected to the terminals 58_r and 58_c of the corrective information computers CI_r and CI_c respectively (Fig. 16) and to a terminal 123 of the ambiguity modulator AM_1 (Fig. 28). The terminals 47_r and 47_c of the voltage readers VR_r and VR_c of Fig. 13 are further connected to the terminals 57_r and 57_c of the two corrective information computers respectively and to two input terminals 121 and 122 respectively of the ambiguity modulator AM_1 (Fig. 28). The output terminals of 59_r and 59_c of the corrective information computers are connected to the input terminals 60_r and 60_c respectively of the modulators MD_r and MD_c respectively of Fig. 17, the output terminals 61_r and 61_c respectively of which are connected to the wipers of the uniselector banks U_{12} and U_{13} respectively, which are shown in Fig. 27.

In Fig. 27, the output terminals of the bank U_{12} are connected through the terminal block TB_8 (which has the same connections as the terminal block TB_6 of Fig. 24) to one terminal of each of the three lamps mr_1 to mr_3 respectively, of the display DS_5, the other terminals of which are connected to earth through a set of relay contacts Sr2 which are closed in a position p_i only after the row limit time for that position has been reached. Similarly the outputs of the bank U_{13} are connected through the terminal block TB_9 to one terminal of each of the lamps mc_1 to mc_4 respectively, the other terminals of which are connected to earth through a set of relay contacts Sc2.

It will be appreciated that the inputs to the two groups of lamps of the display DS_5 increase from levels dependent on variable trigger levels ($Vt_{r(i)}$ or $Vt_{c(i)}$) at a rate dependent on θ in the same way as the inputs to the lamps of the display DS_2 of the Type I co-ordinator increase from a level dependent on the variable trigger level Vt_i (Fig. 3) at a rate dependent on θ. However on account of the sets of contacts Sr2 and Sc2 the corrective information in the two categories (row and column) is never presented in time for responses to be made which vary the charges on the capacitors of the stores ST_r and ST_c, although of course row and column responses made after the row limit times and the column limit times respectively alter the marking variable θ.

Turning now to the ambiguity modulator AM_1 shown in Fig. 28, this comprises two stages, each of which is basically similar to a corrective information computer (Fig. 16) feeding a modulator (Fig. 17). Thus the first stage comprises a network of adding resistors R_{122}, R_{123}, R_{124} and R_{125} from which a potential which is the sum of potentials proportional to the trigger levels $Vt_{r(i)}$ and $Vt_{c(i)}$ and the waveform V_{sm} (Fig. 20) is applied to the control grid of a triode V_{24} acting as a cathode follower. The triode V_{24} has its anode connected to the +350 volt line and its cathode connected to the −150 volt line through a resistor R_{126} and to the control grid of a triode V_{25} through a resistor R_{127}.

The triode V_{25} together with a resistor R_{128} and two transformers T_4 and T_5 constitute a modulator, the secondary winding of the transformer T_5 being split to provide a modulated 50 c.p.s. output potential to a terminal 124 and a similar output potential to the cathode connected to the wiper of the uniselector bank of a rectifier X3. The terminal 124 is U_6, a modulated potential of increasing amplitude thus being applied to the lamp of the display DS_3 selected by the bank U_6.

The anode of the rectifier X3 is connected to earth through a resistor R_{129} and a capacitor C_{11} in parallel. Accordingly a negative rectified potential is integrated across the capacitor C_{11} and this potential is applied to one end of a resistor R_{130}. A further input terminal 125 is connected to the terminal 126 of the marking computer of Fig. 10, which terminal is at the potential θ, and accordingly the potential θ is applied to the terminal 125. This terminal is connected to one end of a resistor R_{131} and the other ends of this resistor and the resistor R_{130} are connected to earth through a resistor R_{132} and to the control grid of a triode V_{26}. Accordingly the potential on the grid of the triode V_{26} is the algebraic sum of a negative potential of amplitude proportional to the amplitude of the envelope of the output at terminal 124 and a positive potential proportional to θ. The triode V_{26} with a cathode load resistor R_{133} acts as a cathode follower feeding a modulator comprising a triode V_{27}, two resistors R_{134} and R_{135}, two transformers T_6 and T_7 and an output terminal 127.

It will be seen that the amplitude of the modulated output at the terminal 127 is increased when θ increases but decreased when the amplitude of the modulated output at the terminal 124 is high. Furthermore the 50 c.p.s. carriers at the terminals 124 and 127 are arranged to be in phase. The terminal 127 is connected to the terminal 104 of the display DS_3 in Fig. 20. Thus all the lamps of the display DS_3 are lit with a brightness which is relatively high when θ is high unless the trigger levels $Vt_{r(i)}$ and $Ct_{c(i)}$ are high for the position p_i in which the co-ordinator is at any instant, but this brightness decreases throughout the duration of the position p_i, whilst the lamp selected by the uniselector bank U_6 is lit with a brightness which is relatively high when the trigger levels $Vt_{r(i)}$ and $Vt_{c(i)}$ are high and which increases throughout the duration of the position p_i.

Turning now to the Type III co-ordinator, this will be described in detail in conjunction with a brief description of a radar training apparatus employing the co-ordinator. Fig. 30 is a block diagram of the complete apparatus, one of the blocks representing the operator OP. The apparatus comprises a P.P.I. display unit DI with a cathode ray tube screen 200 on which a target aircraft is represented by a double spot of light 201 and a pursuing aircraft by a single spot of light 202. The positions of these spots of light are controlled by a radar simulator RS, that of the single spot 202 in response to adjustment of controls of the simulator by the operator and that of the double spot 201 in response to an input to the simulator from the Type III co-ordinator CO. Both the operator and the co-ordinator receive information from the P.P.I. display unit, the operator visually and the co-ordinator electrically.

The operator, by manipulation of the controls of the radar simulator attempts to bring the single spot 202 into coincidence with the double spot 201. The co-ordinator determines an "escape strategy" for the spot 201, adapting this strategy to the operator's ability. It will be appreciated that this strategy cannot be a purely evasive strategy in which the spot 201 always moves directly away from the spot 202, as the operator would always then know what the spot 201 would do at any instant. Accordingly the system adopted in this apparatus is to define two pairs of "pure target strategies", namely:—

1. Move up, represented by SI
   or Move down, represented by SII.
2. Move left, represented by SIII
   or Move right, represented by SIV.

These four strategies may be regarded as the axes of a four-dimensional message space and the output of the co-ordinator as a vector in this space, having components α(SI), β(SII), γ(SIII) and δ(SIV), where α, β, γ and δ, are weighting functions. Thus the co-ordinator determines a mixed strategy by determining the magnitudes of α, β, γ and δ, representing them as four potentials applied by the co-ordinator to the simulator. A further output from the co-ordinator to the simulator may be another potential representing the magnitude of a marking variable θ (analogous to the marking variables θ described in connection with the Type I and the Type II co-ordinators). This potential may be used to control the speed or other characteristic of the target aircraft, or the sensitivity of the actuation of the knobs controlled by the operator.

The radar simulator derives from these five potentials the signals which are fed to the P.P.I. display to control the rate and direction of movement of the spot 201. In one embodiment these five potentials are applied to servo-mechanisms which control the rate of turn and velocity of the target aircraft, also receiving signals enabling them to take account of the prevailing rate of turn and velocity at each instant. However the means provided in the simulator for deriving the said signals do not form part of this invention and are accordingly not described: they are made such that the motion of the spot 201 is realistic, that is, it does not do anything which a spot of light representing a real aircraft cannot do.

The input to the co-ordinator may similarly be regarded as a vector in a four-dimensional message space although the actual input vector employed, as will be hereinafter described, is a vector having components α^1(MI), β^1(MII), γ^1(MIII) and δ^1(MIV), where MI to MIV represent four marking categories, determined by the four quadrants of a set of Cartesian co-ordinates with their origin at the spot of light 202, representing the pursuing aircraft. Thus, for example, the category MI corresponds to the spot of light 201 being in the upper right quadrant. The other correspondences are listed in Table II below.

However each marking category in actual fact corresponds to a pure strategy, since for example, when the category MI obtains it implies that the operator has been employing that strategy which brings the spot 202 into the relationship with the spot 201 defined by this category.

Of the weighting functions α^1, β^1, γ^1 and δ^1 at any instant a selected one is made proportional to the marking variable θ and the others are made zero.

Before proceeding with the description of Fig. 31 and the detailed description of the parts of the co-ordinator, a general description of the nature and mode of operation of the trainable assemblage employed therein will be given. The assemblage is of very wide applicability in training co-ordinators wherein a strategy has to be determined.

The assemblage comprises a store with sixteen capacitors acting as storage elements. The capacitors are charged negatively by a negative potential which increases in magnitude with an increasing degree of success of the operator.

Each capacitor is connected in series with a thermistor, which controls the access of charge to the capacitor.

Each thermistor is indirectly heated by a resistor. The potential applied to each resistor is determined by two "access controllers". Thus the sixteen capacitors are arranged in four columns and four rows, each row and column having four capacitors therein. One access controller controls the access of charge to the four coloumns and the other to the four rows of capacitors.

The four columns correspond to the four marking categories MI to MIV and the four rows to the four strategies SI to SIV. The two access controllers each provide four output potentials, which are the potentials applied to the heating resistors. Thus the first output potential provided by the column access controller and the first output potential provided by the row access controller are combined in an adding network to provide the potential to the heating resistor associated with the capacitor in the first column and the first row. Whilst a simple adding network is employed to derive the potential applied to the heating resistor and at any instant the two potentials from the access controllers are added, the term "combined" has been used in preference to "added". This is because over a period of time the effect of the adding network is not in general to produce an effect which is the sum of the separate effects of the separate potentials, but rather an effect which is between additive and multiplicative. This is so because the heating resistor is a leaky heat-sink. If a high potential has been applied to the adding network from the column access controller the heating resistor is made hot and the heat only slowly leaks away. Therefore for some time thereafter the access of charge to the associated capacitor is relatively high. The heating resistor, thermistor and capacitor form a link in a feedback loop to and from the row access controller and whilst the access of charge to the capacitor is high, the loop gain of this loop is high. If therefore a high potential is provided from the row access controller whilst the loop gain is high the effect of this potential is multiplied with the effect of the potential from the column access controller which caused the loop gain to be high.

Feedback circuits are provided in each access controller the effect of which is to cause different output potentials to become high in succession. In the absence of forcing inputs, hereinafter described, all possible states of the output vector from each access controller (the vector whose components are the output potentials from the controller) occur at some instant, and over a very long period of time with the same frequency. Thus in the absence of forcing inputs the access controllers behave in a random manner.

The four potentials provided by the row access controller are employed as the output of the co-ordinator, as well as for controlling the access of charge to the rows of capacitors. Thus the four potentials are of magnitude α, β, γ and δ and are applied to control the spot 201 (the target aircraft) in the manner already indicated.

As so far described the co-ordinator determines a random sequence of strategies and in the absence of any input the behaviour of the output from the column access controller is similar. The co-ordinator behaves in this manner in order to find a pattern of behaviour of the operator, that is to say some change in the values of the input variables which correlate in any manner, which is possibly a very complicated and time-dependent manner, with the strategies it has adopted and the changes which give rise to them. In order to maintain this search process it is necessary to make the co-ordinator pass through all possible states. Thus, in the absence of an input, apart from changing its output vector, the machine must change through all possible states of receptiveness, since, being in ignorance of what strategy the operator will adopt, it must pass through states which render it sensitive to receiving any of the strategies. Further these states of receptiveness must be conditional upon each possible strategy that is determined by the co-ordinator and each possible time relationship between all of the changes mentioned.

A pattern is imposed on the strategies by providing forcing inputs to the two access controllers. The forcing input to the column access controller is such as to tend to make high the output potential corresponding to the marking category determined at any time (in a manner to be described hereinafter). The forcing input to the row access controller tends to prevent any output potential becoming high when any capacitor in the row of capacitors, the access of charge to which is partially determined by that potential, has a large quantity of charge on it. This latter forcing input is derived as a feedback from the rows of capacitors.

Thus if the co-ordinator has followed a strategy in which the operator has done well, θ will be high, and since when a particular strategy is emphasised the access to the corresponding row of capacitors is made high, one or more of the capacitors of this row will charge up relatively rapidly. This in turn will provide a forcing input to the row access controller and the co-ordinator will tend to change the strategy.

It may be of assistance to point out that there is an analogy between the co-ordinator and the mathematical process of solving a vector (the input vector to the store) in terms of a matrix (the matrix of the magnitudes of the charges on the capacitors of the store) to give a resultant vector (the output vector). The analogy is only partial, mainly on account of the way the different variables involved are dependent on the previous history of the co-ordinator.

Now referring to Fig. 31, which is a block diagram of the Type III co-ordinator CO, four input terminals 203, 204, 205 and 206 are provided, to which are applied, from the display DI of Fig. 30, four potentials representative of X, the x-co-ordinate of the spot 201; X^1, the x-co-ordinate of the spot 202; Y, the y-co-ordinate of the spot 201; and Y^1, the y-co-ordinate of the spot 202, respectively, measured on a set of Cartesian co-ordinates in the plane of the screen 200. The potentials may, for example, be derived from potentiometers, the positions of whose movable contacts represent co-ordinates of the spots of light.

Two subtracting amplifiers AA_1 and AA_2 (which may be of any suitable known form) are connected to the terminals 203 and 204 and the terminals 205 and 206 respectively and provide output potentials of amplitude $p(X—X^1)$ and $p(Y—Y^1)$ respectively, where p is a constant. These potentials are fed firstly to an adding amplifier AA_3 which (using any suitable known circuitry) provides an output potential $\phi=q(|X—X^1|+|Y—Y^1|)$, where q is a constant. Thus the potential ϕ is a measure of the deviation of the spot 202 from the spot 201. Alternatively the adding amplifier AA_3 may provide an output potential $\phi=q^1[(X—X^1)^2+(Y—Y^1)^2]$, which is then a better measure of the deviation. The potential ϕ is fed as one input to a marking computer MC_3. The potentials $p(X—X^1)$ and $p(Y—Y^1)$ are fed secondly to a " selector " SE_4 and set the state of two relays DD and LL therein (shown in Fig. 32 to be described hereinafter). The relay DD is energised only when $p(Y—Y^1)$ is negative and the relay LL is energised only when $p(X—X^1)$ is negative.

The relays DD and LL together may assume four states, each of which defines one of the four relationships between the spot 201 and 202 previously referred to, namely which quadrant of a set of Cartesian co-ordinates with their origin at the spot 202 the spot 201 is in. These states and the relationships they define are listed below in Table II, together with the symbols MI to MIV used to denote these four different relationships, each of which defines a marking category, and is in direct correspondence with a previously adopted pure strategy as previously described.

TABLE II

State of relays	Quadrant of spot 201	Marking Category
DD de-energised, LL de-energised	Upper, right	MI
DD energised, LL de-energised	Lower, right	MII
DD de-energised, LL energised	Upper, left	MIII
DD energised, LL energised	Lower, left	MIV

The marking computer MC_3 also receives an input from two access controllers AC_2 and AC_3 to be described later with reference to Fig. 33, from which it computes a variable ϕ^1, again represented as a potential, representative of the expected deviation of the spot 201 from the spot 202. A marking variable θ, varying between 0 and a fixed limit is computed, and is a measure of the difference between ϕ and ϕ^1, that is between the measured and the expected deviation of the spot 201 from the spot 202. θ is made small when the difference between ϕ and ϕ^1 is large, and large when the difference is small. Thus when θ is large the operator is achieving a high degree of success and conversely. The marking computer provides two outputs, one a positive potential and the other a negative potential, both representative in magnitude of θ. The negative potential is fed to a store ST_5 and the positive potential is fed to the selector SE_4 and to an output terminal 207.

The store ST_5 comprises sixteen capacitors, as will be described with reference to Fig. 34, arranged in four columns corresponding to the marking categories MI to MIV and four rows corresponding to the four pure strategies SI to SIV.

The negative potential representative of θ acts as a charging potential for the capacitors. The access of charge to the capacitors is controlled, however, by the two access controllers AC_2 and AC_3. In physical terms this means that the resistances through which the capacitors are charged are varied by the access controllers.

The access controller AC_2 is a column access controller and, as will be explained in the description relating to Fig. 33, comprises four control devices controlling the access of charge to the capacitors of the four columns respectively. Each of the four control devices is controlled firstly by a feedback from the other three devices and secondly by a forcing input which is the positive potential proportional to θ, fed from the marking computer MC_3, through the selector SE_4 to one of the control devices. At any instant the positive potential is fed to the control device corresponding to the marking category defined at that instant by the relays DD and LL. In the absence of this forcing input the devices, on account of the feedbacks, go through a succession of states in which the access of charge to capacitors in different columns is made relatively high. In physical terms, when the access to any capacitor is high, the resistance through which it charges is relatively low. The forcing input favours making the access to the appropriate column relatively high to an extent proportional to the magnitude of θ.

The access controller AC_3 is a row access controller, identical with the access controller AC_2 and comprising four control devices controlling the access of charge to the capacitors of the four rows respectively. Again each control device receives a feedback input from each of the other three devices and a forcing input. The forcing input to the four devices are negative potentials fed from the store ST_5 to the access controller AC_3 and proportional to the sum of the potentials across the capacitors of the four rows of capacitors respectively.

The output circuits of the control devices of the controlled AC_3 are connected to the store ST_5 to control the access of charge to the rows of capacitors thereof and are also connected to a set of output relays OR_1. The set OR_1, hereinafter described with reference to Fig. 35, comprises four relays associated with the four devices of the row access controller AC_3 respectively. Each relay is energised when the output potential from the corresponding device is above a certain level and de-energised when the output potential is below that level. The output from the co-ordinator is taken from four terminals 208, 209, 210 and 211 also connected to the output circuits of the four control devices respectively of the controller AC_3, and also from the terminal 207.

The potentials on the terminals 208 to 211 are the values of α, β, γ and δ respectively.

In the absence of any forcing inputs, both of the access controllers will pass through a succession of states and thus the output vector, that is the vector whose four components are represented by the four output potentials respectively, from the row access controller AC_3, will vary in a random manner as previously indicated. However the forcing inputs to this access controller will impose some order on its behaviour, since any row of capacitors across which a relatively large total negative potential is stored will provide a large negative forcing input to the associated device in the row access controller. The output from this device is then suppressed and thereby the pure strategy corresponding to this device is suppressed. Furthermore the access of charge to the row of capacitors is reduced, charge tending to be added to other capacitors of the store.

Thus the co-ordinator determines a sequence of mixed strategies. The average rate at which the strategies change is indirectly controlled by a " variance computer " VC_1 which computes a quantity which is analogous to the variance of the magnitudes of the negative charges of the sixteen capacitors of the store ST_5, and will be referred to as the " variance ". Quotation marks are used since it is not a true variance as usually defined, that is as the mean square deviation of quantities about their mean. When the " variance " is high, that is when the magnitudes of the charges on the capacitors are distributed over a large range, in each of the access controllers AC_2 and AC_3 the resistance of a triode forming part of a common cathode load of the four devices in the access controller is made low.

When the resistance is low the effect of any sudden variation in the potential applied to the input of any device is greater than that of less suddenly varying inputs. Thus the access controllers tend to seize upon any well defined characteristic in the forcing inputs to them very readily when the " variance " is high, but not to do so when the variance is low.

The variance computer VC_1 is a Kipp relay circuit of conventional form which is triggered each time any of the relays DD, LL and four relays RR, SS, TT and UU shown in Fig. 36 (and being the four relays of the output relays OR_1 previously referred to) is de-energised. Each time the Kipp relay is triggered it provides an output pulse of constant width and amplitude, and these pulses are integrated in both the row and column access controllers to give the " variance ".

The input to the marking computer MC_3, referred to above, from which it computes the variable ϕ^1 is taken from the two access controllers AC_2 and AC_3. Two potentials, from the access controllers respectively, each substantially proportional in magnitude to the " variance " are added together and the resulting potential is used in the manner described above to compute θ.

There now follows a detailed description of the co-ordinator, omitting however the amplifiers AA_1, AA_2 and AA_3 which may be of any suitable known type as previously stated.

Fig. 32 shows the selector SE_4, comprising two Schmitt trigger circuits of conventional form. The first circuit comprises triodes V_{28} and V_{29}, resistors R_{150} to R_{154} and the winding of the relay DD, serving as the anode load of the triode V_{29}. The second circuit comprises triodes V_{30} and V_{31}, resistors R_{155} to R_{159} and the winding of the relay LL, serving as the anode load of the triode V_{31}. The circuits have input terminals 212 and 213 respectively connected to the output circuits of the amplifiers AA_1 and AA_2 and both circuits are so biased that their relay windings are energised when the potential on their respective input terminals is below earth potential.

The selector further comprises an input terminal 214 connected to an output terminal 266 of the marking computer MC_3 shown in Fig. 37. The terminal 214 is connected through a resistor R_{160} and sets of relay contacts **DD1**, LL1 and LL2 to one of four output terminals 215, 216, 217 and 218 as shown in Table III below:—

TABLE III

State of relays DD	State of relays LL	Marking category	Terminal to which terminal 214 is connected
de-energised	de-energised	MI	215
energised	de-energised	MII	216
de-energised	energised	MIII	217
energised	energised	MIV	218

The output terminals 215, 216, 217 and 218 are connected to four input terminals 219, 220, 221 and 22 respectively of the column access controller AC_2 which will now be described with reference to Fig. 33. The controller comprises four identical control devices each having a pair of triodes, V_{32} and V_{33}, V_{34} and V_{35}, V_{36} and V_{37}, and V_{38} and V_{39} respectively. The four triodes V_{32}, V_{34}, V_{36} and V_{38} have their cathodes connected to a -150 volt line, their grids connected through capacitors C_{12}, C_{13}, C_{14} and C_{15} respectively, in parallel with four grid-leak resistors R_{220}, R_{221}, R_{222} and R_{223} respectively, to earth and through resistors R_{161}, R_{162}, R_{163} and R_{164} respectively to the four input terminals 219, 220, 221 and 222 respectively, and their anodes connected to the grids of the four triodes V_{33}, V_{35}, V_{37} and V_{39} respectively and through resistors R_{165}, R_{166}, R_{167} and R_{168} respectively to the $+350$ volt line.

The four triodes V_{33}, V_{35}, V_{37} and V_{39} have their anodes connected to four output terminals 223, 224, 225 and 226 respectively, and through resistors R_{169}, R_{170}, R_{171} and R_{172} respectively to the $+350$ volt line. Their cathodes are connected through a small resistor R_{173} to a terminal 227 and the anode of a triode V_{40} which has its cathode connected to earth and its grid connected through an integrating network comprising a capacitor C_{16} and two resistors, R_{173} and R_{174} to an input terminal 228.

Feedback is provided from the control device comprising the triodes V_{32} and V_{33} to the other three control devices by the three resistors, R_{175}, R_{176} and R_{177} connected between the anode of the triode V_{33} and the grids of the three triodes V_{34}, V_{36} and V_{38} respectively. Similarly feedback signals are provided from the other control devices by resistors R_{178} to R_{186}.

Thus an input is provided to each of the four said control devices by feedback signals from the other devices and by the forcing input applied to one of the input terminals 219, 220, 221 and 222.

The input to the terminal 228 is the pulses provided by the variance computer VC_1 and these are integrated on the capacitor C_{16} to give the "variance". When the "variance" is high, the triode V_{40} conducts highly and the devices of the access controller pass through a succession of states in which different control devices provide a high output potential at a high rate. The output potentials of the control devices are provided at the terminals 223, 224, 225 and 226.

The row access controller AC_3 is the same as the column access controller AC_2 and accordingly is not drawn separately. When occasion arises to refer to elements of the controller AC_3 the same reference letters and numerals will be used as were used for the controller AC_2, but primed.

The store ST_5 is shown in Fig. 34 and comprises four column bus-bars 229, 230, 231 and 232 connected to four input terminals 233, 234, 235 and 236 respectively, these terminals being connected to the four terminals 223, 224, 225 and 226 respectively of the column access controller AC_2. The store has four row bus-bars 237, 238, 239 and 240 connected to four input terminals 241, 242, 243 and 244 respectively, these terminals being connected to the four terminals 223^1, 224^1, 225^1 and 226^1 respectively of the row access controller AC_3. Four row output bus-bars 245, 246, 247 and 248 are connected to four output terminals 249, 250, 251 and 252 respectively, these terminals being connected to the four input terminals 219[1], 220[1], 221[1] and 222[1] respectively of the row access controller AC_3. A further input terminal 253 is connected to a terminal 267 of the marking computer MC_3 (Fig. 37), the negative potential representative of θ being applied from this terminal.

The functional parts of the store are sixteen identical circuits of which one only will be described, namely the top left hand one in the drawing. A capacitor C_{17} is connected in series with an indirectly heated thermistor R_{187} and a resistor R_{188} between earth and the terminal 253. Thus the capacitor C_{17} is connected to a charging potential through two charging resistors.

The heating resistor of the thermistor R_{187} is shown as R_{189}, in a box, and has one end connected to earth and the other end connected through a resistor R_{190} to the column bus-bar 229 and through a resistor R_{191} to the row bus-bar 237.

If the potential on both the bus-bars 229 and 237 is high the resistor R_{189} gets hot and the resistance of the thermistor R_{187} decreases whereby the access to the capacitor C_{17} is increased. When the access to the capacitor C_{17} is high, the potential across it moves relatively rapidly towards the potential representative of θ on the terminal 253. The access to any capacitor of the store depends on the potentials of the associated row and column bus-bars.

The junction between the capacitor C_{17} and the thermistor R_{187} is connected through a high resistor R_{192} to the row output bus-bar 245. From this it can be seen that the potential on each of the terminals 249, 250, 251 and 252 is proportional to the sum of the potentials across the four capacitors of the four row respectively. The potentials on these four terminals are applied as the forcing inputs to the respective control devices of the row access controller AC_3.

It should be pointed out here that whilst the use of high resistors in the manner indicated is satisfactory for deriving a potential proportional to the sum of potentials across four capacitors, for larger numbers of capacitors a different method would be necessary, such as as a method involving scanning the capacitors, allotting equal intervals of time to each capacitor, and thus producing a varying output potential time-averaged for the capacitors.

The set of output relays OR_1 is shown in Fig. 35 and comprises four Schmitt trigger circuits 254, 255, 256 and 257 of conventional type having the windings of four relays RR, SS, TT and UU respectively as one of their anode loads. The four trigger circuits are provided with four input terminals 258, 259, 260 and 261 respectively, and these are connected to the terminals 223[1], 224[1], 225[1] and 226[1] respectively of the row access controller AC_3. Each of the relays RR, SS, TT and UU is energised or de-energised according to whether the potential on the input terminal of its trigger circuit is below or above a level determined by the biasing conditions of the trigger circuit. Each of these relays has a set of contacts which, with a set of contacts of each of the relays DD and LL, is used in the variance computer.

Thus in Fig. 36 one terminal of each of six capacitors C_{20} to C_{25} is connected respectively through one of six sets of changeover relay contacts RR1, SS1, TT1, UU1, DD2 and LL3, either to a −100 volt line or through one of six resistors R_{200} to R_{205} respectively to a +100 volt line. The other terminals of the capacitors C_{20} to C_{25} are connected together through a resistor R_{206} in series with a resistor R_{207} and a rectifier X_4 in parallel to earth.

The junction of the resistors R_{206} and R_{207} is connected to the grid of a triode V_{41}, which together with a triode V_{42}, resistors R_{208} to R_{212} and a capacitor constitutes a Kipp relay of conventional form. An output terminal 262 connected to the anode of the triode V_{42} is connected to the terminals 228 and 228[1] of the coloumn and row access controllers, AC_2 and AC_3, respectively.

Whenever one of the relays RR, SS, TT, UU, DD and LL is operated or released, a positive or negative voltage pulse is applied to the network comprising the resistors R_{206} and R_{207} and the rectifier X_4. The rectifier is so poled that only negative pulses are applied to the grid of the triode V_{41} and for each pulse so applied a negative pulse of constant amplitude and duration is provided at the terminal 262. These last-named pulses are integrated in the column and row access controllers, AC_2 and AC_3, respectively by the network comprising the capacitor C_{16} and the resistor R_{144} and the network comprising the capacitor C_{16}^1 and the resistor R_{144}^1 respectively. Thus the potentials applied to the grids of the triodes V_{40} and V_{40}^1 are the "variance" of the charges on the capacitors of the store ST_5 and accordingly the potentials at the output terminals 227 and 227[1] are measures of the "variance".

The terminals 227 and 227[1] are connected to two input terminals, 263 and 264, of the marking computer MC_3 shown in Fig. 37. The terminals 263 and 264 are connected through two resistors R_{213} and R_{214} respectively to the grids of two triodes V_{43} and V_{44} respectively, the grids of which are also connected to earth through two capacitors C_{27} and C_{28} respectively. The cathodes of the triodes V_{43} and V_{44} are connected respectively to the junction of two resistors R_{215} and R_{216} connected between earth and the +350 volt line and the junction of two resistors R_{217} and R_{218} connected between earth and the +350 volt line. The anodes of the triodes are connected together through a common anode load R_{219}

to the +350 volt line and to the input to a subtracting amplifier AA_4. It will be seen that the input to this subtracting amplifier is a potential representative of the "variance" and this potential is used as a measure of the expected deviation ϕ^1 of the pursuing aircraft (spot 202) from the target aircraft (spot 201). Another input to the subtracting amplifier AA_4 is provided from the terminal 265 which as previously described is connected to the output of the adding amplifier AA_3 which output is the potential ϕ representative of the actual deviation of the pursuing aircraft from the target aircraft. The subtracting amplifier AA_4 provides as its output a positive potential at terminal 266 and a negative potential at terminal 277, both potentials representing θ in magnitude, varying inversely with the difference (ϕ—ϕ^1).

Whilst the storing means used in the trainable assemblage are conveniently capacitors, as in the embodiments of the invention described, they are not necessarily so. They may be mechanical devices wherein, for example, the displacement of a pointer or the angular position of a wheel represents the stored quantity. Furthermore they may comprise digital storing devices which can store only quantities differing by discrete amounts, rather than continuously variable quantities.

It will be appreciated that the type of store and access control devices described with reference to the Type I and Type II co-ordinators can also be adapted to serve in apparatus concerned with continuously variable responses (such as in the case of a "pursuit skill"). Likewise the type of store and access control devices described with reference to the Type III co-ordinator may be adapted to serve in apparatus concerned with discrete variables.

Among the many modifications which may be introduced into the apparatus is that of adapting the marking device to take more account of errors of one type than of another type. This is an appropriate modification when, in the skill concerned, certain errors are regarded, for instance on economic grounds, as more important than others. In practice such a modification can be achieved, for instance, by varying the values of appropriate resistors in circuits corresponding to different marking categories.

The term "optimum value of the degree of success of an operator" has not been formally defined as it can never be an absolute quantity. It is a quantity which is, in general, different for different operators and for the same operator at different times. It may be relatively low for an operator having a low intelligence quotient or a slow reaction time, or for an operator for whom it is normally relatively high but who is tired.

In the embodiments of the invention described the only kinds of signals representative of the operator's responses that have been considered have been those which have been derived from actual mechanical responses of the operator. For certain purposes it may be advantageous to derive such signals from a device which measures some physiological variable of the operator, for instance the integrated electro-myogram from the frontalis muscle of the operator. Furthermore the signals may be derived under the control of an observer who estimates the value of some psychological variable of the operator.

Likewise the data supplied to the operator may comprise data supplied by the direct operation upon a physiological variable of the operator. For instance one or more drugs may be injected into or otherwise administered to the operator. Again some data may be supplied to the operator by means of sub-threshold signals which are known to register upon a man's mind even though he does not consciously perceive them.

Use of physiological or psychological variable in one or more of the manners indicated may be of value when it is desired to induce certain states in the operator or to derive information about the operator's suitability to perform a certain job. Such use may be made of apparatus according to the invention for purposes of testing for managerial selection, for instance, or for the purposes of experimental psychology.

Apparatus according to the invention is suitable for testing an operator since as already indicated the trainable assemblage can come to have characteristics related to those of the operator. Thus any test carried out with apparatus according to the invention differs from a normal psychological test in that the apparatus takes account of the individual characteristics of the operator.

Apparatus according to the invention may also be used to set up a situation in which the operator is under stress, for instance for the purposes of treatment of psychological disorders. A stress situation may be readily achieved by providing apparatus which applies a stress-promoting variable, such as noise in a pair of headphones, and makes the value of this variable inversely proportional to a variable representing the operator's degree of success.

In many cases, particularly when apparatus according to the invention is being used for purposes such as managerial selection, experimental psychology and psychological treatment, it will be advantageous to attach a monitoring device to the apparatus and thereby obtain a continuous record of some variable, such as that representing the operator's degree of success.

WHAT WE CLAIM IS:—

1. Apparatus for assisting an operator in performing a skill, comprising a marking device adapted to be supplied with input signals representative of the response of an

operator to data supplied to him, and to generate output signals, representative of the operator's degree of success in responding to the data, in at least four channels, each corresponding to a different category, each category being determined by one or more characteristics of the skill, a trainable assemblage having its input coupled to the marking device in such a manner as to have its state determined by the output signals and to generate, in dependence upon such state, from time to time or continuously, control signals suitable to control one or more parameters of the data-supplying means in such a way as to tend to increase the said degree of success to an optimum value, and to maintain the degree of success at this optimum value.

2. Apparatus according to Claim 1, wherein the marking device comprises means adapted to provide successively or simultaneously in each of said channels a potential whose magnitude is representative of the operator's degree of success in all categories over a period of time.

3. Apparatus according to Claim 1 or 2, wherein the trainable assemblage comprises at least four capacitors, the state of the assemblage being representable by a vector having four or more components which are the magnitudes of the charges on the four or more capacitors respectively.

4. Apparatus according to Claims 2 and 3, wherein the said potential is applied through the said channels to the capacitors as a charging potential, the channels containing resistance devices and wherein means are provided to control the access of charge to the capacitors by varying the resistance of the resistance devices in dependence, at least partially, upon the output signals provided by the marking device.

5. Apparatus according to Claim 4, wherein the means for controlling the access of charge to the capacitors are also adapted to vary the access of charge in a random manner.

6. Apparatus according to Claim 1, 2, 3, 4 or 5, comprising means adapted to supply the said data to the operator, response means adapted to receive responses of the operator and to apply the input signals to the marking device and means for applying the control signals to the data-supplying means.

7. Apparatus according to Claim 1, 2, 3 or 4, adapted to teach the operator to perform a skill, in which the data supplied to the operator consists of discrete indications to which the operator is required to make corresponding discrete responses.

8. Apparatus according to Claims 6 and 7, wherein the control signals vary one or more parameters of the data-supplying means in such a manner that the intensity and/or the duration of the different indications is varied in a "patterned manner".

9. Apparatus according to Claims 6 and 7, wherein the control signals vary a parameter of the data-supplying means in such a manner that the frequency of occurrence of different indications is varied in a "patterned manner".

10. Apparatus according to Claim 1, 2, 3 or 4, adapted to teach the operator to perform a skill, in which the data supplied to the operator consists of discrete indications spaced apart in time, each indication requiring a plurality of discrete responses to be made thereto by the operator.

11. Apparatus according to Claims 6 and 10, wherein the control signals vary a parameter of the data-supplying means in such a manner that the number of discrete responses which are required to be made for each indication is varied.

12. Apparatus according to any of Claims 1 to 5, adapted to teach a skill, wherein a body of data is presented to the operator continuously, in response to which the operator is required to determine a strategy.

13. Apparatus according to any of the preceding claims, comprising means adapted to provide corrective information to the operator and to withdraw the corrective information progressively as the operator's degree of success increases.

14. Apparatus according to Claims 6, 7 and 13, wherein the means adapted to provide corrective information are adapted to indicate directly to the operator which response is the correct one to be made.

15. Apparatus according to Claims 6 and 7, having means adapted to introduce ambiguity into the discrete indications, progressively as the operator's degree of success increases, by causing indications other than the correct indication to be provided to the operator as well as the correct indication, but with an intensity less than that of the correct indication.

16. Apparatus according to Claim 7 or 10, wherein the discrete indications are provided in a recurrent sequence, and wherein the marking device is adapted to receive as the said input signals, signals indicating correct and incorrect responses and to provide output signals including a potential representative of the operator's degree of success, which potential is varied in one sense in response to signals indicating correct responses and in the other sense by signals representing incorrect responses.

17. Apparatus according to Claim 7, 10 or 16, comprising means adapted to fix limit times before which responses must be made by the operator if such responses are to have any effect upon the marking device.

18. Apparatus according to Claims 16 and 17, wherein the marking device comprises a set of relays adapted to take different states characterised by the combinations in which its relays are energised and de-energised, the

set of relays normally being in a first state, being in a second state for an inteval of time beginning with a correct response and ending with the limit time for that response, and being in a third state for an interval of time beginning with an incorrect response and ending with the limit time for that response.

19. Apparatus according to Claim 18, wherein the marking device comprises an integrating amplifier, adapted to provide a potential representative of the operator's degree of success, having its input circuit connected in first, second and third configurations when the set of relays is in the first, second and third states respectively.

20. Apparatus according to Claims 16 and 17, wherein the trainable assemblage comprises a plurality of capacitors, each capacitor corresponding to a different indication and wherein means are provided to apply from the marking device a potential representative of the operator's degree of success through the said channels to the capacitors, each channel including a resistor or resistive network, and the potential being applied for an interval of time starting with a correct response to the indication corresponding to the capacitor and ending with the associated limit time for that response.

21. Apparatus according to Claim 17, 18, 19 or 20, wherein the means adapted successively to fix limit times comprise a trigger circuit and means for applying to the trigger circuit a triggering potential rising from a datum level at a rate substantially proportional to the magnitude of a potential representing the operator's degree of success, the trigger circuit triggering when the triggering potential reaches a trigger level and thereby defining one of the limit times.

22. Apparatus according to Claim 21 wherein the means for applying the triggering potential comprise a capacitor which is charged through the conducting path of an electron discharge tube having at least one control electrode, to which a potential representing the operator's degree of success is applied.

23. Apparatus according to Claim 21 or 22, wherein the trigger level for each response is determined by a reading amplifier having its input circuit connected successively to the appropriate capacitors of the assemblage.

24. Apparatus according to any one of Claims 16 to 23, wherein connections within the apparatus appropriate for the different indications and responses are made through a uniselector.

25. Apparatus according to any one of Claims 17 to 23 and Claim 24, wherein the means adapted to fix limit times further provide signals which are applied to advance the uniselector.

26. Apparatus according to Claim 16, wherein a complete response to each indication requires two or more individual responses, each of which may be correct or incorrect, there thus being two or more marking categories.

27. Apparatus according to Claim 26, comprising means adapted to fix successively occurring pluralities of limit times, each plurality of limit times corresponding to a different indication, the responses in different marking categories to an indication having to be made before an associated limit time of the plurality of limit times corresponding to that indication if such responses are to have any effect upon the marking device.

28. Apparatus according to Claim 27 wherein the marking device comprises a plurality of sets of relays, each set corresponding with one marking category and having different states characterised by the combinations in which its relays are energised and de-energised, each set of relays normally being in a first state, being in a second state for an interval of time beginning with a correct response in the corresponding category and ending with the limit time for that response and being in a third state for an interval of time beginning with an incorrect response in the said category and ending with the limit time for that response.

29. Apparatus according to Claim 27 or 28, wherein each plurality of limit times includes a further limit time later than the limit times associated with the responses in the different marking categories.

30. Apparatus according to Claim 29, wherein the marking device comprises a further set of relays adapted to take different states characterised by the combinations in which its relays are energised and de-energised, the further set normally being in a first state, being in a second state for an interval of time beginning with the last response of a number of correct responses constituting a complete response to an indication and ending with the further limit time associated with the indication to which the responses are made, and being in a third state for an interval of time starting with any incorrect response and ending with the further limit time associated with the indication to which the response is made.

31. Apparatus according to Claim 30 wherein the marking device comprises an integrating amplifier, adapted to provide a potential representative of the operator's degree of success, having its input circuit connected in first, second and third configurations when the said further set of relays is in the first, second and third states respectively.

32. Apparatus according to any of Claims 27 to 31, wherein the trainable assemblage comprises a number of sets of capacitors, a different set corresponding to each marking category, a different capacitor in each set corresponding to each indication, and wherein

means are provided to apply a potential representative of the operator's degree of success to each capacitor through a resistor or resistive network for an interval of time starting with a correct response in the marking category corresponding to the capacitor and ending with the limit time determined for that marking category and indication.

33. Apparatus according to Claim 29, 30 or 31, wherein the means adapted to fix pluralities of limit times comprise a plurality of trigger circuits and means for applying to the trigger circuits a triggering potential rising from a datum level at a rate substantially proportional to the magnitude of a potential representing the operator's degree of success, one trigger circuit triggering when the triggering potential reaches a fixed trigger level and thereby determining the further limit time, the other trigger circuits triggering when the triggering potential reaches trigger levels determined by the previous degree of success in the different marking categories respectively and thereby determining the limit times associated with the different marking categories.

34. Apparatus according to Claims 32 and 33, wherein the variable trigger levels are determined by a plurality of reading amplifiers having their inputs connected successively to the capacitors of the assemblage corresponding to successive indications.

35. Apparatus according to any one of Claims 16 to 34, wherein connections within the apparatus appropriate for the different indications and responses are made through a uniselector.

36. Apparatus according to Claim 6 and any one of Claims 16 to 35, wherein the response means comprise a plurality of manually operable members and wherein a like plurality of lamps for supplying corrective informations are provided to identify the operable members respectively, modulating means being provided to cause a lamp identifying an operable member to light up when that member is to be operated in order to make a correct response, and to vary the manner in which the lamps light up in such a way as to withdraw the corrective information thereby provided as the operator's degree of success increases.

37. Apparatus according to Claims 23 and 36 wherein the modulating means comprise an adding amplifier adapted to provide a resultant potential which is the sum of a potential proportional to the output potential provided by the reading amplifier and a potential proportional to the triggering potential, and a modulator adapted to provide an alternating current amplitude-modulated by the said resultant potential.

38. Apparatus according to Claims 34 and 36, wherein the modulating means comprise a different adding amplifier corresponding to each marking category adapted to provide a resultant potential which is the sum of a potential proportional to the output potential provided by the reading amplifier corresponding to the same marking category and a potential proportional to the triggering potential, and a different modulator corresponding to each adding amplifier adapted to provide an alternating current amplitude-modulated by the resultant potential provided by the corresponding adding amplifier.

39. Apparatus according to Claim 6 and any one of Claims 16 to 38, wherein each indication is provided by a lamp which lights up to give the indication, and wherein means are provided to cause the intensity with which the appropriate lamp lights up to decrease as the operator's degree of success increases.

40. Apparatus according to Claim 39, wherein means are provided to cause all lamps to light up with a background intensity of illumination, whereby ambiguity is introduced into the indications.

41. Apparatus according to Claim 6 and any one of Claims 16 to 40, comprising warning means adapted to warn the operator a short time before data is supplied that data is to be supplied and to decrease the length of time between the warning and the supply of the data as the operator's degree of success increases.

42. Apparatus according to Claim 41, wherein the warning means comprise a lamp and are adapted to illuminate the lamp in order to warn the operator.

43. Apparatus according to Claim 41, wherein the data is supplied visually and the warning means are adapted to provide the operator with a brief preview of the data a short time before it is formally displayed.

44. Apparatus according to any of Claims 1 to 6 or to Claim 12, adapted to teach a skill wherein the operator's degree of success may be represented at least partially by comparing an observed quantity with an expected quantity, the apparatus comprising means adapted to provide a potential representative of the observed quantity, means adapted to provide a marking potential representative of the expected quantity and subtracting means adapted to provide a potential representing a compensated marking variable, representative of the difference between the expected quantity and the observed quantity.

45. Apparatus according to Claim 44, adapted to teach a skill wherein the two said quantities are deviations, the observed deviation being the distance between an escaping pointer, spot or light or the like and a pursuing pointer, spot of light or the like whose motion is controlled by the responses of the operator.

46. Apparatus accrding to Claim 44 or 45, wherein the trainable assemblage comprises a plurality of capacitors to which the potential representing a compensated marking variable

is applied as a charging potential through variable resistors.

47. Apparatus according to Claim 46, wherein different capacitors correspond to different marking categories and wherein means are provided to make the access of charge relatively high to a capacitor or capacitors corresponding to the marking category appropriate at any instant.

48. Apparatus according to Claim 46 or 47, wherein different capacitors correspond to different strategy categories, and access-control means are provided to make the access of charge relatively low to a capacitor or capacitors corresponding to a strategy whose employment has increased the degree of success of the operator.

49. Apparatus according to Claim 48, wherein the access-control means are controlled by feedback signals from the capacitors.

50. Apparatus according to Claim 46, 47, 48 or 49, wherein the access of charge to the capacitors is controlled by one or more access controllers each comprising a plurality of control devices, each control device partially or wholly controlling the access of charge to the capacitors of a group of capacitors and being provided with feedback signals from the other devices in such a manner that the access controllers tend to vary the access of charge to different groups of capacitors in a random manner and wherein forcing inputs are provided to the control devices to favour or inhibit the access of charge to specified groups of capacitors.

51. Apparatus according to Claim 50, wherein each control device comprises an amplifier which amplifies voltage signals with substantially no change of phase, the control devices of the access controller being connected to the terminal of a source of operating potential through a common resistive network.

52. Apparatus according to Claim 51, wherein the common resistive network includes the conducting path of an electron discharge valve having at least one control electrode, means being provided to apply to the said control electrode a potential controlling the flow of current through the valve and hence the rate at which the control devices change to different states in which the access of charge is made relatively high to different groups of capacitors is varied.

53. Apparatus according to Claim 52, wherein the variable potential applied to the control electrode is dependent upon the variance of the magnitudes of the charges on the capacitors of the trainable assemblage derived by means adapted to scan the capacitors continuously, to differentiate the voltage waveform thereby derived and to integrate the pulses produced by differentiation.

54. Apparatus according to Claim 47 or 48 and Claim 52, wherein the variable potential applied to the control electrode is derived by means adapted to provide a voltage pulse of substantially constant amplitude and width whenever predetermined signals in different marking and/or strategy categories rise above or fall below predetermined levels and to integrate the said voltage pulses.

55. Apparatus according to Claim 53 or 59, wherein the potential representative of the expected quantity is the said potential applied to the control electrode, or a potential proportional thereto.

56. Apparatus according to any one of Claims 46 to 55, wherein the said variable resistors through which the charging potential is applied to the capacitors are thermistors indirectly heated by further resistors.

57. Apparatus according to any one of Claims 50 to 55 and Claim 56, wherein the further resistors have applied thereto output potentials of different control devices or sums of output potentials of different combinations of control devices.

58. Apparatus according to Claim 6 and any one of Claims 44 to 57, comprising sensitivity control means adapted to vary the extent of the effect which the operator's responses have upon the response means in dependence on the said marking potential.

59. Apparatus according to Claim 58, wherein the response means comprise a knob, or the like, adjusted by the operator and the sensitivity control means comprise a servomechanism adapted to vary the gear-ratio in a drive between the knob, or the like, and the device, the knob, or the like, actuates.

60. Apparatus according to Claim 6 comprising responsive means adapted to measure a physiological variable of the operator and to provide input signals representative of the variable to the marking device.

61. Apparatus according to Claim 60, wherein the responsive means are adapted to measure the integrated electromyogram from the frontalis muscle of the operator.

62. Apparatus according to Claim 1, in combination with means for supplying to the marking device input signals provided by an observer, determining a psychological variable of the operator representative of his responses.

63. Apparatus according to Claim 6, wherein the data-supplying means comprise means adapted to vary directly a physiological variable of the operator.

64. Apparatus according to Claim 63, wherein the data-supplying means comprise means adapted to administer a drug to the operator.

65. Apparatus according to Claim 6, wherein the data-supplying means are adapted to provide information to the operator by means of sub-threshold signals.

66. Apparatus according to any one of the preceding claims comprising a monitoring device adapted to provide a record of one or more variables of the apparatus.

67. Apparatus substantially as hereinbefore described with reference to and as shown diagrammatically in Figs. 1, 2 and 4 to 17 of the accompanying drawings.

68. Apparatus substantially as hereinbefore described with reference to and as shown diagrammatically in Figs. 10, 12 to 17, 19 and 21 to 29 of the accompanying drawings.

69. Apparatus substantially as hereinbefore described with reference to and as shown diagrammatically in Figs. 31 to 38 of the accompanying drawings.

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PROVISIONAL SPECIFICATION

Apparatus for assisting an Operator in performing a Skill

We, ANDREW GORDON SPEEDIE PASK, M.A. Cantab., British Nationality, ROBIN THOMAS MCKINNON-WOOD, M.A., Cantab., British Nationality, and ELIZABETH PASK, B.A., Cantab., British Nationality, all of 5, Jordan's Yard, Cambridge, County of Cambridge, do hereby declare this invention to be described in the following statement:—

Nearly all systems which require a body of data to be transmitted to human operator are inefficient. The inefficiency arises because the human operator has statistically non stationary characteristics which are continually changing in a way which cannot be discerned—i.e., his characteristics cannot be represented as a set of transfer functions—and their change cannot be described. As a result, it is not possible to code the information with which he is presented so that it is optimally matched into his characteristics, and even a type of display which is designed to suit human operators, "on the average" is bound to deviate very far from the ideal for "any individual" or for the same individual at different stages in a control process.

In this description we shall be concerned with the acquisition and the performance of human skills. At the outset I should like to emphasize that there is no hard and fast distinction between the process of learning a skill and that of its actual performance. Although the examples which are used to describe the systems will be chiefly applicable to learning rather than performance, almost any performance gives rise to relevant contingencies which are unlearned, and the skill remains but partly learned throughout. Whenever this is the case the systems may equally well be applied to code the information which the human operator receives and to enable him to give a more efficient performance or to exert more efficient control.

Consider initially, the learning of a manual skill. In order to teach this skill a training routine is devised which will consist, in essentials, of (1) The presentation of a number of different contingencies—and, (2) For each contingency a set of more or less complete instructions about what should be done in order to be—according to some arbitrary or mechanical criterion, "correct", at that stage. The training routine will necessarily suffer from one or more of the following type of defect:—

(a) The rate at which things have to be dealt with may be insufficient to saturate the human operator's attention—he will become "bored" and will attend, instead, to irrelevant data.

(b) The information given to him may make the task too simple—it will be redundant—and this may lead to results similar to (a).

(c) The rate of presentation or the complexity of the situation may be such that the human operator can do nothing about it.

Ideally the task he is set at each stage should be sufficiently difficult to maintain his interest and to create a competitive situation yet never so complex that it becomes incomprehensible. A private tutor in conversation with his pupil seeks, in fact, to maintain this state— which is not unlike a game situation.

Since it is well established (ref. Dr. Hick and others. Q. J. Exp. Psych) that the human operator behaves, functionally, as a discontinuous sampling servomechanism under the circumstances of skilled performance and that he has a finite channel capacity for information transfer (using the term in the Dr. Shannon sense), we may express the conditions (a), (b) and (c) as simply those for efficient transfer in any communication system—namely that the channel capacity shall be utilised for the transfer of relevant information—given the additional proviso that is not it will become saturated with data that is "noise" with reference to the skill, that the redundancy of the data must be minimised and the equivocacy of the information be no greater than a value which can be removed by the receiver-given the further proviso that the receiver must indulge in some decision making or equivocation removing process which if not a relevant process is "noise" and deleterious.

The non stationary character of the human operator does not allow us to evaluate the redundancy, equivocation, etc, etc. Nevertheless it is clear that the conditions are reasonable enough. If we regard a functionally demarked portion of the human operator's brain as a non stationary decision making assemblage we see that there will in general be a large number of states of the system, evoked by one or more definite sensory input signals, which will lead to a particular response operation as an output—for instance there will be many states of this assemblage which mean the signal A leads to the response X as is required by a particular skill and called correct. But the state of the assemblage cannot be discerned, nor indeed, if it could, would there be any way of deciding upon which of these states it was best to establish when, say, teaching the relationship A leads to X. Most certainly the best state will be determined by all other members of the set A, B, ... N and the set X, Y, ... etc., etc., which define the logical structure of the skill. Certainly, also, the "best" state will change and will be different at different stages in the learning process. Clearly the "best" state is another expression of the human operator's preferred way of conceptualising the skill or of grouping the data. The best state is likely to be achieved if the system is minimally constrained by corrective information, given, of course, that there is a reasonable chance of the correct operations being performed. The conditions of the last paragraph are the growth maximising conditions which allow the human operator as much freedom to adopt his own preferred conceptual structure. Indeed it is a commonplace that a skilled person is not simply a man who has learned a set of relations involving signals and response operations, but a person who has learned them in a particular way—in a way which is determined not only by the data and the circumstances under which it must be employed—but also by his individual characteristics.

To match the information into the human operator is equivalent to satisfying these conditions or to encouraging this individual growth process. We shall now consider the device which acts as a statistical coding or matching system.

Since most of my work has been concerned with learning situations the devices are called "TRAINING CO-ORDINATORS" and the resulting system a "CO-ORDINATED SYSTEM". Briefly, a "TRAINING CO-ORDINATOR" or automatic training device consists of an assemblage which like the human operator is non stationary and conditionable or trainable. It is arranged, in the system, to be trained by the performance characteristics of the human operator so that, with reference to the skill, it comes to have characteristics related to his own. Its changes of state are then used to select from a set of possible contingencies which may occur during the performance of a skill and also to code and ultimately to completely obliterate a body of corrective data—defining the correct method of dealing with each contingency. Thus it patterns a training routine to suit the particular human operator and maintains the situation always difficult enough to maintain his interest and never too complex to be incomprehensible to him. In practice it is possible to reduce the training time required, to make it rather independent of the form of the data, to improve retention, and as predicted to maintain interest by setting up a partly competitive game—of the type outlined by Prof. Braithwaite—between the Training Co-ordinator and the Human Operator.

The characteristics of the non stationary assemblage are best illustrated by examples of which several will be presented in detail. Before embarking upon these we note, however that a Training Co-ordinator consists of the following parts.

(1) A display and a control arrangement for the human operator—in general those which are ordinarily used when the skill is performed.

(2) A means of measuring the human operator's performance. The immediately measured variables may be response time averaged with reference to each kind of contingency—in which case the functioning of the system is rationalised by an extension of Dr. Hick's Law. This kind of measure is not a necessary feature. Amount and rate of movement, deviation of a controlled object from a moving object, etc., etc., will do equally well. It must, essentially however, be possible to change the scale of the measurement by means of a feedback derived from the non stationary assemblage.

(3) A means of marking the human operator's actual performance against some arbitrary or mechanical criterion of an ideal performance. In general a switching function is arranged to mark the human operators actual response and one such switching function is generated whenever any one of the contingencies or signals are selected.

(4) A set of possible contingencies from which selections are made by the output from the non stationary assemblage—these contingencies may be biased—some as likely and some as unlikely and they may or may not be tied by a conditional probability matrix to sets of previous responses.

(5) A means of representing what should be done, given a particular contingency, in the form of a display which is presented to and of coding and withdrawing this information.

In the simplest case the representation is direct and the coding and withdrawal amounts to changing the relative intensity or exposure interval of the corrective information associated with each of the contingencies. Likewise in some displays using continuous physical variables the coding amounts to relative changes in representation scale, for, various aspects of the training procedure.

In general the corrective information will be represented in several partial information categories—or represented along several dimensions. In this case the coding will change not only the relative intensity or importance of the information from different contingencies but also the relative importance or the order or exposure interval in a temporal exposure sequence of the corrective clues. For instance if the correct solution is one point out of sixteen possible points any one can be represented in terms of four binary variables. The exposure of these and their order in a temporal exposure sequence can then be determined by the co-ordinator, the exposed time decreasing to 0 as the skill is learned and their relative exposure times decreasing according to the response biases exhibited by a particular man.

(6) A non stationary conditionable assemblage which first of all re-scales—or compensates the input—performance measuring-variables which, after marking, it receives as its input. Secondly it makes selections from the set of possible contingencies in the training routine and finally it codes the corrective information associated with each contingency before it is presented to the human operator in the display.

A schematic diagram of a Training Co-ordinator is shown in Fig. 1 of the accompanying drawings.

Type 1 Co-Ordinator

Purpose of the System

A system of this type is used to train a human operator in the performance of a manual skill, usually part of a repetitive job. The particular feature of Type 1 systems is that the information which he receives at the beginning of the training routine is supplied in the same form as the response which he is required to make. Thus, in a Type 1 system, there is a direct relationship between the signals which define a correct response and the response itself— the human operator is not asked to make any translation.

The Job

In the demonstration model which will be used to illustrate Type 1 systems the human operator is required to press the appropriate one of eight micro switches arranged in a row whenever the display changes. The display consists of a row of eight lights, and in the initial state of the system one only of these is "ON" at any moment. This one light indicates the correct response. The machine itself paces the change in the display, and thus the rate at which the job must be performed. Initially the pace is constant and the rate of presentation is sufficiently slow to allow the human operator to reach the correct response without difficulty before the machine moves on to the next signal.

The machine scans through a sequence of 12 items. In any position in this sequence any one of the eight alternative signals may be arranged by establishing previous connections—some of the signals necessarily occurring more than once. The human operator is provided with a signal—by means of a separate light—which indicates the origin of the sequence. The machine repeats the sequence continually.

When the connections which set up the required series of events are established, a further set of connections are made. These, via the response switches, indicate whether or not any response which is made at a given position in the sequence is correct or an error. The human operator is provided with this information when the machine moves on to the next position in the sequence.

When the human operator's performance improves the rate at which the signals are presented is increased. From the outset, however, he is asked to make correct responses as rapidly as he can, and if possible, to anticipate the co-ordinator. The situation is, in this sense, competitive. Since missing a response is counted similarly to an error he is told to guess where he thinks there is some chance of his being correct rather than doing nothing.

The job outlined is of no inherent merit. It has been employed because it is the simplest and most general arrangement but in practice the signals and the responses are presented in the form which the human operator will normally use. The response array might, for example, be a keyboard, and the signals arranged in a corresponding fashion—(or the signals may be actuators on the keys themselves, to give the human operator tactile information about the correct response).

Nor are there any limitations upon the length of sequence or the number of alternative responses which can be employed in the system. Any number of alternatives less than (as in the present instance) or equal the number of positions in the sequence is quite easy to arrange, though in the latter case each alternative will occur only once in the sequence.

Input and Output Variables to the Co-ordinator

The co-ordinator obtains the following items of data from the human operator's performance.

(1) Whether or not, at each position in the sequence, taken separately, the human operator manages to make a response.

(2) Whether, if he does manage to do so, the response which he makes is correct, or if it is an error.

(3) In the case of a correct response a

measure of the interval between the instant at which he responds and the instant at which the Co-ordinator moves on to the next position in the sequence.

(4) A measure of the average number of correct responses which the human operator makes per unit time.

As a function of these variables the device changes the representation of the display information. The precise manner is difficult to set out, since the assemblage is "indeterminate"—in the sense that one of Dr. Grey Walter's "Tortoises" is indeterminate — It will be best to describe the initial and final states of the systems, commenting upon the transition which takes place without much effort to be exact and then to discuss the action of the Co-ordinator as such. In this way the variables which are changed in the display representation will become apparent at the outset.

(1) Initial State

In the intial state of the system the human operator is provided with completely unambiguous information which specifies each response. The rate at which the co-ordinator exposes the sequence is fairly slow, and an equal amount of time is devoted to each position.

As soon as the human operator starts to play the machine—to compete with it—he will provide a number of correct responses and errors. These are received by the co-ordinator and in subsequent presentations of the sequence those positions in which he has given a correct response are passed over more rapidly than the others, whilst those which have been subject either to no response or to an error response tend to be emphasized because the co-ordinator exposes these signals for a longer time. This operation can be looked upon as a redistribution of the time allocated to each of the positions in the sequence, out of a total sequence exposure time. The extent to which the interval allocated to a previously correct response position is reduced is intially determined by the human operator's response time. Since, however, this is measured in terms of the allowed interval (as in (2) and in (3)) the result is not simple—for the reduced interval reduces, also, the human operator's chance of making a correct response at this position. Moreover, a further operation is performed. Through it, the total sequence exposure time is reduced as determined by the average number of correct responses (as balanced against errors and no responses) which the human operator makes per unit time—the higher his correct response rate, the higher becomes the rate at which he is required to respond, on the average.

Finally, as his correct response rate increases, the ambiguity with which the signals occur is increased. Instead of only one signal light occurring at each position in the sequence, several, or at a later stage, all of the signal lights appear. All except the appropriate light dim out during the interval allowed for the exposure but the rate of dim depends upon the human operators correct to error balance. Thus, at the time when a new position is first exposed there may be an *a priori* one in eight choice which would have to be made by the human operator if he responded as rapidly as he could and was to be sure of getting the correct alternative. The degree of choice is reduced during the interval until no choice is required—but this may be too late for him to make any response for this position. Briefly, the rate at which the correct light becomes unambiguously specified is determined by the human operator's error, increasing with it and *vice versa*. The real difficulty at each stage is determined not only by this but by the duration of the interval. Thus, all in all, the variables of display ambiguity, of time per position in the sequence, and of average rate at which responses must be made if they are to be correct are dependent upon one another and not readily separable. Perceptually—to the human operator—they do not appear as distinct.

(2) Final State

If the correct response rate of the human operator is plotted against time, it is seen to decrease. It undergoes periodic fluctuations until it reaches its final value. At this stage the human operator, whilst making responses at the required rate, is unable to derive any information from the display except for the sequence origin light. All of his responses are correct—and the distribution of intervals spent upon each position has become—after passing through a stage when it was patterned into a rhythmic form by his preferences, substantially equal. To maintain this final state the human operator is consistently performing the previously arranged sequence of operations, given a fixed minimum of information (this need not, incidentally, be no information as is arranged in the present case), without errors (or with an allowable predetermined distribution of errors, if desired), and at a rate rather greater than the minimum which is deemed to be necessary for efficient performance.

He has, thus, learned the skill. In practice the learning time is reduced to less than half of its normal value. It becomes, moreover, surprisingly independent of the type of sequence or of the form in which the display and response arrangements are set up—chiefly because the information is grouped and withdrawn in correspondence with the conceptual grouping which any particular human operator chooses to adopt. Due to the competitive situation which is maintained until the skill is learned—and because the competition is conducted against a device which is—within the scope of the performance—a mirror of the human operator's characteristics—interest is maintained, and an almost hypnotic relationship has been observed, even with quite simple jobs. So far as can be seen at the moment retention of the learned data seems to be very good, as compared with a non co-ordinated training system, using the same human operator.

The Co-ordinator

To consider the transition from the initial to the final state of the system it will be necessary to look at the way in which the input variables are used by the co-ordinator to modify the display.

The description will represent this procedure graphically.

Consider, then, a sequence of n items—the sequence positions—which are exposed in a temporal order, as indicated schematically in Fig. 2 of the accompanying drawings.

Any of the signals and correct response correlates may be associated with these positions, according to the skill to be taught—but once the signals are assigned to positions they remain in these positions and need not be further considered. Thus it will be sufficient to look at the positions themselves, and whether a correct response or an error is produced, if any response, when the human operator deals with them on any particular occasion. Consider any one, say the i-th, position. At some instant t(m) this signal is exposed. At some instant t(s) the human operator makes a response, unless there is "no response" to this "position". At some instant t(n) the co-ordinator moves on to expose the next signal—in the j-th position. These instants are illustrated in Fig. 3 of the accompanying drawings.

A timing circuit which is started by any CORRECT response and which is stopped when the co-ordinator moves on to the next position in the sequence, measures the interval between these events—namely—(t(n)—t(s)) for any CORRECT response. The durations of these intervals are collected separately for each of the positions, i, j, ... etc., etc. The average value of these intervals over several sequences is collected, for each position separately—and these average values will be denoted as T(i), T(j), ... etc., etc.

There is, in the co-ordinator, a relay which goes "ON" for any correct response, regardless of the signal with reference to which it is made, and a further relay which goes "ON" for any error. These relays have contacts which feed into an averaging device, and this device computes the balance of the average number of correct responses against errors per unit time. Thus the value of this average, denoted as θ, will increase for rapid correct responses, will decrease for only a few correct responses, and will decrease at a considerable rate for any errors which are made.

Now the interval of time, (t(n)—t(m)), which the co-ordinator spends upon the i-th position is determined as follows. A potential, V, is made to increase linearly with time during the interval, as indicated in Fig. 4 of the accompanying drawings.

A trigger circuit which moves the co-ordinator on to the next position, clears the timing device, and returns V to a value of k is made to undergo a transition at the points A and B.

It returns to a value of k for a short interval u during which the co-ordinator moves on to the next position in the sequence. The rate at which V increases with time, dV/dt, is proportional to

$$k+s.\theta.$$

where k and s are constants. The point at which a trigger circuit is actuated depends upon the value of (for the i-th position) T(i), (for the j-th position) T(j), etc., etc. In practice it is convenient to connect the T(i) store to the second-level determining—input of a trigger circuit during the i-th position, to connect the store of T(j) to the same point during the j-th position, etc., etc.

Clearly, the value of an interval, $\triangle$t, is proportional to θ.T(i) for the i-th, to θ.T(j) for the j-th position in the sequence.

There are two points which need emphasising—namely—

(1) That whilst it is reasonable to look upon the average correct response rate variable, θ, as determining, via dV/dt, the average rate at which the human operator must deal with signals, θ also functions as a weighting variable. It weights all of the input measures.

(2) A further point relevant to weighting—and of particular importance if the system is studied on the foundation of Dr. Hick's response time law. The measured interval t(n)—t(s) can be looked upon as a measure of response time since this, latter, quantity is simply t(s)—t(m). But the total interval t(n)—t(m) is compensated by the feedback operations described—the overall feedback in θ and the separate feedbacks in T(i), T(j), ... etc., etc. The compensation can be regarded as analogous to a rescaling procedure whereby t(n)—t(m), or, more generally, $\triangle$t which enters into

Input Measure $=\triangle$t—Response Time

becomes a single co-ordinator measuring scale unit, and the above relationship becomes equivalent to

Input Measure=(1—Response Time)

as measured by this non stationary assemblage —the co-ordinator.

Finally, the ambiguity of the signal is determined as follows. The uniselector, dekatron selector, or other scanning element which exposes the positions in the sequence makes a connection—in the latter case energises a diode limiter—which actuates preferentially one predetermined signal only for each position in the sequence. In practice the actuation is, however, only preferential for all of the signals are actuated to some extent. Consider the diagram in Fig. 5 of the accompanying drawings, which diagram is similar to the previous one (Fig. 4). The shaded in region shows the potential applied to a set of modulators which determine the intensity of all of the signals. Thus the signals all occur, at t(m)—but all of them are reduced to 0 between t(s) and t(m) as shown at the i-th position in the diagram, or at t(n) as shown in the j-th position in it. From the device already considered, an average any error variable is computed. It is this variable which is switched to the signal appropriate to the i-th position, when the scanning device is at the i-th position, to the j-th signal at the j-th position, and in a similar manner for the entire sequence. The import of this is that the signal appropriate to the position in question will never have an intensity less than a value S, which is determined by the average number of errors made per unit time. The greater is S, the greater the significance of the signal in the display, other things being equal. It should be noted, however, that other things are not equal if the co-ordinator is working and that the ambiguity of the signal is determined not only by S but also by θ and T(i) for the i-th, T(j) for j-th position signals. Even this simplifies the position too much—for—by ambiguity is implied not only the relative intensity of the relvant signal with respect to the others, but the interval of time spent at increasing relative intensity before t(n). It is this which determines the human operator's chance of making a correct response to the signal at a given level of ambiguity—which forces him to adopt more risky strategies and to rely upon his memory —and it is this complex of physical display variables which is compensated against some psychological difficulty variable when the human operator interacts with the co-ordinator.

During the last paragraph, the phrase signal modulator was used, for the sake of a general viewpoint. In one machine, where the signals are neon lamps, the signal modulators are replaced by a resistance network, and a couple of cathode followers, in an extinction circuit. In practice this kind of economy can often be employed.

TYPE 2 CO-ORDINATOR

THE PURPOSE

This kind of machine is used in a system which operates a training routine where the signals and the required responses are given in different forms. Thus the human operator is required to do a translation from one form to the other, if he is to perform the job sucessfully. Even in the simplest of systems, such as the one which will be used to illustrate Type 2 Co-ordinators, an ability to effect this translation may be either the whole of, or only one part of the skill which he must acquire.

THE SYSTEM

In the demonstration model a job is set up as follows.

A sequence of signals is determined, *a priori*. These signals are represented in two ways—(1) Along a line—(2) In a matrix. There are 12 different kinds of signal, and 12 positions in the sequence, so that each position is unique to one class of signal. The human operator is asked to respond as rapidly as he can, but he is required to respond only in the latter form— namely— by specifying the row and the column reference of the correct item in the matrix representation. He is provided with three "ROW" microswitches and four "COLUMN" microswitches. By pressing down for an instant the appropriate pair—they need not be, and rarely are, pressed down simultaneously—he will specify one of the twelve possible alternatives. If correct, he is given an indication via a white light-marked c^1—if his response is an error, either by having made the incorrect row selection, or the incorrect column selection, or both—he receives an indication via the red light marked e^1. There are thus two different kinds of error, either one or both of which may be committed for any signal.

Alongside the 3.4 array of lights in the display are three row "CLUE" lights, and four column "CLUE" lights.

A B E F L C H D J I K G	←(Class 1 Signals)

	1	2	3	4
i	A	B	C	D
ii	E	F	G	H
iii	I	J	K	L

←(Column Clues)

c^1
e^1

(Row Clues) (Class 2-matrix representation-signals)

Whenever the human operator notes a change in the upper display he is required to place the appropriate signal into the matrix —or to transfer the appropriate item from the upper to the lower display—this is done, as noted already, by a double manual operation performed on a manual response board in which the microswitches are arranged in the same way as the "Clue" lights in the "Display".

As in a Type 1 Co-ordinator System he is asked to anticipate the co-ordinator whenever he can do so.

The skill which he is taught at the end of the training routine will depend upon the arrangement of upper lights, and to some extent upon the circuit parameters of the co-ordinator. As in a Type 1 system the sequence is exposed in a regular way, to start with. Thus, if only a single routine is considered, the human operator may regard the upper display as giving him information about his position in this sequence—in other words he may remember a sequence of events in the matrix display. Alternatively, and always if the arrangement of the upper display is altered during several different training routines, he will tend to deal with the problem as one of relationships between the upper and lower (or matrix) signals (or as a transfer of item problem). It is interesting to note that this analysis of the problem is rather unreal, so far as this kind of system is concerned. We may, indeed, be able to deduce from the human operator's performance which type of concept he has used but when he is actually playing the competitive game, and learning, the human operator is not himself aware of using either type, explicitly. Moreover, it can be demonstrated that a report given afterwards—such as "I used the Clue Lights but not the Upper Display"— is often false. As with the other "Co-ordination" Systems, it is not an explicit set of relationships which is learned but a skill. The meaning of the relationships which are introduced at the outset becomes, in a sense, the skill.

Initial State

The Type 2 Co-ordinator presents a predetermined sequence of signals at a rate which allows the human operator plenty of time to make a correct response—one item per five seconds is quite a satisfactory starting rate. At the outset the signals in the upper display are unambiguously specified, and the clue lights for the row reference and the column appear immediately that the co-ordinator begins to expose a signal. Thus the human operator can afford to neglect the upper display since he is given two completely specified one to one responses. When he makes the correct response, or in the absence of a response, when the machine has waited for the exposure duration, a small light behind the letter in the lower matrix display comes on for a short constant interval of time. In the case of an error—when the red error light will appear also—this provides the human operator with an indication of which item he should have specified at this position in the sequence.

The Transition

A description of the stages between the initial and final states of the system is beset with the same difficulties which were encountered in connection with Type 1 Co-ordinators. Since Type 1 Co-ordinators are in any case comparable, a similar plan will be adopted. The transition will be considered in broad terms. Later the functions of the machine which bring it about will be looked at in greater detail. Fig. 6 of the accompanying drawings illustrates features of the operation of the co-ordinator.

As soon as the human operator begins to make correct responses the following operations take place in the co-ordinator.

(1) He is deprived of information about which signal in the upper display is the relevant signal at any given position in the sequence. As in Type 1 Co-ordinators, the ambiguity of the upper display increases, though complete specification is obtained rather quickly if he makes any errors.

(2) Depending upon his response time and his error to correct balance he is deprived of the information which comes via the clue lights and which converts the job into one which does not require him to effect a translation. The process will be clarified by the following instances:—

(i) Suppose for the i-th signal he had made a correct row specification, but an error had been made with reference to the column specification. Then, in future sequences, the i-th signal would be presented with the row light tending to disappear—it would be retarded by a degree dependent upon the mean value of a response time measure taken for all correct responses in the i-th position in the sequence. Thus, if he could not work out the translation—or could not do so in time— he would have to wait longer to obtain the information which removes the necessity for him to do so with respect to this row variable. On the other hand, the column specification, at which he had previously made an error in the translation, would be increased for the row clue light would appear rather sooner following the initial signal than it had previously.

(ii) If for the i-th signal, both row and column responses are correct, then the row and the column clue lights are both retarded until, eventually, they do not appear before the machine moves on. Thus the i-th signal has to be dealt with from memory—or by guesswork— or to be missed. If an error is made in either or both the row or column specification, the clue lights are reinstated to an appropriate extent.

(iii) Had both been beset with a large number of errors, both row and column lights would tend to appear with the primary signal, as soon as the co-ordinator assumed that position in the sequence.

(iv) Thus, a patterning is laid down in terms of the relative appearance times of the row and column clues. The significance of any error or of a correct response is determined by the mean response time measure with respect to each position in the sequence taken separately, by the previous disparity—or response distribution between row and column for that position in the sequence, and also by a correct response rate variable, θ, which is obtained as in the Type 1 Co-ordinator System.

Unlike the Type 1 Co-ordinator, the amount of time which is spent at each of the positions in the sequence is not changed —except by θ which determines the average time for any position. The specific patterning is laid down in terms of the row and column clue lights,—and determines the amount of time for which a problem of such and such a complexity is presented. Clearly, this paterning comes to mirror any preferences which the human operator has for remembering either the row or the column references of each of the items taken separately.

(3) An average response rate variable, θ, is computed as in the previous systems. The average rate at which the human operator is required to deal with the signals is determined by the value of this variable, which, as above, fixes the amount of time which is spent on any position in the sequence. It should be emphasized that both the ambiguity of the upper part of the display, and the exposure times of the clue lights are dependent upon its value.

Final State

In the final state of the system the ambiguity of the upper display is such that the human operator receives negligible information from it—or, if an auxiliary signal is provided to indicate the start of the sequence, it need not provide any information. The clue lights for both the row and the column references will be considerably retarded and in order to maintain this state of the system the human operator will have to make a correct response before they appear—thus not using the clue light information. The value of θ will be greater than a certain predetermined value and he will be required to respond at not less than the appropriate rate. He must respond without making any errors, or only a predetermined and small number of them. Thus, he will have necessarily learned the skill which is defined by the predetermined relationships and the rate at which this knowledge of them has to be employed.

The Co-ordinator

In many ways this is similar to the previously described co-ordinator. Thus, a trigger circuit is actuated when an increasing positive potential, V, exceeds a certain value. Unlike the previous case, where this value was determined by T(i), or T(j), etc., etc., depending upon the position in the sequence, this value is constant. As before, however, the rate at which V increases is determined by θ.

$$dV/dt/=k+\Pi.\theta.$$

Further, the average correct response rate variable, θ is computed in a comparable manner—both row and column responses being, in this case, grouped together. (In a variant form of the co-ordinator only items which have received BOTH row AND column correct responses contribute to the increase of θ).

When the trigger circuit is actuated the value of V returns to k for a period of fixed duration, u. In this Type 2 Co-ordinator the interval u is used to expose the light which shows which should have been the correct response in the matrix representation part of the display. Only after this is done are the timing circuits cleared and the uniselector moved on to the next position in the sequence (as occurred before).

Previously a number of average measures—T(i), T(j) . . . . etc., etc., were collected. In a Type 2 Co-ordinator—two of such measures, one with respect to the row response, one with respect to the column response, are collected for each position in the sequence. They will be denoted as

$$T(i),\ T(j),\ \ldots\ldots\ T(n).$$
$$T^1(i),\ T^1(j),\ \ldots\ldots\ T^1(n).$$

The uniselector switches these to two different trigger circuits, the store which is connected in this way depending upon the position in the sequence. One of these triggers actuates the row clue light, and one of them actuates the column clue light, and they receive an input from the appropriate stores. Both trigger circuits receive a common input from V.

The stores are loaded in much the same way as in Type 1 Co-ordinators. The remarks made, in that context, about the dependence of the measure— the rescaling of the co-ordinators measure— by θ, might be repeated here. The effect of T(i), T(j), etc., etc., and of $T^1(i)$, $T^1(j)$ etc., etc., upon the input measures with reference to the i-th and the j-th positions in the sequence comparable to the case which has already been dealt with—and becomes equivalent if the "chance" of the human operator making the "correct" response in time, is taken, instead as the amount of decision which he is required to make if he does make a correct response—this amount being determined chiefly by the row and column light appearance.

The waveform V is shown in Fig. 6 which is a sequence diagram of two typical items i and j in a Type 2 C-ordinated System. Only correct responses are shown, thus, both of the increment pairs ($\triangle t(i)$, $\triangle t^1(i)$) and ($\triangle t(j)$, $\triangle t^1(j)$) are added to the corresponding averages, namely ($T(i)$, $T^1(i)$) and ($T(j)$, $T^1(j)$).

General Considerations

As in the case of Type 1 Co-ordinators, the actual training routine which has been used to describe Type 2 Co-ordinators is trivial. All of the remarks which were made upon the previous occasion are, however, equally applicable. Any length of sequence, any number of alternatives can be used—generally the form of the response and the display are those commonly encountered in the job— and, uniquely to Type 2 Systems, any number of discriminative categories or stages in a translation process, or contributive sources of information may be employed. In a perfectly good sense—any number of dimensions may be employed in the specification of a signal.

In this same sense we see that a Type 1 Co-ordinator works in a unidimensional system, that a Type 2 Co-ordinator works in a multidimensional system, and that the class of co-ordinator which will be described in connection with a tactical game or a tactical situation works in a system where the average number of dimensions is determined by the state of the co-ordinator, in much the same way that the average rate of performance is determined in Type 1 Co-ordinators and Type 2 Co-ordinators.

Before describing this class of system, a set of training routines which can be conducted using only Type 1 and Type 2 co-ordinators will be considered, very briefly. One such application, of considerable importance these days, is the set of training routines which are employed when training people to be typists.

The summary below is a not too far fetched programme demonstrating the parts of the job to which the different types of co-ordinator would be applied. Needless to say, numerous different sequences, derived from the same statistics which determine the ordinarily employed typing exercises are required at each stage.

(1) Learning Keyboard Relationships with respect to Rest Keys. Type 2 Co-ordinator. Method. Initially, visual or tactile information given to indicate motion needed on receipt of letter signal. Dimensions with reference to fingers employed. Information withdrawn and signal rate increased as time goes on and performance improves.

(2) Rhythmical Exercises. Typing letter sequences for practice. Keyboard assumed known. Type 1 Co-ordinator. Method. Straight-forward using suitable sets of sequences. Combination of methods could be used.

(3) Irregular Sequences. Type 2 Co-ordinator. Marking of performance with reference to fingers and rest keys.

(4) Commercial English passages. Type 1 Co-ordinator. Sequences with words not letters as the signals. Suitable statistical arrangement of sequences which are used. Here the responses are made on an ordinary typewriter, the keyboard of which is fitted with microswitches. The display might be visual or, alternatively, it might provide tactile information via solenoid actuated movement clues on the keyboard itself. In (1) we are concerned to define the response classes or dimensions in terms not of "Rows" and "Columns" but of fingers—more precisely—sets of possible motions from each of eight

rest keys and the possible kinds of deviation to which these are subject. In (2) we are concerned with using the keyboard microswitches directly connected—and knowing whether a response on a given key—hence a given microswitch— is either an error or a correct response— or if it is missed. Since the machine does not need to deal with kinds of deviation from the ideal it can be of Type 1. In (3) we are clearly concerned with a translation process once again—or at least—with training people to avoid the effect of "noise" or "disturbance" applied (by using unfamiliar or difficult sources of signals) whilst they are doing the translation process (which they are assumed to have learned). In (4) the simpler system can again be used, though the sequences are now complex.

As with ordinary tuition there would be no hard and fast demarkation, and students might run through all of the types of system to refresh their skill.

Finally, although it is only necessary to use Type 1 Co-ordinators and Type 2 Co-ordinators, it would be desirable to use the kind of systems which will now be described for stages (3) and (4).

Using it would maintain a higher level of interest—since it replaces the "sequences" employed as signal sources up to the present —with a source of information which has characteristics i.e., "structure" determined, largely, by the human operator's own performance.

TYPE 3 CO-ORDINATOR
PURPOSE

Type 1 and Type 2 systems are applicable where a sequence (the predetermined sequence set into the machine) is a part of the job which is done when the human operator executes his skill. Their application may be extended to cover training routines for jobs in which the probability of certain contingencies is known beforehand—at least in a number of cases. All in all, however, their application is confined to the very wide class of training routines—or simulated jobs— where (a) When some contingency occurs, some fairly well defined response is required, and (b) Where the order in which events occur is not under the control of the human operator.

There exists a class of occupation which does allow the individual a certain choice about order. It is a very important class, particularly in view of "automation", since it includes the type of control job for which a human operator must always be employed (even though he is simply giving a master programme to a computing machine which performs the lower order calculations automatically). Practical examples appear whenever a human operator is required to make some decision about a "whole"—the totality of data which he receives from a large set of instruments, or a variety of signal sources —and where the decision could not be adequately made merely by adding up in some determinable way the decisions taken about each one separately. I shall call these situations, without any attempt to be rigorous, "Tactical" situations, or tactical jobs. I am not suggesting a hard and fast demarcation line between, say, TYPING (for which Type 1 and Type 2 machines could act as tutors) and CHEMICAL PLANT CONTROL (which is a tactical job of the type under discussion). It cannot be drawn, because Typing at a partially learned stage has tactical-like-characteristics and these are certainly emphasised by a co-ordinated training system. The distinction refers to the constraints which are built into the co-ordinator, the criteria of what is correct and what is in error, and what the ultimate ideal performance amounts to. In the former category of job we know that an ideal typist is a human operator who, given an input sequence of Business English, converts it into print, without any errors and at a rate limited by the typewriter's mechanics or his manual dexterity. No such precise statement can be made about a Chemical Plant Controller, an Aeroplane Pilot, or a television producer. About the former example we know only —(a) A set of rules like the rules of a game which define (i) What does what—for instance what instrument refers to what process, and what control effects what kind of change (ii) Which sorts of signal from the instruments should be regarded as danger signals and which sorts of change should be regarded as detrimental. (b) A number of limits, usually set by the rate at which changes may occur in the process which is being controlled, and by consideration of which arbitrary scale of the MECHANICAL URGENCY of signals and the MECHANICAL IMPORTANCE of effecting certain changes may be set up. But simply because we are concerned with decisions, many of which are about the "whole" rather than the "parts" of the system, a good chemical plant controller cannot be defined as a man who obeys the rules as rapidly as he can, up to his muscular, or his perceptual limits. We judge the good controller "on results", which are not directly related to his "keeping the rules" or otherwise. He is a man who achieves maximum yield for minimum disasters per unit time and who is required to estimate the relative advantage of yield over and against possible disasters according to (say) economic data which he receives (usually) from outside the system. Exactly how he does the job is, in some cases, unknown—even to the human operator himself (notably a test pilot is unable to say HOW he does many of the manoeuvres which he clearly performs). In all cases (truly tactical cases which are not degenerate) there is incomplete knowledge on this point, though certain of the strategies which the human operator might adopt, which do not lead to immediate disaster, and which could, *a priori* be good strategies may be excluded on the grounds that if they were persisted in then they would have unfortunate consequencies.

Thus we shall be concerned to familiarize a human operator with a situation in which a number, say N, contingencies may occur. This is the first part of the task—and requires a co-ordinator such as UNIT 1, which will be described—which sets up the array of contingencies presented during the training routine so that it corresponds with some measure of the human operator's ability to deal with them. As his performance improves the array of contingencies which are presented will be modified and will tend towards the actual distribution found in a given job. (Alternatively, it can maintain the frequencies of occurrence for all the contingencies at their actual values, but weight their representation —for instance by giving an order of priority to them in a presented sequence).

The second requirement is clarified when we examine how the information—the signal —which defines a contingency is to be given. It is axiomatic that in this class of situation (as was the case in the TYPE 2 CO-ORDINATOR systems) no contingency is a clearcut and " atomic " event. The signal which indicates its occurrence may, of course, be " atomic "—say the appearance of a light—but it will always be possible to give partial information—like the row and column references in TYPE 2 CO-ORDINATOR systems. In these systems the reason why the signal could not be clearcut in meaning was quite plain—namely—that the signal and the response were represented differently, and a translation process was required. The basic feature persists without making any restrictions upon the actual type of signal or of response which is made when the job is being done. This feature is that the human operator may, within the terms of the situation, remember at least as many kinds of information about the different contingencies as there are categories of partial information. Thus, in a tactical situation, the Co-ordinator must be concerned with and modify the distribution of the ways in which information regarding the contingencies (partial information, that is to say), about the array of contingencies which it sets up, UNIT 2 performs this function.

TRAINING SYSTEM

Although there are many points of similarity between this, and the previous training systems—it is probably best to look at the tactical game situation in a rather different way, if only to emphasize the freedom of choice at the human operator's disposal. The display—the totality of possible signals—forms an alphabet from which the co-ordinator, by means of selective operations, makes words or signal groups. These occur with varying frequencies so that the display becomes a language source—and it matters very little whether one regards it as a private tutor who is speaking to the human operator—or just as the human operator's environment.

Within the terms of the environment the human operator is perfectly free to make whatever action he wishes—and such an action becomes more like a strategic move than a response—(although the distinction between the strategic move, here, and the response in a Type 1 or a Type 2 Co-ordinated System disappears on more rigorous examination). Having selected some course of action the human operator may follow it through either correctly or he may make an error (the assumption of " correct or an error " is not necessary, degrees of correctness may readily be incorporated, but it will simplify the description). Whether or not the action which the human operator does in fact take, having selected a particular strategy, is deemed correct will be determined by the RULES which were mentioned a page ago. Whether or not, under particular conditions of his " environment ", the human operator has selected a good or bad strategy is determined by higher order tactical rules, which are not directly accessible and refer to the " whole ".

A simple and very general tactical situation game has been set up in which the number of possible contingencies, N is 16. A description of this will clarify the requirements for all such training systems, however specialised they may be. The display and response arrangements will be described, first of all and the Co-ordinator will be described under the headings of UNIT 1 and of UNIT 2 which have already been distinguished functionally.

DISPLAY AND RESPONSE ARRANGEMENTS

The display represents 16 relationships. Symbolically these are expressed as the relationships between signals in one 4.4 matrix and another 4.4 matrix. The response operations permitted are also a set of 16 relationships, which the human operator expresses by selecting any one at a time out of 16 microswitches in a 4.4 array, and finding its unique associate in another array of 4.4 microswitches. The switches and the signals are placed in one to one spatial correspondence. The unique response correlate for each of the microswitches in the array "X" is a microswitch in the array "Y" defined by the "ASSOCIATION ARRAY"—namely—the "GAME RULES".

A practical example would be:—

ARRAY "X".		ARRAY "Y".	
When signal—			
A.B.C.D.		d.e.h.b.	
E.F.G.H.		k.j.c.l.	
I.J.K.L.	is generated, then signal	n.g.f.m.	is generated,
M.N.O.P.		p.i.a.o.	

as given by the relationships—

ASSOCIATION ARRAY A.d,B.e,C.h,D.b, E.k,F.j,G.c,H.i, I.n,J.g,K.f,L.m, M.p,N.i,O.a,P.o, which determine the "RULES".

As before, the two sets of sixteen microswitches are in a one to one correspondence with the display sets of signals.

Occurrence of a contingency in the tactical situation—in many ways analogous to selection of a given position in the sequence in the case of the previous systems—implies

(1) Potential generation of the signals in the display which indicate the relationship required for its solution (whether or not any or all of this information is ACTUALLY supplied depends upon other factors).

(2) Setting up a "CORRECT RESPONSE" templet—namely—a connection whereby (supposing the human operator to select the X member switch belonging to this contingency) the only response marked as "CORRECT" by the Co-ordinator is the Y member switch defined by the association array.

PLAYING METHOD

The Co-ordinator can be programmed in various ways to achieve different structures of game. The simplest of these is to arrange for EITHER the human operator OR the Co-ordinator, but not both, to "play" at any given time.

In this case the solution of the tactical situation is very similar to the sort of "game" with which we are familiar—rather than being a "game" in a theoretical sense only. It is necessary, as the price of setting up this "game" situation, to impose certain constraints in order to avoid absorption states of the system.

Nevertheless, it is probably the simplest programming to describe, and it will be adopted for this purpose.

The human operator is provided with a foot switch, in addition to his two 16 way response boards. When the foot switch is depressed, a number of relays are actuated, together with the necessary delay mechanisms, and the situation is changed from "MACHINE PLAYING" to "HIM PLAYING". The reverse takes place after a fixed interval of time—the "MOVE DURATION"—the passage of this time (i.e., "how long he has left in which to make a response") being indicated by an audible signal.

The human operation is free to press the foot switch and thus to make a move whenever he wishes. Having done so he may select any one of the 16 alternatives in the "X" array. Following this he must give some termination response in the "Y" array—and only one such response will be correct at any stage. Whether his response is correct or an error—the machine is cleared by it, and he is now free to make any other selection he wishes. As mentioned, certain constraints must be applied.

(a) The duration of the move interval must be fixed

(b) The order of X, then Y—then X, then Y—must be fixed.

(c) It is necessary to arrange an exclusion circuit so that the human operator may make any given selection only once during any move interval—thus he may play any number up to and including sixteen selections during a move—but none of them more than once during that move.

(d) The various states of the system—"You must select now"—"You has selected and a response associate must be selected"—"You found the correct associate"—"The associate you found was an error"—"Make next selection anytime you wish"—must be signalled to the human operator.

Thus during the MACHINE PLAYING interval—the machine makes selective operations upon the display alphabet as determined by a UNIT 1, of the Co-ordinator. During the HIM PLAYING interval human operator makes selective operations upon his response boards.

The human operator may be provided with a SCORE variable, represented in the display, and intended to show his success. (In fact, as will be considered later, this variable need not be REPRESENTED). It is the variable analogous to θ in the previous machines, and represents—in terms of games theory—the utility gain to the system as a result of the previous sets of moves. Its computation will be discussed at a later stage. Its values range from 0 to 1, and it increases with correct responses, made rapidly. It decreases in value with an error, or with time wasted. If the system is set up as an explicit game it is necessary to weight the decrease of θ with unused " HIM PLAYING "—move making—time more heavily than with the time during which the " MACHINE IS PLAYING " and the human operator is gaining information from it. The object of the game is to maximise the value of θ, and it will be shown how, when θ is maximised, the human operator is able to deal with the tactical situation at the required rate and in the best possible way.

UNIT 1 CO-ORDINATOR

The UNIT 1 determines the selective operations which are made upon the display alphabet, when the system is in the " MACHINE PLAYING " state.

It receives an input from the human operator's previous responses, and a further input from the computed variable θ.

Consider, first of all, the position when the system is held in the " HIM PLAYING " state. Whenever the human operator makes an " X " selection a relay, corresponding to this particular " X " selection is actuated and this opens up a store—for the I-th selection, the I-th store, for the J-th selection, the J-th store, etc., etc. Let t(m) be the instant at which the selection is made and let t(x) be the instant at which the corresponding response associate, whether correct or an error, is selected. Then, during the interval—t(x)—t(m) for the I-th selection, the average upon the I-th store is decreased in value at a rate $K^1.\theta$. and likewise for the J-th and other store averages. At the instant t(x)—or very shortly afterwards the store in question receives (1). If the response associate which has been selected is correct—an increment of charge added to it—of value $K^{11}\theta$, otherwise, (2). If the response was an error, a decrement of charge removed from it, of the same value.

(When there exists some *a priori* criterion of the significance—say the economic significance—of an error, then the values of the added and subtracted increments, and the increments with reference to the different stores, may be suitably weighted).

In the above, K^1, and K^{11} are constants.

Let the averages on the different stores be called T(I), T(J), etc., etc.

Associated with each class of signal is a relay in the anode circuit of a corresponding trigger device. (A common cathode trigger for instance). Thus there are 16 trigger circuits in this machine, one for the I-th, one for the J-th class of signal, etc., etc.

A potential proportional to T(I) is applied to one input of the I-th trigger circuit, a potential which is proportional to T(J) is applied to the J-th trigger circuit, etc., etc.

The second input of each trigger circuit is taken, via a high resistance, to a cathode follower output point. The anode return of each trigger circuit which does not contain a relay would, normally, be taken to a positive potential via a resistance of comparable value to the relay's resistance. Instead, this anode resistance is split. A part of it is individual for each trigger circuit, a part of it is common to them all. Thus the common resistance, and the separate resistances plus the trigger impedance form a potential divider, the potential at the lower end of the common resistance decreasing as the trigger circuit relays are actuated (assuming the correct sense of input connections to be established). Call this potential U.

When the system is in the state " HIM PLAYING " the potential on the cathode follower output point assumes a value the output of the cathode follower is held at a value v, such that all of the trigger circuit relays are " OFF "—i.e. not actuated—regardless of the values of the store averages.

During the " MACHINE PLAYING " interval a periodic forcing input which must be made a function of U and of θ is applied to the cathode follower.

Perhaps the simplest form is the triangular waveform generated by setting limits determined by the state " All On " and " All Off " —(with reference to the 16 relays). dV/dt is made proportional to θ (as in the previous systems). As V increases more of the trigger circuits come " ON ". As they do so U increases, and this increase is applied as a feedback in the negative sense to decrease the rate of change of V^1. Thus dV^1/dt is determined by θ and by the population of transitions in a given region on the scan—the effect being to scan slowly over a region where the transition probability is high, rapidly otherwise. On receiving a signal from a set of series contacts that all of the relays are " ON " the sense of dV/dt becomes negative, and *vice versa* on receiving the all " Off " signal—thus a triangular scan is generated.

Other types of forcing input—such as a sinusoidal waveform—have been employed.

As will be shown later, θ itself may be used as the input.

If, whenever a relay is in the "On" condition, the associated signal is delivered, we have a device which gives a signal an exposure interval which is determined by its store average, by θ and by the aggregate of store averages. The device also tends to accentuate any grouping of signals in the scan sequence.

It is probably fair to regard the exposure interval as being proportional to the probability of information being obtained from this particular class of signal, when the store averages are arranged to suppress the first grid potentials on the triggers. The resulting compensation is then in the sense of reducing the signal probability of an item as the human operator's average correct response rate for this item increases—i.e. the better he gets at dealing with this contingency the more difficult it becomes for him to find out what it is that he SHOULD DO. This mode of operation is used in the present machine.

On the other hand, an output in the form of the frequency of occurrence of contingencies is often useful. This is readily obtained if the forcing input is made a random fluctuation of mean amplitude determined by θ (the U feedback being also applied). Attached to each of the trigger circuits is an impulse contact which feeds a constant duration delay circuit—one to each contingency. Thus whenever a transition occurs an impulse (which actuates the relay appropriate for a constant duration) is generated. In this way the weighted random input function performs a selective operation upon a configuration of elements which is determined by T(I), T(J) . . . . etc., etc.

Partitioned Feedback And Other Issues

As θ increases, the average rate of presentation increases due to the increasing scan velocity. If the second mode of operation is used, this increase on the part of the co-ordinator is limited by the human operator's ability—at a given stage in his learning process—to deal with the required aggregate of signals per unit time.

If the first mode is used, this limit is not so real—especially when the signals are given a visual presentation, and when, in consequence, "retinal integration" must be taken into account.

The difficulty is overcome by partitioning the θ feedback.

θ is used as before to control the mean scan velocity—but the feedback coefficient of this loop is reduced. A further loop is established, such that, when θ increases the discernibility of the display information is caused to decrease. The physical variable which θ is made to control may, in the case of a visual display, be the intensity of the signals. Alternatively a NOISE may be injected into the system. This NOISE will be any form of disturbance which perturbs the real life working conditions (and will be proportional—NOT—INVERSELY proportional, to θ).

Since θ is a compensated variable, in the sense already considered, and since the measure units of the co-ordinator are equal increments of θ, we should predict that the physical variable used to modulate the discernibility of the display data, would not be critical. Providing, in fact, that some change of discernibility occurs for each change of θ—and in the appropriate sense—we have found this prediction to be borne out in all of the many cases which have been tried in practice. Similar remarks can be applied to the set of variables which are chosen to function as "noise".

Overall Effect

The overall effect is to provide the human operator with a source of information which becomes adapted to his own characteristics. As his SCORE—namely θ—increases, and as he gets better at the job of controlling this tactical situation, so the situation becomes more difficult for him to deal with.

Aspects of the situation which he finds perplexing are accentuated, so that he is forced to practise their solution. But as he is forced to practise, so, also he is given more specific information about what he OUGHT TO do in order to be correct.

Limiting States

Clearly enough, the human operator cannot truly "beat" the machine in this game, unless he "knows" the situation as well as he is required to do, and uses his knowledge in order to give a consistently good performance. Should his performance deteriorate, the system will become instable, and will revert to a previous state in which it is giving the human operator more information about the correct procedure.

There exists, however, the possibility of the human operator not only knowing nothing about what he ought to do, but not being able (except by an ENTIRELY trial and error approach) to gain such knowledge. To prevent this we adopt what appears to be, at first sight, a rather arbitrary expedient. We make the lack of information time dependent —so that the statement about the human operator—"He is forced to either guess or to rely upon his memory, if he is to move"— would be replaced by "He is forced to guess or to rely upon his memory if he is to move within a certain time, otherwise, he can wait and as a result of this delay obtain a complete specification of the correct move".

This statement obtains, already, in the case of the "MACHINE PLAYING" state of the system. That it does not do so during the "HIM PLAYING" state is entirely due to the game structure which has been imposed by the chosen "either it or him—not both—"

type of programme. In practice, we arrange that should the human operator select a particular "X" item, and be unable to make either by use of his memory, or by an "inspired guess", any "Y" selection, then the appropriate Y cell is exposed to him after a certain delay period.

The actual procedure, and the importance of making the human operator pay the price of a time delay, in order to get certain specification (rather than simply denying him this specification absolutely) will become clear when we look at the functions of UNIT 2. For the moment it will be sufficient to note that

(1) The duration of this delay period is necessarily made proportional to the value of θ at each state in the game.

(2) That the whole procedure is justifiable and non arbitrary if the system is examined on a theoretical basis. For here, when we draw the game matrix in its simplest form, the human operator's pure strategies appear as "RISK" and "NO RISK" (in the context of a particular stage in the learning process). Likewise the co-ordinator's pure strategies appear as "COMPLETE SPECIFICATION" and "SPECIFICATION AFTER A PERIOD WHICH DOES NOT ALLOW THE HUMAN OPERATOR TO MAKE A SUCCESSFUL MOVE WITH REFERENCE TO THE AGGREGATE" (in the context of a particular state of the co-ordinator). The strategies of making no move, or no specification, can never become prudential strategies in a partially competitive game of this type.

PRACTICAL USE

There are, very broadly, two ways in which the game can be used. In the first place the co-ordinator is introduced to the human operator as a "private tutor", which is going to give him just as much data as he needs in order to manipulate the tactical situation—and as a result of his successful manipulation to increase the value of the score variable θ. He is told that the characteristics of the co-ordinator will be modified as a result of his performance, and he is observed, in practice, to "train" the "co-ordinator" so that its characteristics suit his personal abilities.

The second method is to introduce the co-ordinator as part of a story or a control situation. The story or situation will be designed to simulate the real life circumstances under which he is required to exercise his skill.

An imaginary instance will serve to illustrate the kind of situation which can be set up using a co-ordinator which determines the frequency of occurrence of events (rather, that is to say, than the exposure intervals).

The imaginary situation deals with projectiles. The co-ordinator is envisaged as able to send projectiles, which will impinge upon the human operator's domain, from any of 16 sites. The human operator is free to oppose this barrage by sending projectiles back at the co-ordinator from any of 16 sites. We constrain the situation—via the association array—by setting up a certain set of relationships, such that if and only if the human operator aims his projectiles correctly will they have any beneficial effect (and reduce the incidence of the co-ordinator's projectiles). We programme the co-ordinator—i.e. we programme its game structure—so that a continual stream of projectiles are being hurled at the human operator. He sets out to reduce this stream—to reduce the rate at which signals are sent for him to deal with—or to reduce the value of θ, by playing back. It is feasible to represent θ in the display as an inverse measure of the damage which the human operator's domain is suffering. But in practice, it is hardly necessary to do so, for the human operator can tell from the feel of the situation how well he is doing.

When he "aims a projectile in return" he "selects an item in the X-Array, and finds some destination for it, in the Y-Array". As time goes on he adopts groups of operations —and it is of interest to note that his choice of strategy is neither entirely short term nor entirely determined by the most frequently occurring—*a priori* the most damaging "projectiles". In other words, supposing that, as a result of his previous moves the "projectile" (I) was impinging upon him very often he would not necessarily play counter (I), namely (i).

His strategies are determined by his ability to control the situation as a whole, and to maintain his control over a given period. Broadly speaking, as the groups of operations which he adopts become larger so does his policy become longer term. The immediate choice of strategy is determined by the state of his knowledge of the control job. If, in the instance cited, he did not know the relationship i-I-precisely he might well refrain from playing counter I since to do so would remove the information defining i-I. Thus the strategies he adopts will often appear, to an outside observer, to be inefficient. They are the best strategies for this particular human being at this particular stage in his learning process, when he is involved in a job that has been continually compensated, with reference to his performance. For brevity call these strategies the best SYSTEM STRATEGIES. In that case a rigorous definition of the co-ordinator's function is that it catalyses the kind of play which uses the best SYSTEM STRATEGIES and causes the human being to learn a skill efficiently on this account.

The initial state of the system is one in which the human operator sustains considerable "damage"—the value of θ being fairly low. The final state is a stationary condition in which the human operator is playing strategies such that he is employing an efficient tactic with respect to the skill defined by the constraints (-i-I), (-j-J), etc., etc., and it corresponds to some value of θ which we can set as the required minimum. But the transition from one state to another is much more difficult than the sequence type arrangements—and a logical description was hardly possible even there. The kind of casual statement which was made in the last example—about the i-I- information—is apt to be false if applied to any actual instance. Consequently no attempt will be made to treat the transition of the tactical game situation in an analytic manner.

The Functions Performed by the Co-ordinator's UNIT 2

Recapitulation of Text

As considered up to this point the system is operating with UNIT 1 as the only explicit component—on examination some other unit is implied—but that is all. The explicit UNIT 1 determines the statistical structure of the source—the human operator's environment—by determining either (a) The frequency with which each class of signal in the display—each letter in the display alphabet—will, on the average occur, or (b) The average duration of time during which these signals are exposed. Apart from this it determines the average rate at which any signals occur—or*—by a simple modification of the scanning technique described at the beginning of the last section it can determine—instead of the average rate, the average effective alphabet size at each stage.

Concept of a System Dimensionality

The UNIT 2 of the co-ordinator determines the way in which the information which is conveyed by the signals is represented to the human operator. As already mentioned there is some similarity—though not complete equivalence—between the phrases "The dimensions of the message space" and the "ways of representing the message". Since there is a matter of argument I shall adopt an arbitrary definition of the term "DIMENSION" as used in the present context—whilst admitting that my definition is by no means satisfactory. Let "DIMENSION" mean any class of data in the display concerning which the co-ordinator can accept a pressure of some relevant control operation which the human operator is allowed to make.

Given this, Type 2 systems are two dimensional. The human being is provided with both row and column clues, and his response operations may be right or wrong in either or both of these two ways. We note, however, that mere provision of the row and column references would not necessarily make the system two dimensional. Nor, on the other hand, would restriction of the manual response to a single operation—say pressing one out of twelve buttons—necessarily reduce it from a two dimensional to a one dimensional arrangement. It would remain two dimensional so long as two categories of error were "marked" by the co-ordinator—and it is immaterial in the abstract case whether the human operator makes two explicit responses which may be either right or wrong—or whether the machine determines two possible categories of error into either or both of which his single response may fall.

* As in the last of the scanning diagrams we determine the range or deviation amplitude of the scan.

Thus, in general, the number of dimensions is equal to any number between 1 and the number of contingencies.

(Alternatively, the number of classes—1, in a closed finite display system—or—generally the number of possible "partial data" classes).

Actually, this last assertion stands upon much more dubious ground than the first definition. It is convenient, for the present purpose, because it is true regarding a wide class of simple structured (and readily describable) systems.

Practical Example

Let us further restrict our attention to those systems which (unlike the Type 2 systems) have dimensions set up according to a symmetrical breakdown (the meaning of this term will become clear in context).

Consider the 16 way practical system which has been the subject of our previous discussion.

It is perfectly simple to dichotomise the Y-ARRAY- in the following manner. The means I have adopted is arbitrary excepting that it is a symmetrical breakdown of the Y-ARRAY-.

a.b.c.d.
e.f.g.h.
i.j.k.l.
m.n.o.p.

Breaks down into four dichotomous categories A.B.C.D. each one of which includes an equal number of elements—thus:—

A includes a, b, c, d, e, f, g, h, B includes a, b, e, f, i, j, m, n, C includes a, b, c, d, m, n, o, p D, includes a, e, i, m, d, h, l. p.

Using the same ASSOCIATION ARRAY as before we can express the correct Y Array correlate for any X Array selection, as defined by the ASSOCIATION ARRAY in terms of a four figure binary member in which, say, i stands for "inclusion", o stands for "not included", and the different positions for A, B, C and D.

Of these the first few are listed below—namely:—

	A.B.C.D.
A related to d expressed as	i. o. i. i.
B related to e expressed as	i. i. o. i.
C related to h expressed as	i. o. o. i.
D related to b expressed as	i. i. i. o.
etc., etc.	

Let each of the categories A, B, C, D be a channel of partial information which is represented in the display and which bears one dichrotomous statement when exposed—i.e. 1 Bit—of information. The display, for instance, may consist of (64) lamps—each in a separate holder—arranged in groups of four each, there being 16 such groups. This is one method used in practice in our demonstration machine.

According to the association array we make any single lamp* in a group of four either blue or yellow, the former colour indicating i, the latter colour, meaning o. The positions of the four lamps are read as follows.

A
B D
C

The groups are represented on the X-ARRAY-

A.B.C.D.
E.F.G.H.
I. J. K. L.
M.N.O.P.

So that, as above, the first line will be—in colour code in practice—the following.

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  i   i   i   i
o i i i o i i o
  i   o   o   i
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etc., etc.

The co-ordinator's UNIT 2 accumulates the following averages:—

S(A), S(B), S(C), S(D), and a further overall average N-. S(A) determines the probability dependent on a particular class of signal—say the I-th-class of signal in the display—that the correct correlate of the I-th-class, say i, will be specified with respect to its A dimension, or representation category. The term probability may be rewritten—given a suitable re-arrangement of the system—as the relative exposure interval of the category A at that instant. S(B) determines similar values for B S(C) for C, and S(D) for D.

The average N determines the average number of categories which will be exposed—i.e.—the average specification of i, given I, and it is related to S(A), S(B), S(C) and S(D), so that if the value of N at some instant provides for the exposure of, say U categories then those U with the greatest S averages will be the U which are in fact exposed.

* In practice there are 2. (64) lamps in the display, there being pairs of yellow and blue lamps only the appropriate one of which is connected at the outset.

N is made inversely proportional to θ. Thus, at the outset, or when the value of θ is low—all of them will be exposed—and if I appears in the display and i will be completely specified, if J, then j will be completely specified. Ultimately, when θ is high, none of them will be exposed. F is a linking coefficient and determines the specification which is given at a particular rate. Its effect is most marked at the higher rates.

(In most of the machines F is not fixed but is made proportional to the value of θ averaged over an empirically determined interval).

The Input to UNIT 2 of the Co-ordinator

There are broadly speaking two ways of deriving an input.

(A) Suppose that we modify the " story " or " situation "—the one about projectiles—so that the human operator is told that he is provided with four signal stations. By combining the information from these signal stations—the display categories—he will be able to discern where a projectile which impinges upon him has come from, but, as he gets better at doing so his signal stations tend to become inefficient. (In a simple system of this type they never transmit MISLEADING information—only NO information—).

His method of response remains the same, however, and he aims back by making a one out of sixteen selection and a one out of sixteen response to it. The method of marking the selection (built into the co-ordinator) is different. Instead of marking his response to his own selection as " right " or " wrong " we set up a switching function whenever he makes an X-ARRAY-selection and this switching function is the binary representation of the appropriate Y-ARRAY-response. Call this the templet.

Next, whenever, after the X-ARRAY-selection he makes some actual Y-ARRAY-response we set up a further switching function—namely the binary representation of the Y-ARRAY-cell which he has selected (and which may be either correct or an error).

The binary number corresponding to his response selection is then compared with the templet. According to the correspondence between the two we note that the human operator may either be right or wrong in any or all of four different ways.

	A.B.C.D.
Suppose for instance that the templet corresponds to - -	i o i o
Then the correct response would also yield and this would be marked as - - - - -	i o i o
	1. 1. 1. 1.

On the other hand, assuming the
same templet, namely - - i. o. i. o.
The response - - - - - i. i. o. o.
would be an error in B and in D

and would be marked - - 1-1. 1- 1.

Let the response time be t(x) then the averages S(A), S(B), S(C), S(D), are added to or penalised to an extent θ.t(x), or, $-\theta$.t(x) according to the marking of the response.

(B) The alternative method of deriving an input requires us to alter the human operator's mode of response. We define, by means of the display—and using some analogy such as signal stations—the course of a projectile. When the human operator aims back he is now required, instead of making a one in sixteen X-ARRAY-selection followed by a one in sixteen Y-ARRAY-selection, to make a one in sixteen X-ARRAY-selection and four separate one in two decisions upon a group of four pairs of switches which set up the switching function for the templet directly. The order in which he makes these decisions is not constrained, nor is the time at which he makes them. Let us call the actual times at which, starting at his X-ARRAY-selection, he makes the Y responses t(A), t(B), t(C), t(D), respectively. Then the marking for the correct response as above will be

θ.t(A)/.θ.t(B)/.θ.t(C)/θ.t(D).

which increments are added to the averages

S(A). S(B). S(C). S(D).

Likewise, for the partial error response as above, the marking will be θ.t(A)/—θ.t(B)/ θ.t(C)/—θ.t(D). which increments are added or subtracted to the respective averages directly. The rationale of weighting the response time measure with θ has not been justified at this point because the case is analogous to those already considered at some length.

Functional Properties

Suppose that the human operator makes either all completely correct or all completely error, or some of both but no partially correct responses. Thus he exhibits no bias towards a particular kind of an error. In this case, as his performance improves and θ increases, and as θ increases so N increases—a point will be reached at which instead of receiving information in all of the display categories for a particular class of signal—he will receive information in no categories—i.e.—no information. The categories are not manifest and will not become manifest until he exhibits a bias by making preferential errors—or—in the case of (B) preferentially distributed response times.

As soon as he does so, however, his chance of obtaining a particular category of information from the display will increase or decrease. If he makes errors with respect to a particular category, his chance of obtaining information in this category about a particular item will increase, if he is consistently correct it will decrease—and a similar remark applies to his response time distribution in the reverse sense—.

Thus the "dimensions" become available as he uses them—until then they remain "latent" in the display—. In (B) they are necessarily explicit for they correspond to stages in a multiple response operation (as noted at the time however the human operator is free to respond in any order with any timing—and may respond coincidently—. In practice the human operator will often play the four decision pairs like a chord).

Modified System

A page ago, when the scanning operation which determines which of the categories will be exposed was being discussed, a weighting coefficient, F was introduced. N is made proportional to F.θ.

If a co-ordinator is set up with F prefixed—the averages S(A), S(B), S(C), S(D), determine simply the chance of the respective category of information, referred to ANY signal class, appearing in the display.

Although such a procedure was adopted during the experimental stages of development it is not consistent with the general theory of these co-ordinators—chiefly because, within that theory, F should be a compensated variable—determining the specification at a given average signal rate and under the human operator's indirect control. It is intuitively clear, and it can be shown more rigorously, that F should be a variable dependent upon the average on the store for the class of signal to which the information refers.

In the type of machine which has been used for the purpose of a practical example, this can be arranged directly by making F proportional to the potential on T(I), if the I-th signal is exposed, to T(J), if the J-th signal is exposed, etc., etc. When UNIT 1 of the co-ordinator is arranged to determine the exposure intervals of the various classes of display signals (rather than the chance of these signals occurring in the display) it is necessary to arrange a feedback which weights each of the averages T(I), T(J), according to the coincident exposure interval and to make N an increasing function of θ and the exposure interval. The result of this is to expose all of the classes of information relevant to a particular selection in the X-ARRAY- if the human operator waits long enough before making a response selection in the Y-Array—. After this selection, N reverts to its normal value, and remains dependent on θ until the next selection.

A Summary

To summarise:—

The human operator receives information from a display in four categories—effectively dimensions—. These become apparent only when he exhibits a preference for dealing with particular categories of contingency. The probability of occurrence of the sixteen classes of signal in the display are likewise determined by his preference for dealing with each of them, whereas the average probability of ANY signal occurring in the display is determined by the variable θ. Looked at in terms of games theory there is a sense in which we can speak about the best "SYSTEM STRATEGIES" as distinct from the best "PROBLEM STRATEGIES"—leading to an immediate correct solution—or the best "HUMAN OPERATOR strategies". The outcome of operating the best "SYSTEM STRATEGIES" may be said to yield a distribution of "System Utilities". Now, one can regard the averages for the stores on the signal classes, namely, T(I), T(J), etc., etc., as being distributions of θ at any given instant, and likewise S(A), S(B), etc., etc., the averages which determine the occurrence of the different categories of information.

It appears possible to regard this array as the distribution of "System Utilities" at any given instant—determining the system utility gain which will result from playing a particular system strategy—. This possibility arises because of the interaction between the human operator and the co-ordinator, on account of which we speak of the variables as being compensated. This, in turn, leading to the idea of a non stationary (in the statistical sense of non stationary) machine which appears stationary with reference to a (by definition) non stationary assemblage—the human operator—.

Thus it is not unreasonable to suppose that a recording, in terms of suitable parameters, of the moment to moment state of the system (which is a perfectly straight-forward thing to do) may yield a very objective measure of the human operator's characteristics—as a kind of mental test—. If the constraints applied to the system define a skill the test would be an "aptitude" test. If the system is constrained to maximise the sum of the difference moduli between the averages it will be a stress test. Further applications are envisaged.

Whilst it is difficult to justify this theoretical framework at any rate without a great deal more data on performance, enough has already been collected to be certain of the practical usefulness of such a technique.

The following diagrams will serve to clarify:—

(1) Tactical situation co-ordinator with exposure interval modulation or

(2) Signal probability modulation. The latter is shown with a display for (3). Mode A and (4). Mode B.

Some Comments

Since the categories remain latent until there is an imbalance the system can be regarded as of variable dimension number, since any weighted combination of the categories can be utilised, as of variable dimension type—and the variables which determine the utilised assemblage are compensated against the human operator's performance characteristics—.

Thus it does not matter greatly what divisions are made when establishing the categories—though in practice we usually select any obvious ones which arise on account of a particular job—. The divisions need not be symmetrical and in certain special cases the maximum or latent maximum number is not necessarily defined.

This is the case in some of the derived continuous systems which will be considered in the next section.

The means of representation in the display is not critical.

One need not, for instance, have four signal lights arranged in groups of four in a 64 light array, in order to represent the four binary category form of the 16 item system which has been discussed. An equally good method is to programme the machine structure so that, on making a particular X-ARRAY-selection the corresponding Y-ARRAY-selection is gradually revealed. Thus, on making his selection in the X-ARRAY- the human operator is presented with 16 lights on a Y-ARRAY- display board. As time goes on sets of these lights are obliterated—corresponding to the various categories A, B, C, D at instants determined by S(A), S(B), S(C), S(D)— and eventually only the one correct item remains. Thus, if he waits for a specification which is complete, the human operator is penalised. He may, if his state of knowledge or his willingness to take a risk is adequate, respond before specification is complete.

In this, the background theory is again implicit, though unnecessary for the practical justification of the device. Briefly, one conceives a decision process going on in the human operator's brain—certain stages of which are aided by his recollections—. The object of the co-ordinator is to code the assistance he receives—as determined by S(A), S(B), S(C), S(D), so that it fits his state of knowledge and helps him where he finds difficulty—but not otherwise—. Stated baldly the theory is not adequate—but it is possible to show that a weighted combination of any selected set of categories may function approximately as any set of categories which the human operator may have selected in his conceptual notion of the job—and it is not asumed that he does in fact select the arbitrary dichotonisation which has been imposed upon the display information—.

Further, instead of determining an explicit probability of occurrence or an exposure interval, the display may be intensity modulated or the information channels subjected to "noise" dependent upon the value of T(I), T(J), etc. etc., and S(A), S(B), etc. etc.

Since the variables are compensated these forms of coding appear—as might be expected —quite satisfactory and equivalent to the more justifiable coding by relative duration or likelihood.

In practice, it is possible to impose a valuable modification upon the system by biasing the various categories. This is equivalent to introducing "degrees of error" or "degrees of success". For instance, it may be decided upon mechanical or other grounds concerned only with the part played by the skill under real life circumstances, that errors of one sort are more important than those of another. This scale of importance can be imposed at the marking mechanism as a bias which results, in effect, in the extraction of a difference signal—between the *a priori* estimate of importance and the human operator's estimate of importance—for each contingency. The difference signals then contribute towards the averages and determine the state of the system.

The scale of importance, moreover, may be derived during the course of a performance as a function of the progressive state of a controlled system of *a priori* determined characteristics.

If, for instance, the control and the display are intended to represent the control of an aeroplane the result of the control up to a given instant may be computed as in a flight simulator and represented as the present state of the aeroplane. (The co-ordinator is determining the contingencies with which the human operator has to deal). This state may be "marked" against a criterion of mechanical stability of the "aeroplane" and the result employed as a feedback to the co-ordinator. (Bearing in mind that the distinction between learning situations and real performance is one of degree only, so far as these tactical situations are concerned, we envisage the use of the co-ordinators as devices which code the representation of many channels of information—as from meters etc. etc.,—into a complex parameter display. They could thus be used as aids to performance in very complex control jobs where the present technique of using an *a priori* determined coding is inadequate).

The aeroplane example really shows how the system can be used to teach the functional characteristics of an assemblage—the aeroplane—. In this sense the co-ordinated system enjoys an entirely general applicability. It has been found possible, empirically, to extend the same latitude which was noted for the display representation to the actual control variables —and for much the same reason—. The response time measure, which has some foundation on Dr. Hick's law, may apparently be replaced by measures of lever movement or other control operations which are relevant to a job. Thus most of the potential applications can be realised in practice—and the tactical situation for which the human operator is to be trained can be anything from a logical or managerial problem to a mechanical skill—.

Finally, there is a class of system which has already been touched upon in connection with mental testing, in which we desire to establish a particular state of the system—or state of the human operator—. Here, a co-ordinator may be used to catalyse the achievement of the desired state—and often, to render it more explicit—. If some variable—say a stress promoting variable like "noise"—is applied to a system set up to simulate a particular job then the human operator will experience greater difficulty. Now if, in the case of a stress promoting variable, we make value of this variable at any instant inversely proportional to θ a potent hypnotic relationship is set up which leads—rather dramatically—to a stress situation. (The results, as a matter of fact, can be really alarming).

Though more difficult to set up in practice much the same kind of thing occurs if some motivation variable is made proportional to the changing value of θ (—it acts as a realistic kind of score variable—). Here the situation is not one of stress but rather of pleasure. The situation is probably analogous to a game or a skill which we ordinarily enjoy doing. It seems possible, by using a co-ordinator in this manner, to create such a situation with certainty.

Clearly, a slight extension of this principle allows one to use a co-ordinated system for the comparison of the stress creating or the motivation creating effects of several different variables, in a very objective manner. It may, as already mentioned, be used to compare the susceptibility of different human operators to a variable of known potency. We have not, as yet, investigated these attributes of the system except in a qualitative manner but there is reason to believe that physiological variables (such as the integrated electromyogram from the frontalis muscle—some index of attentiveness—or the integral of the "a" rhythm "component" of the E.E.G. which has been used previously as an index of the narcosis of a subject) might be employed as the input to the co-ordinator. Again there is the possibility of using physiological variables (rapidly acting dugs, for instance), in place of a display. The idea is not so bizarre as it might seem at first sight—an ordinary servomechanism to control anaesthetic level as a function of the integrated E.E.G. is quite well known—and there may be, here, a very large field of clinical use for the co-ordinators especially in the treatment of mental patients.

CONTINUOUS VARIABLE CO-ORDINATORS

Since the human operator quantises information when he perceives it, there is no hard and fast distinction between the discrete selection jobs already considered and situations which involve continuous display variables (and, or control variables). The electrical methods may differ considerably, however, and it will be worthwhile to exemplify this by one technique which has been adopted.

The technique is applied to a pursuit task (which can be arranged in one or more dimensions) and in which a human operator provided with a velocity control that determines the locus of a pointer—the VEHICLE —is required to follow the course of another pointer—the TARGET—.

Consider the case when the TARGET has no prefixed course.

In this case the TARGET strategies will be entirely determined by the co-ordinator. All other cases may be derived from this by application of a set of constraints—to determine a most probable target course—and then translation of these constraints by means of instructions from the co-ordinator.

Let the pure strategies of the target be:—

s.1. (1) Move left, if the vehicle moves right, right, if left.

s.2. (2) Move right, if the vehicle moves right, left if left.

Also, for the vehicle—which is controlled by the human operator—there are the pure strategies:—

f.1. (1) Move left, if the target moves right, right, if left.

f.2. (2) Move right, if the target moves right, left, if left.

Let any weighted combination of these pure strategies be available and all such mixed strategies be physically represented as degrees of either co-operative or competitive motion.

Conveniently this system can be set up using two motors which are servo controlled and which operate two sets of Y potentiometers, say X(1), (2), etc. etc., and Y(1), (2), etc. etc. The potentiometers X(1), Y(1) have applied across them, initially, a fixed potential which is used as a reference potential for a positional servo-mechanism. Then any situation at time t can be set up as two zeroing loci which correspond to the outcome points of playing two pure or mixed strategies, one from s.1 .... s.2, the other from f.1 .... f.2. The pure strategies will correspond with the ends of the two tracks, respectively. The potentiometers X(2), Y(2), form a sensory bridge device whereby a variable θ, derived at time t, is resolved into its s.1, s.2, f.1, f.2, components. The value of θ is then averaged with respect to these components. Call the average values, V(s1), V(s2), V(f1), V(f2) and cause the potentiometer X(1) to have maintained across it, instead of a fixed potential, a potential V(s1)—V(s2), whilst the potentiometer Y(1) has a potential V(f1)—V(f2) maintained across it. Consider, then, a further servo-mechanism which equates the position of the target and the vehicle using as a reference scale the now aberant scales on X(1) and Y(1). The motion of the target will now be as required if we make the correction rate at any instant, instead of become θ.u.

The variable θ is conveniently derived from two further potentiometers X(3), Y(3), across which is applied an alternating potential at same suitable carrier frequency—say about 500 c.p.—. The output is taken in this case from between the two moving arms on the potentiometers and its rectified and averaged value will be the average value of the target to vehicle deviation moduli, thus, by definition—θ—.

Whilst θ, in the system described is distributed about only four pure strategy points —i.e., the signal is applied to the moving arms of only two potentiometers and resolved into only four components—the procedure can be extended to any desired number of variables.

Finally consider two further potentiometers X(4), Y(4), which provide a potential that represents the position of the target and the vehicle in the display. Their moving arms may, for instance, be taken to deflection plates on cathode ray tubes or to meters which are deflected proportionally to the motor movements. Suppose that the potential across these potentiometers is constant then the display representation will be on a constant scale with respect to the actual motion. If, however, the potential across them is dependent upon θ the display scale or representation scale will increase—and thus deviations will become more readily discernible as the average deviation increases and less as it decreases.

Systems of this type have been used successfully and since the continuous physical variables present a more realistic job are very suitable for building up stress situations and for the similar procedures outlined in the previous section.

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6, Bream's Buildings, London, E.C.4.

Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press.—1961
Published at the Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained

Fig. 1.

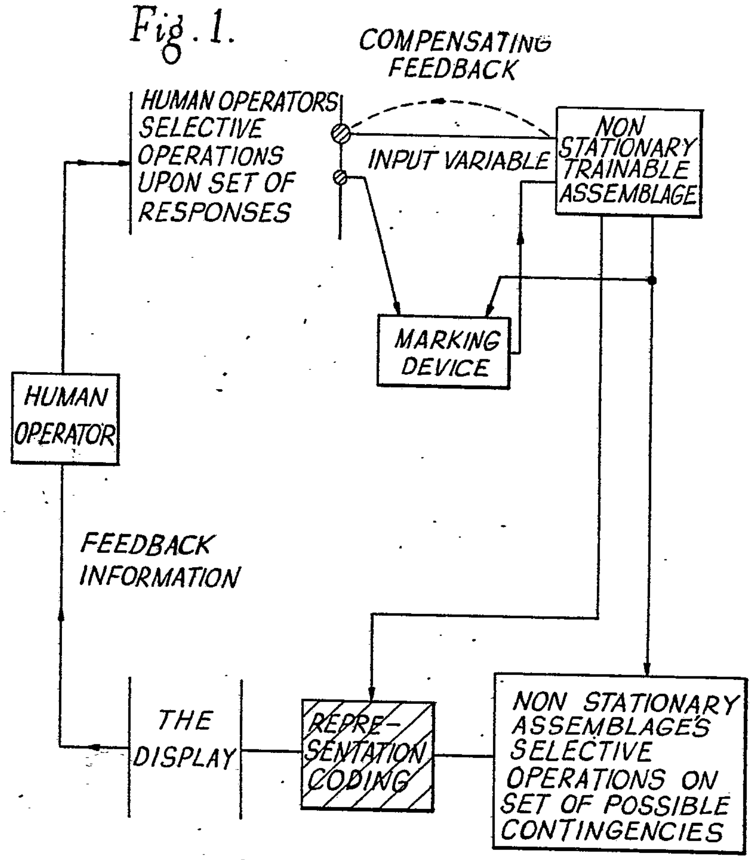


Fig. 2.

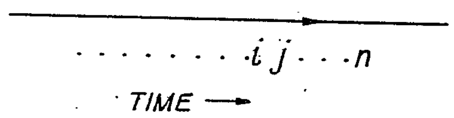


Fig. 3.

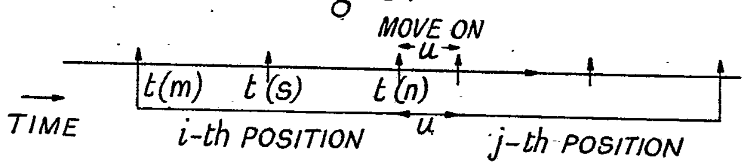


Fig. 4.

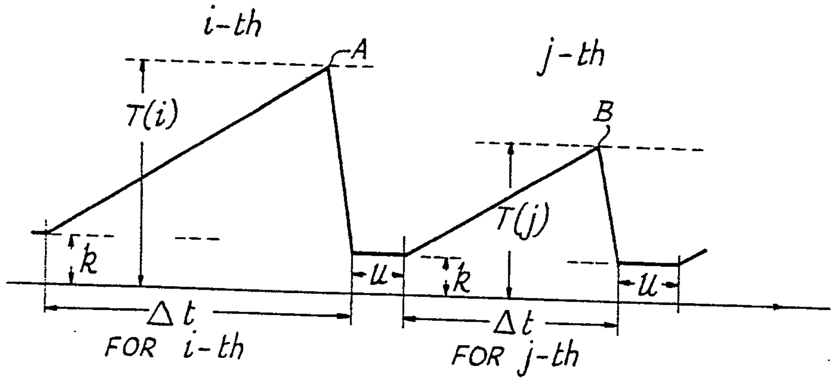
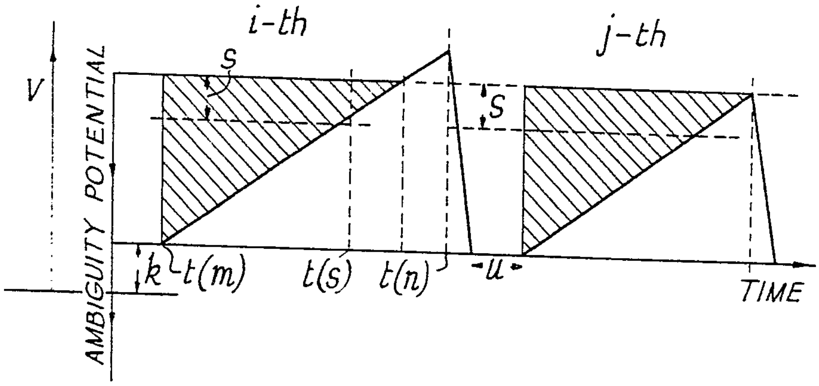

i-th
A
j-th
T(i)
B
T(j)
k
u
k
u
Δt
FOR i-th
Δt
FOR j-th

Fig. 5.


i-th
j-th
V
S
S
AMBIGUITY POTENTIAL
k
t(m)
t(s)
t(n)
u
TIME

866279 PROVISIONAL SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 2 & 3

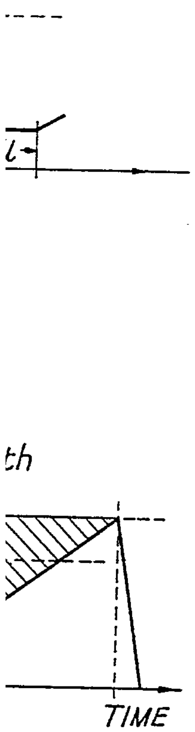


Fig. 6.

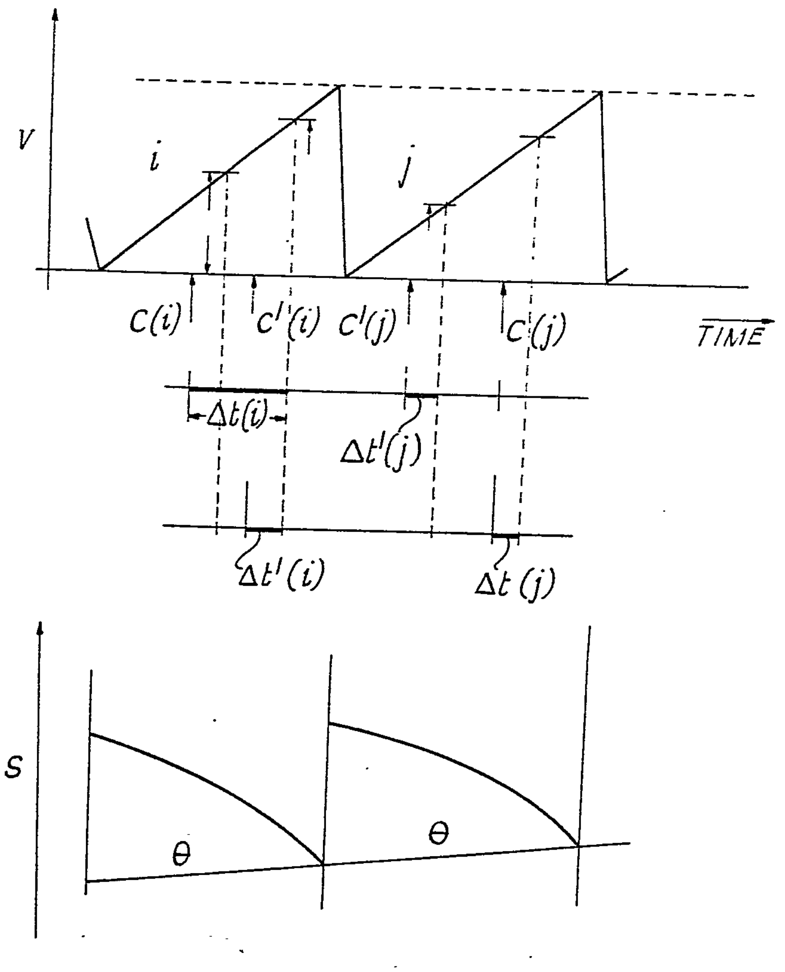


Fig. 4.

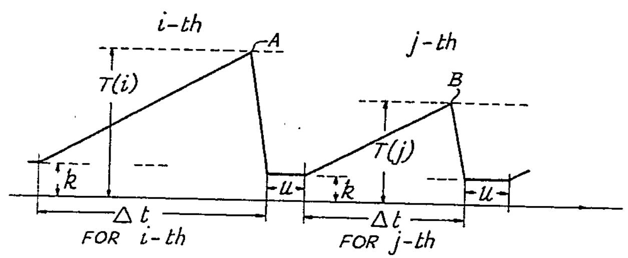


Fig. 5.

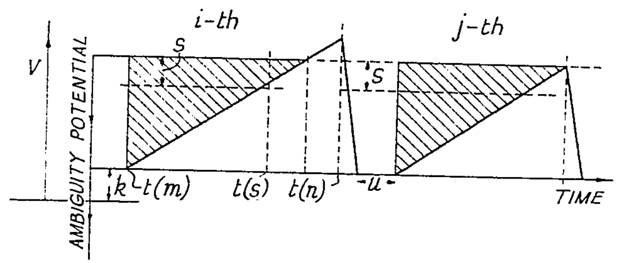
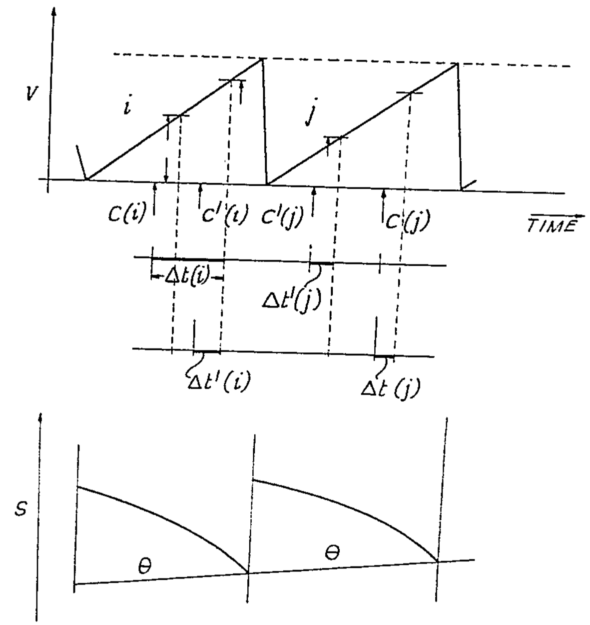


Fig. 6.



866279 COMPLETE SPECIFICATION

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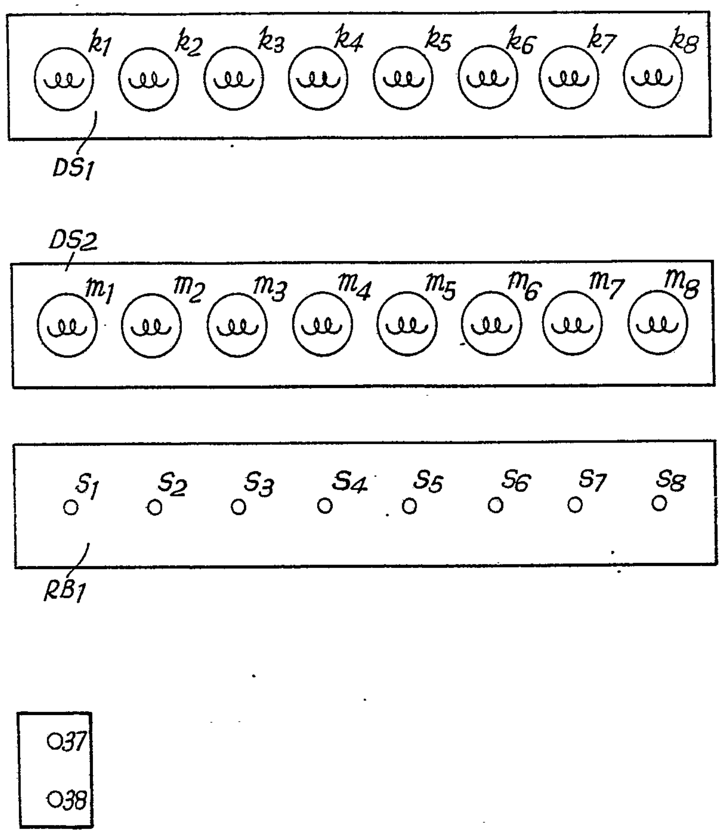
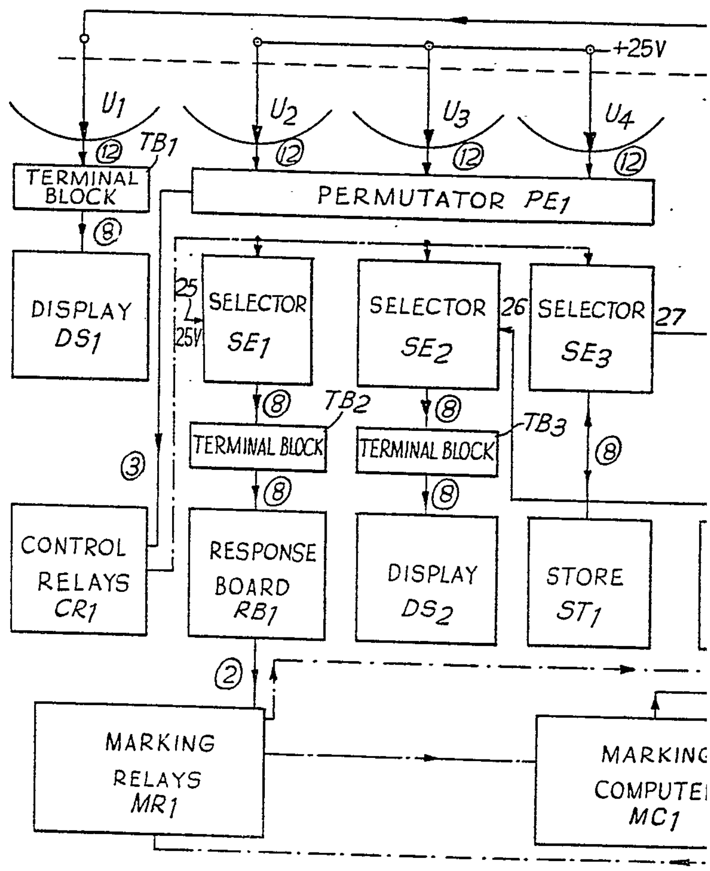
Sheet 1

Fig. 1.





+25V
U1
U2
U3
U4
12
TB1
TERMINAL BLOCK
PERMUTATOR PE1
8
DISPLAY DS1
25
25V
SELECTOR SE1
SELECTOR SE2
26
SELECTOR SE3
27
TB2
TERMINAL BLOCK
TB3
3
CONTROL RELAYS CR1
RESPONSE BOARD RB1
DISPLAY DS2
STORE ST1
2
MARKING RELAYS MR1
MARKING COMPUTE MC1

866279 COMPLETE SPECIFICATION
26 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 2

Fig. 2.

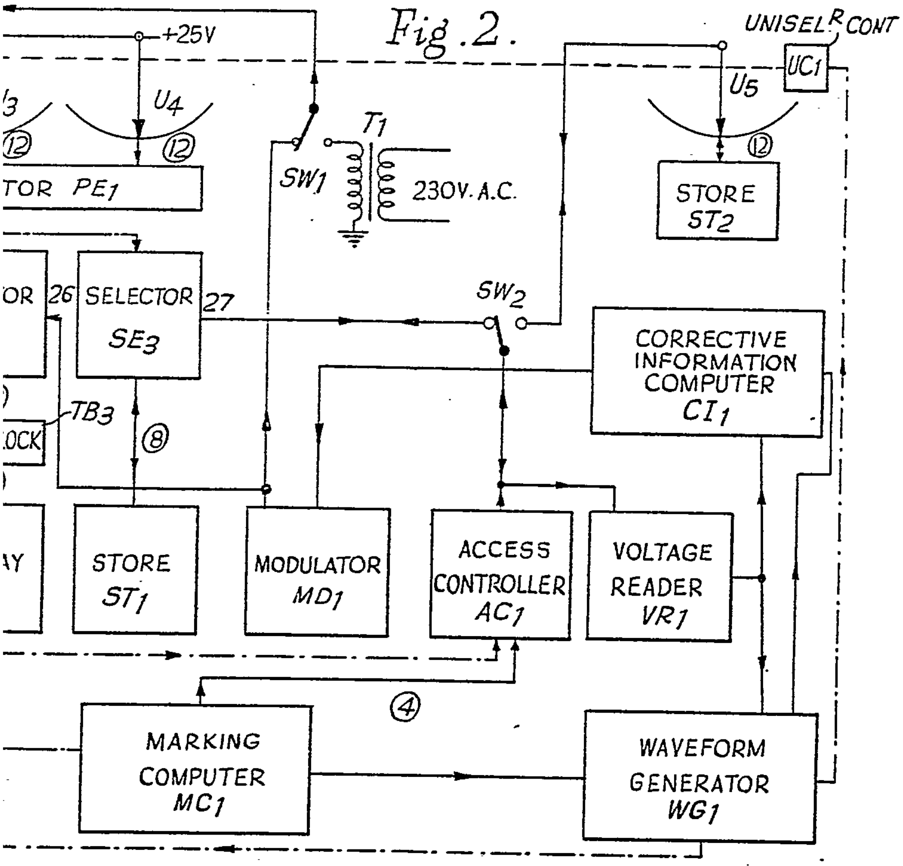


Fig. 2.

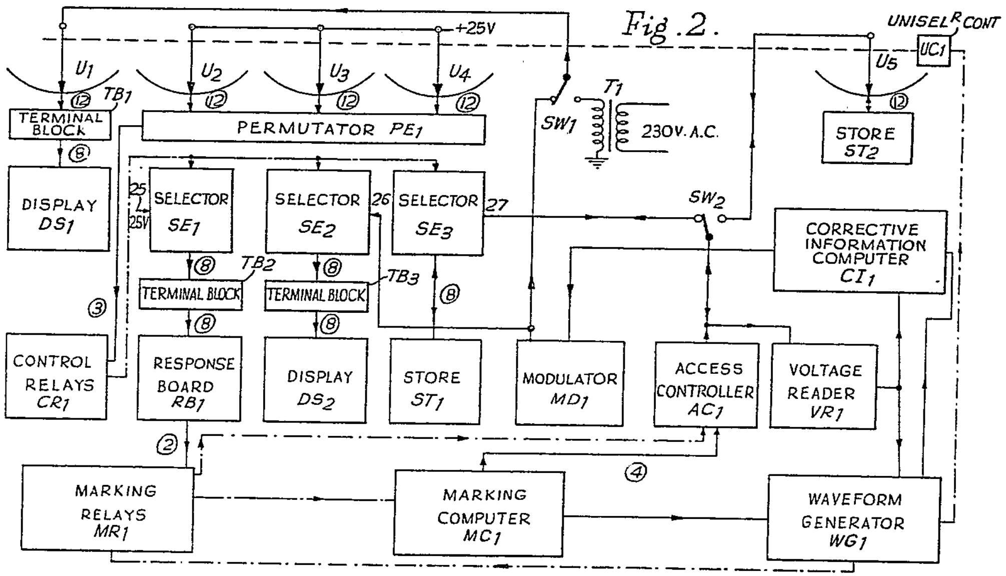
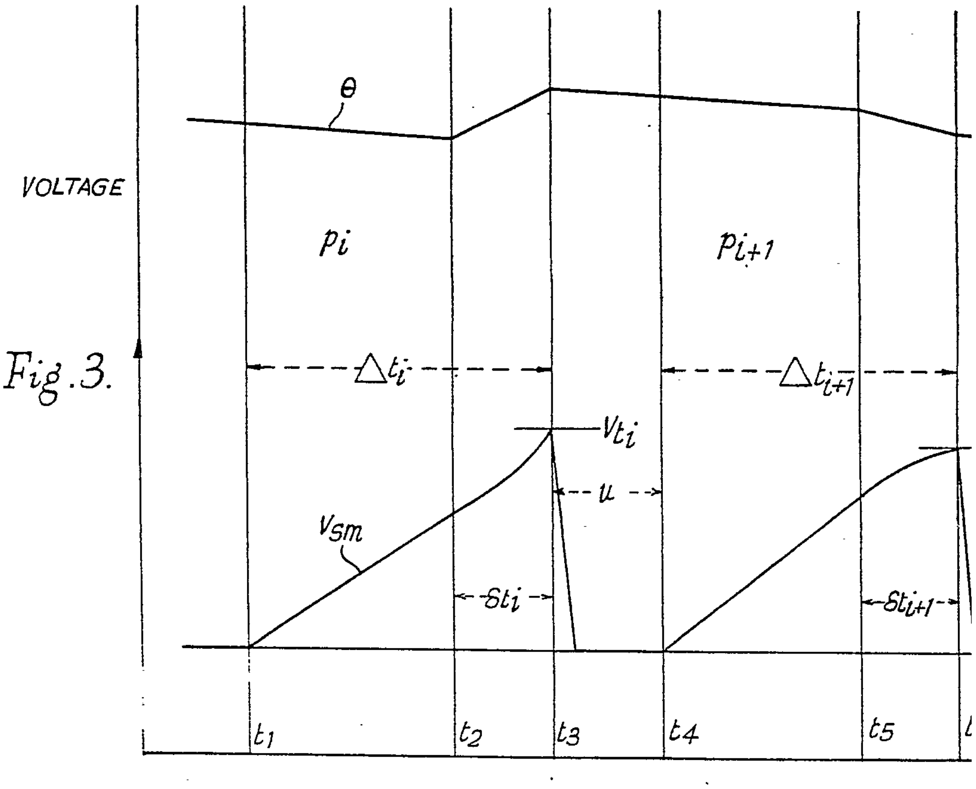

UNISEL R CONT
UC1
U1
U2
U3
U4
U5
+25V
TB1
TERMINAL BLOCK
PERMUTATOR PE1
SW1
T1
230V. A.C.
STORE ST2
DISPLAY DS1
SELECTOR SE1
SELECTOR SE2
SELECTOR SE3
25
25V
26
27
SW2
TB2
TB3
TERMINAL BLOCK
TERMINAL BLOCK
CORRECTIVE INFORMATION COMPUTER CI1
CONTROL RELAYS CR1
RESPONSE BOARD RB1
DISPLAY DS2
STORE ST1
MODULATOR MD1
ACCESS CONTROLLER AC1
VOLTAGE READER VR1
MARKING RELAYS MR1
MARKING COMPUTER MC1
WAVEFORM GENERATOR WG1

Fig. 3.



θ
VOLTAGE
p_i
p_{i+1}
Δt_i
Δt_{i+1}
V_{t_i}
u
V_{sm}
δt_i
δt_{i+1}
t_1
t_2
t_3
t_4
t_5

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Sheet 3

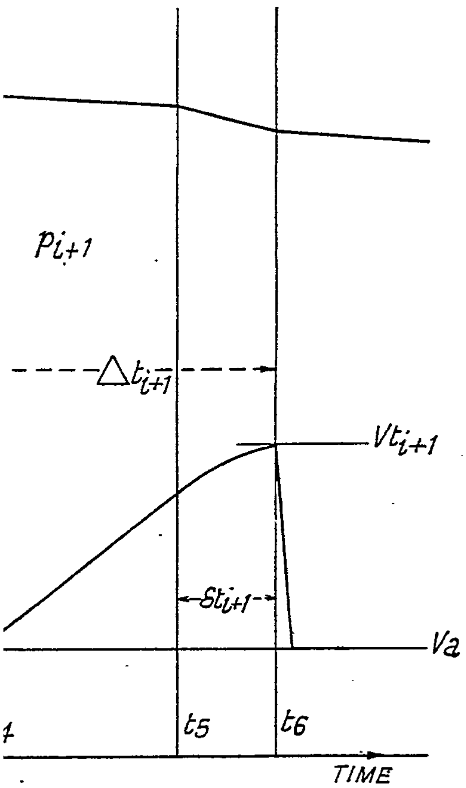
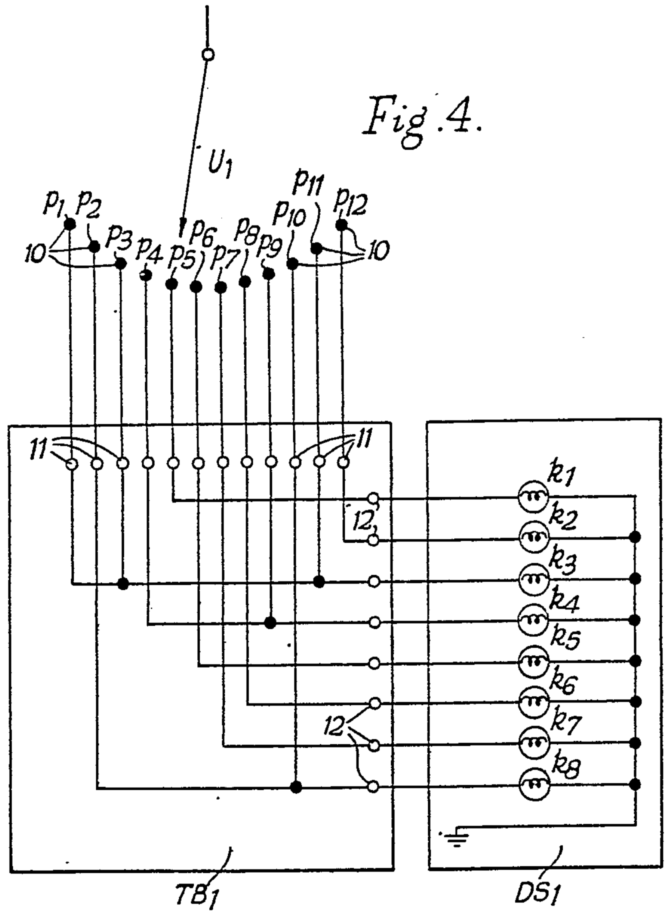


Fig. 4.



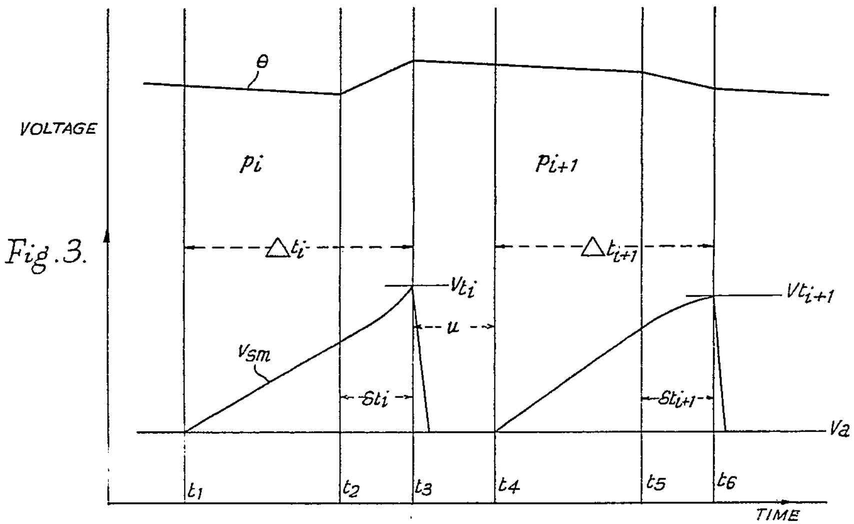

VOLTAGE
θ
pi
pi+1
Δti
Δti+1
Vti
Vti+1
u
Vsm
δti
δti+1
Va
t1
t2
t3
t4
t5
t6
TIME

Fig. 3.

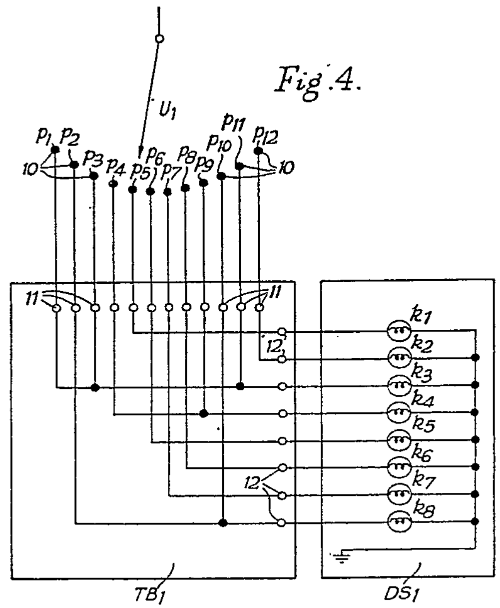
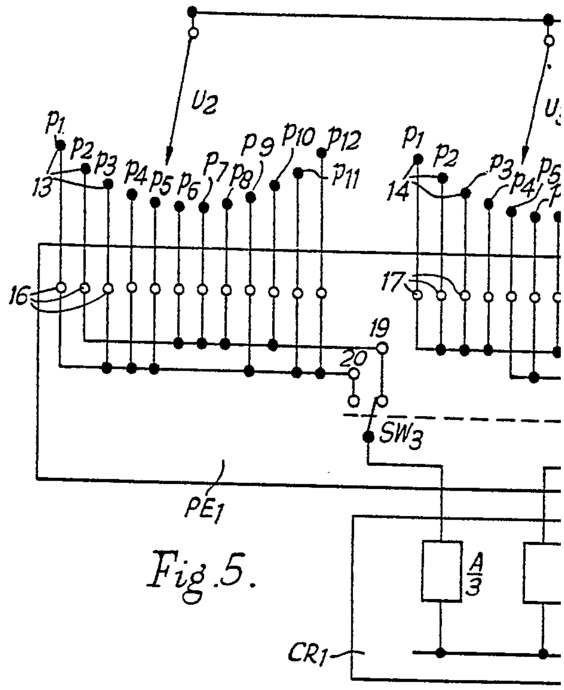
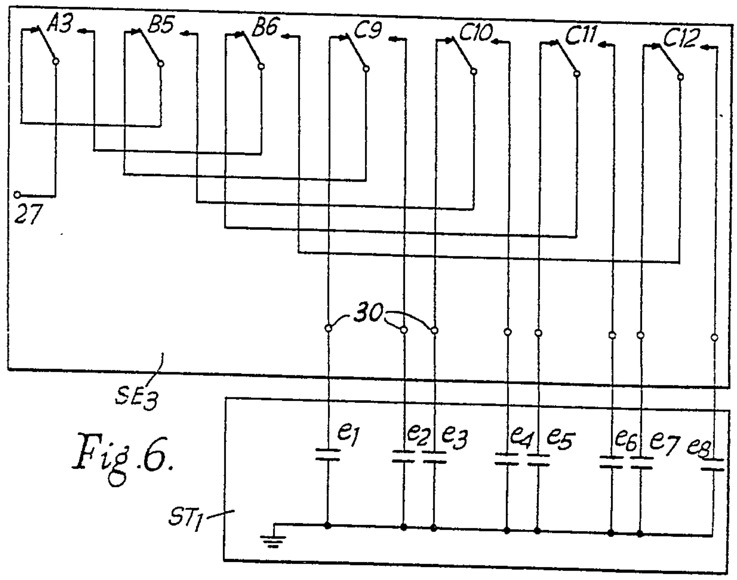

U1
p1 p2 p3 p4 p5 p6 p7 p8 p9 p10 p11 p12
10
11
12
k1 k2 k3 k4 k5 k6 k7 k8
TB1
DS1

Fig. 4.



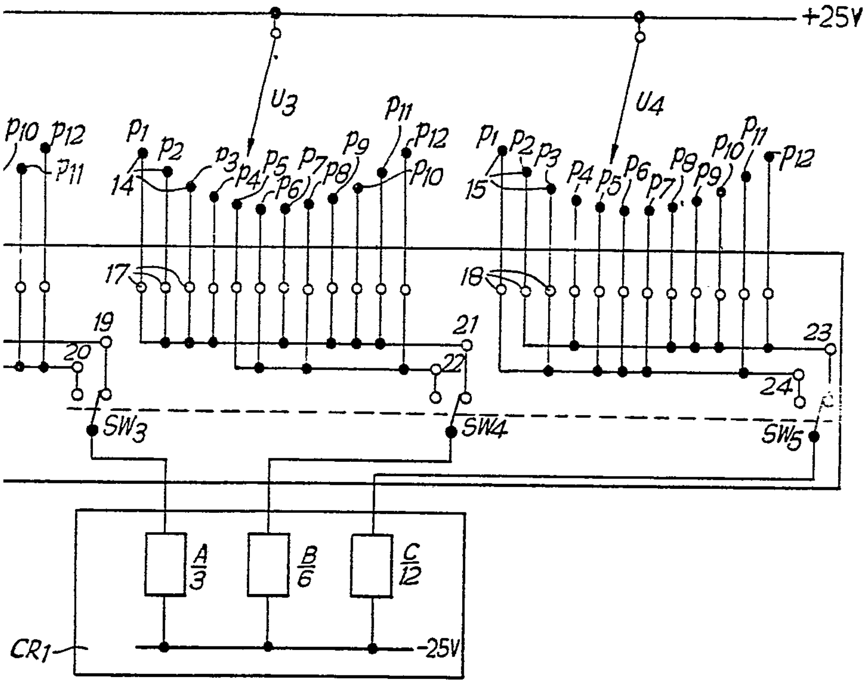
U2
U3
p1 p2 p3 p4 p5 p6 p7 p8 p9 p10 p11 p12
13
14
16
17
19
20
SW3
PE1
A
3
CR1

Fig.5.



A3
B5
B6
C9
C10
C11
C12
27
30
SE3
e1 e2 e3 e4 e5 e6 e7 e8
ST1

Fig.6.


+25V
U3
U4
p1
p2
p3
p4
p5
p6
p7
p8
p9
p10
p11
p12
14
15
17
18
19
20
21
22
23
24
SW3
SW4
SW5
A/3
B/6
C/12
CR1
-25V

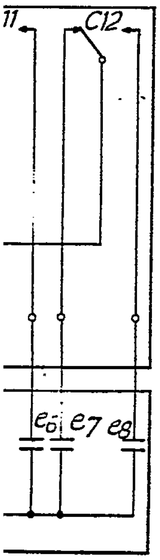
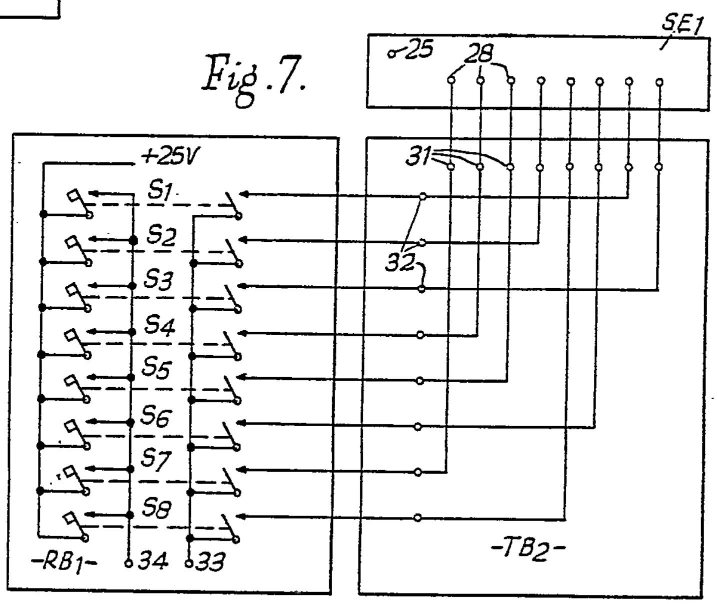

C12
e6
e7
e8

Fig.7.


SE1
25
28
31
32
+25V
S1
S2
S3
S4
S5
S6
S7
S8
-RB1-
34
33
-TB2-

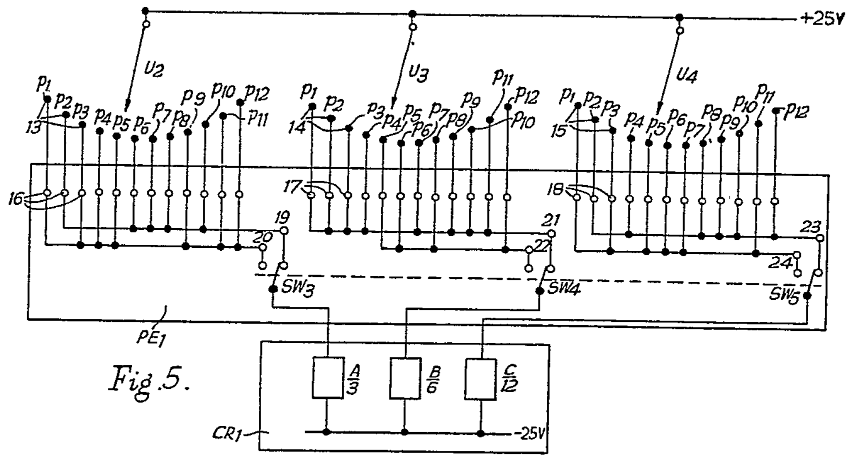


Fig.5.

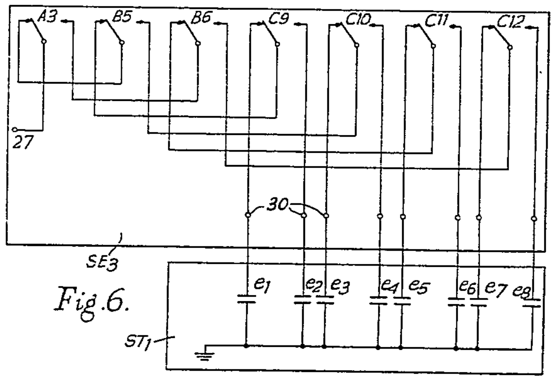


Fig.6.

Fig.7.

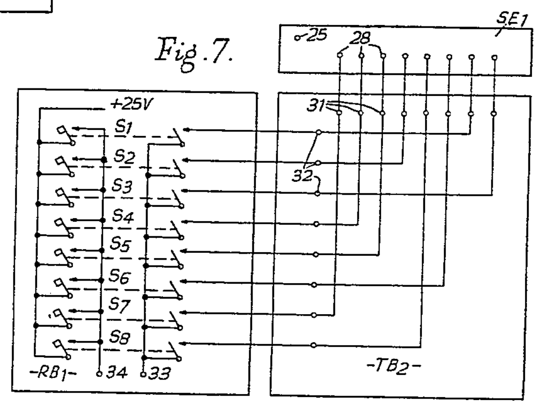


Fig.9.

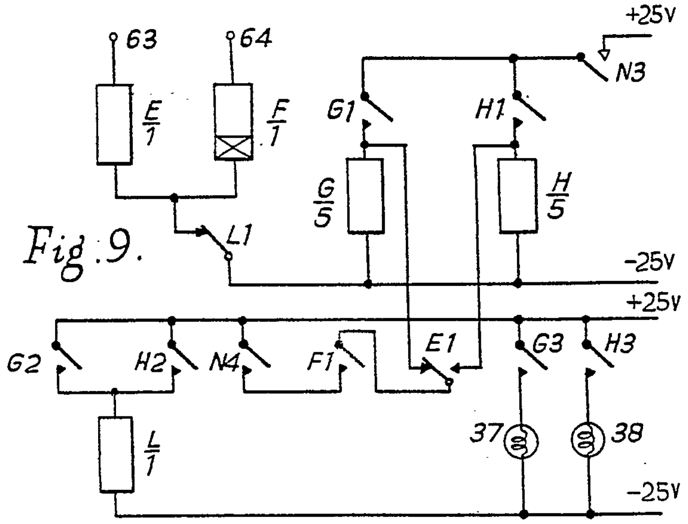
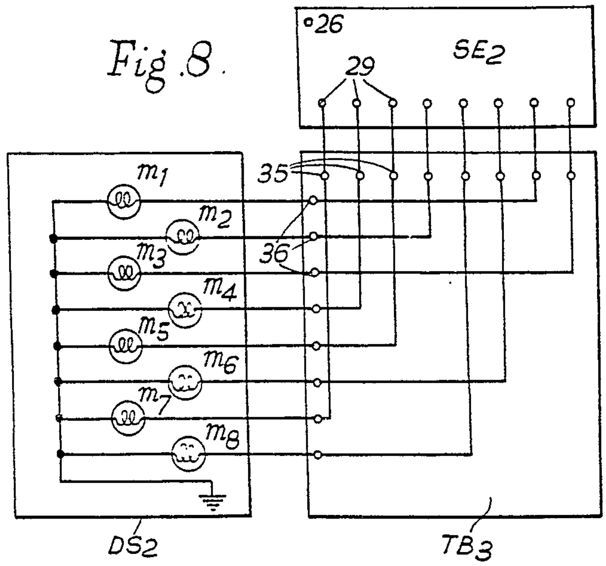

63
64
E/1
F/1
+25V
N3
G1
H1
G/5
H/5
L1
-25V
+25V
G2
H2
N4
F1
E1
G3
H3
L/1
37
38
-25V

Fig.8.


26
SE2
29
35
36
m1
m2
m3
m4
m5
m6
m7
m8
DS2
TB3

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26 SHEETS This drawing is a reproduction of the Original on a reduced scale
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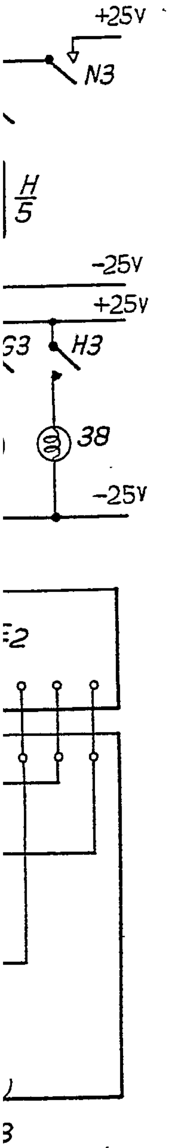

Fig.13.

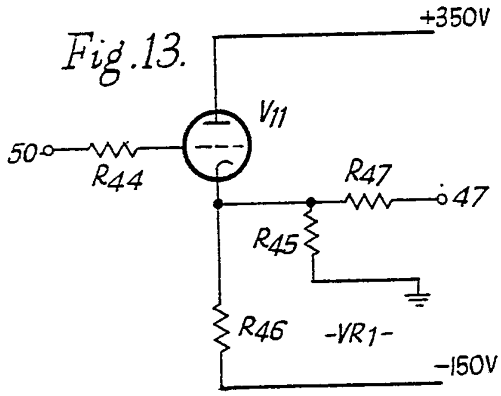

Fig.14.

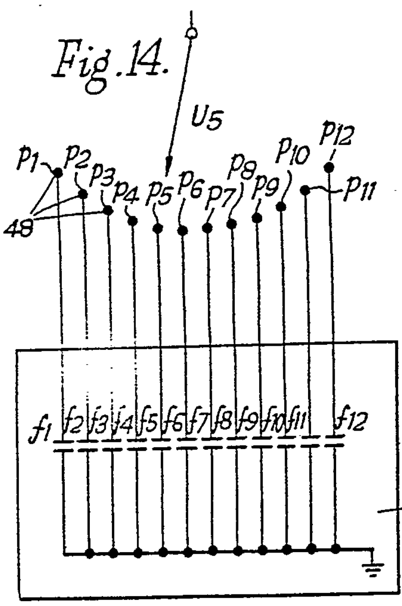

Fig.15.

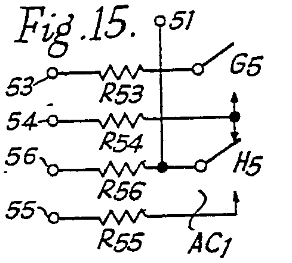

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Fig. 9.

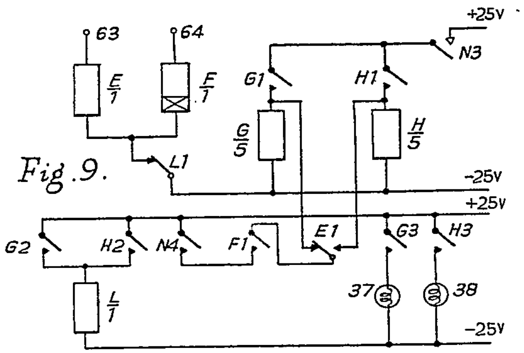


Fig. 8

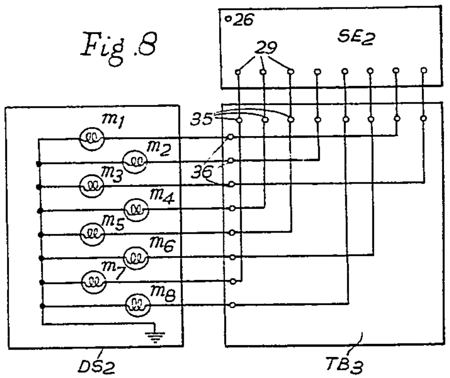


Fig. 13.

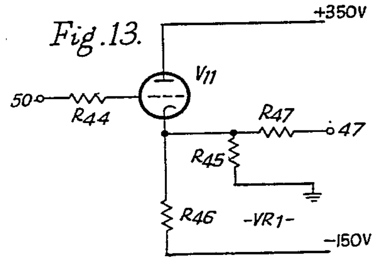


Fig. 14.

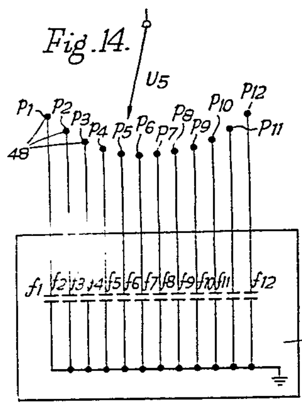


Fig. 15.

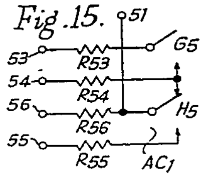


Fig. 11.

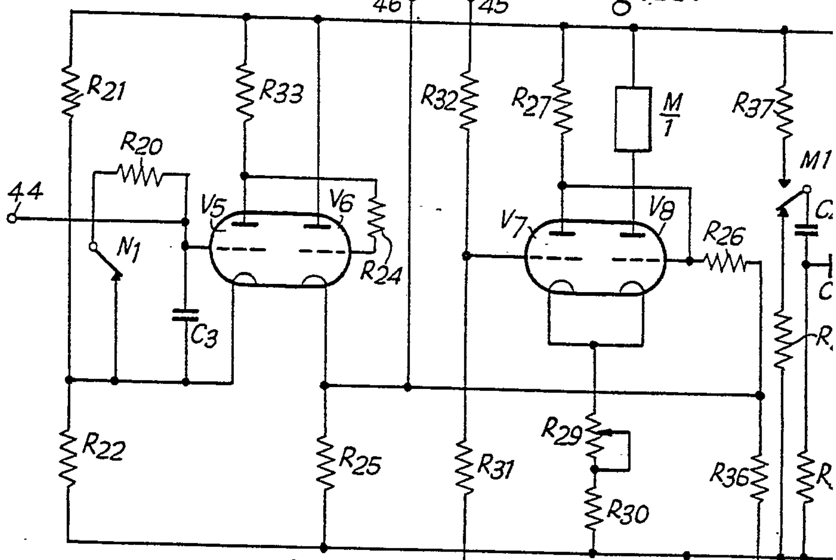
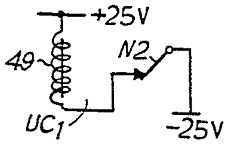


Fig. 12.



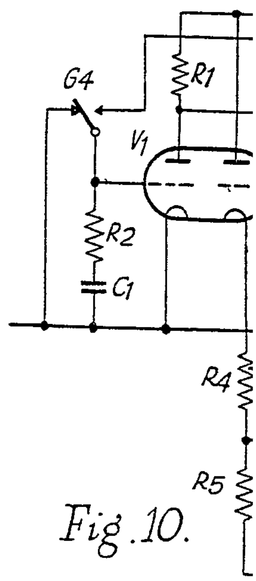
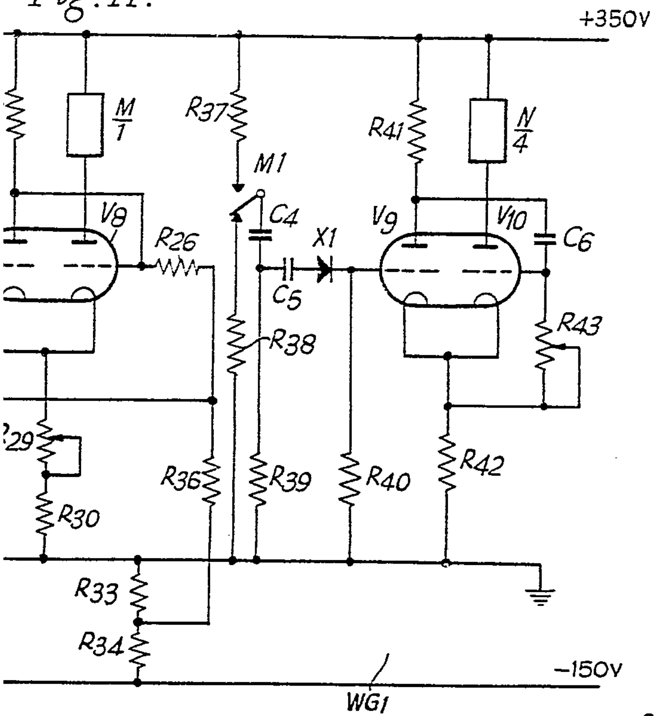


Fig. 10.

Fig.11.


+350V
M/1
R37
R41
N/4
M1
C4
X1
V9
V10
C6
V8
R26
C5
R38
R43
R29
R36
R39
R40
R42
R30
R33
R34
-150V
WG1

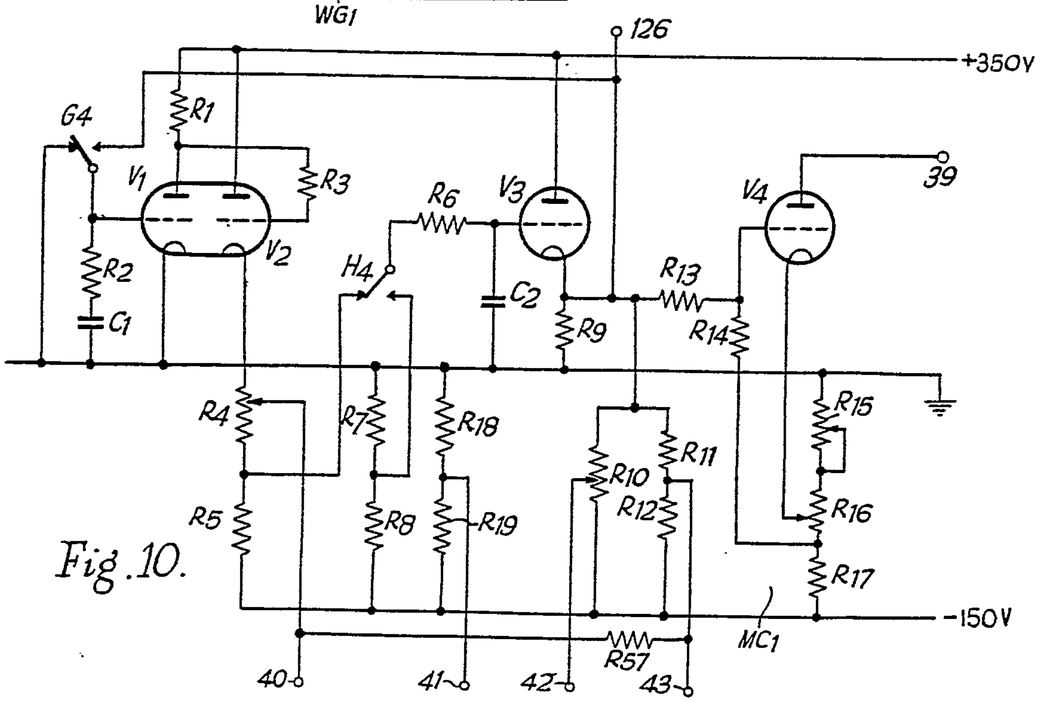

126
+350V
G4
R1
R3
V1
V2
R6
V3
V4
39
R2
C1
H4
C2
R13
R9
R14
R4
R7
R18
R15
R10
R11
R12
R5
R8
R19
R16
R17
-150V
MC1
R57
40
41
42
43

Fig.10.

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Fig. 11.

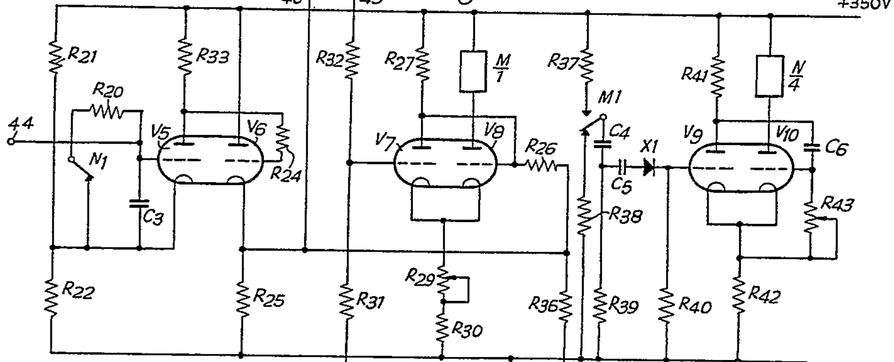
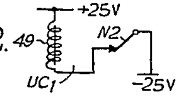


Fig. 12.



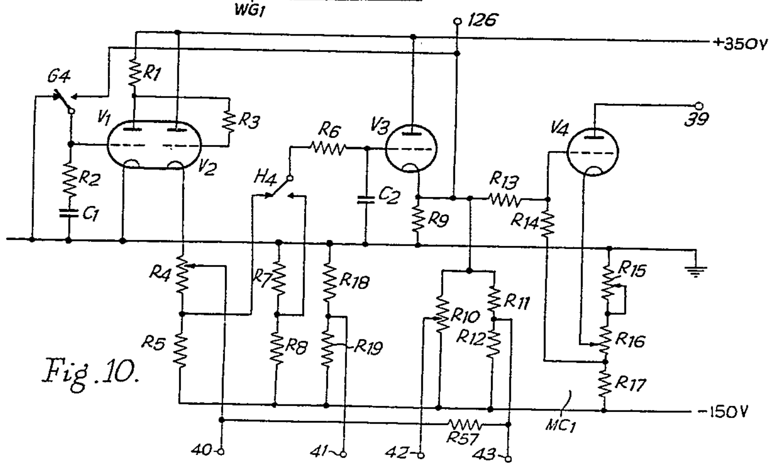
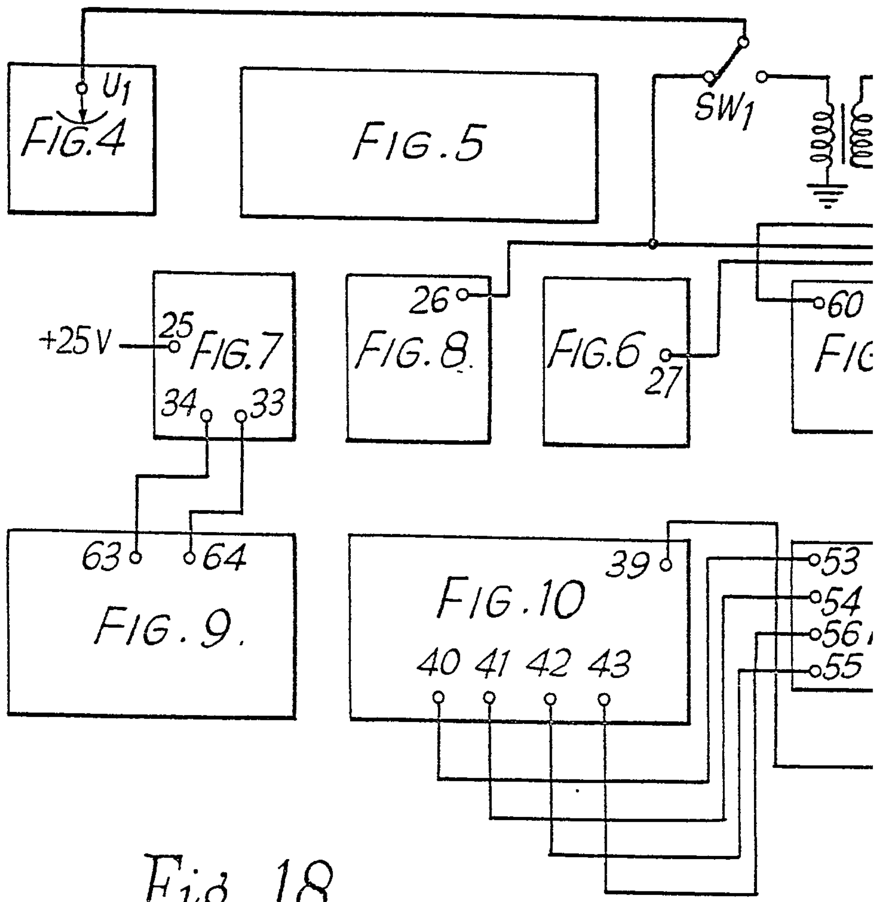
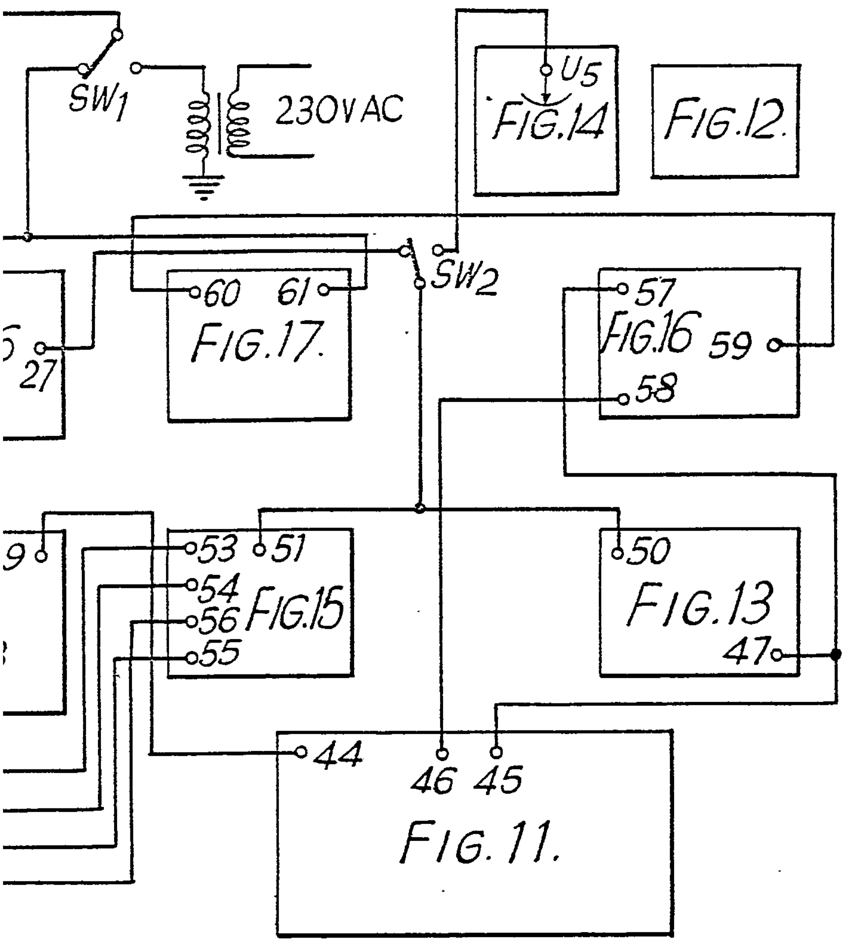


Fig. 10.



U1
FIG.4
FIG.5
SW1
+25V
25
FIG.7
34
33
26
FIG.8.
FIG.6
27
60
FI
63
64
FIG.9.
39
FIG.10
40 41 42 43
53
54
56
55

Fig. 18.


SW1
230V AC
U5
FIG.14
FIG.12.
60
61
SW2
27
FIG.17.
57
FIG.16
59
58
53
51
54
56
55
FIG.15
50
FIG.13
47
44
46
45
FIG.11.

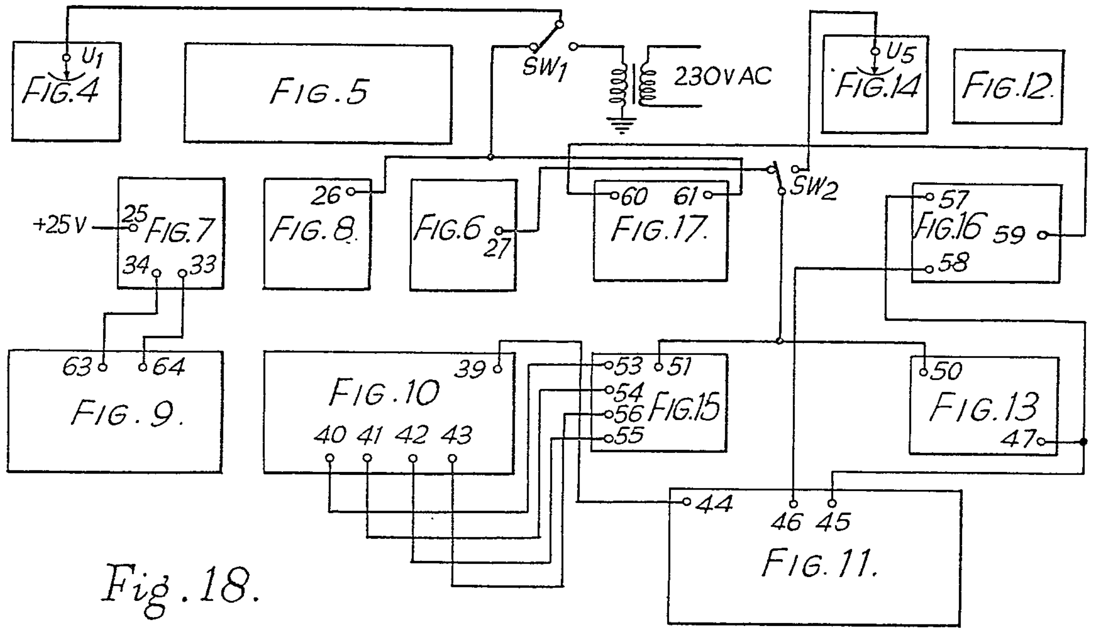

U1
FIG.4
FIG.5
SW1
230V AC
U5
FIG.14
FIG.12.
+25V
25
FIG.7
34
33
26
FIG.8.
FIG.6
27
60
61
FIG.17.
SW2
57
FIG.16
59
58
63
64
FIG.9.
FIG.10
39
40 41 42 43
53
51
54
56
55
FIG.15
50
FIG.13
47
44
46 45
FIG.11.

Fig. 18.

Fig.16.

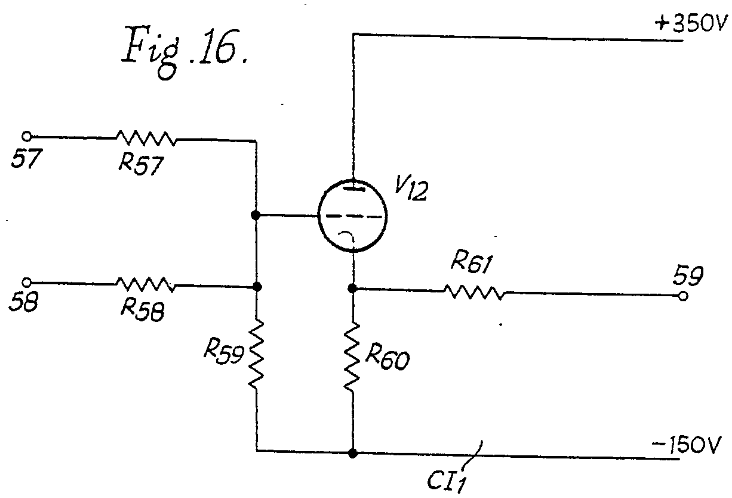
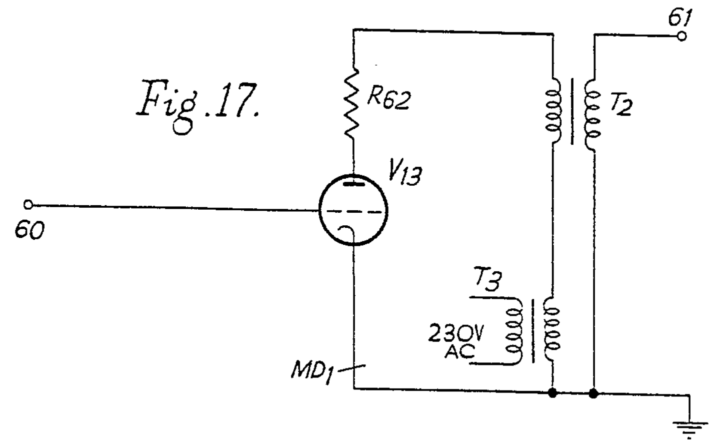

+350V
57
R57
V12
58
R58
R61
59
R59
R60
-150V
CI1

Fig.17.


61
R62
T2
V13
60
T3
230V
AC
MD1

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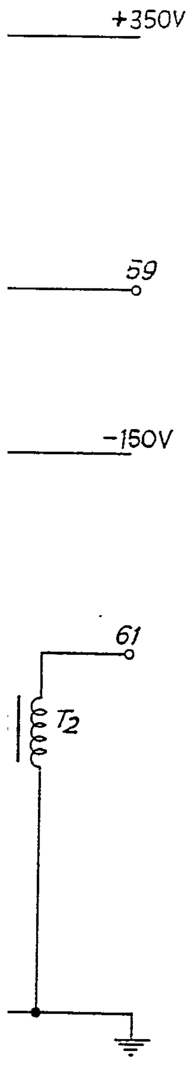

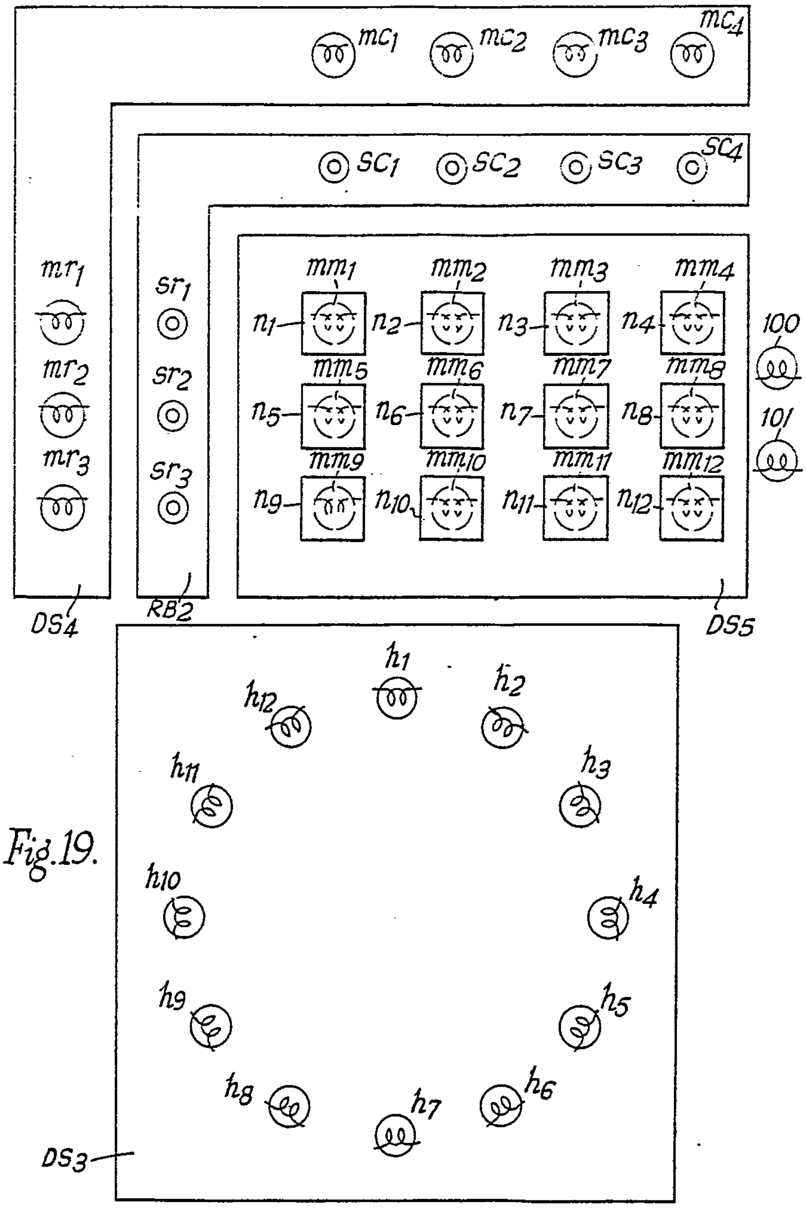

Fig.19.

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Fig.16.

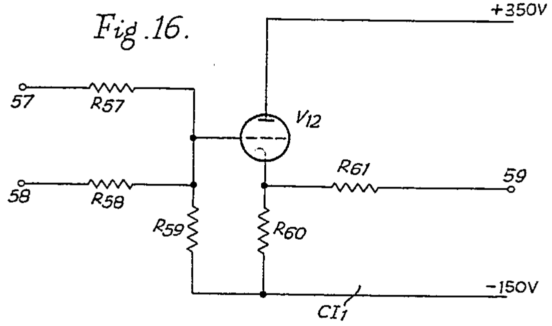


Fig.17.

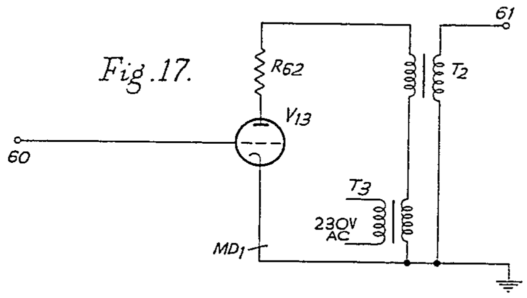
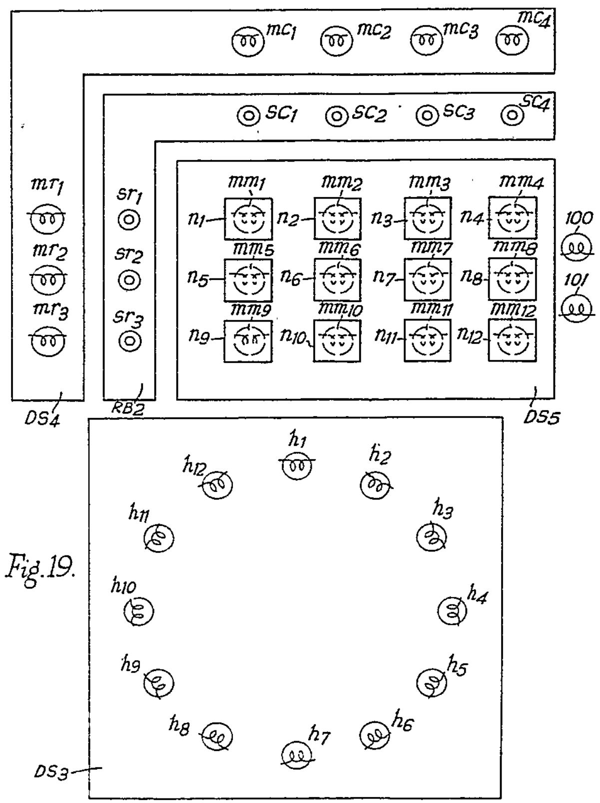
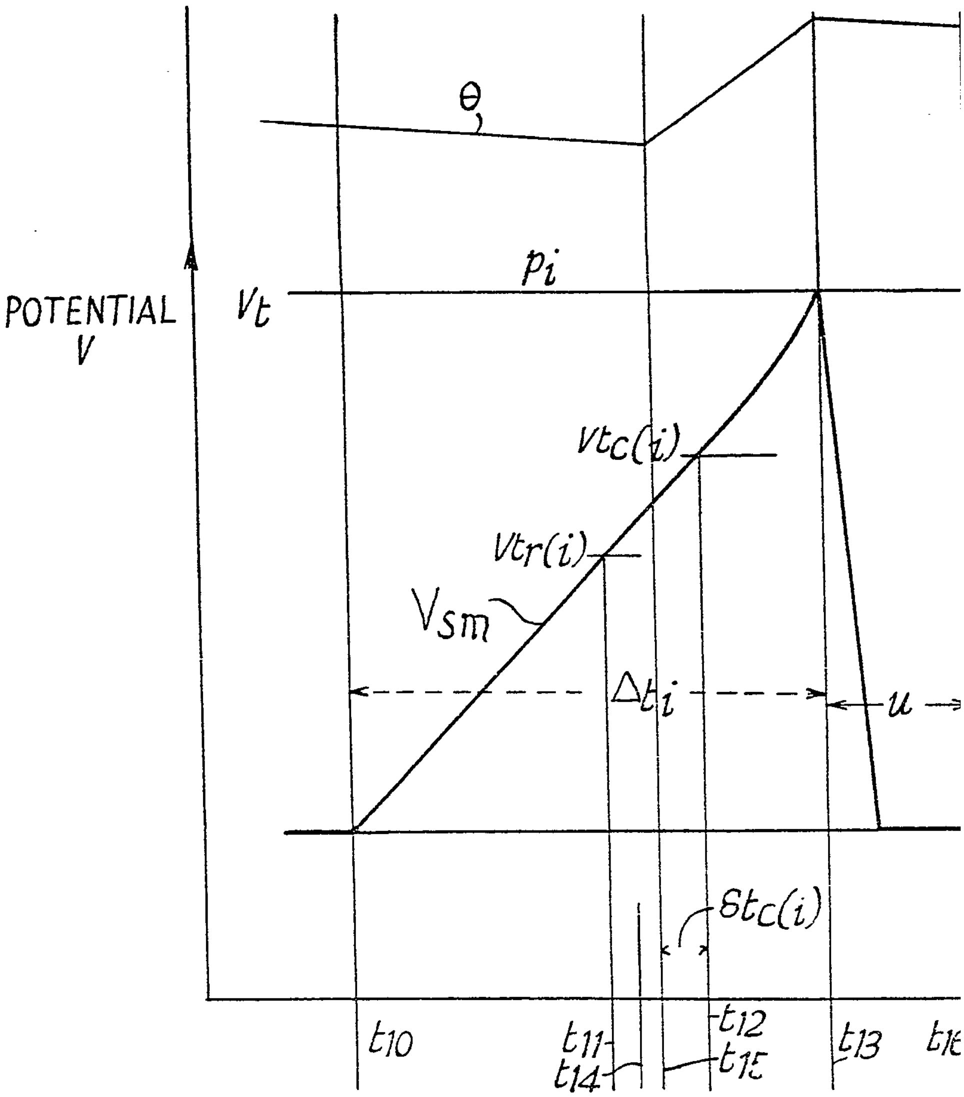


Fig.19.





θ
p_i
POTENTIAL
V
V_t
$V_{tc(i)}$
$V_{tr(i)}$
V_{sm}
Δt_i
u
$\delta t_{c(i)}$
t_{10}
t_{11}
t_{14}
t_{12}
t_{15}
t_{13}

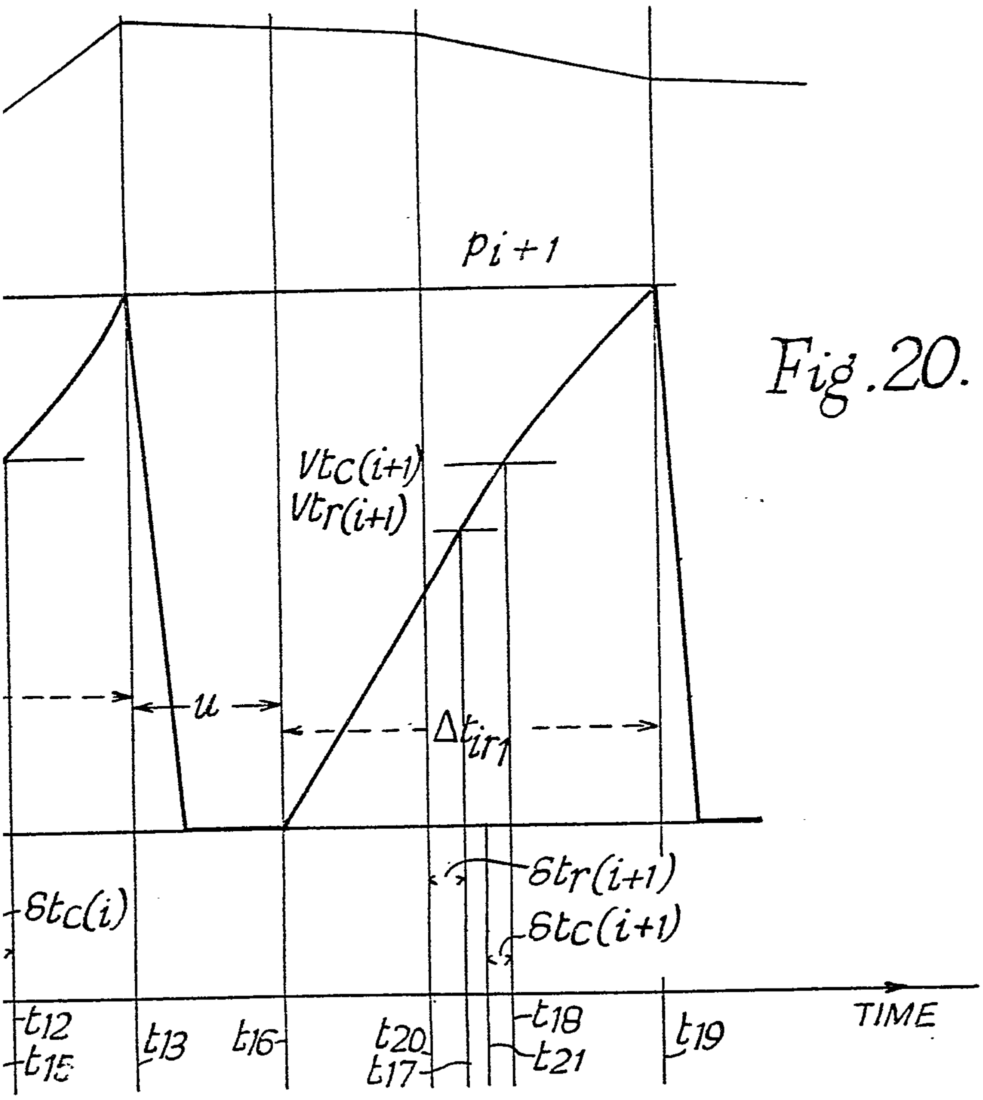

$p_i + 1$
$V_{tc}(i+1)$
$V_{tr}(i+1)$
u
Δt_{ir1}
$\delta t_r(i+1)$
$\delta t_c(i)$
$\delta t_c(i+1)$
TIME
t_{12}
t_{15}
t_{13}
t_{16}
t_{20}
t_{17}
t_{18}
t_{21}
t_{19}

Fig. 20.

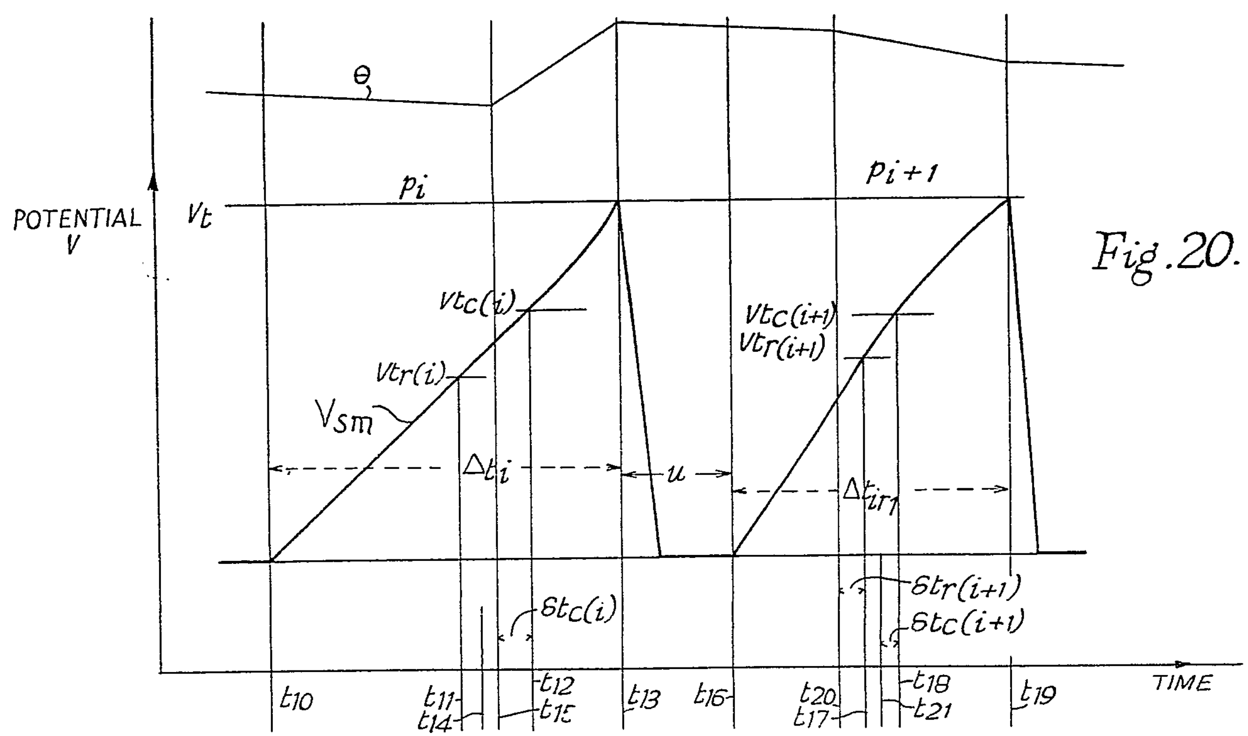
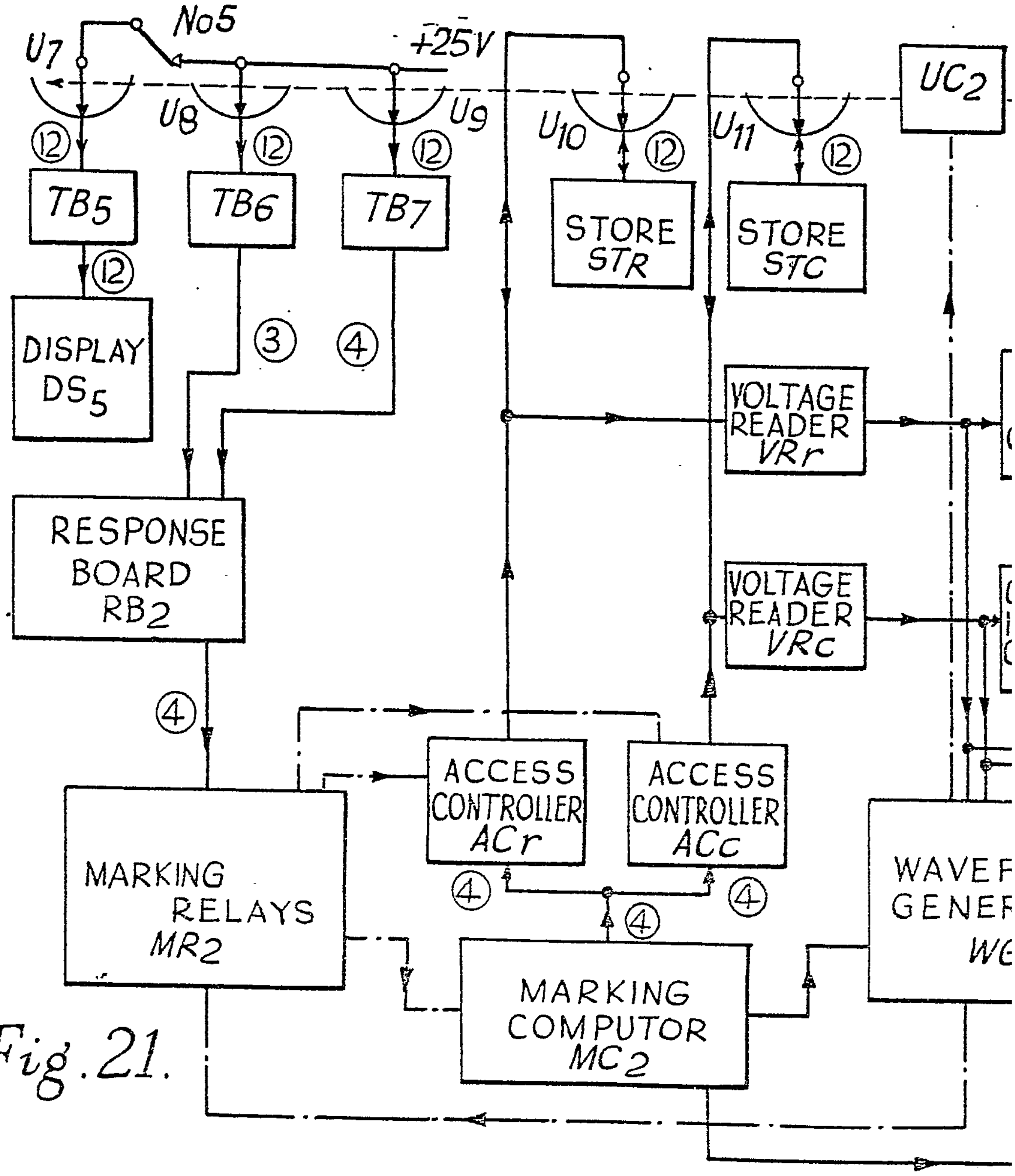

POTENTIAL
V
Vt
θ
pi
pi+1
Vtc(i)
Vtr(i)
Vsm
Δti
u
Δtir1
Vtc(i+1)
Vtr(i+1)
δtc(i)
δtr(i+1)
δtc(i+1)
t10
t11
t14
t12
t15
t13
t16
t20
t17
t18
t21
t19
TIME

Fig.20.



No5
+25V
U7
U8
U9
U10
U11
UC2
TB5
TB6
TB7
STORE STR
STORE STC
DISPLAY DS5
VOLTAGE READER VRr
VOLTAGE READER VRc
RESPONSE BOARD RB2
ACCESS CONTROLLER ACr
ACCESS CONTROLLER ACc
MARKING RELAYS MR2
MARKING COMPUTOR MC2
WAVEF GENEF WG

Fig. 21.

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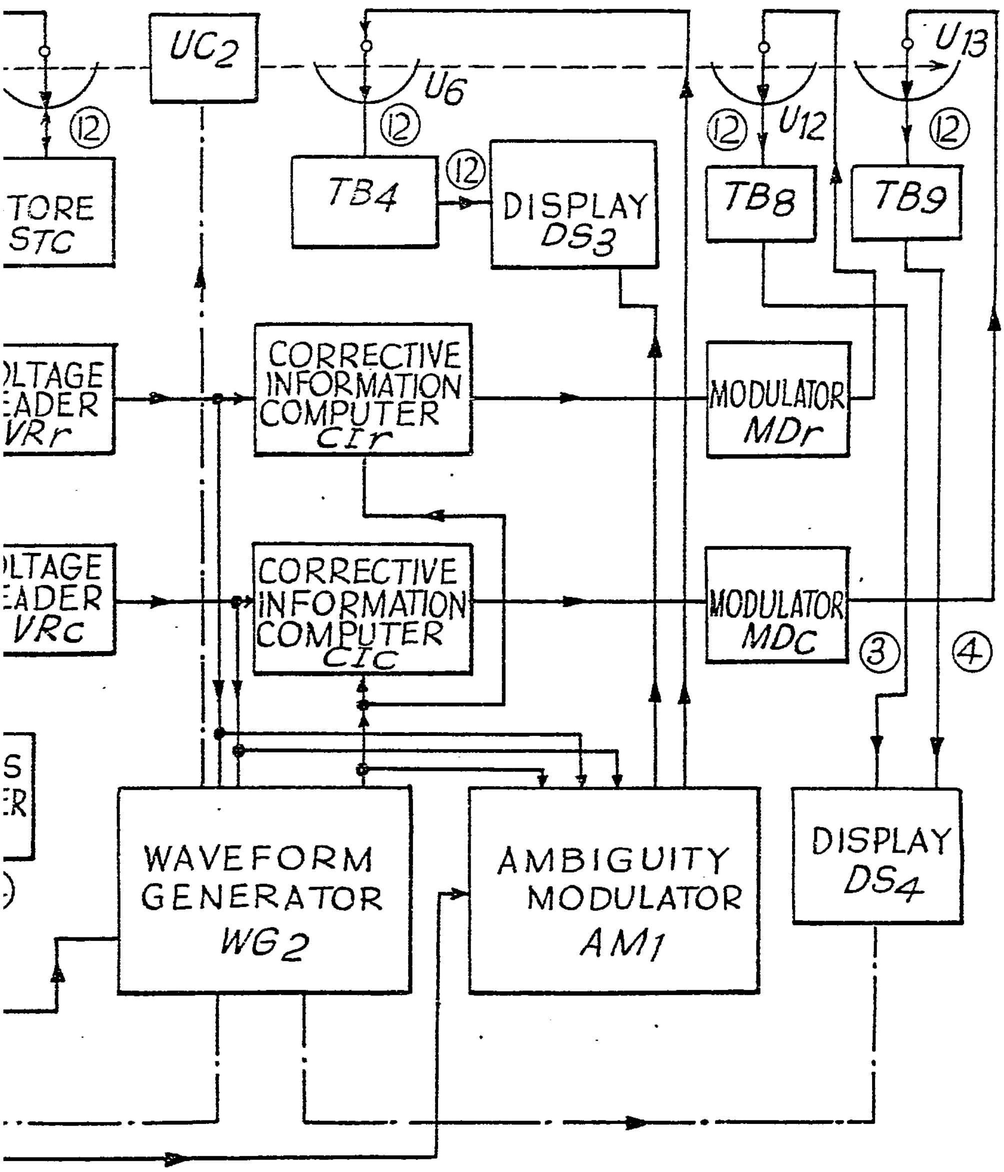
Sheet 12



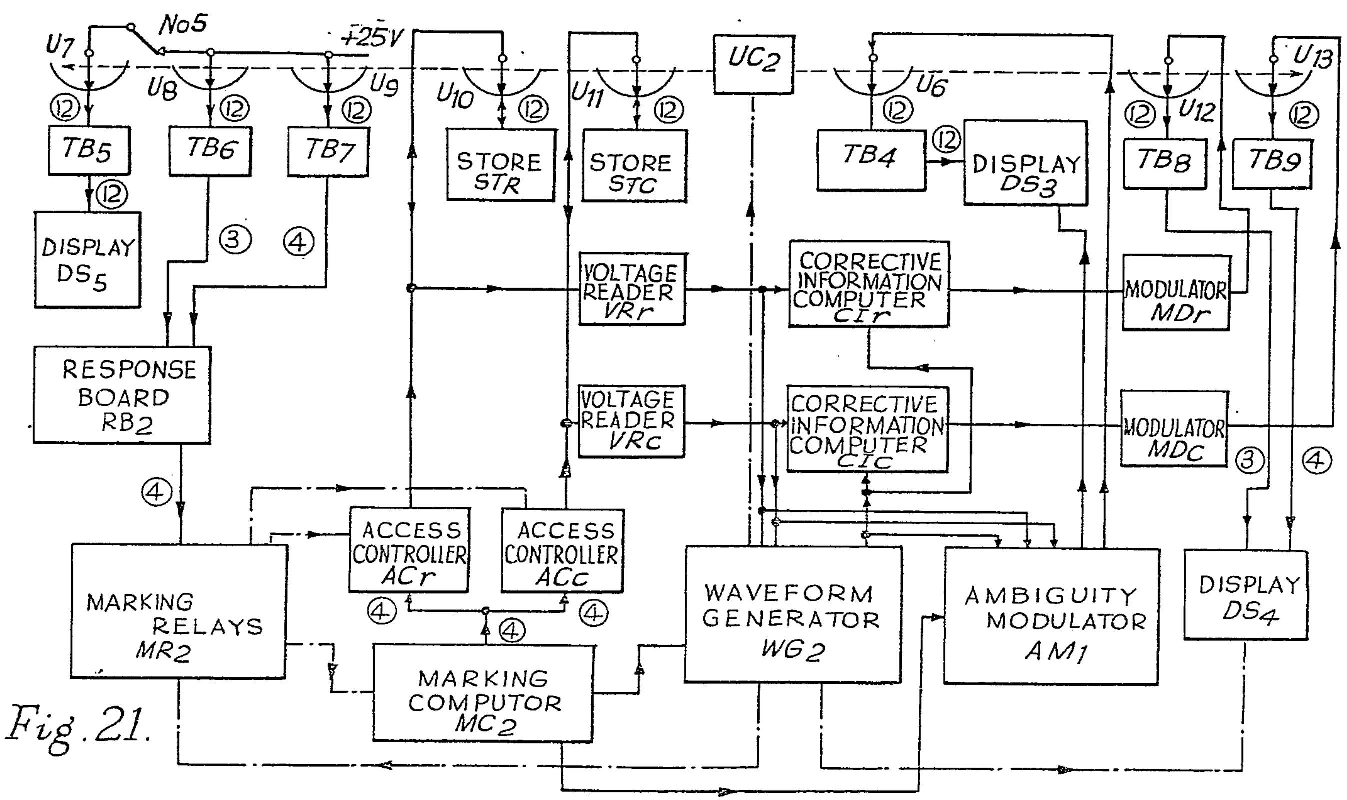
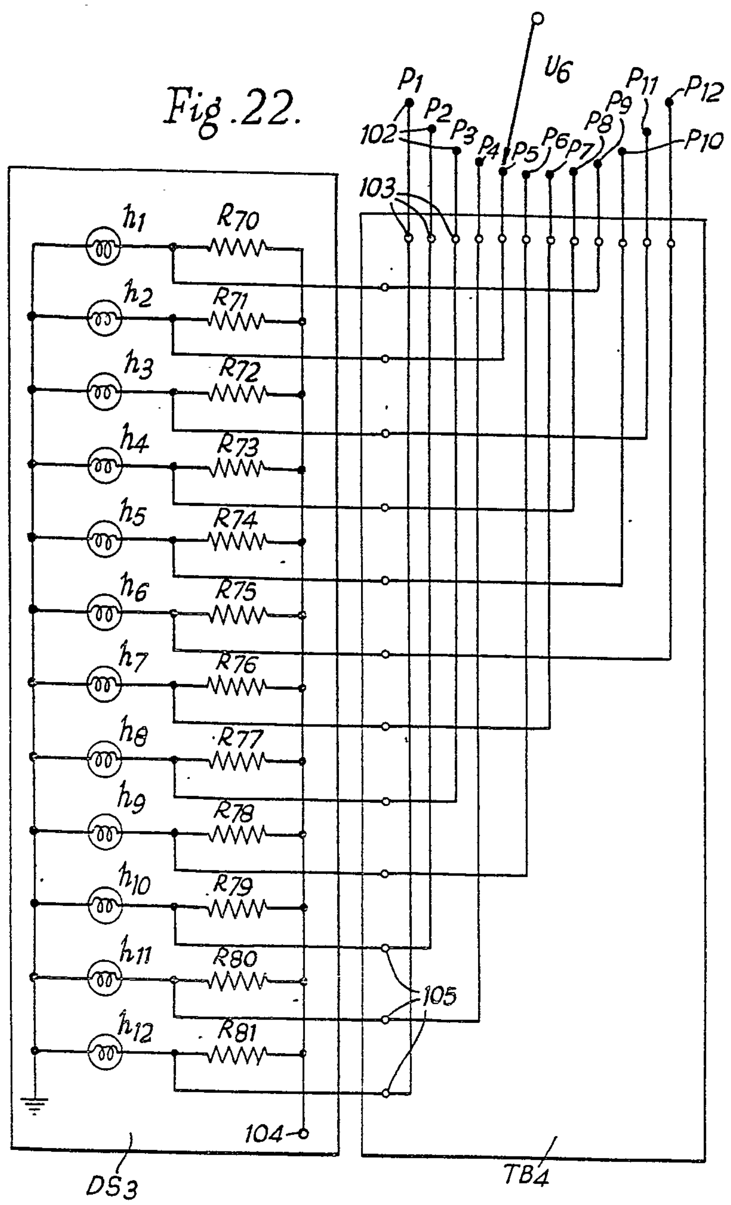

U7
No5
+25V
U8
U9
U10
U11
UC2
U6
U12
U13
TB5
TB6
TB7
STORE STR
STORE STC
TB4
DISPLAY DS3
TB8
TB9
DISPLAY DS5
VOLTAGE READER VRr
CORRECTIVE INFORMATION COMPUTER CIr
MODULATOR MDr
RESPONSE BOARD RB2
VOLTAGE READER VRc
CORRECTIVE INFORMATION COMPUTER CIc
MODULATOR MDc
ACCESS CONTROLLER ACr
ACCESS CONTROLLER ACc
MARKING RELAYS MR2
WAVEFORM GENERATOR WG2
AMBIGUITY MODULATOR AM1
DISPLAY DS4
MARKING COMPUTOR MC2

Fig. 21.

Fig. 22.



U6
P1
P2
P3
P4
P5
P6
P7
P8
P9
P11
P12
P10
102
103
h1
R70
h2
R71
h3
R72
h4
R73
h5
R74
h6
R75
h7
R76
h8
R77
h9
R78
h10
R79
h11
R80
h12
R81
105
104
DS3
TB4

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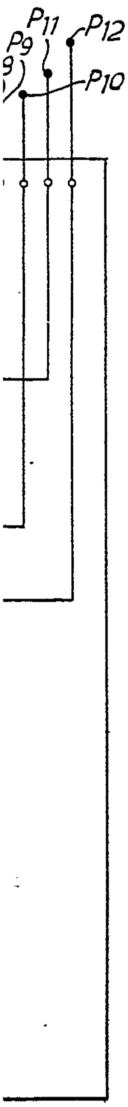
Sheets 13 & 14



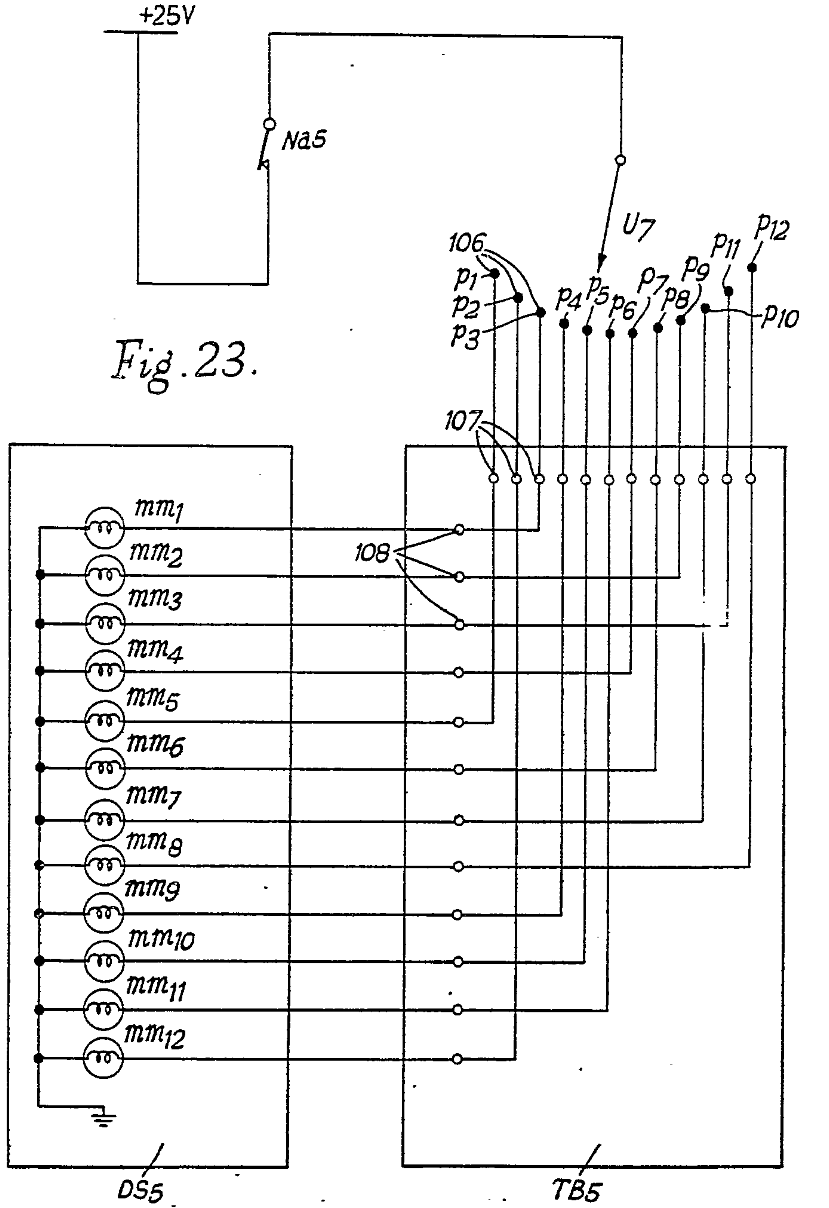


Fig. 23.

Fig. 22.

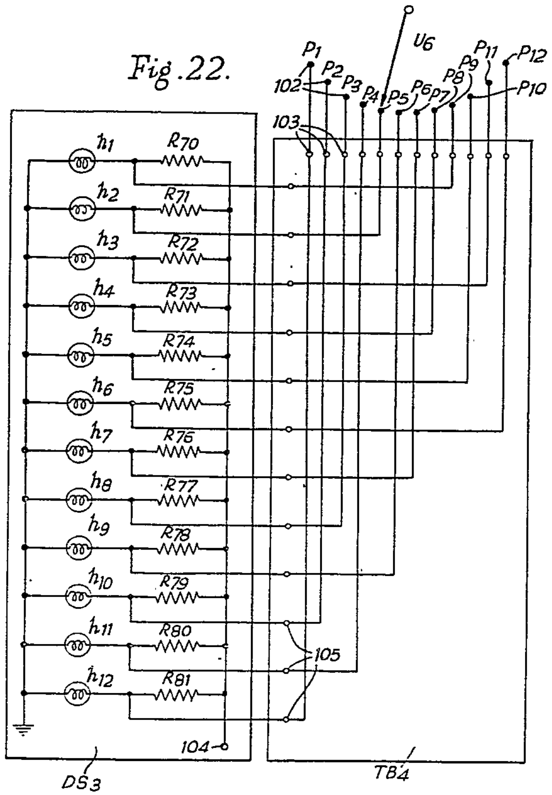
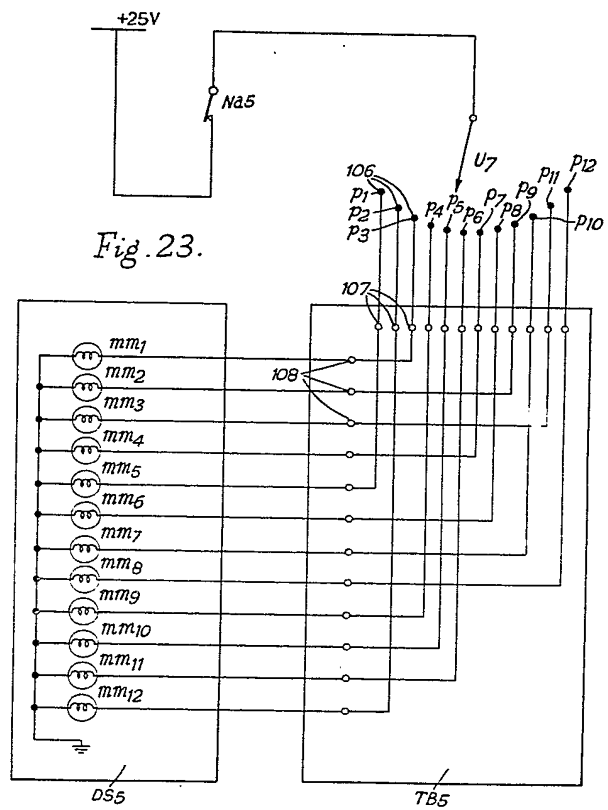
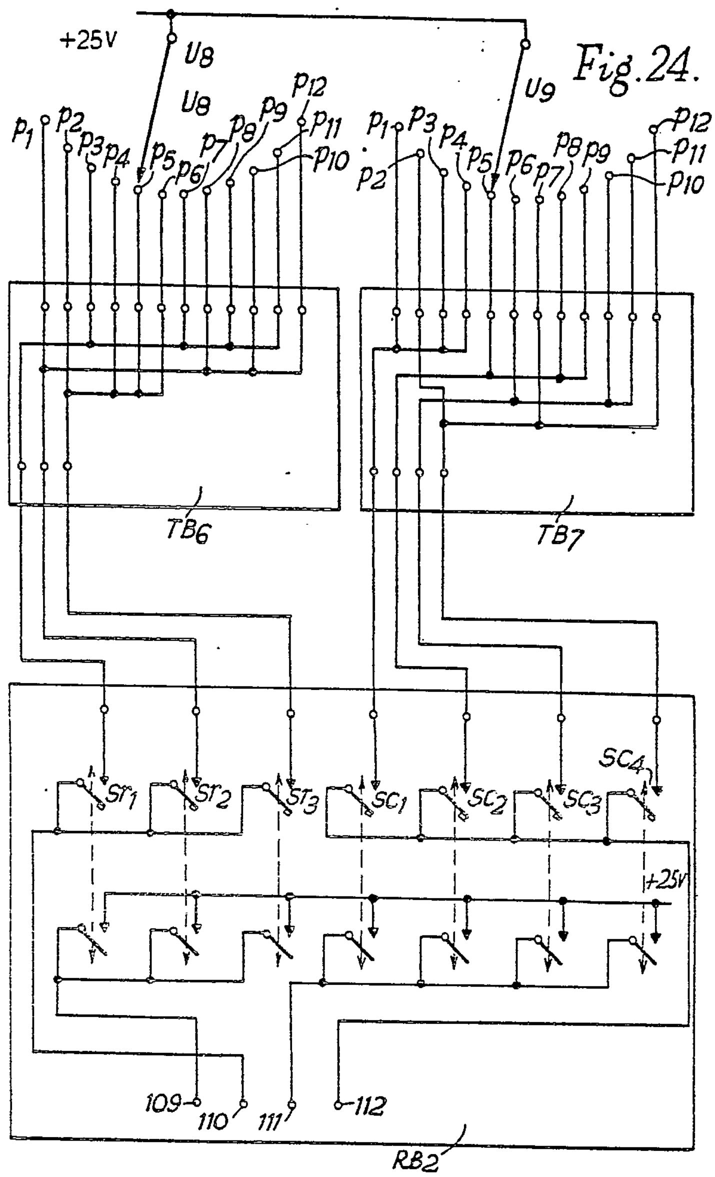
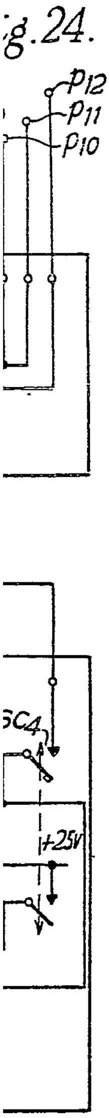

P1
P2
P3
P4
P5
P6
P7
P8
P9
P11
P12
P10
U6
102
103
h1
h2
h3
h4
h5
h6
h7
h8
h9
h10
h11
h12
R70
R71
R72
R73
R74
R75
R76
R77
R78
R79
R80
R81
105
104
DS3
TB4

Fig. 23.


+25V
Na5
U7
106
P1
P2
P3
P4
P5
P6
P7
P8
P9
P11
P12
P10
107
108
mm1
mm2
mm3
mm4
mm5
mm6
mm7
mm8
mm9
mm10
mm11
mm12
DS5
TB5


+25V
U8
U9
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
TB6
TB7
ST1
ST2
ST3
SC1
SC2
SC3
SC4
+25V
109
110
111
112
RB2
Fig. 24.

866279 COMPLETE SPECIFICATION
26 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheets 15 & 17



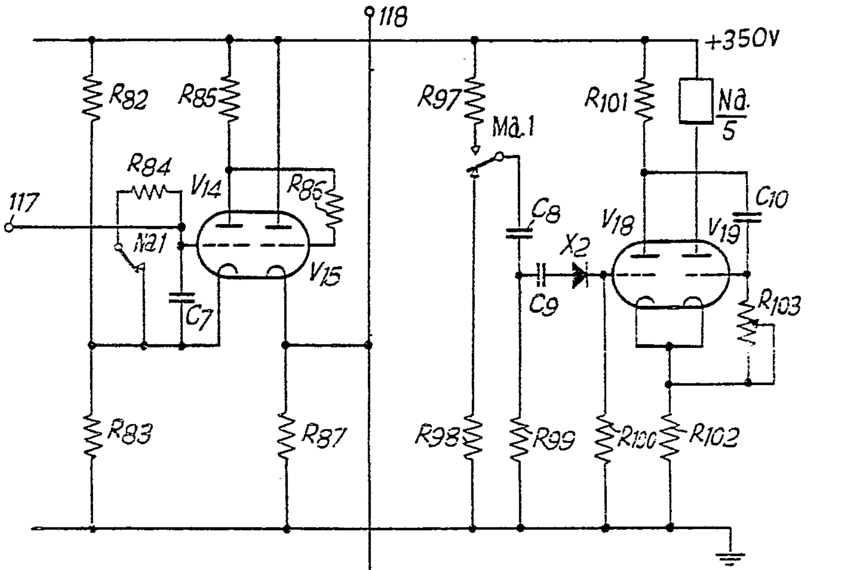
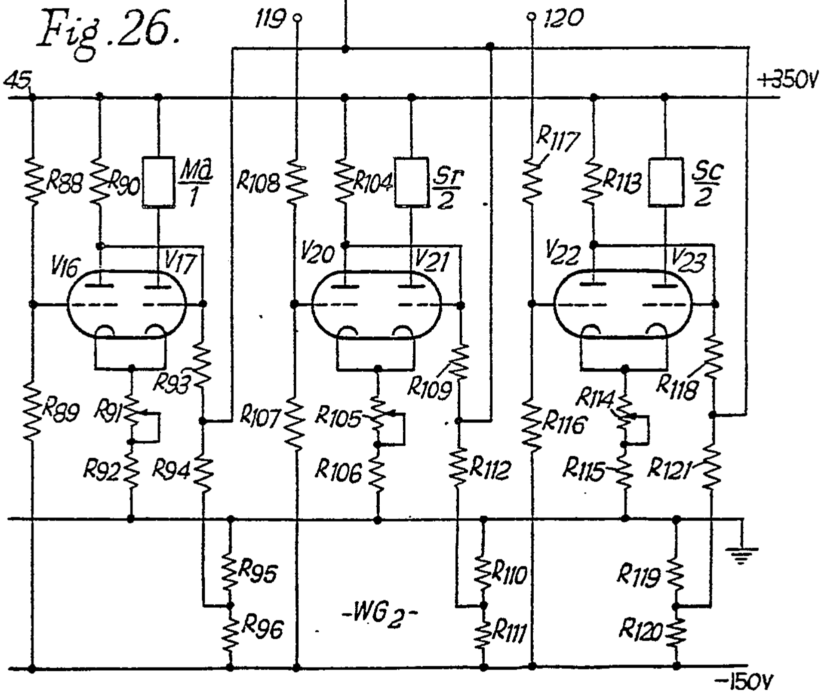


Fig.26.



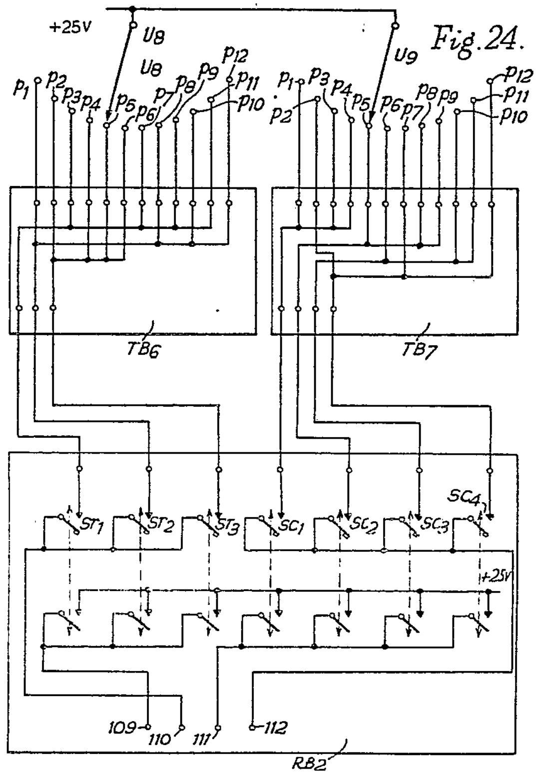

+25V
U8
U9
P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12
TB6
TB7
ST1 ST2 ST3 SC1 SC2 SC3 SC4
+25V
109 110 111 112
RB2

Fig. 24.

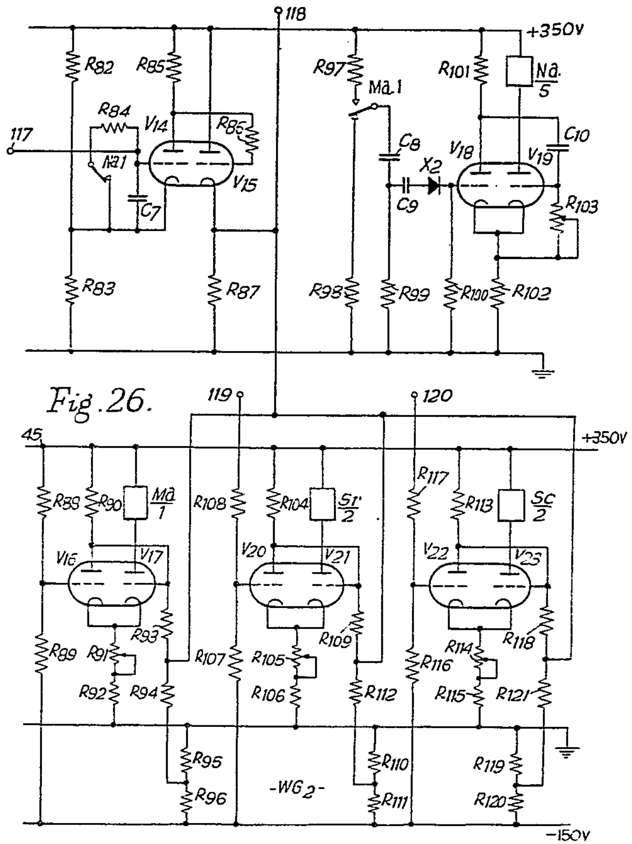
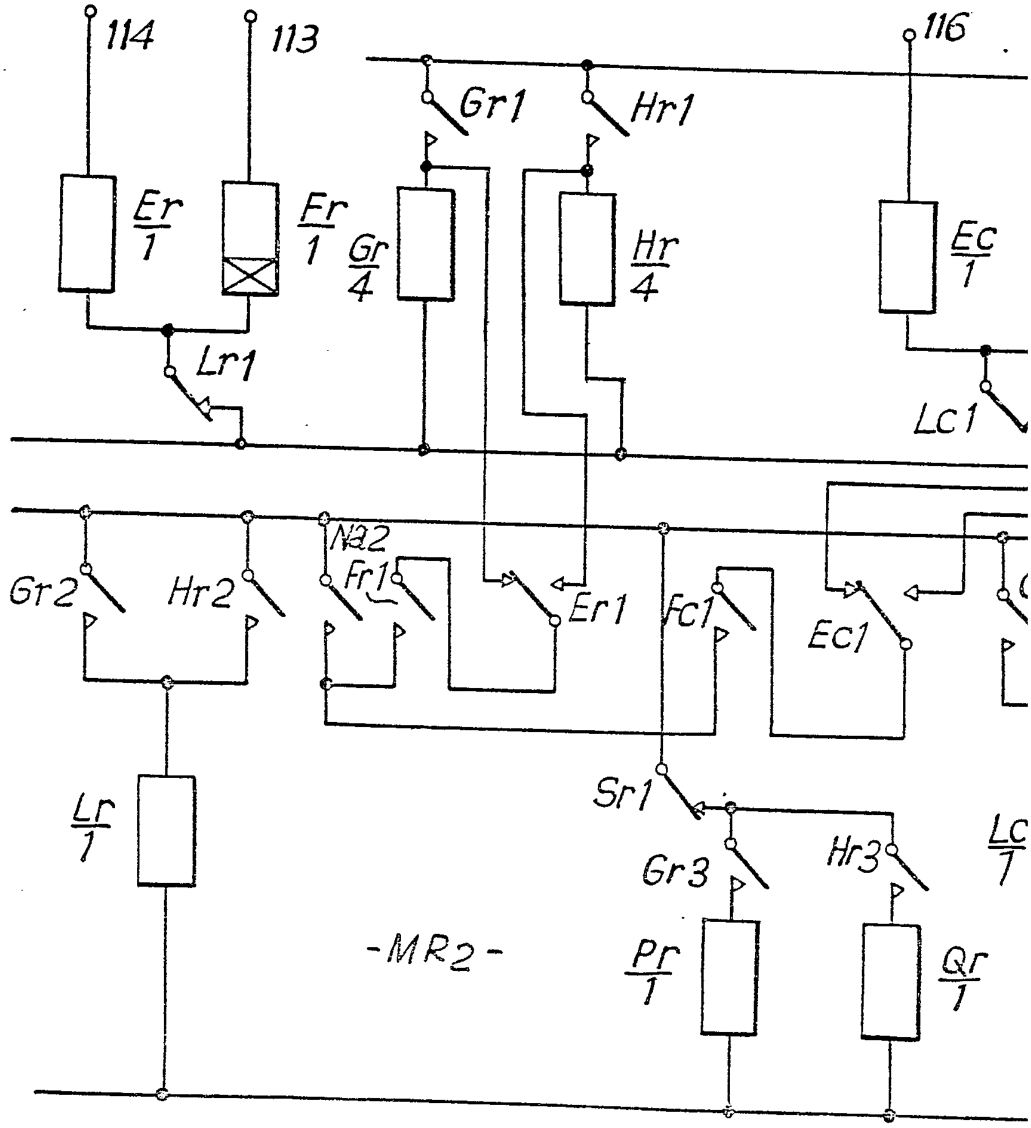

118
+350V
117
R82 R85 R84 R86 V14 V15 Na1 C7 R83 R87
R97 Ma.1 C8 X2 C9 V18 V19 C10 R101 Na/5 R103
R98 R99 R100 R102
119 120
45 +350V
R88 R90 Ma/1 V16 V17 R89 R91 R92 R93 R94 R95 R96
R108 R104 St'/2 V20 V21 R107 R105 R106 R109 R112 R110 R111
R117 R113 Sc/2 V22 V23 R114 R116 R115 R118 R121 R119 R120
-WG2-
-150V

Fig. 26.



114
113
116
Er
1
Fr
1
Gr
4
Hr
4
Ec
1
Gr1
Hr1
Lr1
Lc1
Gr2
Hr2
Na2
Fr1
Er1
Fc1
Ec1
Lr
1
Sr1
Gr3
Hr3
Lc
1
-MR2-
Pr
1
Qr
1

866279 COMPLETE SPECIFICATION
26 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 16

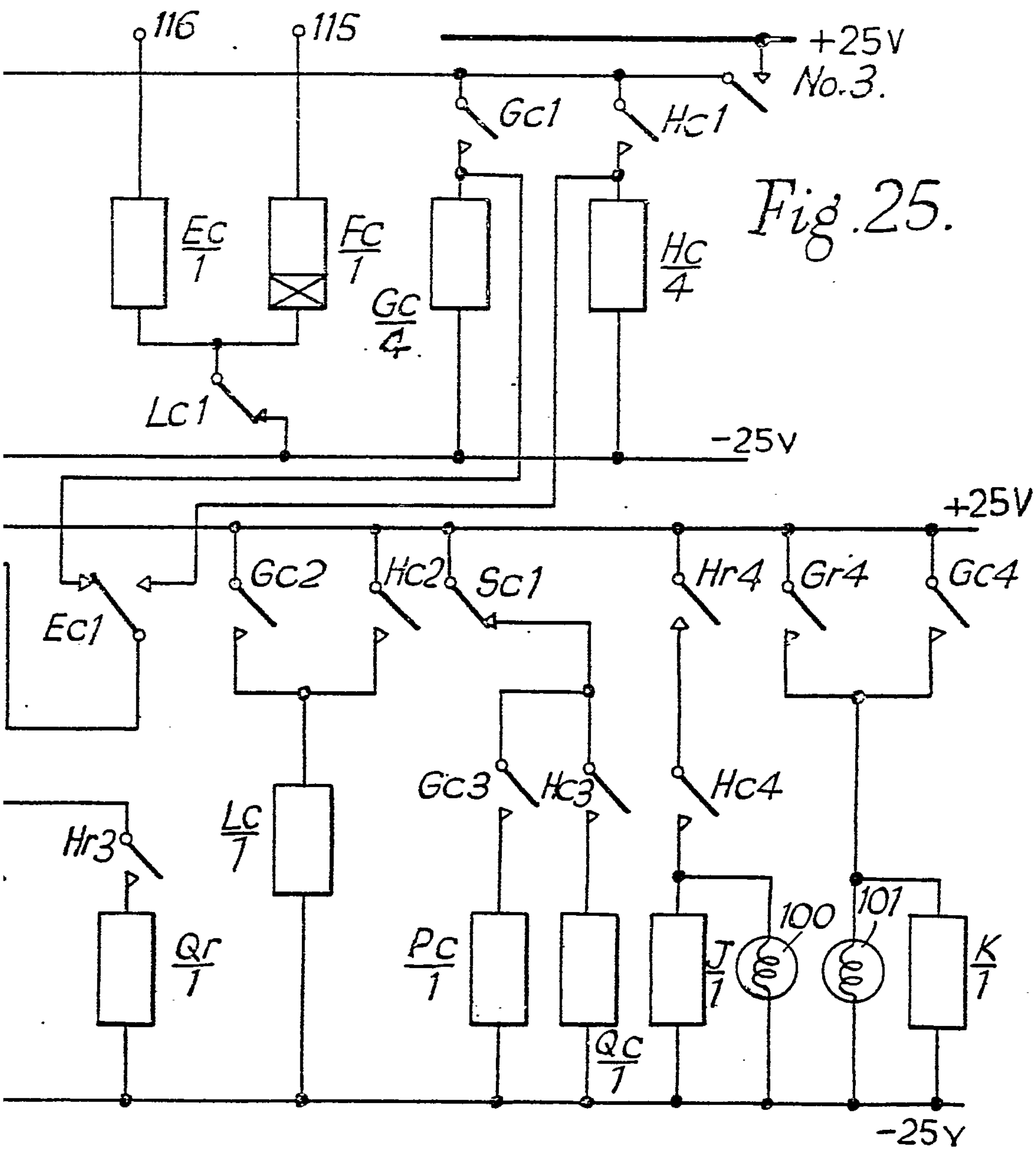


Fig. 25.

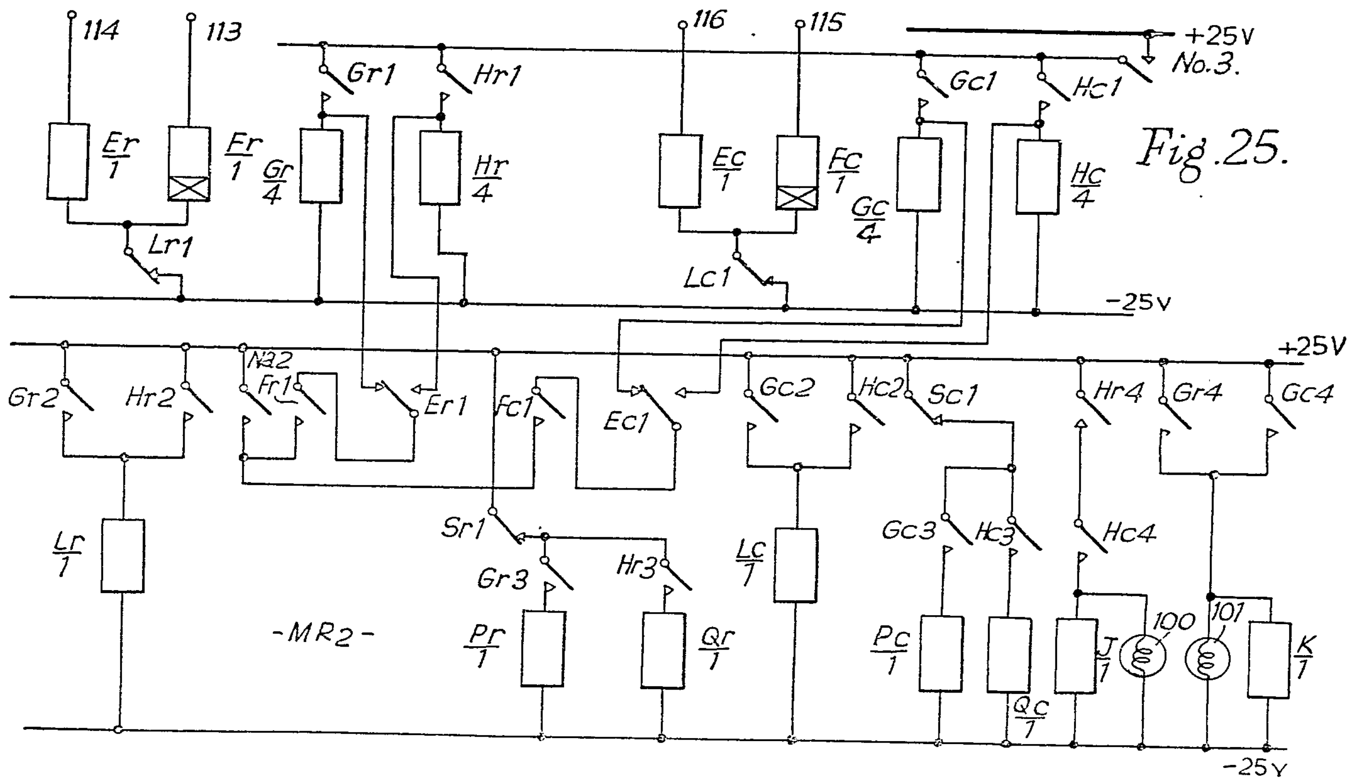
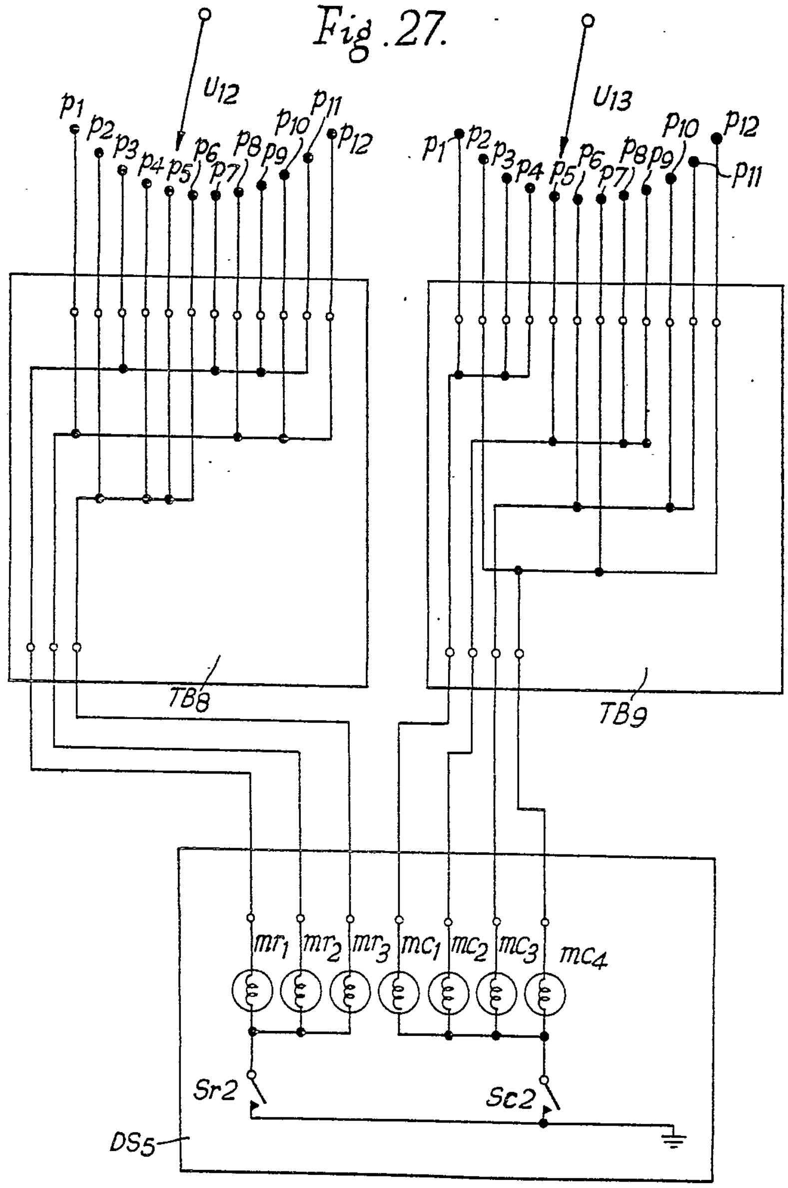

114
113
116
115
+25V
No.3.
Gr1
Hr1
Gc1
Hc1
Er/1
Fr/1
Gr/4
Hr/4
Ec/1
Fc/1
Gc/4
Hc/4
Lr1
Lc1
-25V
+25V
Gr2
Hr2
N22
Fr1
Er1
Fc1
Ec1
Gc2
Hc2
Sc1
Hr4
Gr4
Gc4
Lr/1
Sr1
Gr3
Hr3
Lc/1
Gc3
Hc3
Hc4
-MR2-
Pr/1
Qr/1
Pc/1
Qc/1
J/1
100
101
K/1
-25V

Fig. 25.

Fig. 27.


U12
p1
p2
p3
p4
p5
p6
p7
p8
p9
p10
p11
p12
U13
p1
p2
p3
p4
p5
p6
p7
p8
p9
p10
p11
p12
TB8
TB9
mr1
mr2
mr3
mc1
mc2
mc3
mc4
Sr2
Sc2
DS5

866279 COMPLETE SPECIFICATION
26 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheets 18 & 20

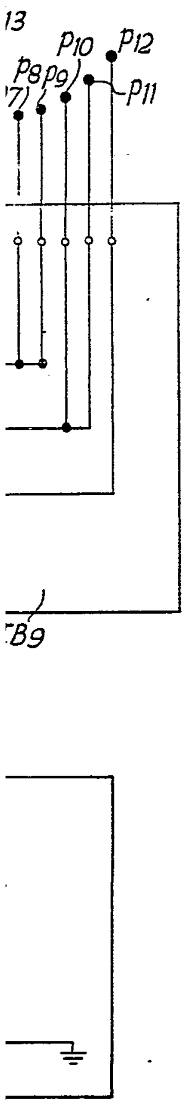
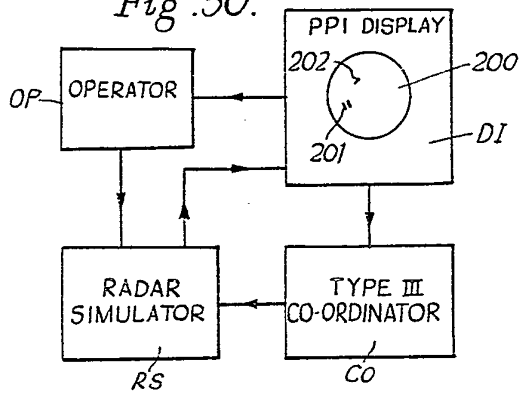


Fig.30.



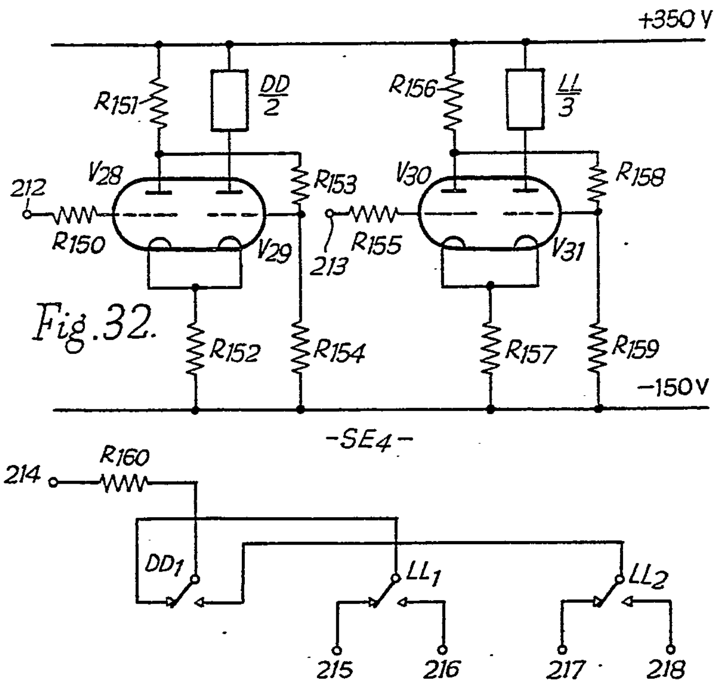


Fig.32.

Fig.27.

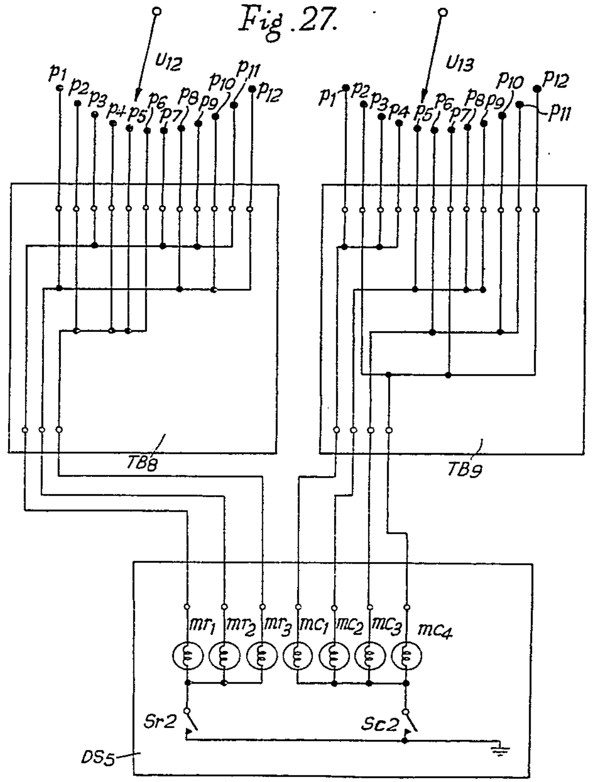


Fig.30.

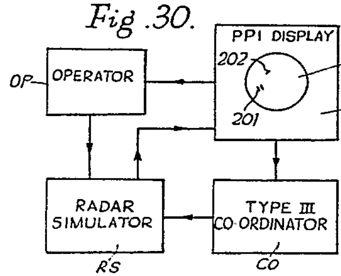
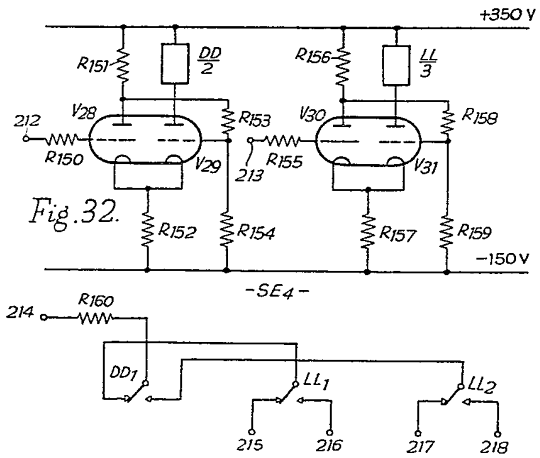


Fig.32.



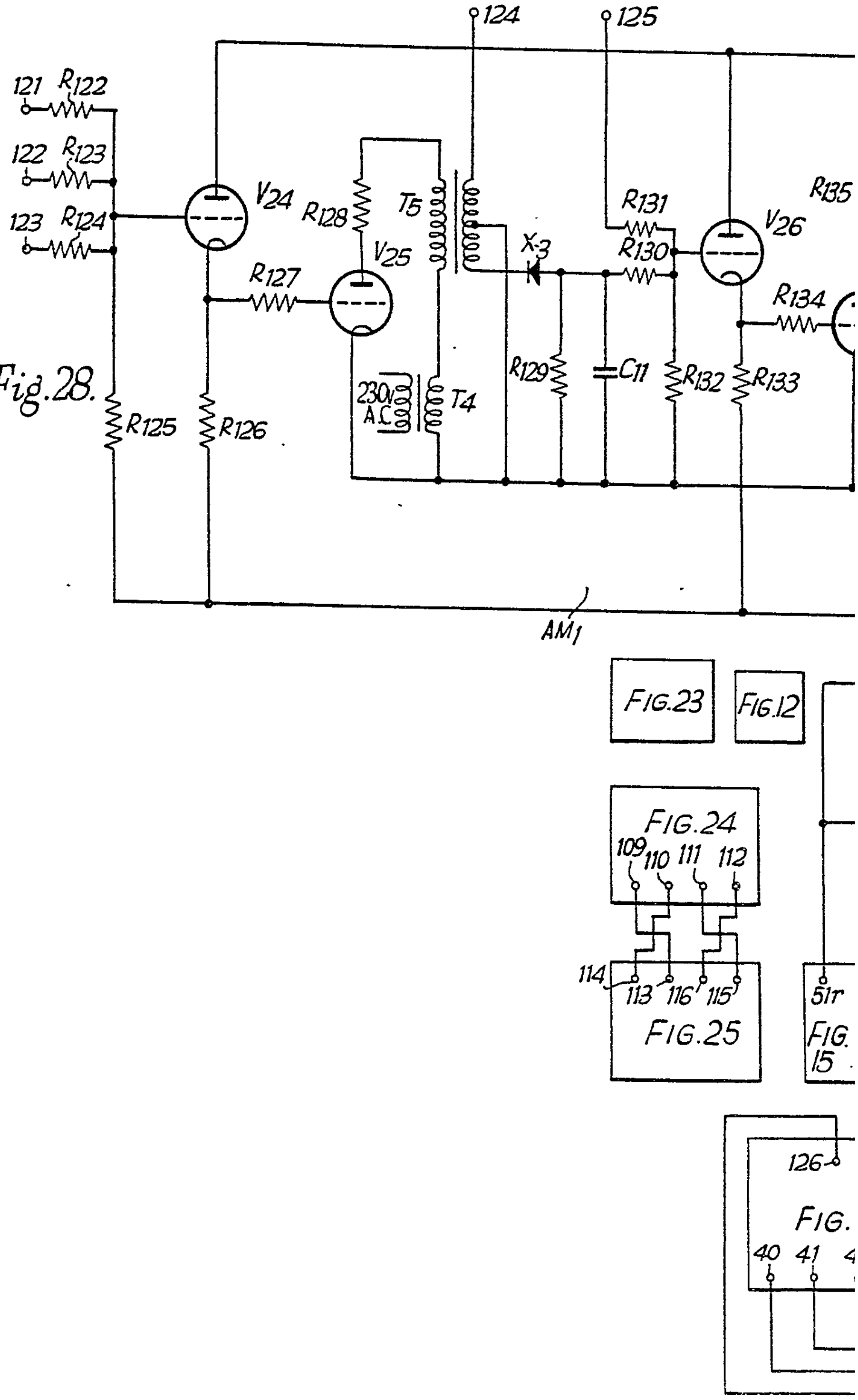
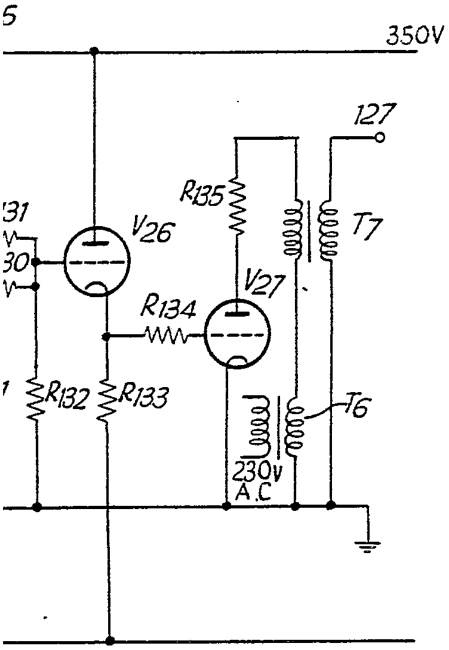

124
125
121
R122
122
R123
123
R124
V24
R128
T5
V25
R127
X3
R131
R130
V26
R135
R134
R129
C11
R132
R133
230V A.C.
T4
R125
R126
AM1
FIG.23
FIG.12
FIG.24
109
110
111
112
114
113
116
115
FIG.25
51r
FIG. 15
126
FIG.
40
41

Fig.28.


350V
127
R135
T7
V26
V27
R134
R132
R133
T6
230V
A.C

.Fig.29.

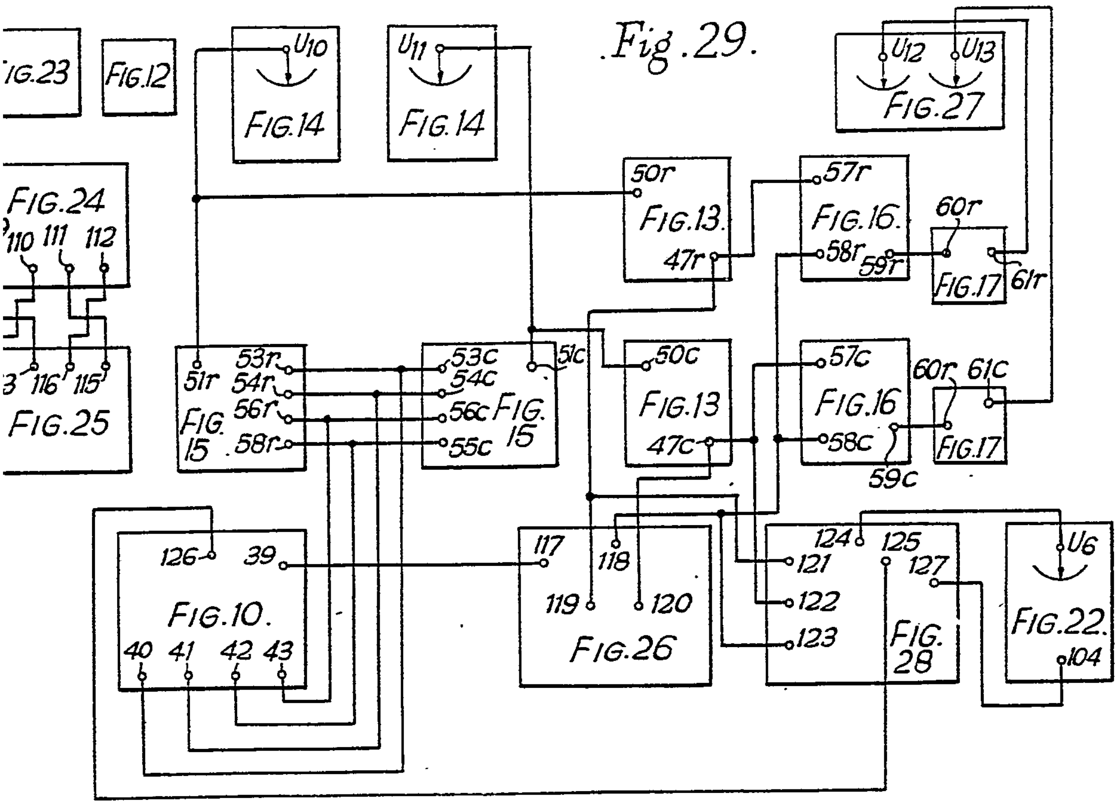


FIG.12
U10
FIG.14
U11
FIG.14
U12
U13
FIG.27
FIG.24
110 111 112
50r
FIG.13.
47r
57r
FIG.16.
58r
59r
60r
61r
FIG.17
116 115
FIG.25
51r 53r 54r 56r 58r
FIG. 15
53c 54c 56c 55c
FIG. 15
51c
50c
FIG.13
47c
57c
FIG.16
58c
59c
60r 61c
FIG.17
126 39
FIG.10.
40 41 42 43
117 118 119 120
FIG.26
124 125 127
121 122 123
FIG. 28
U6
FIG.22.
104

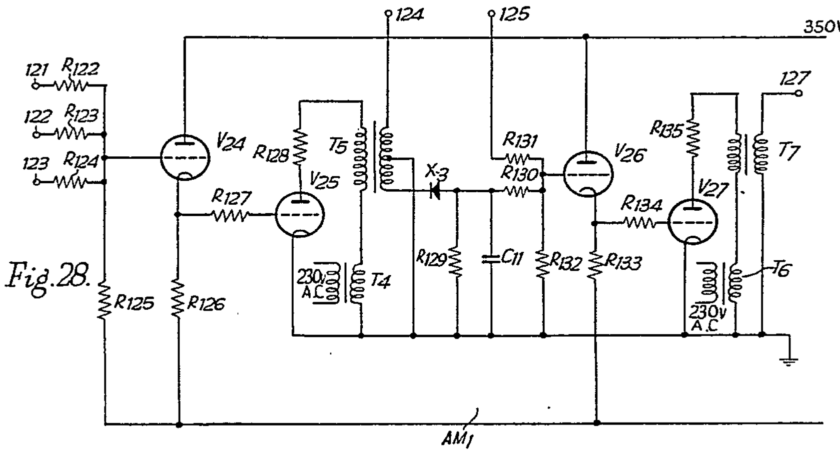

124
125
350V
121 R122
122 R123
123 R124
V24
R128
T5
V25
R127
R125
R126
230V A.C.
T4
X3
R129
C11
R131
R130
R132
V26
R133
R134
R135
V27
T7
127
T6
230V A.C.
AM1

Fig. 28.

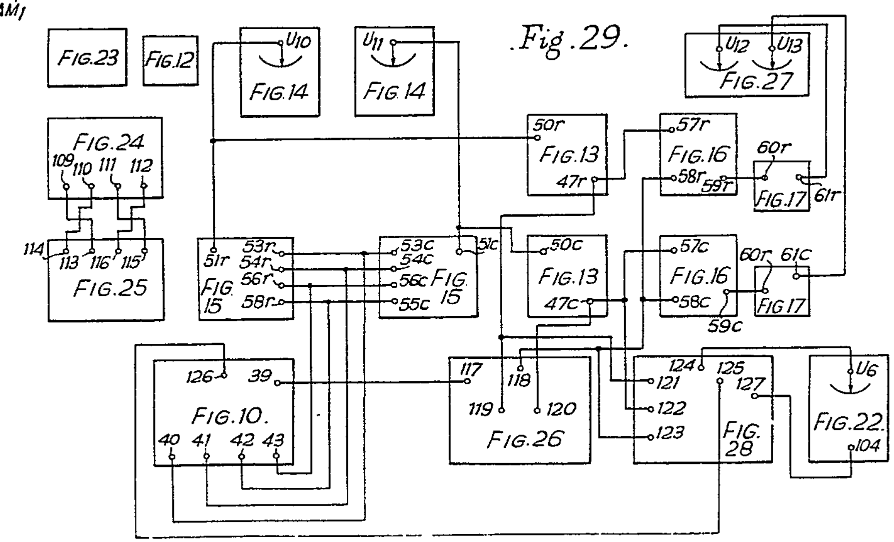
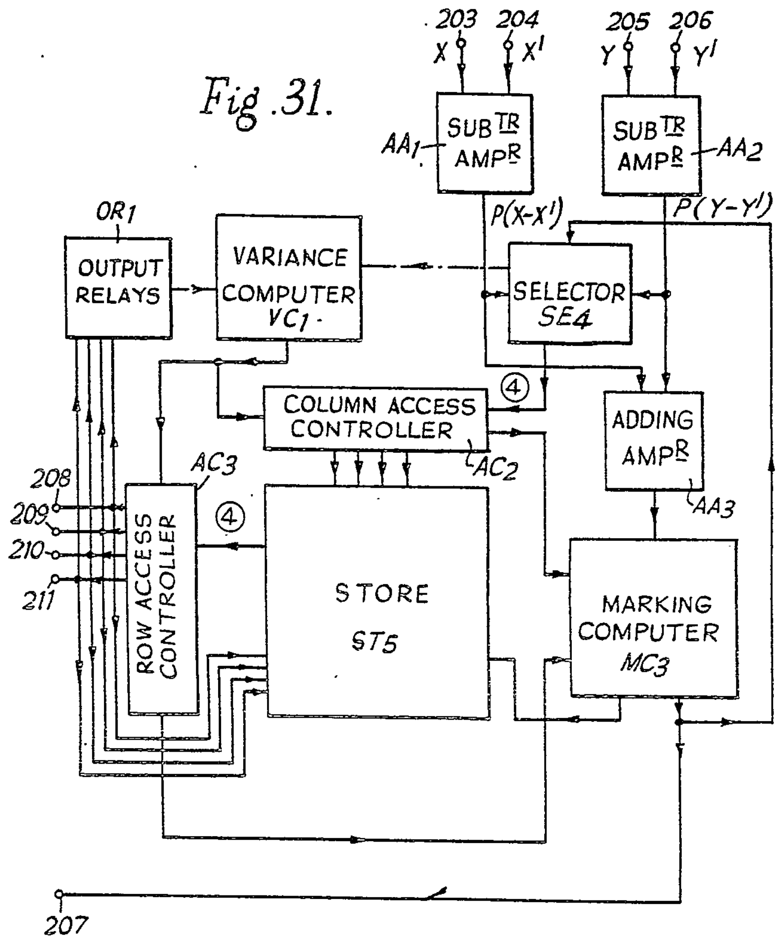


FIG.23
FIG.12
U10
FIG.14
U11
FIG.14
U12
U13
FIG.27
FIG.24
109 110 111 112
114
113 116 115
FIG.25
51r
53r
54r
56r
58r
FIG. 15
53c
54c
56c
55c
51c
FIG. 15
50r
FIG.13
47r
50c
FIG.13
47c
57r
FIG.16
58r
59r
60r
61r
FIG.17
57c
FIG.16
58c
59c
60r
61c
FIG 17
126
39
FIG.10.
40 41 42 43
117
118
119
120
FIG.26
124
125
121
122
123
127
FIG. 28
U6
FIG.22.
104

Fig. 29.

Fig. 31.



203
204
205
206
X
X'
Y
Y'
SUB TR AMP R
SUB TR AMP R
AA1
AA2
P(X-X')
P(Y-Y')
OR1
OUTPUT RELAYS
VARIANCE COMPUTER VC1
SELECTOR SE4
4
COLUMN ACCESS CONTROLLER
AC2
ADDING AMP R
AA3
AC3
208
209
210
211
ROW ACCESS CONTROLLER
4
STORE ST5
MARKING COMPUTER MC3
207

866279 COMPLETE SPECIFICATION

26 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 21 & 22

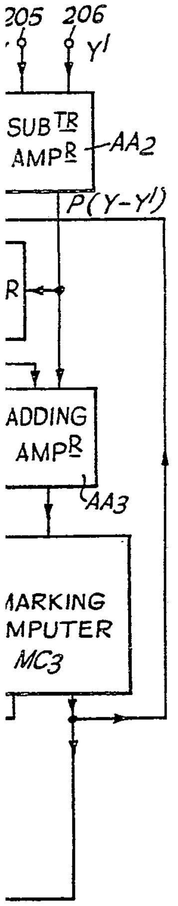
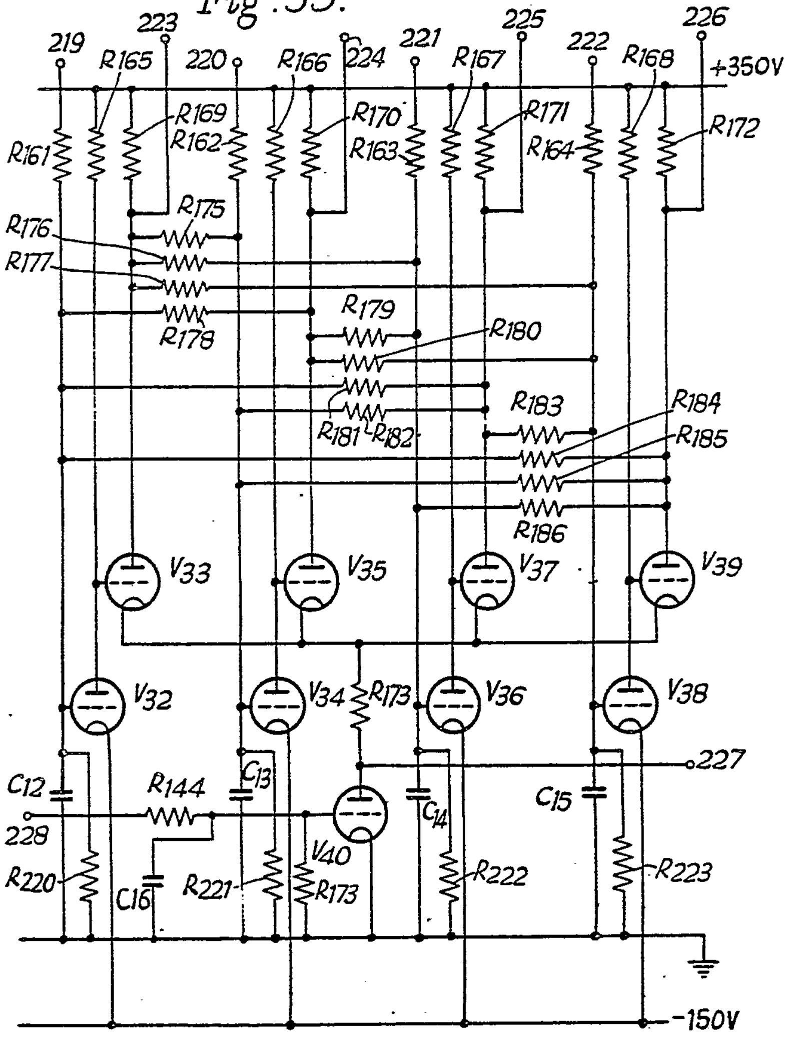


Fig .33.



−AC2−

Fig. 31.

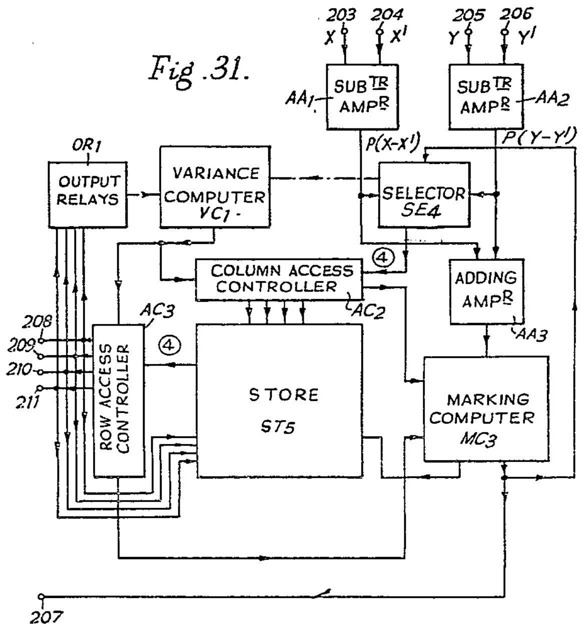

203
204
X
X'
205
206
Y
Y'
SUB TR AMP R
AA1
SUB TR AMP R
AA2
P(X-X')
P(Y-Y')
OR1
OUTPUT RELAYS
VARIANCE COMPUTER VC1
SELECTOR SE4
4
COLUMN ACCESS CONTROLLER
AC2
ADDING AMP R
AA3
208
209
210
211
AC3
ROW ACCESS CONTROLLER
4
STORE
ST5
MARKING COMPUTER MC3
207

Fig. 33.

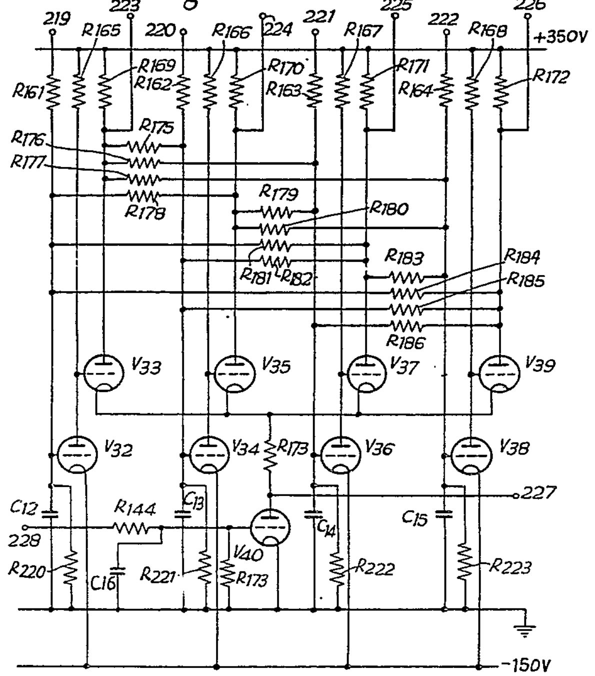
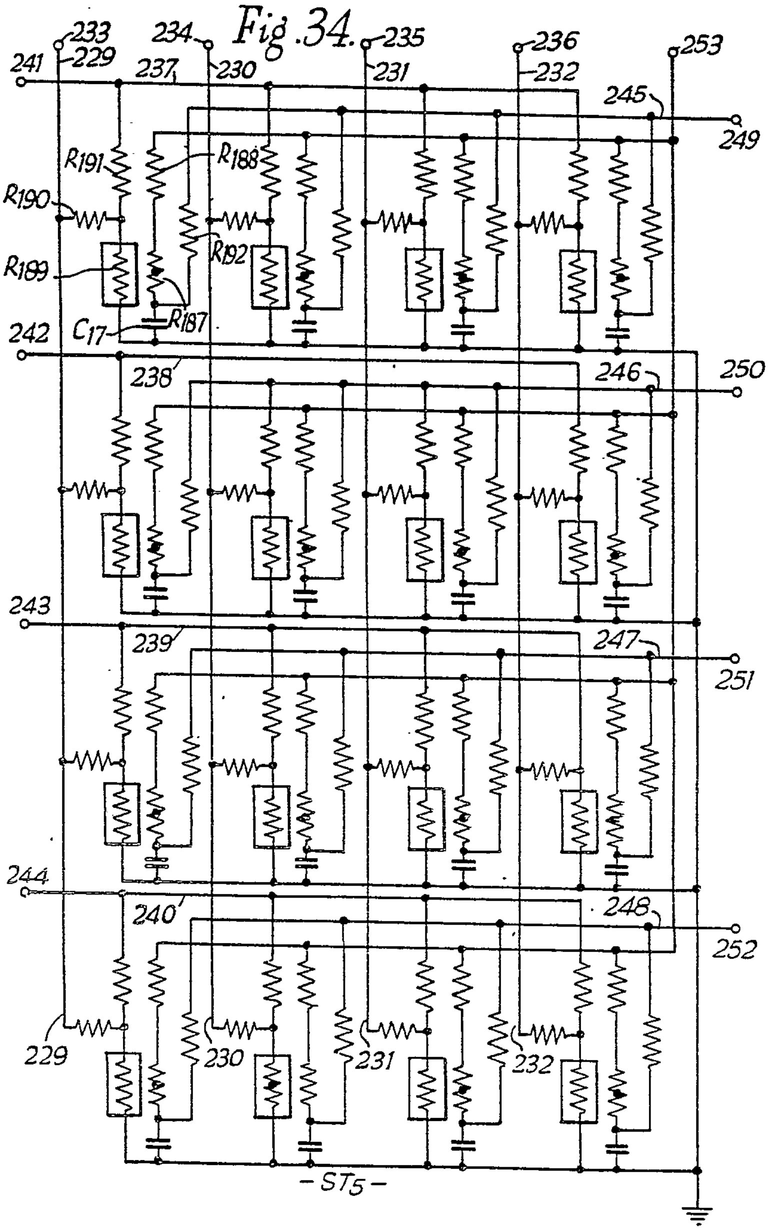

219
223
220
224
221
225
222
226
+350V
R165
R166
R167
R168
R161
R169
R162
R170
R163
R171
R164
R172
R175
R176
R177
R178
R179
R180
R181
R182
R183
R184
R185
R186
V33
V35
V37
V39
V32
V34
R173
V36
V38
227
C12
R144
C13
C14
C15
228
V40
R220
C16
R221
R173
R222
R223
-150V
-AC2-

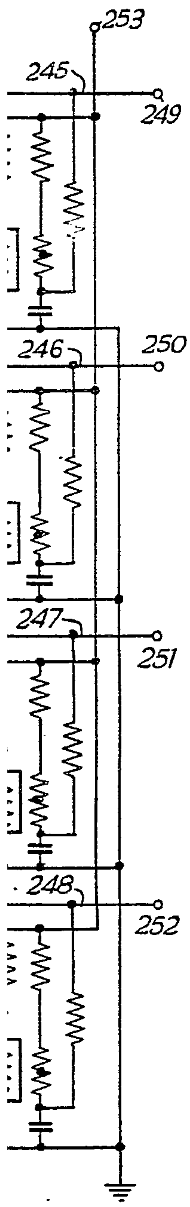
Fig. 34.


233
229
234
230
235
231
236
232
253
241
237
245
249
R191
R188
R190
R192
R189
R187
C17
242
238
246
250
243
239
247
251
244
240
248
252
229
230
231
232
-ST5-

866279 COMPLETE SPECIFICATION

26 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheets 23 & 24



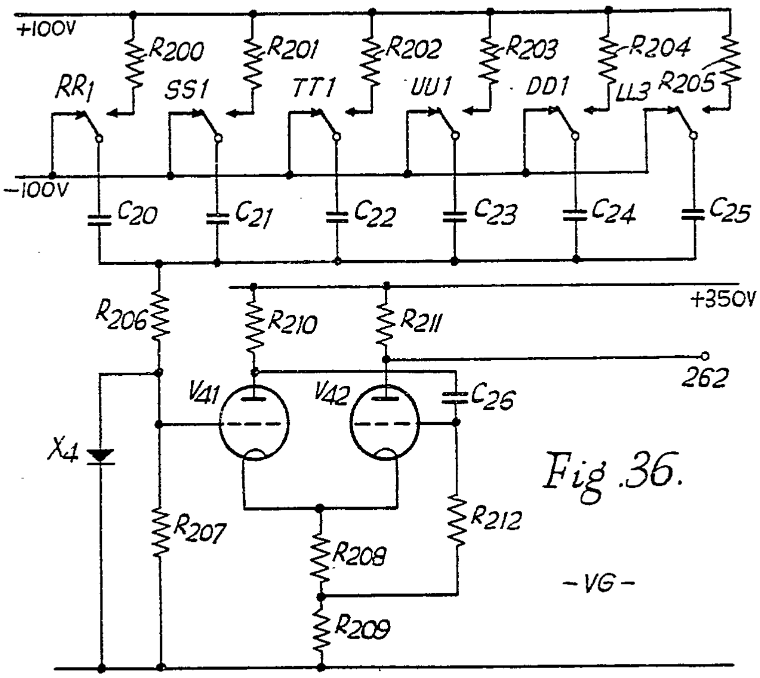


Fig.36.

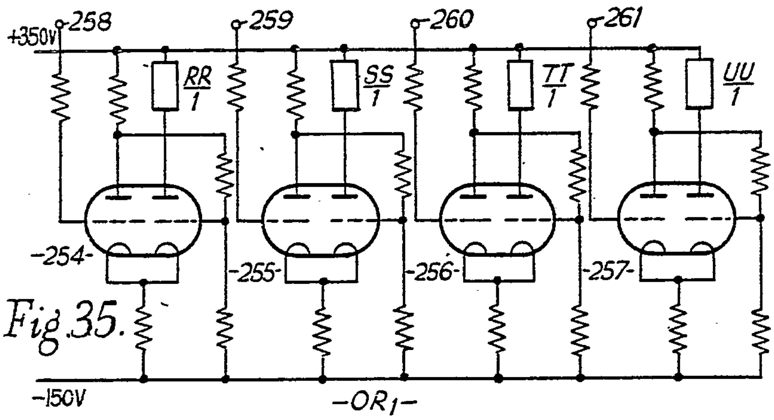


Fig.35.

866279 COMPLETE SPECIFICATION

26 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheets 23 & 24

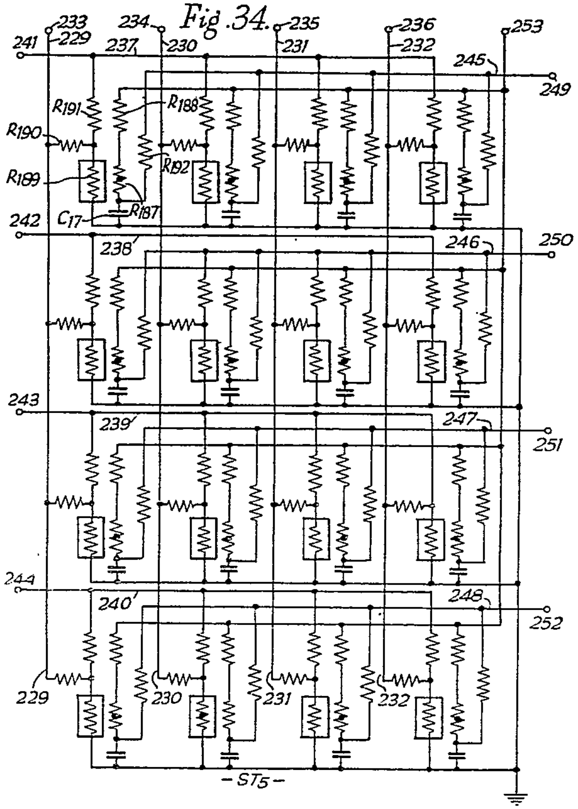


Fig.34.

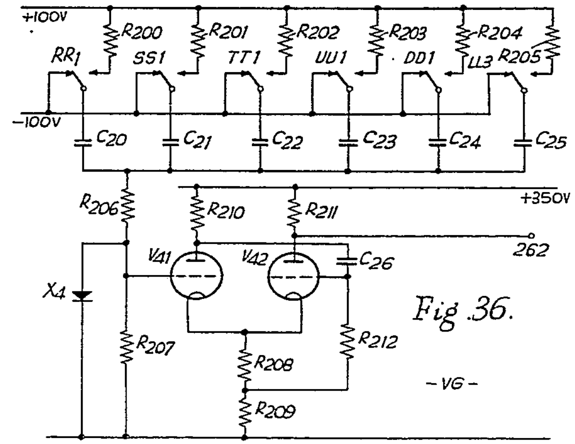


Fig.36.

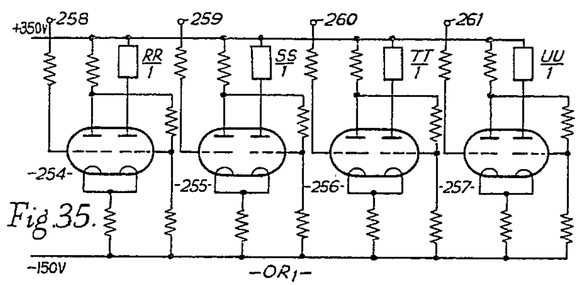
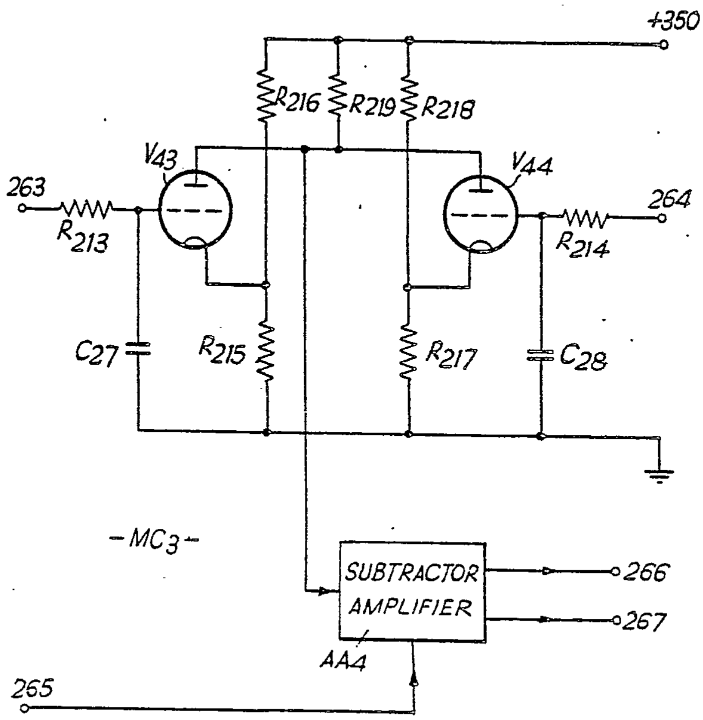


Fig.35.

Fig. 37.



+350
R216
R219
R218
V43
V44
263
R213
264
R214
C27
R215
R217
C28
-MC3-
SUBTRACTOR
AMPLIFIER
AA4
266
267
265

866279 COMPLETE SPECIFICATION

26 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheets 25 & 26

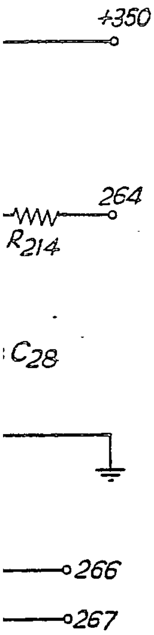


Fig. 38.

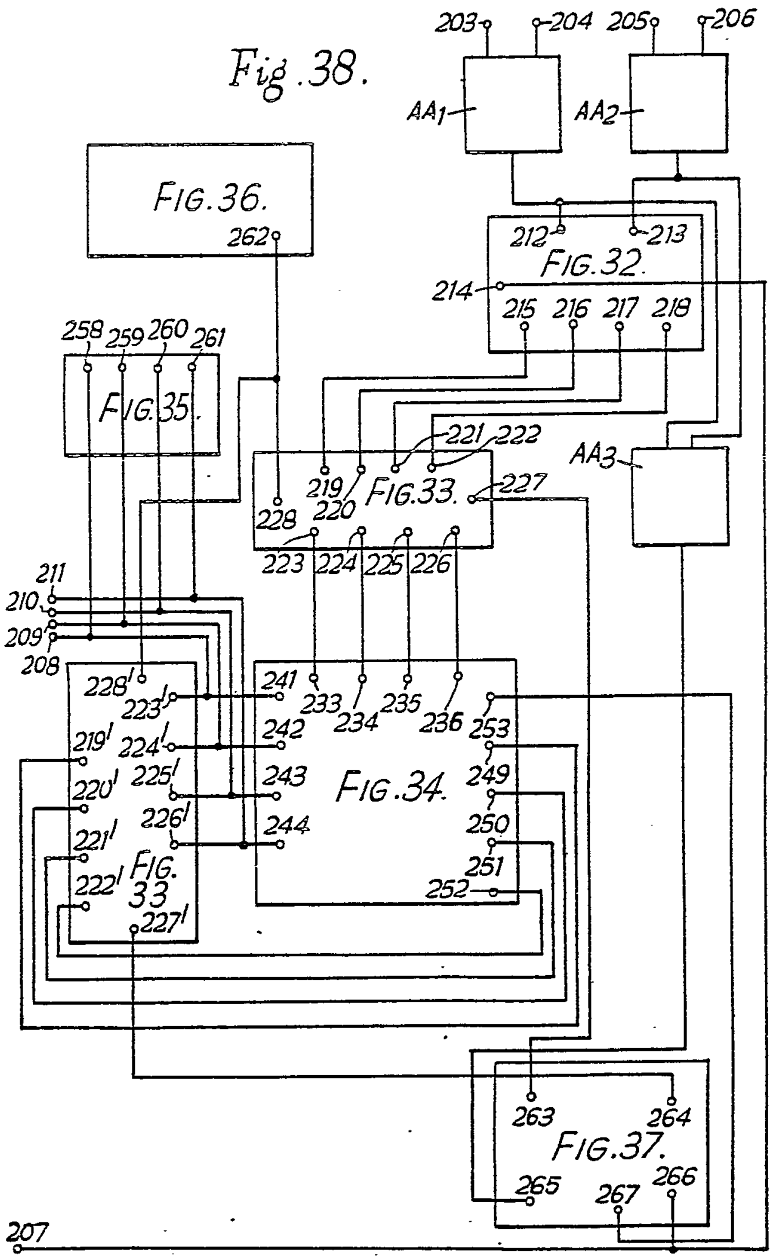


Fig. 37.

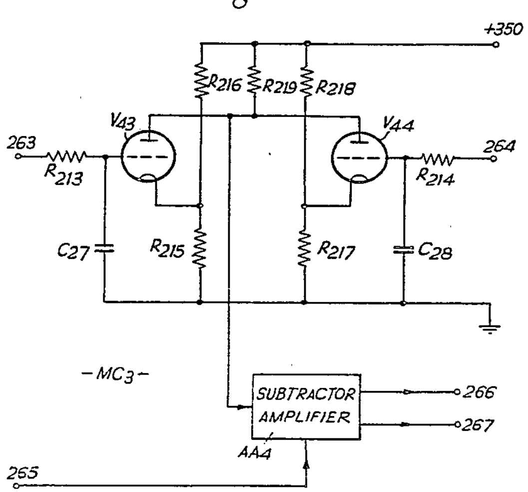
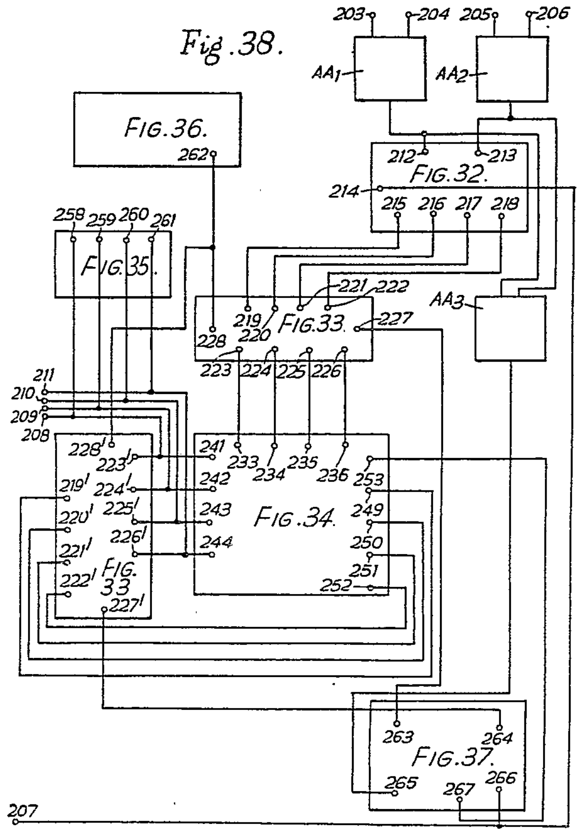

+350
R216
R219
R218
V43
V44
263
R213
264
R214
C27
R215
R217
C28
-MC3-
SUBTRACTOR AMPLIFIER
AA4
266
267
265

Fig. 38.


203
204
205
206
AA1
AA2
FIG. 36.
262
212
213
FIG. 32.
214
215 216 217 218
258 259 260 261
FIG. 35.
221 222
AA3
219 220 FIG. 33. 227
228
223 224 225 226
211
210
209
208
228' 223'
241 233 234 235 236 253
219' 224'
242
220' 225'
243 FIG. 34. 249
226'
221'
244 250
222' FIG. 33' 251
227'
252
263 264
FIG. 37.
265 267 266
207