Feb. 17, 1953 P. S. GOODWIN 2,629,056

VOLTAGE SENSITIVE CIRCUIT

Filed Oct. 12, 1951 4 Sheets-Sheet 1

FIG. 1.

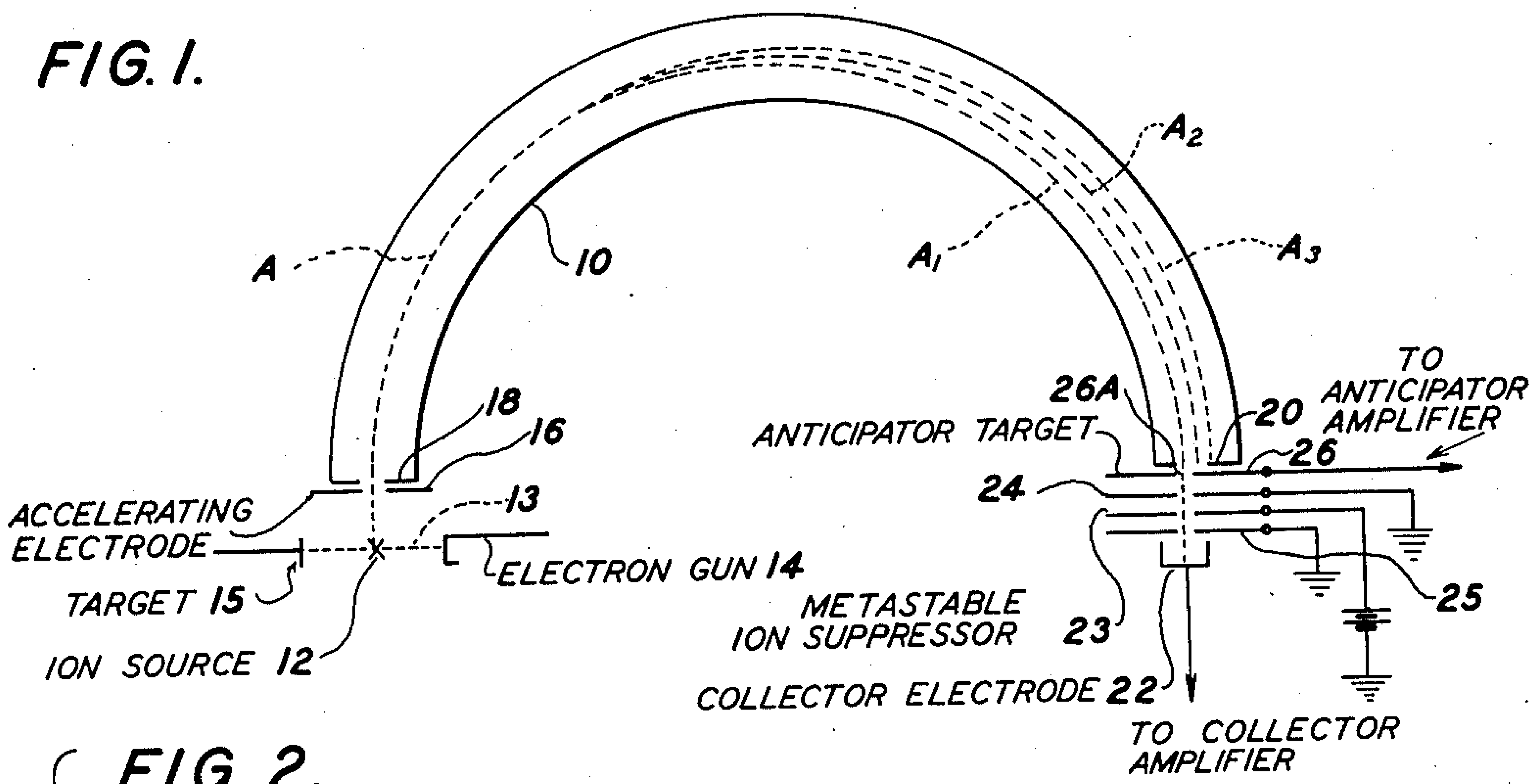

FIG. 2.

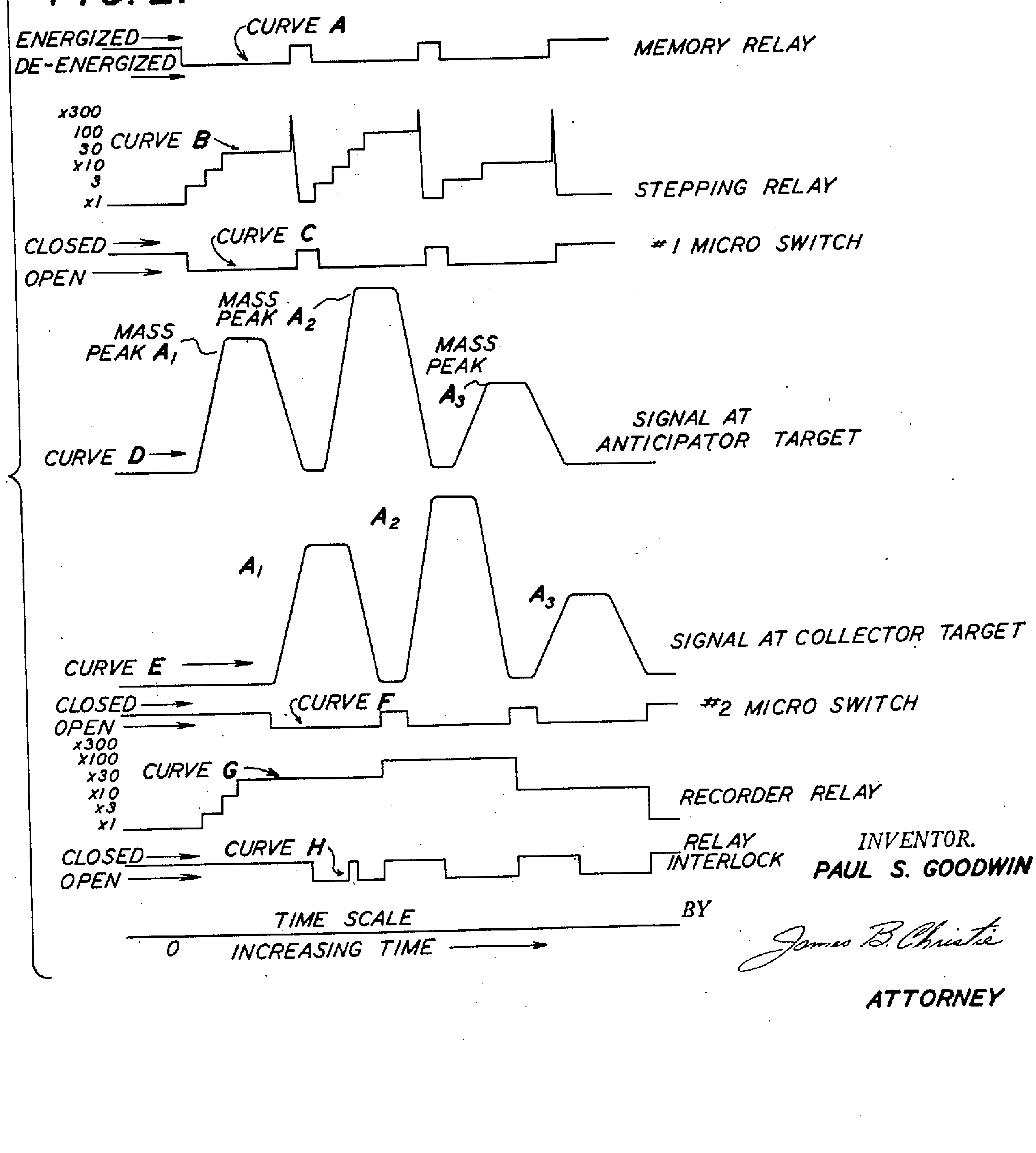

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FIG. 3.

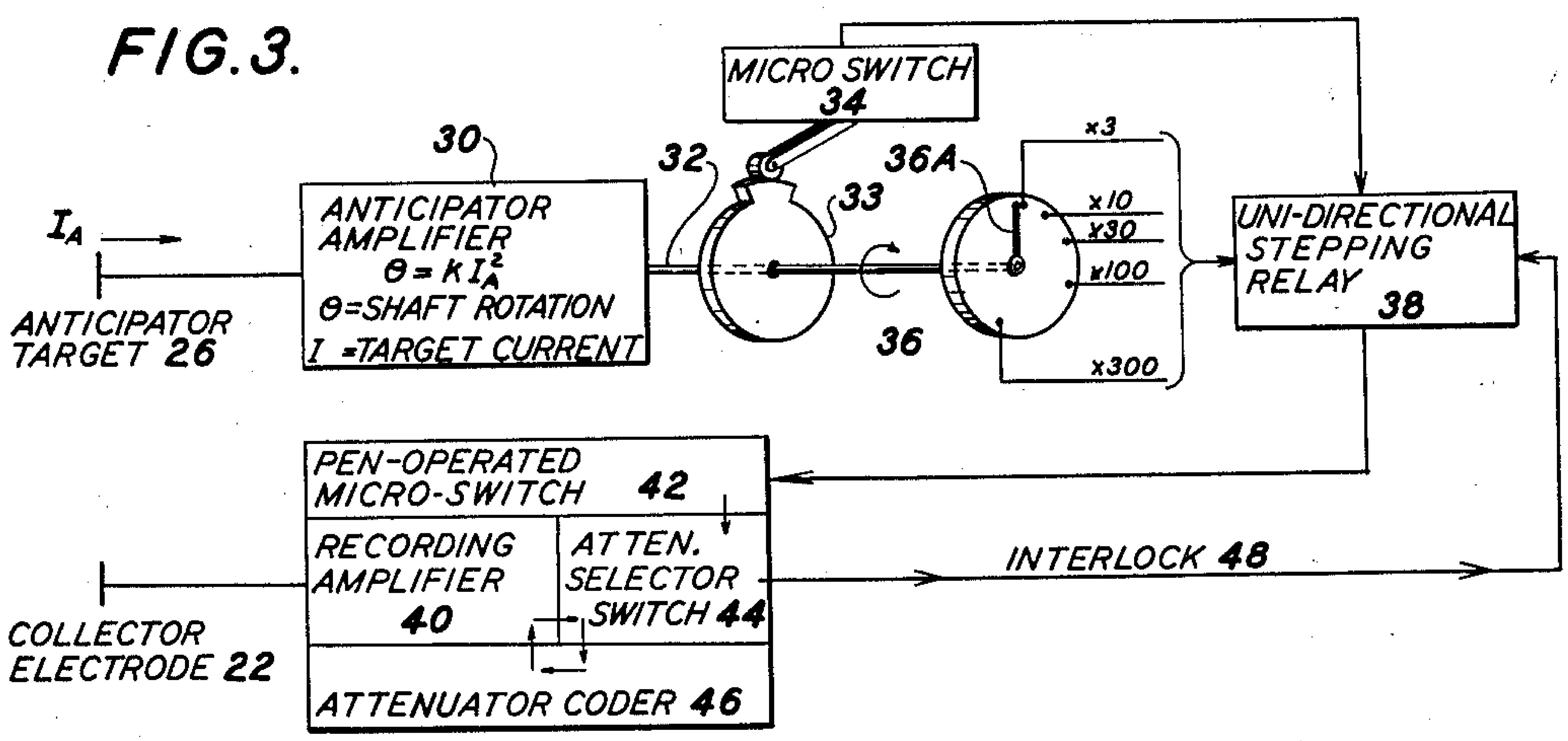
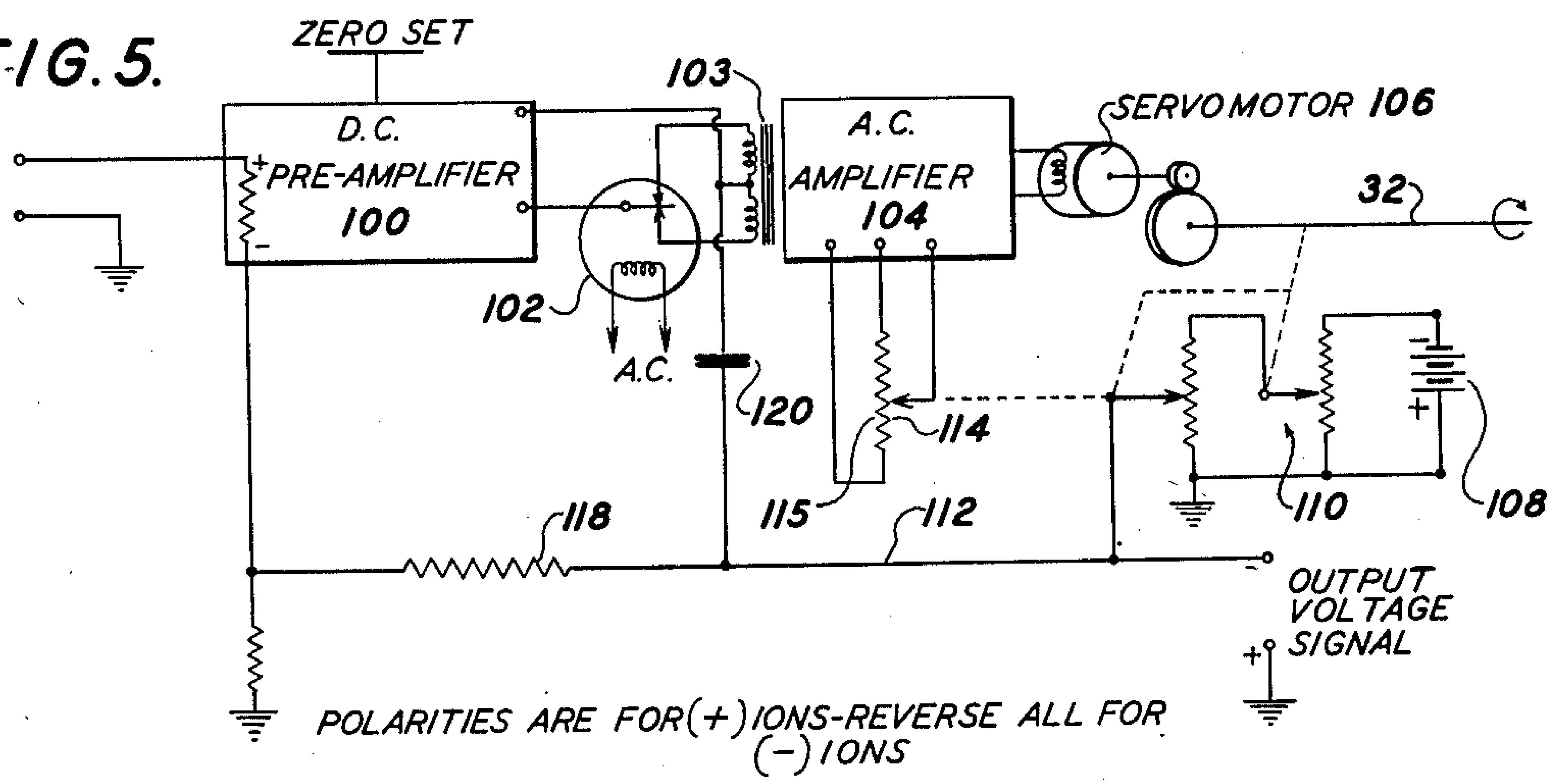


FIG. 5.



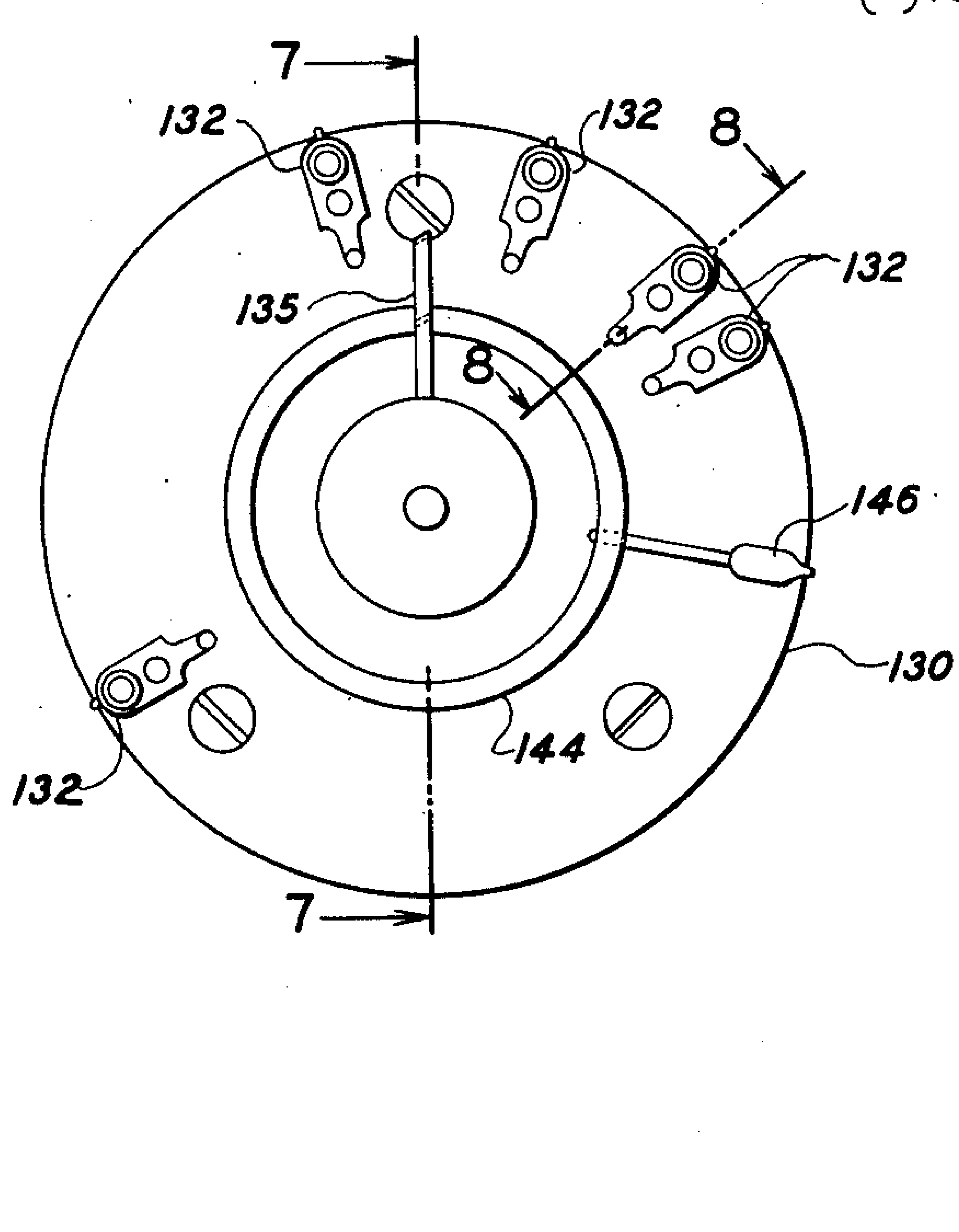


FIG. 6.

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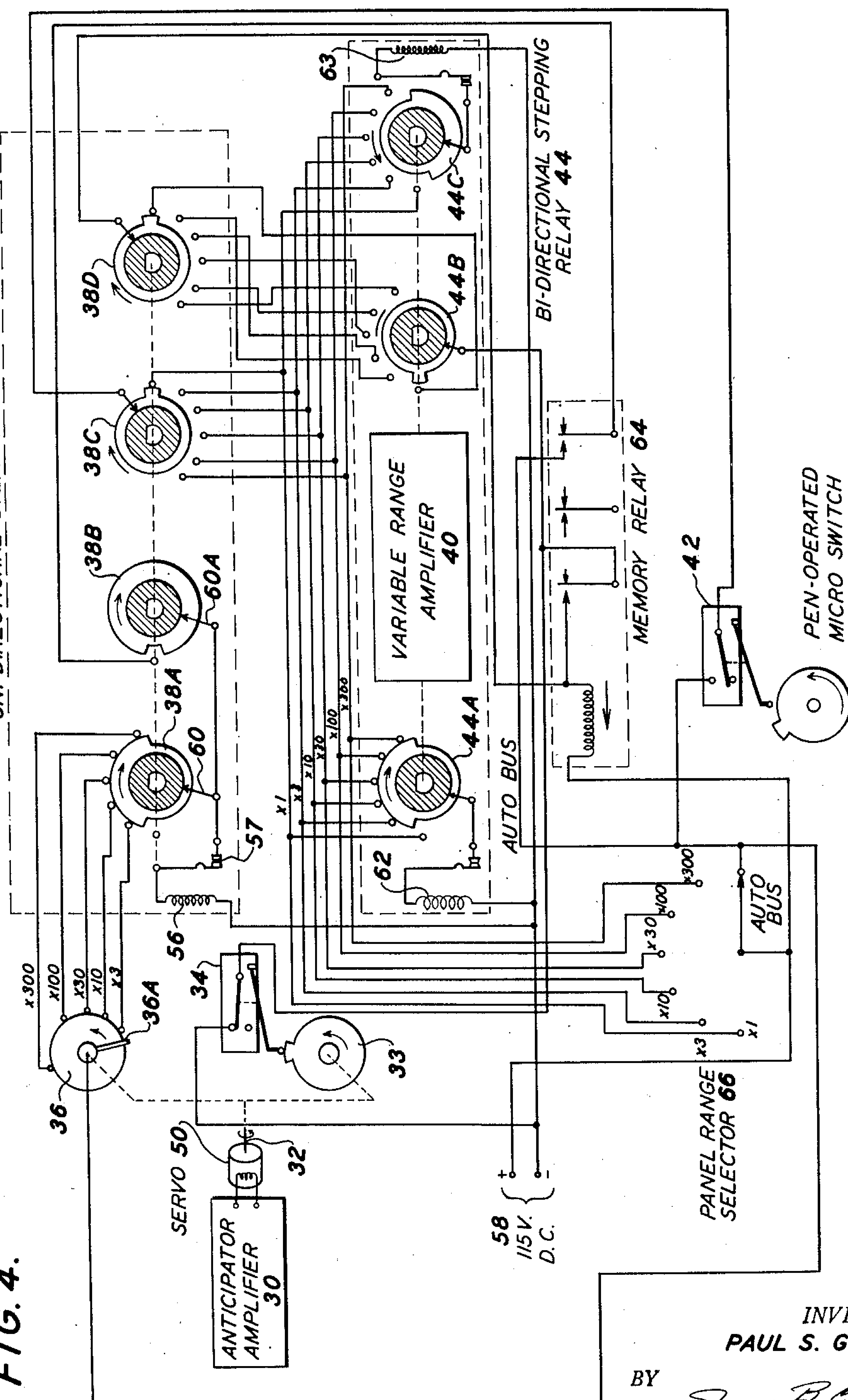

FIG. 4.

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FIG. 7.

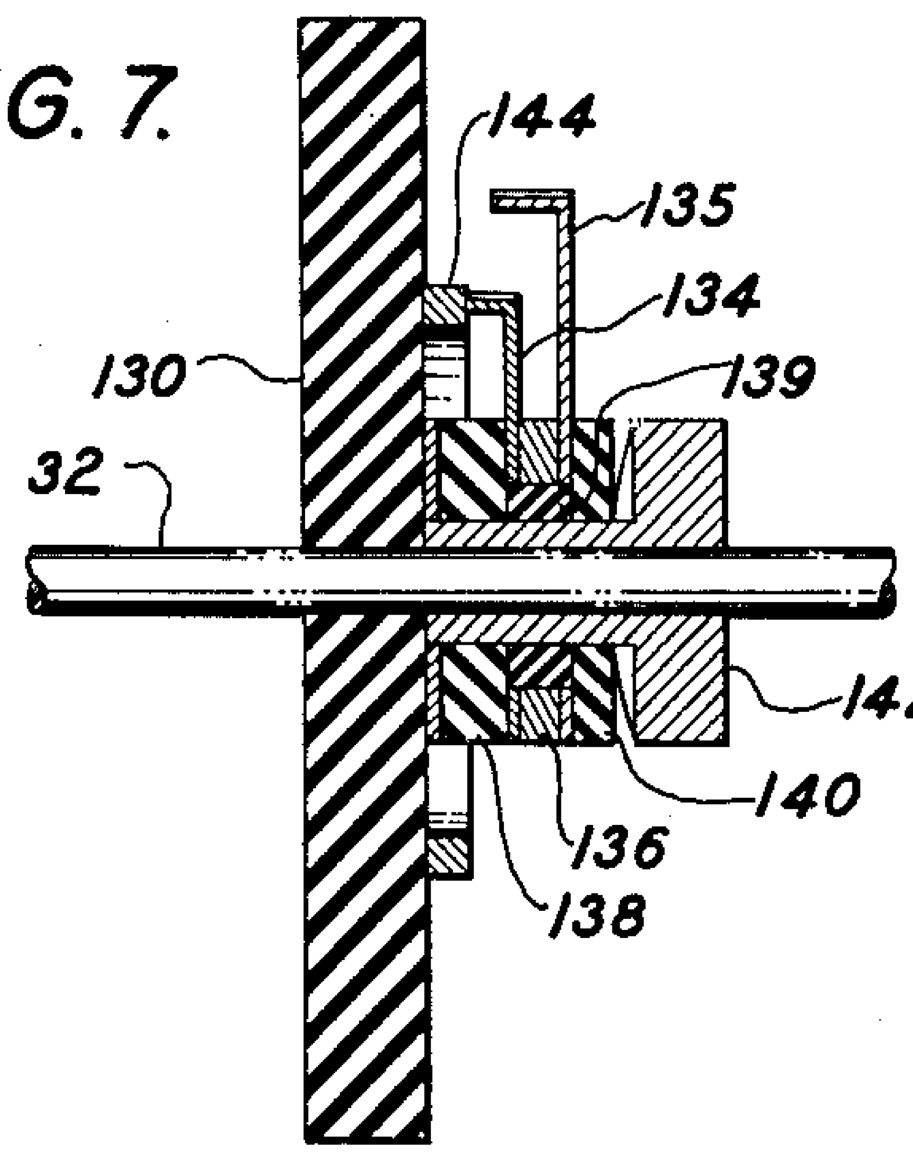


FIG. 8.

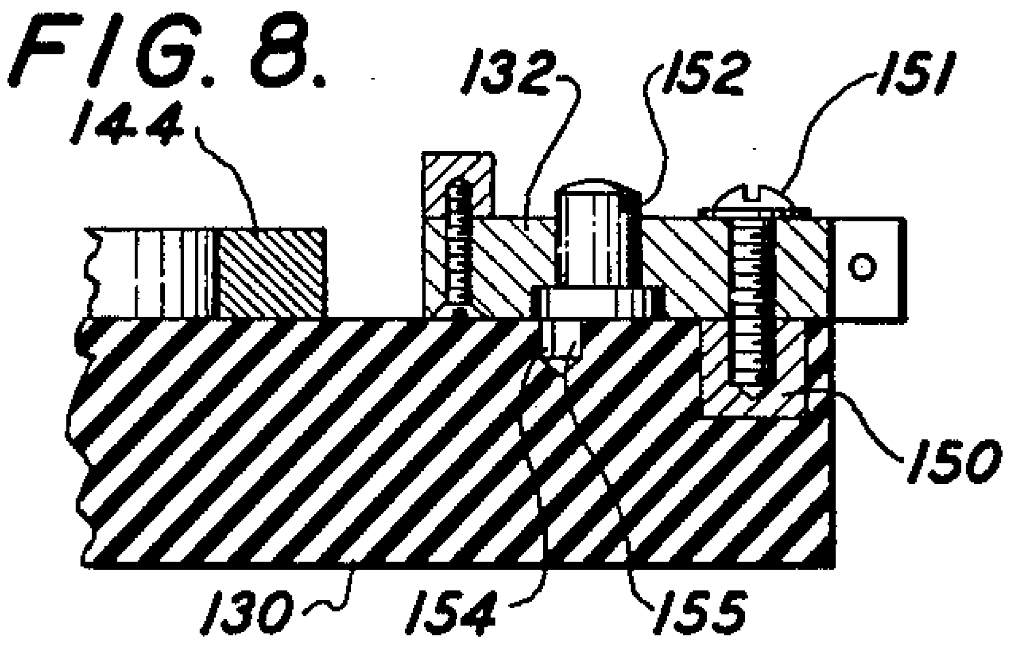


FIG. 9.

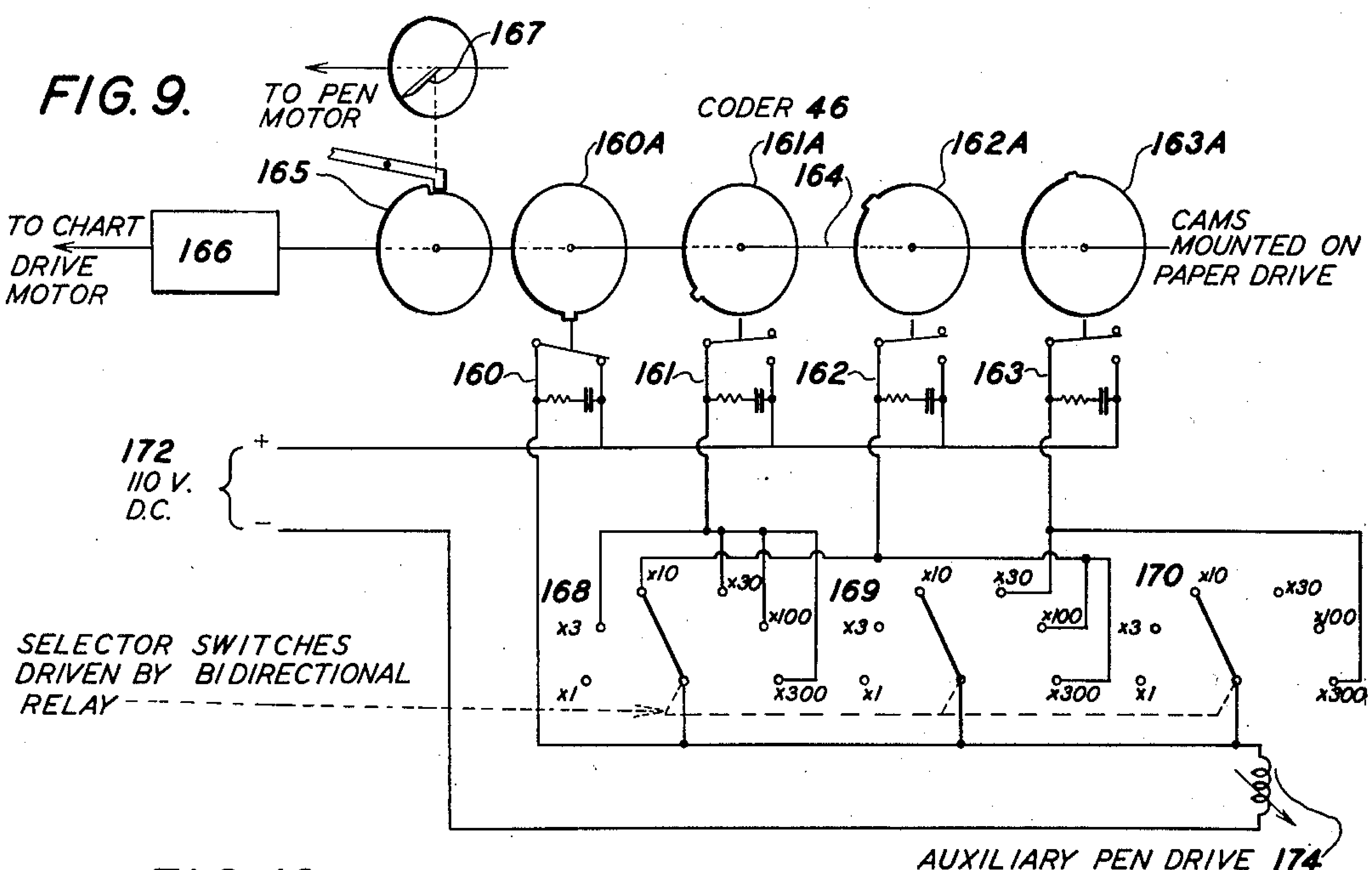
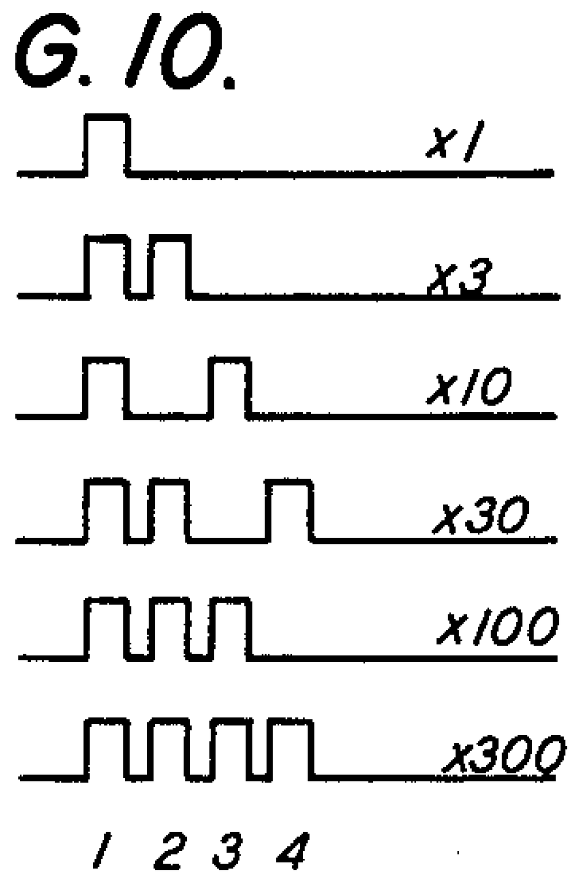


FIG. 10.



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Patented Feb. 17, 1953

2,629,056

UNITED STATES PATENT OFFICE

2,629,056

VOLTAGE SENSITIVE CIRCUIT

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Application October 12, 1951, Serial No. 251,092

30 Claims. (Cl. 250—41.9)

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This invention has to do with improvements in voltage sensing circuits for controlling operation of an interconnected system responsive to the magnitude of voltage signals fed to the sensing circuit. This application is a continuation-in-part of my co-pending application S. N. 182,691, filed September 1, 1950, and now abandoned.

One important application of a circuit of the type herein described is as an anticipator or automatic attenuator circuit for a mass spectrometer. The following description is based on this type of application with no intention of limiting the invention which is adapted to the control of any interrelated apparatus based on the magnitude of an input signal.

The principle of mass spectrometry is in general one of ionizing a sample to be analyzed, as by an electron beam, segregating ions in accordance with their mass-to-charge ratio by inducing spatial separation thereof, and selectively discharging, as at a collector electrode, ions of a given mass-to-charge ratio. The current developed by discharge of a group or beam of ions of the same mass-to-charge ratio is proportional to the partial pressure of the particles in the original sample from which these particular ions were derived. Hence, a method is afforded for calculating the concentration of these molecules in the sample.

In analyzing a sample for more than one component, the segregated ion beams constituting a part or all of the mass spectrum of the particular sample are successively focused on the collector electrode so that a plurality of separate discharge currents are obtained, each being proportional to the number of ions in a particular beam. The mass spectrum is scanned in this fashion by varying one or more of the parameters affecting the spatial separation between ions of differing mass-to-charge ratio.

The currents produced by ion discharge are generally converted to appropriate voltages across a dropping resistor, the voltages are amplified, and the amplified signals are recorded on either a multichannel recorder such as an oscillograph or on a single channel recorder such as a pen and ink recorder. The recorded signals appear as separate peaks on the record with each peak representing ions of a different given mass-to-charge ratio, the recorded trace returning to "zero" or a base level between succeeding peaks. The peak heights are determined by the recorder sensitivity as well as by the number of ions of the given mass-to-charge ratio represented by the given peak.

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Because of the wide differences in the number of ions which may be encountered in different beams as a result of wide concentration spreads in the original sample, it is necessary, when using a single channel recorder, to provide means for varying the sensitivity of the recorder so as to adapt it to this wide variation in ion abundance. If such provision is not made, the less abundant ions of a given spectrum will not develop a peak of sufficient height on a record having a full scale sensitivity such as to accommodate the most abundant ions. This principle has been recognized in the prior art, and various so-called anticipator circuits have been suggested for anticipating the ion abundance in successive beams of the spectrum and suitably adjusting the sensitivity of the recorder in advance of each separate peak.

In general, these anticipator circuits employ a double collector system in the analyzer tube of the mass spectrometer. The two ion targets are so arranged that a so-called auxiliary or anticipator target receives the full ion current signal in advance of the collector target. The anticipator signal is amplified and fed into a calculating device which selects the optimum attenuation range to be used in recording the data when the same signal arrives at the collector target. The information as to the proper attenuation range is delivered from the calculator to the main recording channel at a preselected time intermediate the recording of succeeding peaks. Automatic selector switches are provided in the main channel operative responsive to the information supplied thereto from the calculator to establish the proper attenuation level. A recording amplifier including manually operated attenuation selector switches is described and illustrated in my co-pending application Serial No. 82,337, filed March 19, 1949, and the improved anticipator circuit described herein is well suited to function in conjunction with the recording amplifier described in said application.

In general a recording amplifier produces movement of the tap of a balancing potentiometer responsive to and in proportion to the magnitude of the input signal. The amplifier and potentiometer are included in a null network so that the balance position of the potentiometer gives a measure of the input signal. A pen or other recording means is connected to record the excursions of the potentiometer slider. By varying the full scale voltage across the potentiometer slidewire, the sensitivity of the network can be varied in inverse ratio. The anticipator circuit of the instant invention is designed to automatically vary this full scale voltage in response to the intensity of an ion beam sensed in advance of the time that this beam is focused on the collector electrode. Mass spectrometry is not limited in any sense to poteniometric recording, such recording being described herein in conjunction with the circuitry of the present inventon only as illustrative of one typical application.

I have now developed a simplified voltage sensitive circuit of greater reliability and greater flexibility than those disclosed in the prior art, and ideally suited for use as an anticipator circuit in mass spectrometry. The greater reliability of the circuit of the invention is due in part to the provision of protective devices preventing accidental loss of the information stored in the calculator prior to its transfer to the recording channel and to protect against premature transfer of this information. The system of the present invention is made repetitive so that after transfer of the desired information to the recording channel and attenuation thereof, the calculator will be reset to await the next signal.

Accordingly, in one aspect the invention contemplates in a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a variable range recording amplifier, the combination comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, a stepping relay circuit, means connected between the anticipator electrode and the stepping relay circuit to energize and set the latter in proportion to the current developed at the anticipator electrode, means operable responsive to the setting of the stepping relay circuit to vary the sensitivity range of the recording amplifier and as a function of the setting of the stepping relay circuit, and means operable to reset the stepping relay circuit.

The invention comprises the combination set forth above as well as improvements in various elements of the combination. In accordance with the invention the means connected between the anticipator electrode and the stepping relay circuit to energize and set the latter, comprises an amplifier of new and improved design which is adapted to receive the minute currents from the anticipator electrode and convert these to an equivalent mechanical shaft rotation proportional to the square of the magnitude of the input current. The means for transferring electrical to mechanical energy is thought to constitute an improvement over any prior art devices. The equivalent mechanical shaft rotation may be utilized for any control or regulatory purpose, regulation of the sensitivity of a mass spectrometer recorder being only one of innumerable applications of this type.

The stepping relay circuit for reasons of economy is preferably a stepping relay, although a number of parallel connected individual relays may be employed to accomplish the same function.

The invention will be more clearly understood by reference to the following detailed description taken in conjunction with the accompanying drawings wherein:

Fig. 1 is a schematic diagram of a conventional 180° mass spectrometer provided with the usual collector electrode and an anticipator electrode for adapting the mass spectrometer to the circuit of the invention;

Fig. 2 is a series of graphs showing the nature of the signals developed by various elements of the anticipator circuit;

Fig. 3 is a block diagram of the anticipator circuit of the invention and its relationship to the recording amplifier;

Fig. 4 is a more detailed circuit diagram of the anticipator network of the invention;

Fig. 5 is a circuit diagram of the anticipator amplifier which constitutes one element of the circuit of Fig. 4;

Fig. 6 is a plan view of a specially designed selector switch forming a component part of the anticipator circuit;

Fig. 7 is a section taken on the line 7—7 of Fig. 6;

Fig. 8 is an enlarged section taken on the line 8—8 of Fig. 6;

Fig. 9 is a diagram of a coding device including an auxiliary pen for marking the record in the region of each ion peak to identify the attenuation range at which the peak was recorded; and

Fig. 10 shows the code developed by the system of Fig. 9.

As might be expected, the conditions for successful operation of the present anticipation system are dependent in part upon the characteristics of the collector system in the mass spectrometer itself. Fig. 1 is a diagram of a conventional 180° analyzer type mass spectrometer with a collector system in accordance with the invention. The diagram shows an analyzer tube 10 provided at one end with an ion source 12. Ions are produced in the ion source by an electron beam 13 developed at an electron gun 14 and directed against an electron target 15. An accelerating electrode 16 intermediate the source 12 and an inlet slit 18 in the analyzer tube propels ions from the source as a heterogeneous beam A into the analyzer tube. In the analyzer tube under the influence of a transverse magnetic field established by conventional means (not shown), the heterogeneous ion beam A is broken into a plurality of separate beams A_1, A_2, A_3, the ions of each beam being of the same mass-to-charge ratio differing from the mass-to-charge ratio of the ions in the other beams. An exit slit 20 in the end of the analyzer tube 10 opposite the ion source gives access to a collection system which includes a conventional collector electrode 22, a metastable ion suppressor electrode 23, shield electrodes 24, 25 and an anticipator target electrode 26.

The anticipator electrode 26 is provided with a slit 26A aligned with exit slit 20 in the analyzer tube and narrower than the exit slit so that ion beams passing through the exit slit may strike the anticipator target 26 or may pass through the slit 26A therein depending upon the focusing of the beam. In the illustration, the ion beam A_1 is focused through the exit slit and through the slit 26A in the anticipator target to strike the collector electrode. The adjacent ion beam A_2 is likewise focused through the exit slit 20 but strikes the anticipator target while the ion beam A_3 is not focused on the exit slit 20 and discharges on the walls of the analyzer tube. In scanning the spectrum, which in this instance comprises the three ion beams A_1, A_2, A_3, the beams are shifted to the left with respect to the exit slit 20 so that the beam A_1 will shift out of focus with respect to the exit slit **20** while the beam A_2 will focus on the slit **26A** in the anticipator target and at the same time the beam A_3 will focus through the exit slit onto the anticipator target.

The exit slit **20** is made just wide enough to receive adjacent masses while the slit **26A** in the target electrode is narrow enough to resolve between adjacent masses, these relationships being maintained for the highest mass range to be encountered in any given instrument. Thus, it is conventional to design a mass spectrometer to analyze materials within a given mass range and in the present instance the exit slit and slit in the anticipator electrode are proportioned as described and with respect to the highest ion masses to be encountered in the particular instrument in which they are employed. Spatial separation between adjacent ion masses is a function of the reciprocal of the ion mass so that resolution of high mass ions automatically insures resolution of lower mass ions.

The signals received at the anticipator target **26** and the collector electrode **22** are shown in curves D and E of Fig. 2 in which time is increasing from left to right. These two curves clearly show that when a portion of the ion beam passes through the slit in the anticipator target it is collected by the main target; the signal A_1 in curve E lying intermediate, from a time standpoint, the signals A_1 and A_2 of curve D. Thus the signals received by both targets are the same with the collector signal lagging the anticipator signal. This means that by the time the main channel recorder has started to record a peak responsive to the discharge of ions of a given mass at the collector electrode, the crest of that same peak must, of necessity, have passed the anticipator target. In the drawing it is clear that before the peak A_1 received at the collector electrode can be recorded, the same peak A_1 as shown in curve D will already have passed the anticipator target. This characteristic of the collector system insures that the top of the peak has reached the anticipator target and that no further signal increases will occur in the anticipator channel until the next peak arrives.

As mentioned above, another characteristic of the collector system which is important to the functioning of the present invention is that all peaks return substantially to zero or to a base level before the arrival of the next peak. This is insured by proper dimensioning of the slit system so that the slit **26A** in the anticipator electrode will resolve adjacent masses up to the largest mass to be encountered, and exit slit **20** in the analyzer tube will resolve between alternate adjacent masses so that only one mass at a time will strike the anticipator electrode.

Fig. 3 shows a block diagram of the elements comprising the complete automatic anticipation system and their relationship to each other. The system comprises an anticipator amplifier **30** connected to receive a signal from the anticipator target **26** and to convert this signal to an angular displacement θ of a shaft **32** proportional to the square of the ion current. A first cam **33** is mounted to rotate with the shaft **32** and to actuate a micro-switch **34**. A multiple contact selector switch **36** is mounted with the selector arm **36A** driven by shaft **32** to successively contact contact points identified as **X3**, **X10**, etc. The several contact points and the selector arm **36A** are electrically connected to a unidirectional stepping relay **38** which is actuated in one direction as the contact arm **36A** makes contact with each of the successive contact points.

Throughout the following description and in the drawings the designations **X1**, **X3**, **X10**, etc., as applied to various contact points and connecting leads signify that these elements are component parts of separate circuits which are appropriately selected by the means hereinafter explained to control the full scale voltage across the aforementioned balancing potentiometer. Thus the circuit with elements labelled **X3** is connected to automatically increase the voltage across the potentiometer by a factor of 3 when this circuit is suitably energized through the anticipator network. The sensitivity of the recording amplifier circuit will, as a result, be altered by the reciprocal of this factor.

A recording amplifier **40** is connected to receive current from the collector electrode **22**, the recording amplifier being provided for this use with a pen operated micro-switch **42** and an attenuator coder **46**. The unidirectional stepping relay **38** is connected through the pen operated micro-switch **42** to an attenuator selector switch **44** and is homed with the latter so that when the circuit is completed through the micro-switch **42** the attenuator selector switch **44** is set to match the stepping relay **38**. The selector switch **44** is connected through an interlock lead **48** to the unidirectional stepping relay **38** and the micro-switch **44** is likewise connected to the relay **38**, the two operating in unison to reset the stepping relay at the appropriate time and in a manner hereinafter described.

The anticipator amplifier **30** receives minute currents from the anticipator target **26**, converting these currents to an equivalent rotation of the shaft **32**. The input vs. output relation of the amplifier is given by the equation $\theta = kI_A^2$ where θ represents the angular rotation of shaft **32**, I_A is the current developed at the anticipator target and k is a constant of proportionality. A given rotation of shaft **32** in response to a signal developed at the anticipator target will cause the selector arm **36A** of switch **36** to rotate clockwise as shown in the drawing. The several contacts identified as **X3**, **X10**, etc., of the selector switch **36**, are nonuniformly distributed around the periphery of the switch in such a manner that they correspond to full scale currents of the several multiplier ranges of the recording amplifier. After the arm of the selector switch passes a given contact an electrical circuit is completed to the stepping relay **38** causing the relay to assume a position corresponding to the contact so energized. A mechanical locking system within the relay holds it in this new position until electrically instructed to change. The process repeats for each contact passed on the "upswing" of the contact arm so that the relay is successively set at positions corresponding to **X3**, **X10**, **X30**, etc., of the full scale sensitivity of recording amplifier **40**.

Due to the unidirectional nature of the stepping relay, it does not change position with counterclockwise rotation of the contact arm. Thus, if for a given signal the contact arm **36A** attains the contact **X30**, the relay will pass through three steps and will remain locked in this position even as the contact arm **36A** counter-rotates responsive to a diminution of the ion current back to the position shown in the drawing.

Fig. 4 is a more detailed circuit diagram of the anticipator system showing anticipator amplifier **30** connected to drive a servomotor **50** which in turn drives shaft **32** in the described relation to the anticipator amplifier input current I_A. As in the block diagram of Fig. 3, the shaft **32** is connected to drive a cam **33** operating a micro-switch **34** and to drive selector arm **36A** of the selector switch **36**. The orientation of the contacts on the selector switch **36** results in a unique relationship between the selector switch and the other elements of the circuit which is described in greater detail hereinafter and particularly with reference to Figs. 6 to 8. The unidirectional stepping relay **38** comprises four wafers 38A, 38B, 38C, 38D mounted on a common shaft and a driving solenoid **56** electrically connected to the wafers **38A**, **38B** by a normally closed interpreter arm **57**. The solenoid is connected to be energized by a source **58** of D. C. voltage when the circuit is completed through one of wafers 38A, 38B. The several contacts X3, X10, etc., of the selector switch **36**, are electrically connected to a like number of contacts on the wafer **38A** of the unidirectional relay. These wafers are rotated by energization of solenoid 56 responsive to electrical energy delivered through one of the wafers **38A**, **38B**. The wafers 38C, 38D are ganged with the wafers 38A, 38B and electrically connected to the bi-directional stepping relay **44** comprising in Fig. 4 the ganged wafers 44A, 44B, 44C and the driving solenoids **62**, **63**. The unidirectional anticipator relay 38 thus homes the attenuator relay 44 when an electrical connection is made between the two. The bi-directional relay **44** comprises the wafer **44A** which effectuates upscale drive, the wafer **44C** which effectuates downscale drive and wafer **44B** which with wafer **38D** of relay 38 constitutes an interlock. The relays 38 and 44 are homed so that an upswing in the anticipator relay **38** produces a corresponding upswing in the attenuator relay **44** whereby the range of amplifier **40** is altered accordingly.

The network shown in Fig. 4 also includes a memory relay 64 and a panel mounted selector switch 66.

The operation of the attenuation system is best described by tracing its response to a given set of ion discharge signals and having reference to Figs. 2, 3 and 4 of the drawing. Starting from zero time (see Fig. 2) at which there is no discharge signal at either the anticipator or collector targets, the condition of the circuit is as follows:

1. Zero signal at both targets, at which condition the cam operated micro-switch **34** and the pen operated micro-switch **42** are closed. The memory relay **64** may be in either position.

2. Both stepping relays 38 and **44** are in the X1 position, this being the position of greater sensitivity of the amplifier **40** and as shown in Fig. 4.

As scanning of the mass spectrum is commenced, the first result is the appearance of a discharge signal at the anticipator target and responsive rotation of output shaft **32** of the anticipator amplifier. When this signal reaches a magnitude in the neighborhood of 75% of full scale of the X1 range, the cam operated micro-switch 34 opens which affects de-energization of the memory relay **64**. The purpose of this interconnection is to prevent resetting of the unidirectional relay 38 to X1 position during the period when there is an appreciable signal present at the anticipator target. As explained above, energy to reset this relay originates at the source **58** and is delivered to the

reset wafer 38B through the manual range selector **66** (when set in the automatic position) and the memory relay **64**.

As the anticipator amplifier output shaft continues its rotation responsive to increasing signal at the anticipator target, the arm of the non-linear selector switch 36 makes contact with the X3 connection to stepping relay 38. Since the panel range selector 64 is in the automatic position, voltage will appear at the X3 contact of wafer 38A. The arm **60** of wafer **38A** is thereby energized and current flows through the normally closed interpreter arm **57** to actuate solenoid **56** and thence to ground. When energized, the solenoid produces a 30° rotary motion of all the wafers of relay **38**, this being the angular displacement of the X1, X3, X10 etc., contacts. In the last degree or so of this rotation, interpreter contact 57 is broken by a built-in eccentric cam which de-energizes the solenoid. The solenoid then returns to its initial position where it is ready to receive any further impulse. As the arm 36A of switch 36 continues its upscale swing, it will contact points X10, X30, etc., until it reaches an attenuation setting corresponding to the maximum or peak value of the signal received at the anticipator target. Each time the arm passes one of the contacts on the upswing, the wafers of relay 38 are rotated 30° in the above described manner.

Since a condition of no signal on the main target has been assumed as the starting point, the arm of wafer 38C has been energized during the above described process. This in turn has energized the respective X3, X10, etc. buses of the bi-directional stepping relay **44** as contact is made sequentially from X1 to X30. Due to the characteristics of wafers 44A, 44B, the solenoid **62** has been energized to bring about a setting of each of the wafers of relay **44** in time phase with relay 38. Since both relays are at the same multiplier range, an interlock is established between wafers 38D and **44B** through the memory relay, thus setting up one of the two prerequisites for resetting relay **38**.

The interlock is a protective circuit that allows resetting of relay **38** only after relay **44** has received and made use of the information set up on relay **38**. Due to the characteristics of the collector system (see Fig. 1), as soon as the signal developed at the anticipator target responsive to discharge of a given beam begins to decrease, it will begin to build up on the main target. This condition is illustrated graphically in curves D and E of Fig. 2. As the recording pen leaves its zero or base position to record a peak, the pen operated micro-switch **42** opens removing the voltage from the arm of wafer 38C. This breaks the drive connection between relays 38 and 44 and prohibits alteration of the setting of relay **44** while the recording amplifier is in the process of recording a peak.

As the relay 44 is driven from the X1 to the X3 setting, etc. it automatically increases the full scale voltage applied across the slidewire of the recording potentiometer in increments corresponding to 3 times, 10 times, etc. of the minimum voltage value. Each voltage increase reduces the full scale sensitivity correspondingly so that the recorder is automatically set to record the incipient peak at the maximum on-scale sensitivity. As an aid in reading the final record, coding means 46 (see Fig. 3) are preferably provided for recording directly on the chart adjacent to each peak, the sensitivity range at which that peak was recorded. One suitable coding device is shown diagrammatically in Fig. 9 and typical code symbols are shown in Fig. 10.

As the particular ion beam continues to shift from the anticipator target to the collector target, the anticipator signal falls toward zero and eventually reaches the point referred to as 75% of full scale of X1 range. At this point the cam operated switch 33 closes, energizing memory relay 64. This satisfies the second requirement for resetting the anticipator relay, the first requirement as already mentioned being the interlock between wafers 38D and 44B. The closing of the memory relay causes a voltage to appear on the single contact of wafer 38B. Since relay 38 is now in the X30 position, the notch in the periphery of wafer 38B is actually in a position 90° clockwise from that shown in Fig. 4. Connection is thereby made between the contact and the wafer arm and from thence through the interpreter switch 57 to energize solenoid 56. The solenoid operates to drive all of wafers 38A, 38B, 38C, 38D clockwise in 30° increments to the X1 position at which point the contact and arm of wafer 38B are no longer in electrical connection. The value of the interpreter switch is thus evident for in its absence solenoid 56 would lock itself in the energized position and only a 30° rotation of the wafers would be achieved. Interruption of the current permits the solenoid to return to its original position to pick up another tooth in the conventional ratchet linkage between the solenoid and the shaft upon which the wafers are mounted. The unidirectional stepping relay has thus returned to a position to respond to and calculate the range of the next peak in the series.

If the next peak is of sufficient intensity to drive the unidirectional relay to the X100 position, the functioning of the circuit will be as follows. During the time relay 38 is stepping to this position no action will take place in relay 44 since the pen operated switch 42 remains open until the pen approaches zero after recording the previous peak at the X30 attenuation range. At this point the linkage between relays 38 and 44 is re-established and voltage will flow from the X100 contact of wafer 38C to the X100 bus of relay 44 and to the X100 contact of wafer 44A. Relay 44 will then change in the manner above described to the X100 position, changing at the same time the voltage applied across the recording potentiometer. When the pen switch 42 opens (as the recording pen leaves its zero position) and the anticipator signal falls to zero, the anticipator relay is again reset to the X1 position.

If the next succeeding peak is of smaller magnitude, say corresponding to an X10 attenuation, relay 44 will be stepped down from the X100 to the X10 position. When wafer 38C is energized after relay 38 is stepped to the X10 position and the pen switch again closes, the X10 bus of relay 44 will be energized and connection is made to wafer 44C instead of wafer 44A. The circuit is then completed through this wafer to the second driving solenoid 63 which drives relay 44 in a counterclockwise direction to the X10 position.

The entire operation can be appreciated by reference to Fig. 2 which shows the conditions of the various circuit elements throughout the described sequence. In Fig. 2, curves D and E show respectively the signals developed at the anticipator and collector targets, with the peaks in the latter signal corresponding in time to the minima of the former. Curve C portrays the position of the cam operated micro-switch 33 which opens as the anticipator signal reaches 75% of full scale sensitivity of the X1 range on the upswing and remains open until the signal diminishes to this value. The memory relay (curve A) is de-energized when the cam operated micro-switch is open, that is during the time a signal is being developed at the anticipator target. As described above, this prevents application of a reset signal to wafer 38B of relay 38 during this interval. In curve B the corresponding settings of the unidirectional relay for peaks of X30, X100, and X10 intensity are shown respectively. Since this relay is unidirectional it is driven each time it is reset to the X300 position before returning to the X1 position. The pen operated micro-switch 42 remains open during the recording of the ion peaks in the collector channel and closes when the recording pen is substantially in the zero position so that driving connection is maintained between relay 38 and relay 44 only during these intervals. The settings of the bi-directional relay 44 are shown by curve G. This curve as compared to curve B illustrates the difference in the operation of the bi-directional and unidirectional relays. The latter passes through the complete range from each separate discharge signal while the bi-directional relay varies up and down scale in conformity with each significant setting of the unidirectional relay. Curve H of Fig. 2 shows the positions of the relay interlock, i. e. the periods in which wafer 38C of relay 38 and wafer 44B of relay 44 are connected and disconnected.

A circuit diagram of the anticipator amplifier itself is shown in Fig. 5. This amplifier is somewhat simliar to the recording electrometer amplifier described in my above mentioned copending application with certain changes and modifications incorporated therein to adapt it to accomplish the desired function in the present instance. The amplifier circuit includes a D. C. pre-amplifier 100, the output of which is connected through a chopper 102 and a transformer 103 to an A. C. amplifier 104. The output of the A. C. amplifier 104 is connected to one coil of a servomotor 106 which drives the shaft 32, which, in turn, drives the selector switch 36 and cam 33 as above described (see Fig. 3). In this instance the amplifier has but one sensitivity range equivalent in full scale signal to the X300 range on the recording amplifier. This sensitivity range is determined by the magnitude of the D. C. source 108 which is of the same value as the corresponding D. C. source of the recording amplifier. In the present anticipator amplifier circuit, unlike the recording amplifier, a non-linear potentiometer circuit 110 is connected to the source 108 and the sensitivity of the amplifier at very small signal levels is achieved by this non-linear potentiometer circuit which effectively increases the resolution of the potentiometers at these low signal levels.

The non-linear relationship between the rotation of the output shaft 32 which is ganged to the non-linear potentiometer circuit 110 and the output voltage from the potentiometer circircuit results in a varying gain around a feed back loop 112 connected between the potentiometer circuit 110 and the D. C. pre-amplifier. As mentioned above, this relationship is such that the angular rotation of the output shaft 32 is proportional to the square of the input current to the D. C. amplifier. The effective loop gain therefore is directly proportional to the output shaft angular position and is, therefore, low at low signal levels and high at high signal levels. However, to achieve the required resolution and sensitivity it is necessary to maintain a constant loop gain irrespective of the shaft position. A third feed back loop 114 is provided for this purpose. This loop includes a potentiometer 115 which is mechanically connected to the potentiometer circuit 110 and is hence driven by the output shaft 32. This gain potentiometer 115 reduces the gain of the amplifier 104 as the feed back signal increases, thus compensating for the change in feed back loop gain caused by the non-linear potentiometer 110.

The feed back loop 112 also includes a resistor 118 connected between the potentiometer 110 and the input to the D. C. pre-amplifier 100 and a capacitor 120 connected between the potentiometer 110 and the input transformer 103 to the A. C. amplifier, all as described in greater detail in my aforesaid co-pending application.

The various alterations in the circuit of the recording amplifier described in said application and the anticipator amplifier shown in Fig. 5 produces significant differences in performance. By way of example, if it is assumed that a pure trapezoidal pulse were applied simultaneously to the inputs of the recording and anticipator amplifier and that an instantaneous comparison was made of the two output shaft positions, it could be shown that the two shafts would turn at the same speed as long as both amplifiers were lagging behind the applied signal. Therefore, for a full scale signal there would be no appreciable difference in shaft position between the two amplifiers which is the correct relationship for their cooperative effort. If it is next assumed that a signal whose amplitude is one-half full scale is applied to both amplifiers, the amplifiers accelerate together and reach the same maximum velocity. The total time required for the recording amplifier to reach the final value of half full scale is just half that required for it to reach full scale. However, the time required for the anticipator amplifier to reach half full scale is 70.7% of the time required to reach full scale as it must travel that fraction more in order to achieve the same output voltage as the recording amplifier. It is obvious, therefore, that the anticipator amplifier shown in Fig. 5 is materially different from the recording amplifier shown in my co-pending application and has an entirely different function.

The selector switch 36 driven by the output shaft of the anticipator amplifier is shown in greater detail in Figs. 6, 7 and 8. Referring to these figures the switch comprises an insulating disk 130 journaled on shaft 32. A plurality of contacts 132 are mounted adjacent the periphery of the disk 130 and are irregularly spaced from each other so that each contact will represent a given fraction of the full scale range of the recording amplifier when the shaft 32 is rotated responsive to the square of the input current to the anticipator amplifier. Contact arms 134, 135 are mounted to rotate with the shaft 32 and are electrically connected to each other by a conductive washer 136 and are insulated from the shaft 32 and from the disk 130 by insulating rings 138, 139, 140. The assembly is held on the shaft by a bushing 142. A conductive ring 144 is mounted on the face of the disk 130 in the path of contact arm 34 and is electrically connected to the circuit through a separate contact 146. The contact arm 135 is positioned to make contact with the contacts 132 upon rotation of the shaft 32, and as such contacts are made a circuit is completed from the ring 144 through the two arms 134, 135 to the contacts 132.

Even with the separation of range change points as achieved by the square law characteristics of the anticipator amplifier, the location of the several contacts in degrees from the zero reference point must be maintained to very close tolerances. Tolerances as close as one-tenth of one degree are required and once the location of the contact point has been achieved, the contact and switch arm must reproduce their initial contact to within 0.05 degree. These factors, plus errors due to tolerances in replacement parts, make it desirable to provide for adjustment of the contact. A selector switch in accordance with the invention permits very fine adjustment of the contacts in the manner shown in enlarged section of Fig. 8. In the figure the contact 132 is screwed to a plug 150 inserted in the face of the disk 130 and is pivotable about this point. A shaft 152 is rotatably mounted through the contact element 132 and is provided with an eccentric stud 154 projecting into a receiving hole 155 in the disk 130. Adjustment of the contact is achieved by pivoting the same about the pivot screw 151 by rotation of the eccentric 152. In a preferred embodiment, the eccentric is proportioned so that a 3° rotation of the eccentric produces a one-tenth of a degree rotation of the contact about the pivot point 151. In this manner, the switch may be serviced periodically to maintain the desired range change point, as well as materially reducing production tolerances and cost.

A highly satisfactory coding mechanism is shown diagrammatically in Fig. 9. The coder is designed to automatically mark the record with one of the symbols shown in Fig. 10 as each mass peak is recorded to provide means for determining at a glance the attenuation range at which each peak was recorded. The coder 46 shown in the drawing includes four cam operated switches 160, 161, 162, 163, arranged to be actuated by companion cams 160A, 161A, 162A, 163A. The several cams are mounted on a common shaft 164 connected through a latch mechanism 165 and a slip clutch 166 to be driven by the chart drive motor. The latch 165 is connected in turn to be actuated by the pen drive motor through a sprocket 167 so that each time the recording pen begins upscale movement the latch mechanism is released to allow one revolution only of the cams 160A ,161A, etc.

A bank of selector switches 168, 169, 170 is connected to the bi-directional relay 44 (see Fig. 4) so that the switch arms are homed with the range settings of the relay. A voltage source 172 is connected through the cam switches and selector switches to an auxiliary pen drive 174. The first cam switch is connected directly across the source through the pen drive so that with each revolution of the cam shaft 164 an impulse is delivered through this switch to the auxiliary pen drive. As shown in Fig. 10 the number (1) pip appears in each symbol and standing alone represents the X1 attenuation range. The several cams 160A etc. are oriented with respect to each other to give a slight time delay between actuation of the several switches. The switches 161, 162 and 163 are connected through the bank of selector switches to the auxiliary pen drive in such a manner that the several traces shown in Fig. 10 are produced at the indicated attenuation ranges. For example, the X1 contact of each of the selector switches is dead so that there is no connection between the 2nd, 3rd and 4th cam switches and the auxiliary pen drive when the selector switch arms are homed at the X1 position. As a result only the number (1) pip appears on the record. at the X10 position shown the third cam switch is connected through selector switch 163 to the auxiliary pen drive so that pips (1) and (3) appear on the record to identify this particular attenuation range. The circuit is easily traced to show how all of the symbols represented in Fig. 10 are developed responsive to the corresponding setting of the selector switch bank.

Although the voltage sensitive circuit of the invention has been described and illustrated as including an improved selector switch, a specific coding circuit and other particular elements, the invention is not limited to these particular elements which merely represent preferred construction.

I claim:

1. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a recorder for recording the signals developed by ion discharge at the collector electrode, the combination comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, a stepping relay circuit, means connected between the anticipator electrode and the stepping relay circuit to energize and set the latter in proportion to the current developed at the anticipator electrode, means operable responsive to the setting of the stepping relay circuit to vary the sensitivity range of the recorder as a function of the setting of the stepping relay, and means operable to reset the stepping relay circuit after each signal is received at the anticipator electrode.

2. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a recorder for recording the signals developed by ion discharge at the collector electrode, the combination comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, an anticipator amplifier, a stepping relay circuit, means operable responsive to the output of the anticipator amplifier to set the stepping relay in proportion to the current developed at the anticipator electrode, means operable responsive to the setting of the stepping relay circuit to vary the sensitivity range of the recorder as a function of the setting of the stepping relay, and means operable to reset the stepping relay circuit only after the sensitivity of the recorder has been correspondingly determined.

3. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a recorder for recording the signals delevoped by ion discharge at the collector electrode, the combination comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, a stepping relay circuit, an anticipator amplifying circuit including means for developing a mechanical motion responsive to the magnitude of the anticipator signal, means connected between the amplifying circuit and the stepping relay circuit to energize and set the latter in proportion to the magnitude of said mechanical motion, means responsive to the setting of the stepping relay circuit to vary the sensitivity range of the recorder as a function of the setting of the stepping relay, and means operable to reset the stepping relay circuit after each signal is received at the anticipator electrode.

4. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a recorder for recording the signals developed by ion discharge at the collector electrode, the combination comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, a first stepping relay circuit, an anticipator amplifying circuit, a selector switch, means operable responsive to the output of the anticipator amplifier to set the selector switch, means connected between the selector switch and the stepping relay circuit to energize and set the latter in accordance with the setting of the selector switch, a second stepping relay homed with the first relay, means operable responsive to the setting of the second stepping relay to vary the sensitivity range of the recorder as a function of the setting of the stepping relay, and means operable to reset the first stepping relay circuit only after the recorder sensitivity has been determined by the second stepping relay.

5. In a mass spectrometer having a source of ions, means for segrating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a variable range recording potentiometer circuit including a recording pen, and a variable voltage source connected across and adapted to determine the sensitivity range of the potentiometer, an automatic range selecting circuit comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, an anticipator amplifier network including a servomotor and adapted to develop rotation of the motor proportional to the current develped at the collector electrode, a multicontact selector switch connected to be actuated by rotation of the motor, a unidirectional stepping relay, means connecting the stepping relay to the selector switch and means including a voltage source operable to step the stepping relay responsive to energization of each successive contact of the selector switch, a bi-directional stepping relay, the unidirectional relay being interconnected with the bi-directional relay so that the latter homes to the maximum position of the unidirectional relay after each reset thereof, and means for resetting the unidirectional relay independently of the bi-directional relay when the discharge current at the anticipator electrode falls below a fixed level.

6. Apparatus according to claim 5 wherein the anticipator amplifier network comprises a D. C. amplifier with a relatively high input impedance and low output impedance, a converter for converting the output of the D. C. amplifier to an A. C. variation thereof, an A. C. amplifier for amplifying the output of the converter, a motor

connected to be actuated by that part of the output of the A. C. amplifier which is in phase with the converter, a fixed voltage source, a non-linear potentiometer circuit connected across the voltage source, and a feed-back loop connecting the output of the non-linear potentiometer circuit to the D. C. amplifier to produce a null system.

7. Apparatus according to claim 5 wherein the anticipator amplifier network comprises a D. C. amplifier with a relatively high input impedance and low output impedance, a converter for converting the output of the D. C. amplifier to an A. C. variation thereof, an A. C. amplifier for amplifying the output of the converter, a motor connected to be actuated by that part of the output of the A. C. amplifier which is in phase with the converter, first and second slidewire potentiometers, a source of voltage connected across the first potentiometer, the second potentiometer being connected between the slider of the first potentiometer and the source of voltage, a first feed-back loop connecting the slider of the second potentiometer to the D. C. amplifier to produce a null system, a second feed-back loop connecting the slider of the second potentiometer to the input of the A. C. amplifier, a third feed-back loop in the A. C. amplifier to vary the gain thereof inversely with respect to the variation in the magnitude of the feed-back signal and including a third potentiometer, and means connecting the sliders of the several potentiometers to be adjusted by said motor.

8. Apparatus according to claim 5 wherein the multicontact selector switch comprises a rotatable contact arm, a plurality of radially disposed and angularly spaced contacts adapted to be contacted upon rotation of the contact arm, each contact comprising a pivotally mounted body and means for adjusting the angular orientation of the body with respect to the contact arm.

9. Apparatus according to claim 5 wherein the multicontact selector switch comprises a base, a first contact arm rotatably mounted to sweep over the face of the base, a second contact arm rotatably mounted to sweep over the face of the base, the second arm being shorter than the first arm and in electrical connection with the first arm, a conductive ring mounted on the base in the path of the second arm and adapted to have a voltage source connected thereto, a plurality of radially disposed and angularly spaced contacts adapted to be contacted by and upon rotation of the first arm, each contact comprising a body pivotally mounted to the base, and means for adjusting the angular placement of the body with respect to the base.

10. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a variable range recording potentiometer including a recording pen, and a variable voltage source connected across and adapted to determine the sensitivity range of said potentiometer, an automatic range selecting circuit comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, an anticipator amplifier network including a servomotor and adapted to develop a motor rotation proportional to the current developed at the anticipator electrode, a multicontact selector switch connected to be actuated by rotation of said motor, a unidirectional stepping relay comprising a stepping wafer, a reset wafer, and a homing wafer, means connecting the stepping wafer to the selector switch and means including a voltage source operable to step the stepping relay responsive to energization of each successive contact of said selector switch, a bi-directional stepping relay comprising an upscale drive wafer, and a downscale drive wafer, the homing wafer of the unidirectional relay being interconnected with the driving wafers of the bi-directional relay so that the latter homes to the maximum position of the unidirectional relay, and means for energizing the reset wafer of the unidirectional relay when the discharge current at the anticipator electrode falls below a fixed level.

11. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a variable range recording potentiometer including a recording pen, and a variable voltage source connected across and adapted to determine the sensitivity range of the potentiometer, an automatic range selecting circuit comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, an anticipator amplifier network including a servomotor and adapted to develop an output shaft rotation proportional to the current developed at the anticipator electrode, a multicontact selector switch connected to be actuated by rotation of said shaft, a unidirectional stepping relay comprising a stepping wafer, a reset wafer and a homing wafer, means connecting the stepping wafer to the selector switch and means including a voltage source operable to step the stepping relay responsive to energization of each successive contact of the selector switch, a bi-directional stepping relay comprising an upscale drive wafer, and a downscale drive wafer, the homing wafer of the unidirectional relay being interconnected with the driving wafers of the bi-directional relay so that the latter homes to the maximum position of the unidirectional relay after each reset thereof, and means for energizing the reset wafer of the unidirectional relay when the discharge current at the anticipator electrode falls below a fixed level.

12. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a variable range recording potentiometer including a recording pen, and a variable voltage source connected across and adapted to determine the sensitivity range of the potentiometer, an automatic range selecting circuit comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, an anticipator amplifier network including a servomotor and adapted to develop an output shaft rotation proportional to the current developed at the anticipator electrode, a cam operated micro-switch and a multicontact selector switch connected to be actuated by rotation of the shaft, a unidirectional stepping relay comprising a stepping wafer, a reset wafer, a homing wafer and an interlocking wafer, means connecting the stepping wafer to the selector switch and means including a voltage source operable to step the stepping relay responsive to energization of each successive contact of the

selector switch, a bi-directional stepping relay comprising an upscale drive wafer, a downscale drive wafer and an interlocking wafer, the homing wafer of the unidirectional relay being interconnected with the driving wafers of the bi-directional relay so that the latter homes to the maximum position of the unidirectional relay after each reset thereof, and the interlock wafers of each relay being interconnected, and a third relay connected between the interlocking wafers and the reset wafer to reset the unidirectional relay when the third relay is energized and said interlocking wafers are de-energized, the cam operated switch being operable to de-energize the third relay during the periods in which an ion signal is received at the anticipator electrode.

13. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successive focusing ions of differing mass-to-charge ratio on the collector electrode, and a variable range recording potentiometer including a recording pen, and a variable voltage source connected across and adapted to determine the sensitivity range of the potentiometer, an automatic range selecting circuit comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, an anticipator amplifier network including a servomotor and adapted to develop an output shaft rotation proportional to the current developed at the anticipator electrode, a first cam operated micro-switch and a multicontact selector switch connected to be actuated by rotation of said shaft, a unidirectional stepping relay comprising a stepping wafer, a reset wafer, a homing wafer and an interlocking wafer, means connecting the stepping wafer to the selector switch and means including a voltage source operable to step the stepping relay responsive to energization of each successive contact of the selector switch, a bi-directional stepping relay comprising an upscale drive wafer, a downscale drive wafer and an interlocking wafer, the homing wafer of the unidirectional relay being interconnected with the driving wafers of the bi-directional relay so that the latter homes to the maximum position of the unidirectional relay after each reset thereof, and the interlock wafers of each relay being interconnected, a third relay connected between the interlocking wafers and the reset wafer to reset the unidirectional relay when the third relay is energized and the interlocking wafers are de-energized, the first cam operated switch being operable to de-energize the third relay during the periods in which an ion signal is received at the anticipator electrode, and a second cam operated switch connected between the source of power and the homing wafer of the unidirectional relay and operable responsive to movement of the recording pen to break driving connection between the unidirectional and bi-directional relays during the period when the pen is recording a signal received at the collector electrode.

14. In a mass spectrometer having a source of ions, means for segregating the ions in accordance with their mass-to-charge ratio, a collector electrode, means for successively focusing ions of differing mass-to-charge ratio on the collector electrode, and a variable range recording potentiometer including a recording pen, and a variable voltage source connected across and adapted to determine the sensitivity range of the potentiometer, an automatic range selecting circuit comprising an anticipator electrode positioned to receive ions in advance of the collector electrode, an anticipator amplifier network including a servomotor and adapted to develop an output shaft rotation proportional to the current developed at the anticipator electrode, a first cam operated micro-switch and a multicontact selector switch connected to be actuated by rotation of said shaft, a unidirectional stepping relay comprising a stepping wafer, a reset wafer, a homing wafer and an interlocking wafer, means connecting the stepping wafer to the selector switch and means including a voltage source operable to step the stepping relay responsive to energization of each successive contact of the selector switch, a by-directional stepping relay comprising an upscale drive wafer, a downscale drive wafer and an interlocking wafer, the homing wafer of the unidirectional relay being interconnected with the driving wafers of the bi-directional relay so that the latter homes to the maximum position of the unidirectional relay after each reset thereof, and the interlock wafers of each relay being interconnected, a third relay connected between the interlocking wafers and the reset wafer to reset the unidirectional relay when the third relay is energized and the interlocking wafers are de-energized, the first cam operated switch being operable to de-energize the third relay during the periods in which an ion signal is received at the anticipator electrode, a second cam operated switch connected between the source of power and the homing wafer of the unidirectional relay and operable responsive to movement of the recording pen to break driving connection between the unidirectional and bi-directional relays during the period when the pen is recording a signal received at the collector electrode, and a coding circuit actuated responsive to upscale movement of the pen to indicate on the record the sensitivity range setting of the recording potentiometer.

15. Apparatus according to claim 14 wherein the coding circuit comprises a plurality of cam operated switches, a like number of cams mounted to operate the switches responsive to movement of the recording pen, a source of power, an auxiliary recording pen and means interconnecting the auxiliary pen with the source of power and the cam operated switches so that a different trace is produced for each sensitivity range selected by the bi-directional relay.

16. Apparatus according to claim 14 wherein the coding circuit comprises a plurality of cams mounted on a common shaft rotatable through a slip clutch responsive to movement of the recording medium, a latch mechanism operable responsive to movement of the recording pen to permit one revolution of the common shaft for each upswing of the recording pen, a separate cam operated switch in operative engagement with each of the cams, the cams being arranged to engage and close the switches in time delayed sequence and once for each complete revolution of the shaft, a plurality of selector switches mechanically connected to the bi-directional relay, an auxiliary recording pen driving means, a source of power, and means interconnecting the several switches, the auxiliary pen driving means and the source of power so that a different trace is recorded on the recording medium by the auxiliary recording pen for each sensitivity range setting of the recording potentiometer.

17. A selector switch comprising a rotatable contact arm, a plurality of radially disposed and

angularly spaced contacts adapted to be contacted upon rotation of the contact arm, each contact comprising a pivotally mounted body, and means for adjusting the angular placement of the body with respect to the contact arm.

18. A selector switch comprising a first rotatable contact arm, a second rotatable contact arm shorter than the first arm and in electrical connection with the first arm, a conductive ring mounted to be contacted by the second arm, a plurality of radially disposed and angularly spaced contacts adapted to be contacted upon rotation of the first arm, each contact comprising a body pivotally mounted to the base, and means for adjusting the angular placement of the body with respect to the base.

19. A selector switch comprising a base, a first contact arm rotatably mounted to sweep over the face of the base, a second contact arm rotatably mounted to sweep over the face of the base, a conductive ring mounted on the face of the base in the path of the second arm, a plurality of radially disposed and angularly spaced contacts adapted to be contacted by and upon rotation of the first arm, each contact comprising a body pivotally mounted to the base, and means for adjusting the angular placement of the body with respect to the base.

20. A selector switch comprising a base, a first contact arm rotatably mounted to sweep over the face of the base, a second contact arm rotatably mounted to sweep over the face of the base, a conductive ring mounted on the face of the base in the path of the second arm and adapted to be connected to a voltage source, a plurality of radially disposed contacts spaced angularly from each other at irregular intervals and adapted to be contacted by and upon rotation of the first arm, each contact comprising a body pivotally mounted to the base, and means for pivoting the body about the point of mounting to adjust the angular placement of the body with respect to the base.

21. A selector switch comprising a base, a first contact arm rotatably mounted to sweep over the face of the base; a second contact arm rotatably mounted to sweep over the face of the base beneath the first arm and about the same axis, the second arm being shorter than the first arm and in electrical connection with the first arm, a conductive ring mounted on the base in the path of the second arm and adapted to be connected to a voltage source, a plurality of radially disposed and angularly spaced contact members, each contact member comprising a body having a soldering lug at one end and a contact post at the other disposed in the path of rotation of said first contact arm, the body being pivotally affixed adjacent one end to the base, and a pin journalled in the body and having an eccentric lug journalled in the base so that rotation of the pin produces angular displacement of the body about the pivot, and means for releasably fixing the angular placement of the body with respect to the base.

22. A voltage sensitive circuit for controlling the operation of an interconnected system responsive to the magnitude of an electrical signal, comprising an amplifier including an electromechanical transducer adapted to develop displacement of the mechanical element of the transducer responsive to and in proportion to the magnitude of an electrical signal applied to the amplifier, a selector switch having a movable contact operable responsive to displacement of the mechanical element and a plurality of fixed contacts, a source of power connected to the movable contact, a first stepping relay, means connecting the fixed contacts to the first stepping relay and for stepping the relay responsive to current flow from the switch to the relay, and a second stepping relay homed with the first stepping relay to step in response to the setting of the first stepping relay, the second stepping relay being adapted to be mechanically coupled to said interconnected system for varying the operation thereof in response to the setting of the second stepping relay.

23. A voltage sensitive circuit for controlling the operation of an interconnected system responsive to the magnitude of an electrical signal, comprising an amplifier including an electromechanical transducer adapted to develop displacement of the mechanical element of the transducer responsive to and in proportion to the magnitude of an electrical signal applied to the amplifier, a selector switch having a movable contact operable responsive to displacement of the mechanical element and a plurality of fixed contacts, a source of power connected to the movable contact, a unidirectional stepping relay, means connecting the fixed contacts to the unidirectional stepping relay and for stepping the relay as each of the contacts are contacted by the movable contact, a bi-directional stepping relay homed with the first stepping relay to step in response to the upscale setting of the first stepping relay, the second stepping relay being adapted to be mechanically coupled to said interconnected system for varying the operation thereof in response to the setting of the second stepping relay, and means for resetting the unidirectional relay without altering the setting of the bi-directional relay.

24. A voltage sensitive circuit for controlling the operation of an interconnected system responsive to the magnitude of an electrical signal, comprising an amplifier including an electromechanical transducer adapted to develop displacement of the mechanical element of the transducer responsive to and in proportion to the magnitude of a voltage signal applied to the amplifier, a micro-switch and a selector switch operable responsive to displacement of the mechanical element, a unidirectional relay, a source of power connectable through the contacts of the selector switch to the unidirectional stepping relay whereby the relay is stepped as a circuit is completed through each of the contacts, a bi-directional stepping relay homed with the unidirectional stepping relay to step in response to the maximum setting of the unidirectional stepping relay for each voltage signal received, the second stepping relay being adapted to be mechanically coupled to said interconnected system, and means operable to reset the unidirectional relay when the micro-switch is closed.

25. In a circuit for the measurment of small currents and the conversion of such currents to a corresponding displacement of a mechanical element, the combination comprising a D. C. amplifier with a relatively high input impedance and low output impedance, a converter for converting the output of the D. C. amplifier to an A. C. variation thereof, an A. C. amplifier for amplifying the output of the converter, a motor connected to be actuated by that part of the output of the A. C. amplifier which is in phase with the converter, a non-linear slidewire potentiom-

eter, a fixed source of voltage connected across the potentiometer, a first feed-back loop connecting the slider of the potentiometer to the D. C. amplifier to produce a null system, a second feed-back loop in the A. C. amplifier to vary the gain of the A. C. amplifier and including a potentiometer, and means connecting the sliders of the several potentiometers to be adjusted by the motor.

26. In a circuit for the measurement of small currents and the conversion of such currents to a corresponding displacement of a mechanical element, the combination comprising a D. C. amplifier with a relatively high input impedance and low output impedance, a converter for converting the output of the D. C. amplifier to an A. C. variation thereof, an A. C. amplifier for amplifying the output of the converter, a motor connected to be actuated by that part of the output of the A. C. amplifier which is in phase with the converter, first and second slidewire potentiometers, a fixed source of voltage connected across the first potentiometer, the second potentiometer being connected between the slider of the first potentiometer and one side of the source of voltage, a first feed-back loop connecting the slider of the second potentiometer to the D. C. amplifier to produce a null system, a second feed-back loop connecting the slider of the potentiometer to the input of the A. C. amplifier, a third feed-back loop in the A. C. amplifier to vary the gain thereof and including a third potentiometer, and means connecting the sliders of the several potentiometers to be adjusted by the motor.

27. In a circuit for the measurement of small currents and the conversion of such currents to a corresponding displacement of a mechanical element, the combination comprising a D. C. amplifier with a relatively high input impedance and low output impedance, a converter for converting the output of the D. C. amplifier to an A. C. variation thereof, an A. C. amplifier for amplifying the output of the converter, a motor connected to be actuated by that part of the output of the A. C. amplifier which is in phase with the converter, a source of voltage, a non-linear potentiometer circuit connected across the source of voltage, and a feed-back loop connecting the output of the non-linear potentiometer circuit to the D. C. amplifier to produce a null system.

28. A coding circuit for use with a variable range recording amplifier which comprises a plurality of cam operated switches, a like number of cams mounted to operate said switches responsive to the movement of the recording pen of the variable range recording amplifier, a source of power, a plurality of selector switches connected to be set in accordance with the range setting of the recording amplifier, an auxiliary recording pen and drive means therefor, and means interconnecting the auxiliary pen drive means with the source of power, cam operated switches, and selector switches so that a different impulse sequence is delivered to the auxiliary pen drive means for each sensitivity range setting of the recording amplifier.

29. A voltage sensitive circuit for controlling the operation of an interconnected system responsive to the magnitude of an electrical signal, comprising a stepping relay circuit, means connected to the stepping relay circuit to energize and set the latter in proportion to the electrical signal, means operable responsive to the setting of the stepping relay circuit for controlling the operation of the interconnected system as a function of the setting of the stepping relay, and means operable to reset the stepping relay circuit between the successive electrical signals.

30. A voltage sensitive circuit for controlling the operation of an interconnected system responsive to the magnitude of an electrical signal, comprising a stepping relay circuit, an anticipator amplifier circuit including means for developing a mechanical motion responsive to the magnitude of the electrical signal, means connected between the amplifier circuit and the stepping relay circuit to energize and step the latter in proportion to the magnitude of said mechanical motion, means operable responsive to the setting of the stepping relay circuit for controlling the operation of the interconnected circuit as a junction of the setting of the stepping relay circuit, and means operable to reset the stepping relay circuit between successive electrical signals.

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No references cited.