

Dec. 17, 1935.

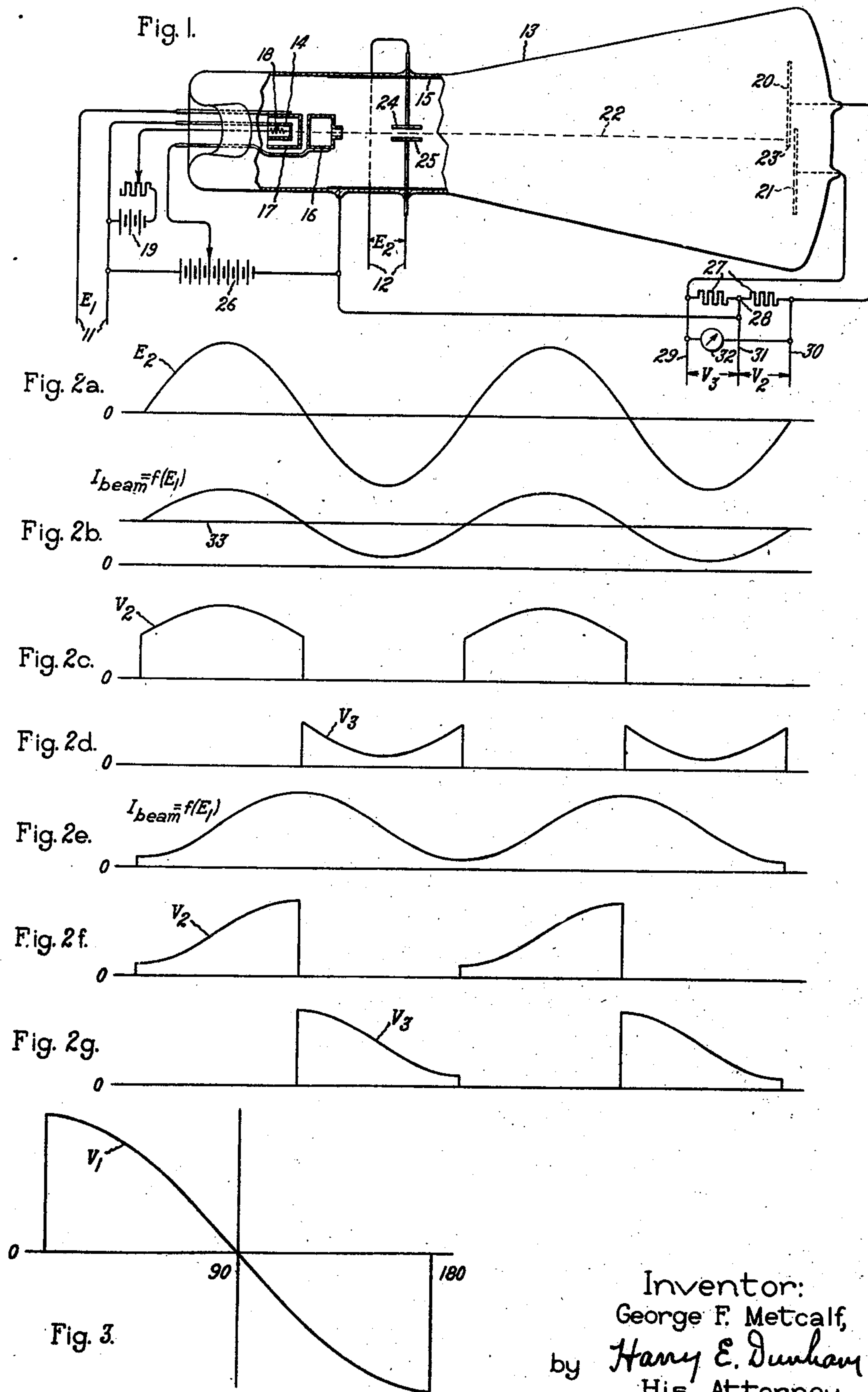
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2,024,979

CATHODE RAY APPARATUS

Filed March 23, 1934

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 4.

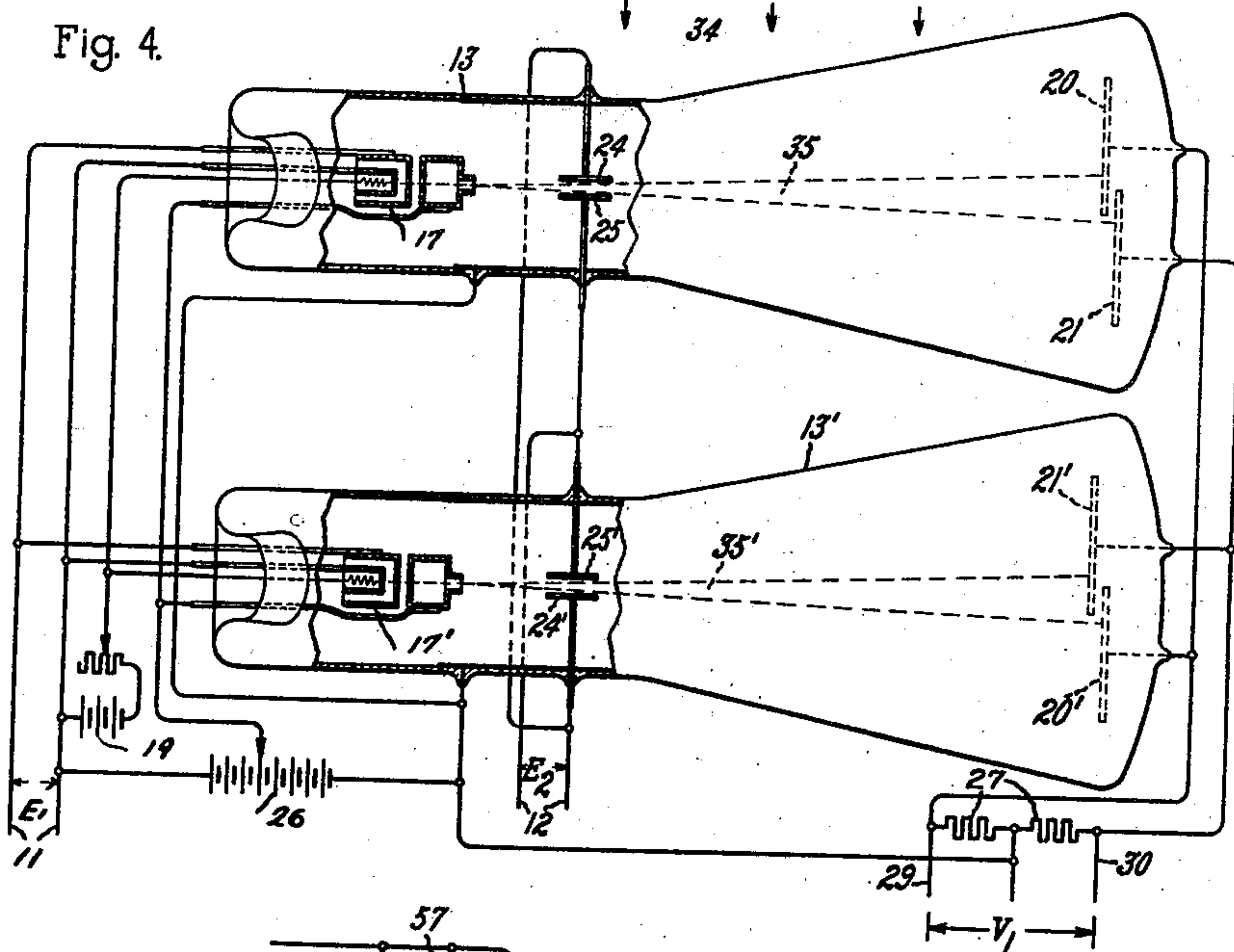


Fig. 7.

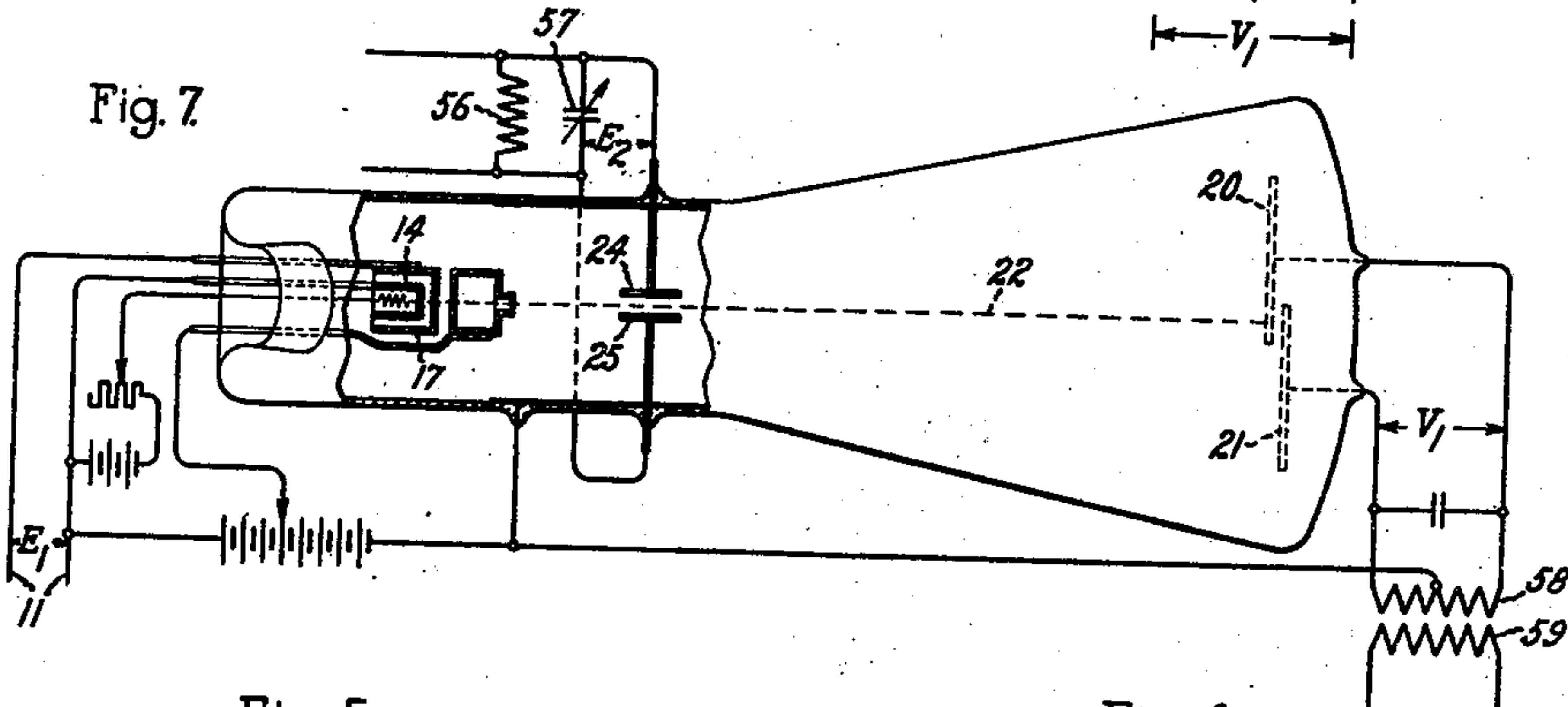


Fig. 5.

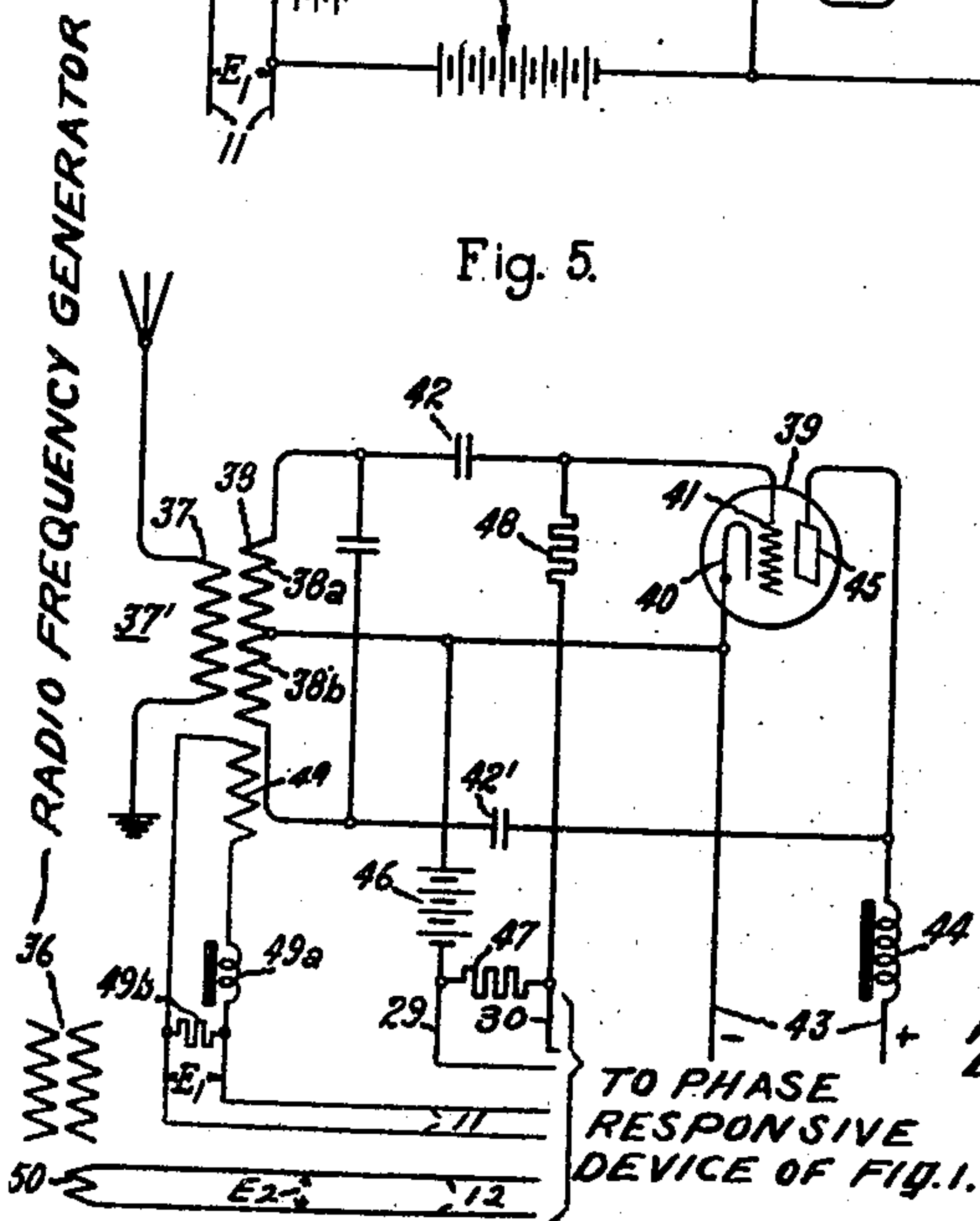
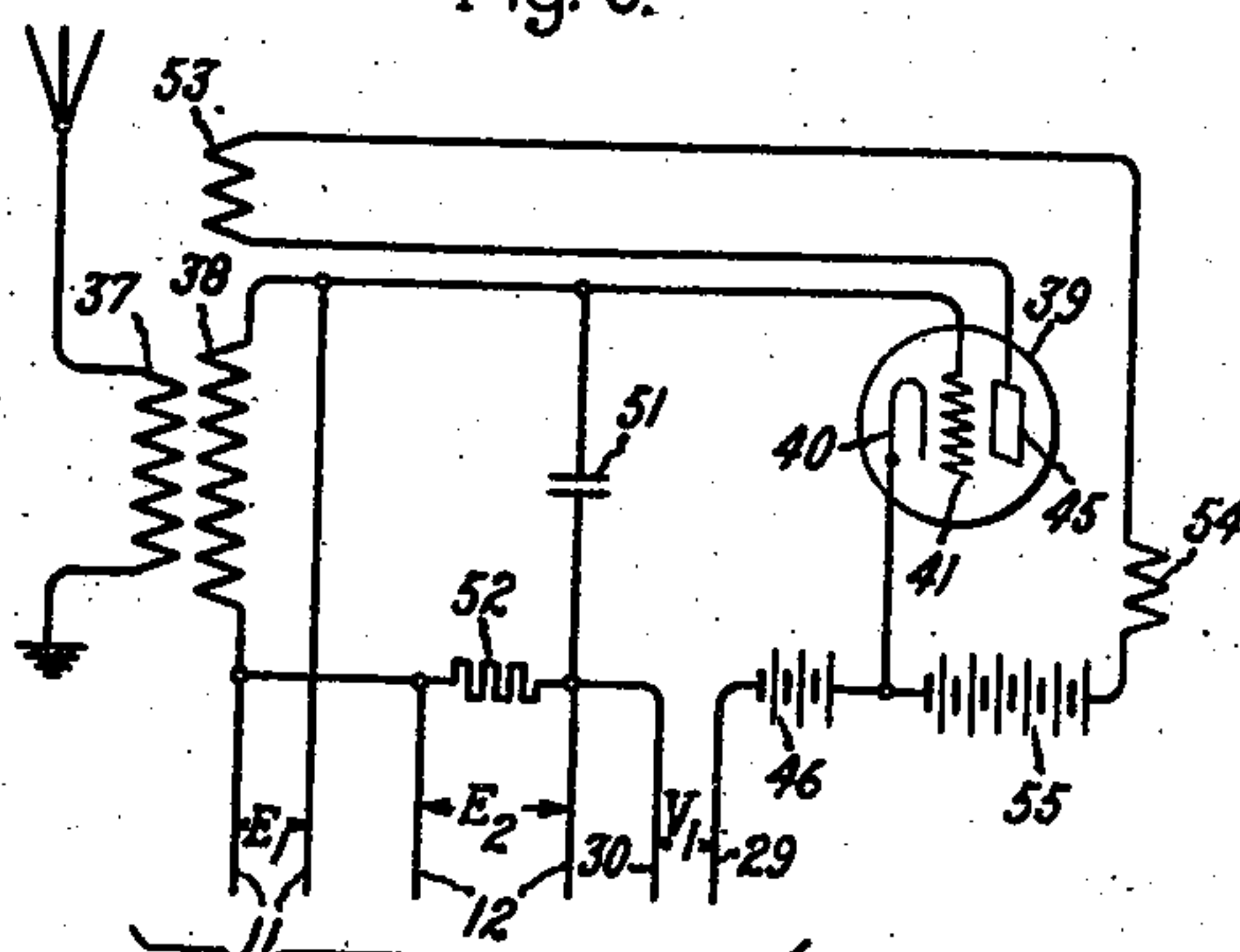


Fig. 6.



TO PHASE RESPONSIVE DEVICE OF FIG. 1.

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UNITED STATES PATENT OFFICE

2,024,979

CATHODE RAY APPARATUS

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New York

Application March 23, 1934, Serial No. 717,045

7 Claims. (Cl. 250—27)

My invention relates to electric beam apparatus and concerns particularly phase angle and power factor responsive apparatus, methods of measuring phase angle, and methods of controlling electrical apparatus in response to variations in phase angle in which electric beam or cathode ray devices are employed.

It is an object of my invention to provide an improved device and method for measuring phase angles and power factors at high frequencies.

Other objects of my invention are the provision of arrangements for controlling high frequency apparatus in response to variations in phase angle.

One of the objects of my invention is also the provision of an arrangement of electric beam apparatus in which the effects of stray fields upon the electrified beams are overcome.

Another object of my invention is to provide an arrangement for synchronizing two radio frequency waves even though the principal wave may be varying in frequency.

Still another object is to provide an arrangement for controlling the amount of regeneration of a regenerative amplifier in order to obtain the maximum regeneration without producing oscillation.

A further object of my invention is the employment of electric beam devices in connection with amplifying apparatus of the superheterodyne type.

Other and further objects and advantages of my invention will become apparent as the description proceeds.

In carrying out my invention in its preferred form, I employ an arrangement for producing a stream of electrified particles and means for deflecting the stream in response to variations in voltage. Preferably, the electrified stream is produced in an exhausted envelope containing an anode and containing a cathode from which the electrified particles issue. The apparatus is arranged so that the intensity of the electrified stream varies in response to one of two voltages, the phase angle between which must be determined, and the stream is deflected in response to the other of the two voltages. A pair of collecting plates is provided to intercept the stream of electrical particles on either side of their mean path so that variations in phase relationship between the two control voltages produce variations in the amount of charge collected by the plates, and consequently, variations in the potential difference between the two plates.

The potential difference produced between the

two plates is utilized to energize an indicating device in the case of phase-angle measurements, or to control the desired apparatus where apparatus is to be operated or regulated in response to variations in the phase angles.

The features of my invention which I believe to be novel and patentable will be pointed out in the claims appended hereto. A better understanding of my invention, itself, may be obtained by referring to the following description taken in connection with the accompanying drawings in which Fig. 1 is a circuit diagram of a phase-angle responsive device arranged in accordance with my invention and in which an electronic beam apparatus is represented partially in section; Fig. 2, parts *a* to *g*, inclusive, are curves representing graphically the operation of the apparatus illustrated in Fig. 1; Fig. 3 is another curve representing a relationship between phase angle and voltage output of the apparatus illustrated in Fig. 1; Fig. 4 represents a modification of the apparatus of Fig. 1 arranged to minimize the effect of stray or external fields on the operation of the apparatus; Fig. 5 is a circuit diagram of an electrical apparatus in which two radio frequency waves are maintained in synchronism; Fig. 6 is a circuit diagram of a regenerative amplifier in which the degree of regeneration is controlled in accordance with my invention; and Fig. 7 is a circuit diagram of a superheterodyne amplifier including a schematic representation of an electronic beam device for producing amplification in accordance with my invention.

Referring now more in detail to the drawings in which like reference characters designate like parts throughout, in Fig. 1, I have represented a type of apparatus illustrating a simple form of my invention. In this form of my invention, the apparatus is employed for measuring the phase angle between two voltages E_1 and E_2 applied at the terminals 11 and 12, respectively. The apparatus includes means for producing a stream of electrified particles, the intensity of which varies in response to variations in the magnitude of the voltage E_1 , means for deflecting the stream of electrified particles in response to variations in the magnitude of the voltage E_2 , and means for determining the average intensity of the electric stream on either side of its mean path.

The apparatus may take the form of an envelope 13 containing a cathode 14 and an anode 15, here shown as consisting of a metallic band deposited on the inner surface of the envelope 13. Preferably, a focusing element 16 is also

employed, as well as a grid or beam intensity controlling element 17. The envelope 13 is sufficiently exhausted to permit the emission of electrified particles from the cathode 14.

I have found that satisfactory results may be obtained by arranging the apparatus in accordance with the construction of the type of apparatus known as a cathode ray tube and I prefer to utilize a stream of electrified particles, known as "cathode rays", which are generally understood to be a stream of electrons, but my invention is not limited to this particular type of apparatus.

In the form of apparatus illustrated, I have shown the heating filament 18 energized by a source of current 19 for the purpose of facilitating the emission of electrons from cathode 14. The apparatus includes, in addition to the just mentioned elements of an ordinary cathode ray tube, a pair of collecting plates 20 and 21. These are mounted, preferably, in the end of the envelope 13 away from the cathode 14 on either side of the mean path of the electronic stream issuing from the cathode 14 through the focusing element 16. In the type of apparatus illustrated, the axis 22 of the mean electron path is normally approximately along the longitudinal axis of the envelope 13.

The plates 20 and 21 may be arranged with a slight gap between them in a transverse direction intersected by the axis 22 of the mean path of the electronic stream but, preferably, the plates 20 and 21 are mounted as shown slightly overlapping with their adjacent ends spaced in a longitudinal direction to avoid electrical contact between the plates. In this manner any given ray or portion of the electronic beam must fall upon either plate 20 or plate 21 and the electronic beam can have no position at which it, or a portion of it, passes between the collecting plates instead of impinging upon at least one of them as would be the case if the collecting plates 20 and 21 were placed in the same plane and spaced apart transversely. One obtains therefore the effect of infinitesimal transverse spacing along the lower edge 23 of plate 20. Any desired means for deflecting the electronic stream may be employed, such as electromagnetic deflecting coils or electrostatic deflecting plates, for example, but, for the sake of illustration, I have shown a pair of deflecting plates 24 and 25 connected to the terminals 12 through suitable leads.

In order to cause the electrons emitted by the cathode 14 to be projected longitudinally through the envelope 13, a source of current 26 is provided for producing the requisite potential difference between the anode 15 and the cathode 14. The focusing element 16 is connected to a point at intermediate potential in the current source 26 in a manner well understood by those skilled in the art. The collecting plates 20 and 21 may, if desired, be joined by a resistor 27 having its midpoint 28 connected to the anode 15 to permit charges accumulated by plates 20 and 21 to leak off. The plates 20 and 21 are connected to the terminals 29 and 30, which serve as the output terminals of the device, and the midpoint 28 of resistor 27 may also, if desired, be connected to an output terminal 31. A suitable voltage-responsive device 32, preferably one drawing little or no current in order to avoid disturbing the potentials of the plates 20 and 21, is connected between the output terminals 29 and 30.

Although the apparatus may be arranged to operate with the electric beam or stream of electrical particles, either in the form of a narrow

shaft or a flat sheet deflectable in its direction of thickness, obviously greater output may be obtained by arranging the apparatus to emit a flat sheet of electrical particles. Since the drawings represent partial sections cut by planes parallel to the direction of deflection, the flat sheet beam 22 is seen from the edge and appears in the drawings, the same as a round shaft or pencil shaped beam would appear.

The operation of the apparatus in Fig. 1 may be better understood from a consideration of the curves shown in Fig. 2. Fig. 2a represents the variations in the instantaneous values of the voltage E_2 , the horizontal line designated by the symbol "O" being the neutral axis. Vertical distances from the neutral axis O represent the instantaneous values of the voltage E_2 and the horizontal distances along the axis O represent the duration of time. Fig. 2b represents the variations in intensity of the current beam designated by the symbol " $I_{\text{beam}} = f(E_1)$ " produced by variations in the voltage E_1 when the voltages E_1 and E_2 are in the same phase relationship, I_{beam} being a function of E_1 . In Fig. 2b, the horizontal line 33 represents the average value of the beam current and the horizontal line O represents zero values of beam current. It will be seen that the beam current does not reverse in direction but merely fluctuates in amplitude. The variations in amplitude are produced by the variations in voltage between the grid 17 and the cathode 14 designated by the symbol E_1 .

The apparatus may either be so arranged that a relatively fine electronic beam is produced and the beam impinges upon either plate 20 or plate 21, or it may be arranged in such a manner that a relatively broad beam is produced which impinges partly on plate 20 and partly on plate 21. The operation will first be explained when the construction is such as to produce the former condition.

The apparatus may also either be arranged in such a manner that the plates 20 and 21 accumulate the charges deposited thereon by the electric beam 22 so that the potentials of the plates 20 and 21 are dependent upon the time integrals of the beam currents falling on either plate, or the apparatus may be so arranged that the charges leak off substantially as quickly as deposited. In the former case, the resistor 27 would be omitted or made of very high resistance to permit charges to leak off slowly after a reading; in the latter case, a somewhat lower value of resistance would be employed. In either case, the potential difference between plates 20 and 21 will depend upon the phase variations in beam intensity and deflection as will now be explained. The symbols " V_2 " and " V_3 " refer to the potentials of the plates 20 and 21, respectively, with respect to the anode 15.

If the plates 20 and 21 are connected as shown through the two halves of a resistor 27 to the anode 15, the beam current will flow back to the anode 15 through the resistor 27 so that the voltage drops V_2 (Fig. 2c) and V_3 (Fig. 2d) will be proportional to the beam currents during the periods when the beam 22 is intercepted by the plates 20 and 21, respectively. When the voltage E_2 is positive, the beam 22 will obviously be deflected in one direction, which will be assumed to be upward so that the beam 22 will be intercepted by the plate 20 and, when the voltage E_2 is negative, the beam 22 will be deflected in the opposite direction so as to be intercepted by the plate 21. Accordingly, the voltage V_2 will follow approxi-

imately in wave shape the curve of 2b during the positive half cycle of E_2 and drop to zero during the negative half cycle of E_2 as shown in curve 2c. Similarly, the voltage V_3 will follow the shape of curve 2b during the negative half cycle of voltage E_2 and drop to zero during the positive half cycle as indicated in Fig. 2d.

When the voltages E_1 and E_2 are in quadrature with E_1 lagging, variations in beam current will lag 90 degrees behind those shown in Fig. 2b and will follow the curves shown in Fig. 2e. The voltages V_2 and V_3 likewise will follow the portions of the curve 2e occurring during the positive and negative half cycles, respectively, of the voltage E_2 so as to follow the curves shown in Figs. 2f and 2g. It will be apparent from inspection of the figures that, when the voltages E_1 and E_2 are in phase, the average value of V_2 is greater than the average value of V_3 but, as the voltages get out of phase, the difference between V_2 and V_3 will gradually fall until the average values of V_2 and V_3 are equal at 90 degrees phase shift, as shown in Figures 2f and 2g. The difference between the average values of voltages V_2 and V_3 may be designated by the symbol " V_1 " which is also the difference in voltage between plate 20 and plate 21.

In a similar manner, if the apparatus is arranged to accumulate electric charges on plates 20 and 21, the voltages V_2 and V_3 will depend upon the integrated beam currents and will be proportional to the areas under the curves of Figs. 2c and 2d or Figs. 2f and 2g, respectively. Consequently, whether resistor 27 has extremely high resistance or relatively low resistance, the potential difference V_1 between plates 20 and 21 will depend upon the phase relationships between E_1 and E_2 .

Fig. 3 represents the variations in values of V_1 with variations in phase relationship between E_1 and E_2 . It will be seen that V_1 is a maximum when E_1 and E_2 are in phase and falls to zero when E_1 and E_2 are in quadrature, and reverses and increases to a negative maximum when E_1 and E_2 become 180 degrees out of phase. The voltage-responsive device 32, consequently, may be calibrated so as to read directly the phase angle between voltages E_1 and E_2 for any given average value of E_1 . Owing to the fact that the curve V_1 has a relatively large slope near the value 90 degrees, my apparatus forms a particularly sensitive instrument for the measurement of phase angles near 90 degrees or quadrature.

The explanation of the operation which has just been given has been primarily with reference to a construction of the electronic beam device producing a relatively fine electronic beam, but, in general, the operation will be similar when the arrangement is such that a relatively broad beam is produced. The operation with the relatively broad beam will be referred to more in detail in connection with the description of the balanced arrangement of Fig. 4 in which are illustrated electron beam devices 13 and 13', each arranged to produce a relatively broad beam 35 or 35'.

Since the cathode ray device has been found to respond very rapidly to variations in voltage, this device may be used for measuring phase angles of very high frequency waves, such as those encountered in radio frequency apparatus. Obviously, the apparatus may serve also as a power factor meter if one of the voltages E_1 or E_2 is made proportional to the current variations in a circuit in which the power factor is to be measured. This may be done, if desired, in a manner

similar to that described hereinafter in connection with Fig. 6.

In some cases, it may be desirable to guard the apparatus against the effects of external magnetic or electrostatic fields. This may be done, if desired, by employing the balanced arrangement disclosed in Fig. 4. An external electrostatic field in the direction of the arrows 34, shown in Fig. 4, or an electromagnetic field perpendicular thereto would tend to deflect the beam 22 of Fig. 1 in addition to the deflection produced by the voltage E_2 so that, where a stray field of great strength is present, accuracy of the readings might be impaired. The effect of the deflection produced by an external or stray field may be compensated for by employing two balanced electronic beam devices 13 and 13'. The two devices are arranged symmetrically, that is, the corresponding deflection plates 24 and 24' connected to one of the terminals 12 are located on the sides of the tubes 13 and 13' away from each other, and the other two corresponding deflection plates 25 and 25' connected to the other of the terminals 12 are located toward each other. In a similar manner, the corresponding collecting plates 20 and 20' are away from each other and the corresponding collecting plates 21 and 21' are toward each other.

The arrangement illustrated in Fig. 4 is primarily of value where the apparatus is adjusted to produce wide beams 35 and 35'. If it be assumed that the direction of the stray field 34 is such as to deflect both beams 35 and 35' downward, then the amount of electric charge deposited by the beams 35 and 35' upon collecting plates 20 and 21' will be decreased, whereas the amount of charge deposited upon plates 21 and 20' will be increased. Since, however, plates 20 and 20' are electrically connected and plates 21 and 21' are also electrically connected, the total amount of charge deposited upon plates 20 and 20' and likewise upon plates 21 and 21' or the total currents to terminals 29 or 30 will remain unchanged so that the potential difference between terminals 29 and 30 and the magnitude of the voltage V_1 will be substantially unaffected by the stray field 34.

The operation of each of the tubes illustrated in Fig. 4, adjusted to produce wide beams, is substantially the same as that of the tube in Fig. 1, adjusted to produce a very narrow beam. Although reversals in polarity of the voltage E_2 in Fig. 1 will cause the beam 22 to shift entirely from one collecting plate 20 or 21 to the other, a similar operation is obtained with a broad beam which falls upon both collecting plates 20 and 21 and merely changes the relative amounts of charge deposited upon plates 20 and 21 as the beam is deflected. That is, whereas in the former case the entire beam current flows either to one collecting plate or the other depending upon the polarity of the voltage of the deflecting plates 24 and 25, in the latter case, beam current flows to both plates but the net beam current or the excess of beam current flowing to one plate over that flowing to the other still flows to one collecting plate or the other, depending upon the polarity of the deflecting plates. The voltage V_1 , which is the potential difference between parts 29 and 30, depends, of course, on the excess current or the algebraic difference between the currents flowing in the two portions of resistor 27 and not alone upon the absolute current in either portion.

Curves 2c to 2g apply rigorously to the case where beam 22 is very narrow. However, if the

beam is broadened, the shapes of the curves V_2 and V_3 will merely be modified and the ultimate resultant operation will be qualitatively the same, although it may be that a slight modification of the shape of calibration curve (Fig. 3) would take place. The curves V_2 and V_3 will then vary with values of E_2 as well as with values of I_{beam} as previously explained. However, as in the previous case, the difference between V_2 and V_3 will be greatest when the voltages E_1 and E_2 are in phase or 180 degrees out of phase as indicated by curve V_1 in Fig. 3 and the voltages V_2 and V_3 will be equal when the voltages E_1 and E_2 are in quadrature.

My invention is not limited to use as a phase indicator or a simple phase-responsive device but, obviously, includes arrangements in which an operation is controlled in response to variations in phase relationship. For example, in Fig. 5, I have illustrated an arrangement for automatically maintaining two radio frequency waves in synchronism. The windings 36 represent a portion of a radio frequency generator which is to serve as the principal wave source with which a second

generator is to be kept in synchronism. The windings 37 and 38 and the discharge tube 39 with its associated circuitry are connected to the terminals 29 and 30 of Fig. 1. However, my invention is not limited to this precise arrangement.

It will be understood that the resistors 47 of Fig. 5 and 27 of Fig. 1 may, if desired, be replaced by a single resistor connected between the terminals 29 and 30 or, if desired, may also be eliminated entirely. Likewise, if desired, the voltage V_1 may be amplified before its connection to resistor 47. It has been found that the frequency as well as the phase of a radio frequency generator of the discharge tube oscillator type may be varied by varying the grid bias. If the grid is maintained slightly more positive, the wave is accelerated, that is, the phase is advanced somewhat and the frequency tends to increase. Likewise, if the grid is maintained somewhat more negative, the wave is decelerated or the phase is retarded and the frequency tends to decrease. This phenomenon is known as the "frequency pulling" effect and is well known to those skilled in the art.

Thus, by controlling the grid bias of the discharge tube oscillator, the frequency and phase of the wave generated can be varied. In the arrangement of Fig. 5, the voltage V_1 is connected to the grid of the discharge tube oscillator through a variable resistor 47. By varying the resistance of 47, the grid bias can be adjusted, thereby controlling the frequency and phase of the wave generated. This arrangement is useful for automatically maintaining two radio frequency waves in synchronism.

The circuit of Fig. 5 includes a radio frequency generator 36, a discharge tube oscillator 39, and a variable resistor 47. The generator 36 is connected to the terminals 29 and 30, and the oscillator 39 is connected to the same terminals through the resistor 47. The voltage V_1 is connected to the grid of the oscillator 39 through the resistor 47. By varying the resistance of 47, the grid bias can be adjusted, thereby controlling the frequency and phase of the wave generated.

37' are provided and a phase-responsive device is connected thereto to control the frequency-varying means in response to the phase relationship between the two waves E_1 and E_2 . A satisfactory arrangement, for reasons which will be explained hereinafter, is for example, to have the resistor 47 of Fig. 5 connected to the terminals 29 and 30 of Fig. 1. However, my invention is not limited to this precise arrangement.

It will be understood that the resistors 47 of Fig. 5 and 27 of Fig. 1 may, if desired, be replaced by a single resistor connected between the terminals 29 and 30 or, if desired, may also be eliminated entirely. Likewise, if desired, the voltage V_1 may be amplified before its connection to resistor 47. It has been found that the frequency as well as the phase of a radio frequency generator of the discharge tube oscillator type may be varied by varying the grid bias. If the grid is maintained slightly more positive, the wave is accelerated, that is, the phase is advanced somewhat and the frequency tends to increase. Likewise, if the grid is maintained somewhat more negative, the wave is decelerated or the phase is retarded and the frequency tends to decrease. This phenomenon is known as the "frequency pulling" effect and is well known to those skilled in the art.

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circuit in order to produce regeneration. Any desired type of coupling, such as inductive, capacitative, or conductive coupling, known to those skilled in the art, may be employed. Or, as will be understood by those skilled in the art, coupling may also, in certain cases, take place by virtue of the inherent electromagnetic or electrostatic induction between elements of the tube 39 or portions of the conductors forming the circuit. In the form of apparatus here shown by way of illustration, the plate circuit of the discharge tube 39 consists of the anode or plate 45, the feed-back or regenerative coil 53, which is in inductive relation with the secondary winding 38, the translating device 54, and the source of anode potential 55. The translating device 54 may be a pair of headphones of a radio receiving set, the primary winding of a transformer connecting the one stage of a radio receiver to subsequent stages, or any other suitable device as will be understood by those skilled in the art.

In radio frequency circuits of the regenerative type, the amplitude of the response obtained in the tertiary or output circuit supplying the translating device 54 may be increased by increasing the coupling between the grid or the secondary and the plate circuits, in the arrangement illustrated, the coupling between the regenerative winding 53 and the secondary winding 38. If the coupling is increased excessively, however, the circuit may be set in oscillation so that energy is radiated or transmitted by the apparatus through the winding 37 and the apparatus becomes ineffective as a radio receiver since it tends to oscillate at its natural frequency instead of reproducing faithfully the wave form to be received, which is applied to the winding 37. The coupling between the secondary and tertiary circuits may be modified by modifying the mutual inductances between the primary and tertiary windings 38 and 53, or by varying the grid bias, or in any other suitable manner. The method of controlling the degree of coupling by varying the grid bias, has been illustrated and my invention will be described in connection with an embodiment in which it is carried out in this manner.

Maximum regeneration and amplification may be obtained by permitting the power factor of the secondary circuit, that is, of the current flowing in the secondary winding 38, to become a minimum without actually dropping to zero, at which point oscillation ordinarily commences. The power factor of the circuit obviously depends upon the phase relationship between the voltage and current in the winding 38 and the angular relationship between these quantities is referred to as the power factor angle. Accordingly, an apparatus of the type illustrated in Fig. 1 may be utilized for controlling the amount of regeneration of a circuit shown in Fig. 6. The leads 11 of Fig. 1 are connected across the winding 38 and the leads 12 of Fig. 1 are connected across the series impedance 52 in which the voltage drop E_2 obviously varies with the current flowing if the impedance 52 comprises resistance. The impedance 52 may, of course, also be made inductive or capacitative, in which case the leads 12 would be connected thereto through a phase shifting network. Obviously, if desired, leads 11 and 12 may be interchanged in Fig. 6.

As previously explained, when the voltages E_1 and E_2 of Fig. 1 are in quadrature, that is, when the power factor of the secondary circuit of Fig.

6 is zero, the voltage V_1 drops to zero, whereas, as the power factor increases and the current represented by the voltage E_2 lags less than 90 degrees, the voltage V_1 increases. The connections are such that, as the power factor increases indicating that the degree of regeneration is decreasing, the grid potential will be increased by virtue of the increase in magnitude of the voltage V_1 so that the coupling between secondary and tertiary circuits will be increased. The constants of the circuits may be so chosen that any desired coupling will be obtained for a given power factor indication. However, if the coupling tends to become too great so as to approach the point at which the circuit would begin to oscillate, the power factor drops toward zero and the voltage V_1 becomes so small that the coupling is decreased and the circuit is prevented from beginning to oscillate. In this manner, the circuit may be adjusted for maximum regeneration without danger that oscillation will take place.

In the arrangement of Fig. 7, I have illustrated a form of my invention in which the phase-responsive apparatus is used to form a superheterodyne or beat frequency amplifier, that is, an amplifier in which a local oscillator or heterodyne circuit is used in connection with the incoming wave. Preferably, although not necessarily, a broad focus electric beam device of the type illustrated at 13 or 13' in Fig. 4 is employed. In this arrangement, the incoming wave is connected to the terminals 11 and corresponds to E_1 of the arrangements previously described, and the local oscillator is connected across the deflecting plates 24 and 25 corresponding to the voltage E_2 of the arrangements previously described. The local oscillator is schematically represented by means of an inductance 56 and a variable condenser 57. The local oscillator need not be described in detail since such devices are well known in the art in connection with radio circuits known as superheterodyne circuits.

Although I have illustrated the incoming wave as being connected to the terminal 11 and the local oscillator as being connected to the deflecting plates 24 and 25, the reverse arrangement may also be employed, it being essential only that one of the waves be connected to the terminals 11 to modify the intensity of the electronic beam 22 and the other of the waves be connected to deflecting plates 24 and 25 to deflect the beam 22.

In the operation of the apparatus, the local oscillator E_2 will be tuned to a frequency differing slightly from the frequency of the incoming wave E_1 . Consequently, the phase relationship between the variations in intensity of the beam 22 and the transverse deflections of the beam 22 will vary and the potential difference between the deflecting plates 20 and 21 will vary in accordance with the curve V_1 of Fig. 3, which, of course, represents only a half cycle of the variation as previously explained. The frequency of the wave V_1 will depend upon the frequency of the incoming wave E_1 and the frequency of the local oscillator E_2 , and it has been found that this frequency will be a frequency intermediate to that of E_1 and E_2 as in connection with superheterodyne or beat frequency amplifiers of other types.

The output wave V_1 of the amplifier may be connected, if desired, to the primary winding 58 of a transformer, the secondary winding 59 of which forms a part of the circuit of an intermediate stage amplifier of the type well known in

connection with radio frequency circuits. Variations in amplitude of the incoming wave E_1 result in corresponding variations in the amplitude of the voltage V_1 which may, if desired, as already explained, be further amplified by means of an intermediate stage amplifier, but the amplitude of the output wave V_1 will be very much greater than that of the incoming wave E_1 since very small variations in potential between the cathode 14 and the grid 17 may produce comparatively great variations in the intensity of the electronic beam 22, and likewise very small variations in voltage between the deflecting plates 24 and 25 may control the full energy of the beam 22.

I have herein shown and particularly described certain embodiments of my invention and certain methods of operation embraced therein for the purpose of explaining its principle and showing its application, but it will be obvious to those skilled in the art that many modifications and variations are possible and I aim, therefore, to cover all such modifications and variations as fall within the scope of my invention which is defined in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A device responsive to phase angle between two voltages comprising in combination with means delivering two alternating-current voltages having frequencies of substantially the same order of magnitude, an exhausted envelope, means therein for producing a stream of electrical particles, means connected to one of said voltage-delivering means for varying the intensity of said stream in response to one of said voltages, and means connected to the other of said voltage-delivering means for deflecting said stream to either side from a mean path in response to the other of said voltages, a pair of collecting plates intercepting said stream of electrical particles on either side of the axis of said mean path, and means responsive to difference in potential between said collecting plates.
2. A device responsive to phase angle between two voltages comprising in combination with means delivering two alternating-current voltages having frequencies of substantially the same order of magnitude, an exhausted envelope, an anode and a cathode therein, means for maintaining a difference in potential between said anode and cathode to produce an electrical field causing a stream of electrical particles to travel from said cathode through said envelope, a control grid, one of said voltage-delivering means being connected to said cathode and said control grid to vary the intensity of said stream of electrical particles in response to voltage, means connected to the other of said voltage-delivering means for deflecting said stream to either side from a mean path in response to voltage, and a pair of collecting plates intercepting said stream of electrical particles on either side of the axis of said mean path, and means responsive to difference in charges collected by said collecting plates.
3. A device responsive to phase angle between two voltages comprising in combination, a pair of exhausted envelopes, means therein for producing relatively broad streams of electrical particles, means for varying the intensity of said streams in response to one of said voltages, and means for deflecting said streams in opposite directions from their mean paths in response to the

other of said voltages, collecting plates, a pair for each of said envelopes intercepting the stream of electrical particles of said envelope on either side of the axis of its mean path, and means responsive to difference in potential between the collecting plates in either of said envelopes, each collecting plate of one envelope corresponding to and being electrically connected to the collecting plate on the opposite side thereof of the other envelope so that corresponding collecting plates intercept deflected streams of electrical particles simultaneously, and the total charge collected by a pair of connected plates is unvaried by deflection of both beams in a given direction in response to an external field.

4. A phase-regulated amplifier of the regenerative type comprising in combination, an electric valve having an anode, a cathode and a control element, an element for picking up radio frequency waves to be amplified and connected between said cathode and said control element to form therewith a control circuit, a feed-back element and an auxiliary current source connected between said anode and said cathode to form therewith an output circuit coupled to said control circuit by said feed-back element, and a phase-responsive device controlling the coupling between said control and output circuits, said phase-responsive device being responsive to the phase difference between the current and voltage in said control circuit and being arranged to reduce the coupling between said control and output circuits as phase quadrature is approached and to increase the coupling as the phase angle becomes less than ninety degrees.

5. Phase-controlled apparatus for synchronizing two alternating current waves in frequency and phase comprising in combination, a phase-responsive device for producing a voltage dependent in magnitude and sign upon the phase relationship of two alternating voltages applied thereto, voltage-responsive means for accelerating and decelerating one of said alternating waves in response to positive and negative voltages, respectively, the voltages produced by said phase-responsive device being applied to said wave accelerating and decelerating means, and means for applying to said phase-responsive means voltages bearing predetermined phase relationships to said alternating current waves.

6. Phase-controlled apparatus for synchronizing two alternating current waves in frequency and phase comprising in combination, a phase-responsive device for producing a voltage dependent in magnitude and sign upon the departure from quadrature relation of two alternating voltages applied thereto, voltage responsive means for accelerating and decelerating one of said alternating waves in response to positive and negative voltages, respectively, the voltages produced by said phase-responsive device being applied to said wave accelerating and decelerating means, and means for applying to said phase-responsive means voltages respectively in phase with one of said alternating current waves and in quadrature with the other of said alternating current waves.

7. A phase-responsive device comprising in combination, means for producing a local alternating voltage wave of a predetermined frequency, means for receiving an incoming alternating voltage wave to be amplified, an exhausted envelope, means therein for producing a stream of electrical particles, means for varying the intensity

5 of said stream in response to one of said voltage waves, and means for deflecting said stream to either side from a mean path in response to the other of said alternating voltage waves, a pair of collecting plates intercepting said stream of electrical particles on either side of the axis of said mean path, the variations in potential be-

tween said plates thereby having a beat frequency intermediate to the frequencies of said incoming wave and said local wave, and following with greater amplitude variations in intensity of said incoming wave.

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