

Feb. 3, 1948.

H. F. WILDER ET AL

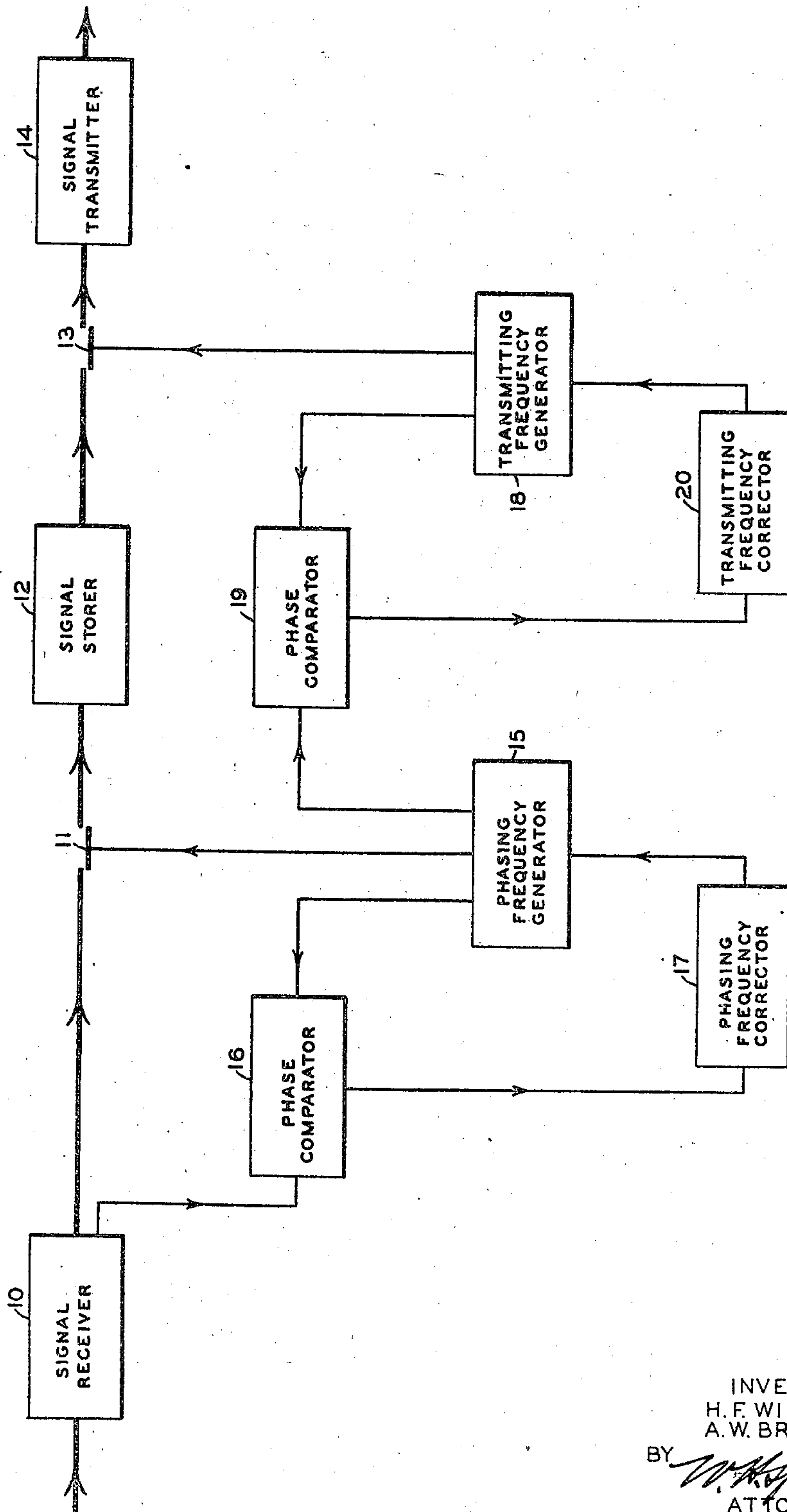
2,435,259

FREQUENCY CONTROL APPARATUS

Original Filed June 14, 1940

6 Sheets-Sheet 1

FIG. 1



INVENTORS
H. F. WILDER
A. W. BREYFOGEL
BY *W. A. Sproule*
ATTORNEY

Feb. 3, 1948.

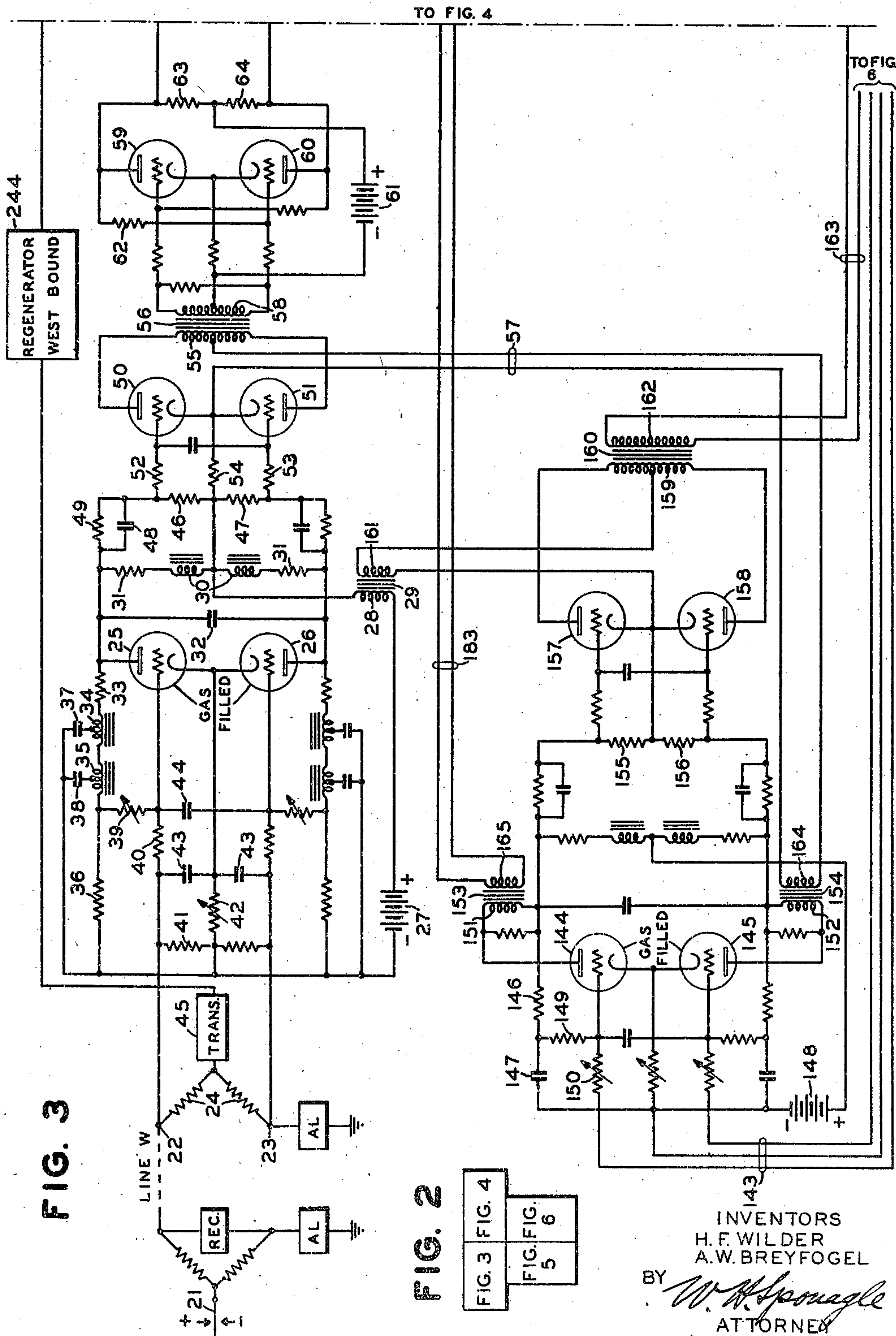
H. F. WILDER ET AL

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H. F. WILDER ET AL

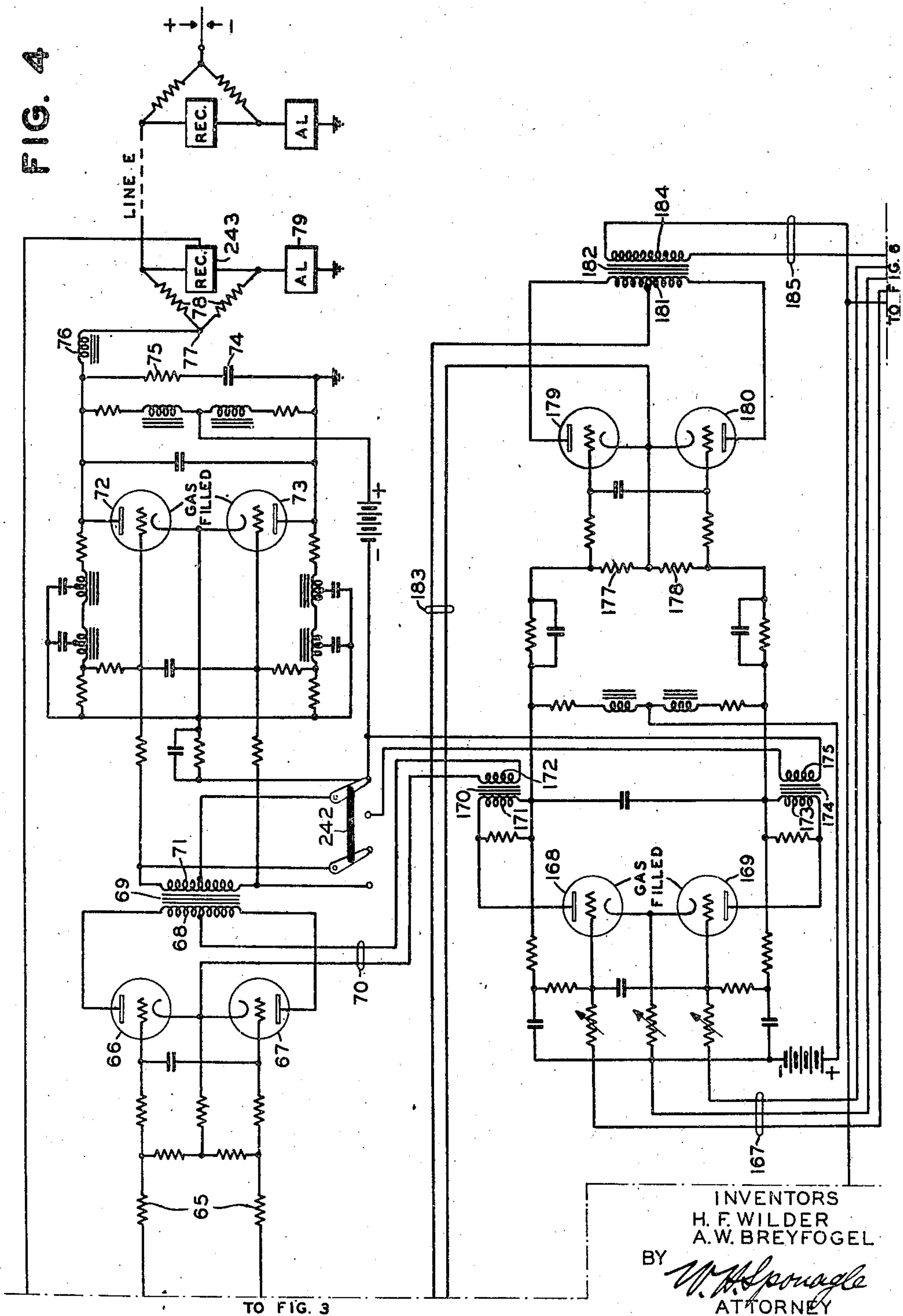
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FREQUENCY CONTROL APPARATUS

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FIG. 4



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TO FIG. 8

INVENTORS
H. F. WILDER
A. W. BREYFOGEL
BY *W. H. Sponagle*
ATTORNEY

Feb. 3, 1948.

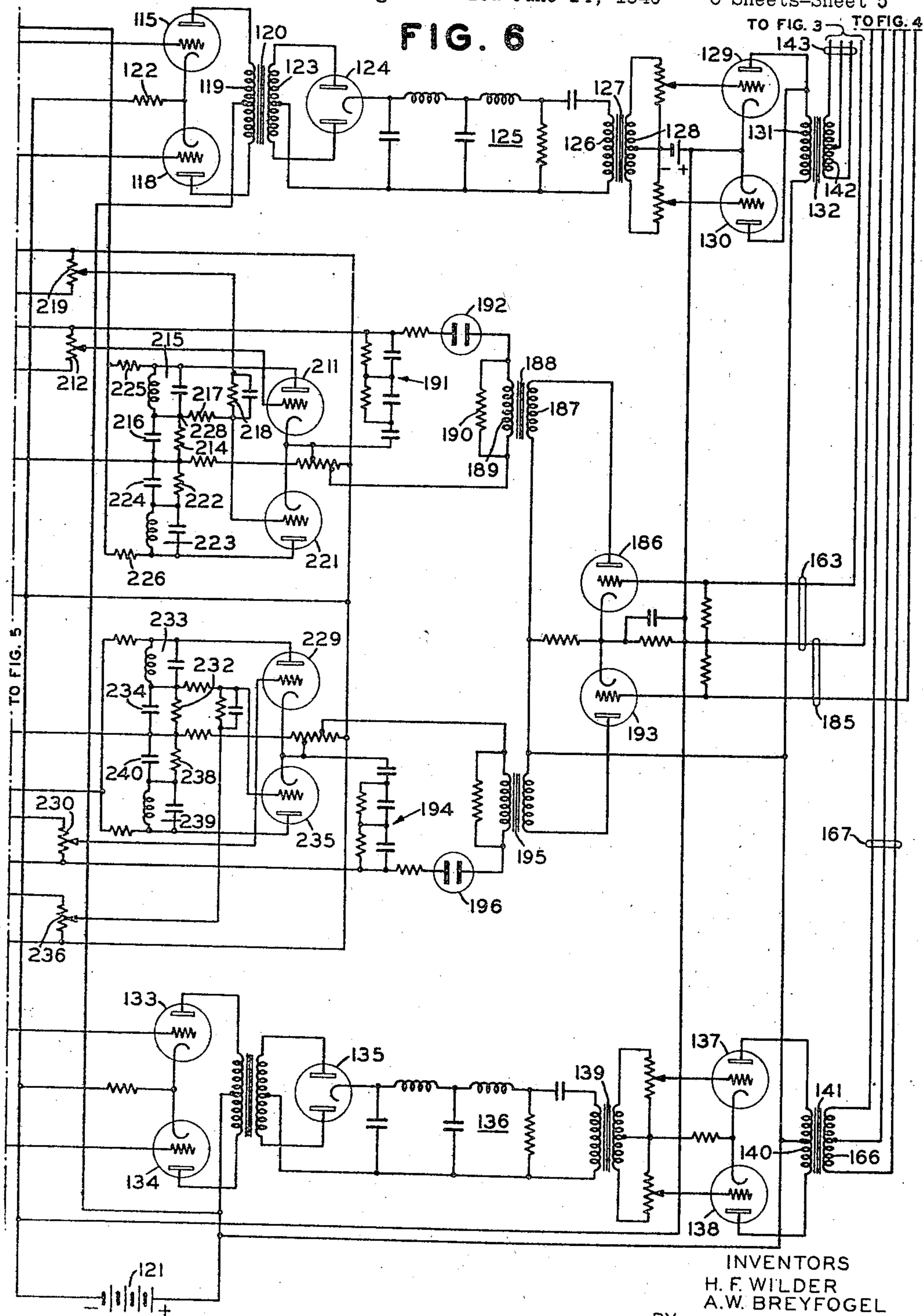
H. F. WILDER ET AL

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FREQUENCY CONTROL APPARATUS

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6 Sheets-Sheet 5



INVENTORS

H. F. WILDER
A. W. BREYFOGEL

BY *W. W. Sponagle*
ATTORNEY

Feb. 3, 1948.

H. F. WILDER ET AL

2,435,259

FREQUENCY CONTROL APPARATUS

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6 Sheets-Sheet 6

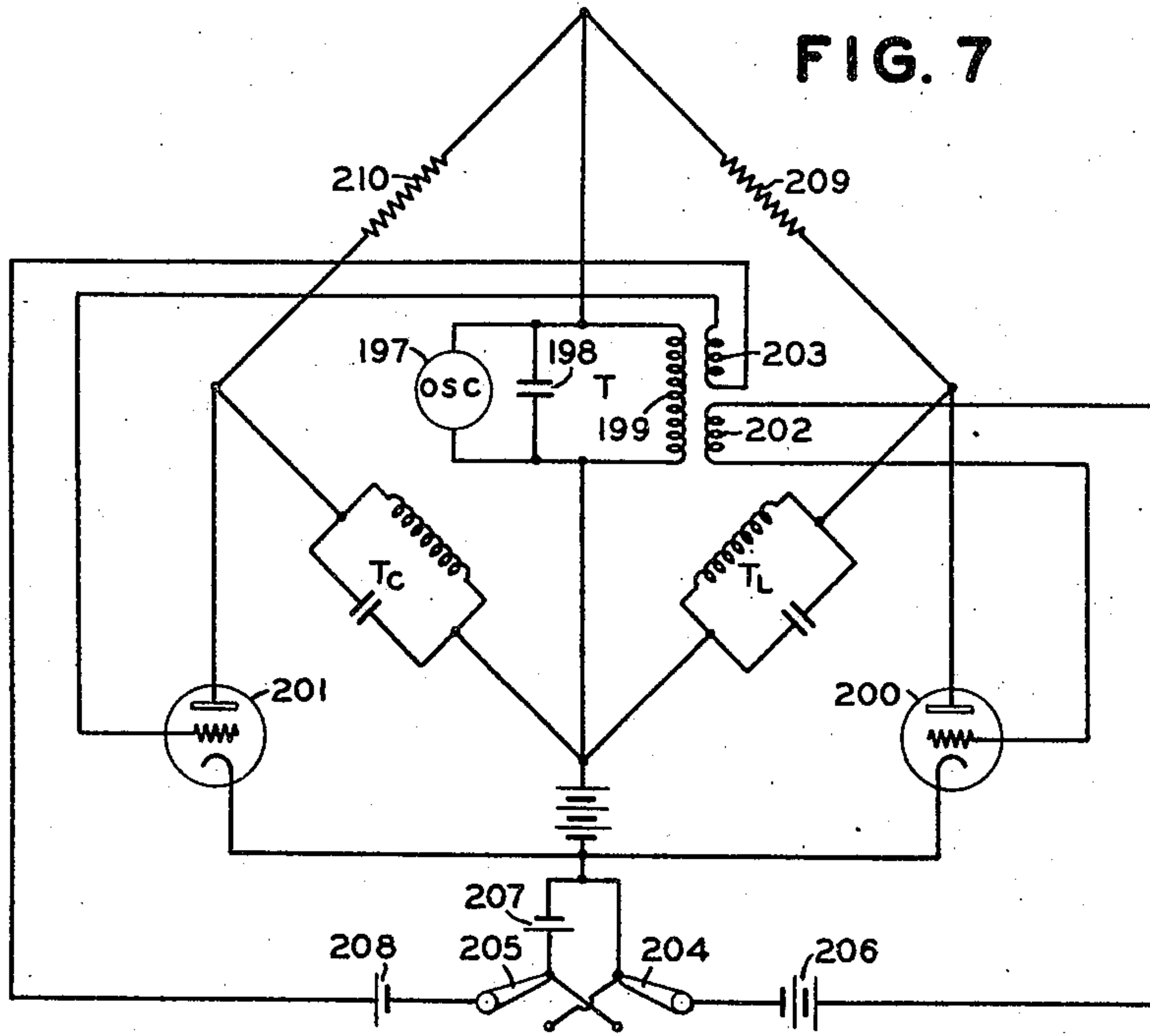


FIG. 8

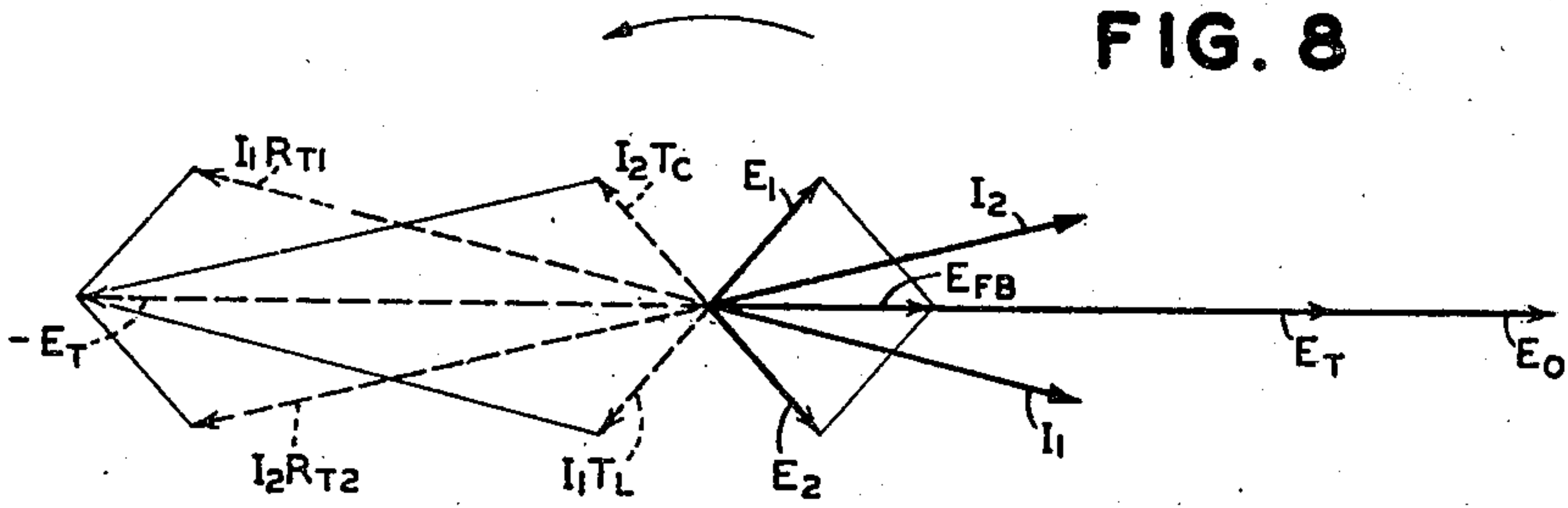
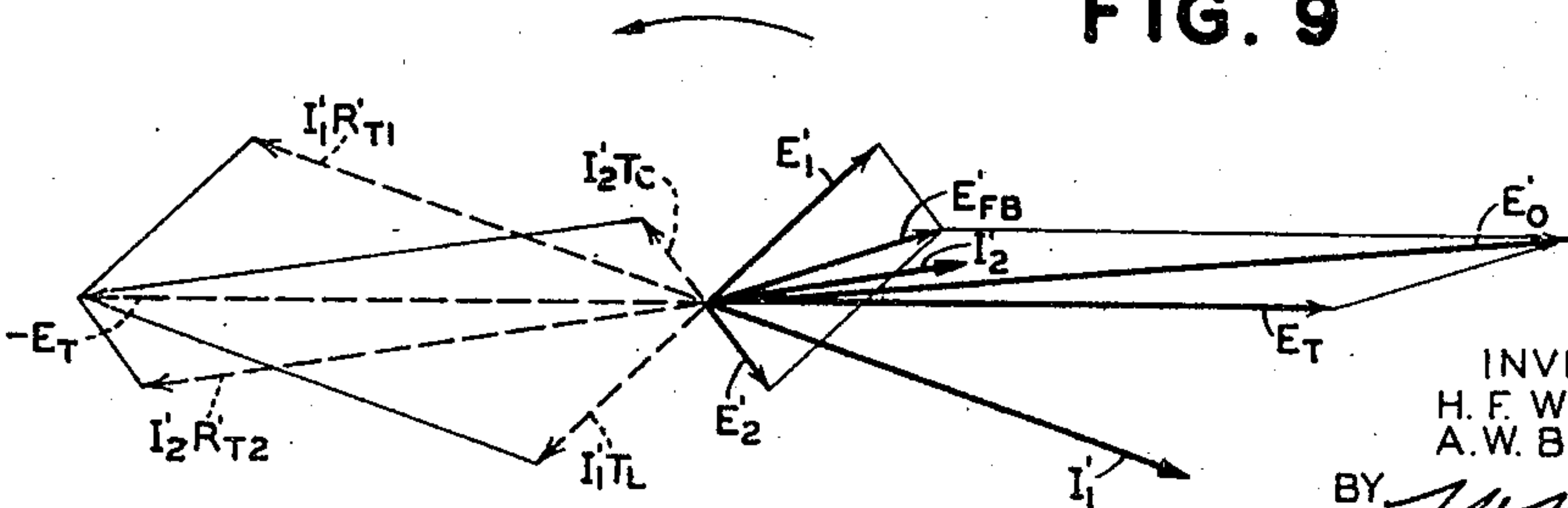


FIG. 9



INVENTORS
H. F. WILDER
A. W. BREYFOGEL
BY *W. W. Sponagle*
ATTORNEY

UNITED STATES PATENT OFFICE

2,435,259

FREQUENCY CONTROL APPARATUS

Harold F. Wilder, Wyckoff, N. J., and Albert W. Breyfogel, Howard Beach, N. Y., assignors to The Western Union Telegraph Company, New York, N. Y., a corporation of New York

Original application June 14, 1940, Serial No. 340,462. Divided and this application September 30, 1942, Serial No. 460,218

6 Claims. (Cl. 250—36)

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This invention relates to synchronous communication systems and has particular reference to apparatus employed for the repetition of the signals in high speed printing telegraph systems.

The present case is a division of a copending application of H. F. Wilder and A. W. Breyfogel, Serial No. 340,462, filed June 14, 1940, and entitled "Electronic regenerative repeater," now Patent No. 2,333,281, issued November 2, 1943. The instant invention is disclosed in an improved telegraph repeater of the regenerative type which receives, from one section of a line, signals that may be distorted in magnitude and shifted in phase and transmits them into the next line section at accurately spaced time intervals and free from amplitude distortion.

It is an inherent characteristic of any regenerative repeater to introduce a small amount of phase shift into the retransmitted signals. This is evident when it is considered that in order to correct the phase shift of incoming signals, some adjustment of the local means for timing the retransmission of the regenerated signals is necessary if the phase shift of the incoming signals is predominantly in one direction for a substantial period of time. Obviously, a change in the frequency of the local timing means effects a change in the spacing of the intervals at which the signals are retransmitted. In view of this condition the improved telegraph repeater minimizes, insofar as it is practicable, the amount of phase shift which is introduced into the retransmitted signals.

The phase shift is minimized by providing means for effecting a double integration or scanning of the received signals before they are retransmitted. The effect of such a system is to reduce by the square of the phase shift produced by a single integration or scanning the amount of phase shift present in the retransmitted signals. For example, if the received signal is shifted in phase by five units, a single integration may reduce this by four-fifths, or in other words, to a phase shift of one unit. If now the resultant signal is scanned a second time, it is possible to reduce the shift of one unit by four-fifths, or in other words, to a phase shift of one-fifth of a unit. Thus, it is seen that the final signal is shifted in phase only one-twenty-fifth of the amount of phase shift present in the received signal.

In effecting the double integration of the received signals, means are provided for varying independently the frequency of one alternating current generator so that it may be maintained in phase with the average phase of a relatively small

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group of such signals. Additional means are provided for varying independently the frequency of a second alternating current generator so that its output may be shifted in phase to correspond to a sustained phase shift of the received signals over a relatively large period of time.

The instrumentalities provided for the attainment of these two results insure the correction of each signal which is mutilated by fortuitous disturbances, and at the same time prevent the reflection of individual corrections into the retransmitted signals, unless these individual corrections are of such a nature that there appears to be a trend in one direction or the other with reference to a fixed frequency.

Another feature of the repeater is the provision of circuits used in conjunction with tubes of the gaseous arc discharge type wherein only the starting of the tubes is controlled by a grid. Heretofore, because it was necessary to negatively bias the tubes below the critical firing potential, the operation of this type of tube has been dependent upon the building up by the incoming signals of some value of positive potential to overcome a portion of the negative bias. Such arrangements were therefore effective only after a reversal by the signals from one polarity to the opposite polarity had actually occurred. This, of course, introduced an undesirable time lag in the response of the tube and at the same time operated the tube when the slope of the incoming signal was at something less than its maximum value. At such a time a signal is quite susceptible to the effects of interference, and as a consequence it frequently happened that an incorrect response was obtained by the receiving tubes. The circuits provided for obviating these difficulties cause the receiving tubes to operate exactly at the time of signal reversal, while the slope is at a maximum and the wave front is the least apt to be distorted by interference.

It is an object of the invention to provide novel means for changing the frequency of an alternating current.

Another object of the instant invention is the provision of novel oscillator frequency control circuits.

Still another object of the invention is to provide a novel frequency divider whereby alternating current having a desired frequency may be obtained from another alternating current having a frequency which is a multiple of the desired frequency.

These and other subordinate objects of the invention are attained by apparatus disclosed here-

in by way of illustration. A regenerative repeater embodying the novel features of the invention will be described in conjunction with the accompanying drawings, of which:

Fig. 1 is a block diagram showing the relation between the various units comprising the novel repeater;

Fig. 2 illustrates the arrangement of Figs. 3, 4, 5, and 6;

Fig. 3 shows the signal receiving and storing portions of the repeater and also the apparatus for effecting the first integration or scanning of the signals;

Fig. 4 shows the transmitting portion of the repeater, and also the apparatus for effecting the second integration or scanning of the signals;

Fig. 5 shows the electronic oscillators and some of their associated circuits for obtaining the two alternating current potentials utilized in the repeater;

Fig. 6 shows the remaining apparatus necessary for the generation of the alternating current potentials, and also the apparatus employed to vary the frequency of the alternating current generators;

Fig. 7 illustrates in simplified form the principles of the frequency changing or modulating apparatus; and

Figs. 8 and 9 are vector diagrams of the voltages and currents present in the circuits of Fig. 7.

The repeater embodying the invention will first be described in a general manner without reference to any of the details. Accordingly, reference is made to Fig. 1 of the drawings which illustrates in schematic form the inter-relation among the various units of the repeater and also those employed to control the operation thereof. The path traversed by the signals in passing through the repeater may be traced by the heavy solid lines in the direction indicated by the arrows. The incoming signals which may be distorted both as to amplitude and phase are received by a signal receiver 10. At suitable intervals corresponding approximately to twice the highest signal reversal frequency a device which in effect is a switch 11 is closed, thereby repeating the received signals into a signal storer 12. The stored signals are subsequently repeated, upon the closure of another switch-like device 13, to a signal transmitter 14 by means of which they are retransmitted into the next section of line as substantially undistorted signals.

There is provided a source of alternating current, termed herein a phasing frequency generator 15, which operates at a frequency of substantially twice that of the line signal reversals. One function of the phasing frequency generator is to close the switch-like device 11 once per cycle of its alternating current output. The output of the phasing frequency generator is also compared as to its phase relation with the received signals by means of an apparatus which is known as a phase comparator 16. A phase shift of an incoming signal with respect to the alternating current of the phasing frequency generator is detected by the phase comparator 16 and a suitable signal is transmitted to an apparatus termed herein a phasing frequency corrector 17. This apparatus is effective to alter the frequency of the alternating current generated by the phasing frequency generator in such a manner that the alternating current is brought into phase with the received signals. The timing of the frequency corrector circuits is such that the frequency of the phasing frequency generator is varied in re-

sponse to like phase shifts occurring successively in each of a relatively small group of received signals.

In general there are two causes of phase shifting of the received signals. One is the effect of interference effects which are generally known as fortuitous disturbances. This type of phase shifting is of an unpredictable nature and may cause one signal to be retarded in phase and the following signal may be affected so that it is advanced in phase. Consequently, when only this type of phase shifting is present, the phasing frequency corrector 17 will be constantly operating alternately to speed up and to retard the phasing frequency generator. The average frequency taken over a period of time will therefore remain constant.

If, however, the periodic device which is employed to time the transmission of the signals at the remote station is operated at a slightly different frequency from the phasing frequency generator, the average frequency of this generator will not remain constant but will operate at a different frequency from that at which it originally operated. It therefore becomes necessary to alter the frequency of the periodic device used to time the retransmission of the signals from the repeater or, in other words, the time interval or spacing between successive closures of the switch-like device 13 must be changed. The closures of the device 13 are controlled by means of a transmitting frequency generator 18 in a manner similar to that of the phasing frequency generator 15 with respect to the switch 11. Also, the two generators 15 and 18 are constantly compared as to their phase relation by means of a phase comparator 19. A disagreement between the two generators is detected by means of the comparator 19 and an appropriate signal is sent to a transmitting frequency corrector 20. In this case, however, the timing of the corrector apparatus 20 is considerably slower than the timing of the corrector 17. By reason of this arrangement, individual discrepancies between the frequencies of the generators 15 and 18 are not immediately employed to alter the frequency of the generator 18. Thus, a phase difference between the generators which would call for a speeding up of the generator 18 and a subsequent phase difference which would call for a slowing down of the generator 18 in effect cancel one another, producing no change in the frequency of generator 18. But if the corrections indicated by the comparator 19 are of such a nature that the number of one predominates over the other, or in other words, if it appears that there is a trend in one sense or the other, the transmitting frequency corrector 20 then becomes effective to make the appropriate change in the frequency of the transmitting frequency generator.

Thus, it is seen that the organization of the instrumentalities comprising the repeater is effective to regenerate each distorted received signal and to transmit these signals at accurately spaced intervals. The apparatus comprising the phasing frequency generator 15, the phase comparator 16, and the phasing frequency corrector 17 is immediately responsive to each small group of like phase shifts occurring in the received signals while the apparatus comprising the transmitting frequency generator 18, the phase comparator 19 and the transmitting frequency corrector 20 is responsive only to a trend in one sense or the other of the received signals with respect to the transmitting frequency generator.

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18. Such an arrangement provides the benefits to be derived from correcting for substantially every phase shift and at the same time minimizes the variations in frequency of the retransmitted signals.

For a detailed description of the regenerative repeater embodying the instant invention, reference will be made to Figs. 3, 4, 5 and 6, arranged as indicated in Fig. 2. The repeater shown here in detail is employed to relay signals in one direction over a system which is arranged for duplex operation. The signals are originally transmitted by means of the usual arrangements for transmission employed in a synchronous telegraph system. Such a transmitter is illustrated diagrammatically by the device 21 and is connected by a line W extending from the remote station to the receiving apparatus of the repeater. The signals appear as potentials between the points 22 and 23 of the line terminating impedances 24. These potentials are used to control the operation of a pair of gaseous arc-discharge tubes 25 and 26 by means of connections made to the respective control grids of these tubes. Space current is supplied to the receiving tubes by a source of potential 27, the positive terminal of which is connected through the winding 28 of a transformer 29 to the mid-point of a symmetrically arranged network, each branch of which contains an inductance 30 and a resistance 31, and to the respective anodes of the receiving tubes. These tubes are operated alternately in response to reversals of polarity of the line signals impressed thereon. Since it is a characteristic of this type of tube that an arc discharge initiated between the cathode and anode under the control of the grid continues until the anode-to-cathode potential is reduced below the critical value, a commutating condenser 32 is connected between the anodes of the tubes in a well known manner to extinguish the arc in one tube when an arc discharge is started in the other tube.

It is also a characteristic of this type of arc discharge tube that a discharge is initiated when the potential of the grid with respect to the cathode becomes less negative than some critical value. In operating tubes of this type in response to polarized telegraph signals heretofore it has been necessary to bias the tubes negatively sufficiently to prevent the operation of both of the tubes when the signal potentials became zero. Hence, in order to operate one of the tubes it was necessary that the signal potential applied to the grid become positive in an amount sufficient to reduce the negative bias to the critical firing potential. Consequently, the operating time of the tube after the received signal had reversed from one polarity to another varied appreciably because of the variation of the slopes of the wave fronts of different signals and also because, at this time, the signals are more susceptible to the effects of interference than at the time of reversal from one polarity to the other. The repeater embodying this invention is provided with means for operating the receiving tubes at the instant of reversal of the line signals. Hence, their operation then becomes entirely independent of signal amplitudes and is entirely dependent upon the phase of the received signals. This type of operation is secured by providing novel feed-back circuits between the anode and grid elements of the respective receiving tubes. Also, both of the transmitting tubes are provided with identical feed-back circuits (dif-

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fering only in the magnitude of the feed-back potential as described hereinafter) and the other tubes of a similar type which are used elsewhere in the repeater are provided with similar feed-back circuits but which have different timing characteristics. Accordingly, only one of each of these feed-back circuits will be described in detail.

There is connected between the anode of the tube 25 and the negative terminal of the source of potential 27 a series connection of a resistance 33, two choke coils 34 and 35, and a resistance 36. Condensers 37 and 38 are connected between intermediate points of the respective choke coils 34 and 35 and the negative terminal of the source 27. The condensers are shunted by a series connection of resistances 39, 40 and 41. A connection is also made to these shunting resistances at the point common to resistances 39 and 40 to the grid of the tube 25. The choke coils and the condensers comprise a delay network of such a character that when a high positive potential is applied between the anode and the cathode of the tube 25, the potential which is applied to the grid of this tube by the network remains substantially unchanged for a predetermined period of time. At the expiration of this time the grid feed-back potential is increased positively substantially instantaneously to a predetermined value. The resistances 33 and 36 are for the purpose of damping oscillations between the inductive and capacitive elements of the network after the predetermined feed-back potential has been reached. The resistances 39, 40, and 41 comprise a potentiometer or voltage divider whereby the predetermined grid potential may be obtained from the potential to which the condensers become charged. The cathodes of the respective tubes are connected through a common resistance 42 to the negative terminal of the battery 27. Thus, the voltage drop across this resistance produced by the current flowing through the tube which is conducting serves to bias the grid of the non-conducting tube negatively with respect to its associated cathode. This bias is sufficient to prevent operation of the tube in the absence of other grid potentials.

For the purpose of describing the action of the positive feed-back circuit, assume that the tube 25 is conducting and the tube 26 is non-conducting. When a signal of the proper polarity is impressed upon the receiving impedances 24, the tube 26 is rendered conducting and, by means of the extinguishing action of the commutating condenser 32, the tube 25 is rendered non-conducting. The fixed negative bias is applied to the grid of the tube 25 as described. At the same time substantially the full potential of the source 27 is impressed between the anode and the cathode of this tube. While the tube is conducting, the positive potential applied to the anode is relatively small and as soon as the arc in this tube is extinguished, the potential applied to the anode is materially increased. This increased potential is applied to the delay network of the choke coils and condensers and, depending upon the constants of the network, a short time thereafter the condensers 37 and 38 will instantaneously charge to the full potential of the source 27. However, until this happens, the positive feed-back potential which is applied to the grid of this tube is maintained at a small value approximating zero and the tube is controlled by the negative bias and the signal voltage. Therefore, it will be appreci-

ated that any fluctuation or oscillation of the received signals which does not reach or exceed the potential necessary to reduce the negative bias to the critical firing value of the tube 25 is ineffective to produce this result at this time. The importance of this feature is that once a signal has been received and is registered by means of the tubes 25 and 26, there is introduced into the system a time delay during which the receiving tubes are disabled so far as small disturbances of the received signals are concerned. The delay is long enough to normally permit steady state signal conditions to be established. When such a condition has been established, the receiving tube 25 which is non-conducting at this time is substantially instantaneously conditioned to receive the following signal. This condition is such that a predetermined positive feed-back potential is applied between the grid and the cathode of this tube which is, in itself, just capable of overcoming or neutralizing the negative bias applied to this tube to an extent sufficient to render the net bias equal to the critical firing potential. However, since the potential appearing at the point 22 of the receiving network is negative with respect to the cathode of the tube 25, the tube remains non-conducting. But, when the following signal is received and the potential at the point 22 with respect to the cathode of the tube 25 becomes zero as it is about to reverse from negative to positive, the tube is controlled solely by the net biasing potential. Since this potential at this time is the critical negative firing potential, an arc discharge is started in the tube 25. It has been demonstrated that such an event extinguishes the arc in the tube 26 and thereafter for a predetermined time disables this tube as far as input potentials of less than the value necessary to reduce the negative bias to the critical firing potential are concerned. Therefore, it is evident that even though the potential appearing at the point 22 does not immediately become positive but instead becomes slightly negative with respect to the cathode, the tube 25 will remain conducting and the tube 26 will remain non-conducting, provided that this potential does not become negative enough to produce a corresponding positive potential at the point 23 which is equal to or in excess of the potential necessary to overcome the fixed negative bias to the extent required to produce the critical grid-to-cathode firing potential of the tube 26. Such a signal is frequently encountered in practice and is caused by interference effects being superimposed upon the telegraph signals. These interference effects are frequently of an oscillatory nature having a relatively short duration so that ultimately the potential reversal which initiated conduction in the tube 25 is completed, thereby rendering the point 22 positive and the point 23 negative with respect to the cathodes of the receiving tubes. The delay which is introduced into the application of the positive feed-back potential to the input circuits of the receiving tubes is sufficient to prevent all but the most violent and longest sustained interference effects from interfering with the proper operation of the receiving system.

The nature of the local biasing circuits of the receiving tubes is such that, in the absence of signaling potentials, the tubes will oscillate. It has been found that optimum results are obtained when the biasing circuits are adjusted to cause the tubes to oscillate at approximately twice the maximum signal reversal frequency.

It should be pointed out that these feed-back

circuits are not absolutely essential for the satisfactory operation of the repeater. However, they do improve its operation so that it is possible to repeat higher frequency signals which may be subjected to higher levels of interference, and for this reason are included in the preferred form of the invention. Another feed-back arrangement which also has been found to give excellent results is that which is provided for some of the other gaseous arc discharge tubes employed herein and is described in a subsequent portion of the specification.

Condensers 43 and 44 are connected as shown to the input circuits of the receiving tubes 25 and 26 for the purpose of by-passing certain high frequency charging currents generated by the operation of the westbound transmitted 45 which is employed to send signals to the remote station connected to the line W. The inductances 30 and the resistances 31 connected in the plate circuits of the receiving tubes are resonant and critically damped at a frequency which is about twice the highest dot telegraph signal reversal frequency. The purpose of this arrangement is to insure that the potential which appears between the anodes of these tubes shall produce signals which have a substantially square wave form. In order to accomplish this result it is necessary that the inductances 30 be wound on separate cores so that there is no inductive interaction between them.

The respective anodes of the receiving tubes are connected to the extreme terminals of a series connection of resistances 46 and 47. Each of the connecting circuits includes an identical network for the purpose of producing a pronounced peak at the beginning of each signal impulse. One of such networks comprises a condenser 48 connected in shunt with a resistance 49. Thus, the signals which are received from the line are repeated by the receiving tubes 25 and 26 and appear as square-topped potentials impressed across the terminals of resistances 46 and 47.

The terminals of these resistances are connected respectively to the grids of a pair of tubes 50 and 51 through resistances 52 and 53, respectively. The cathodes of these tubes are connected by means of a resistance 54 to the midpoint of the resistances 46 and 47. For the purpose of this description the tubes 50 and 51 will be referred to as the first pick-up tubes and they may be of the 6Z7 type or any equivalent capable of amplifying signals in the voice frequency range. As the polarity of the received signals reverses, the polarity of the potential impressed upon the input circuits of the first pickup tubes reverses so that, for example, when the grid of the tube 50 is positively biased to render this tube conducting, the grid of the tube 51 is negatively biased, thereby preventing this tube from conducting space current. The anodes of the first pick-up tubes are connected to the terminals of a primary winding 55 of a coupling transformer 56. Conductors 57 are connected to the cathodes of the tubes and to the midpoint of the winding 55 and are periodically energized by means of a locally generated impulse so that space current may be furnished through one of the portions of the winding 55 to the output circuit of whichever one of the first pick-up tubes is conditioned for conduction by means of the relayed signal. On the average, this impulse is supplied over the conductors 57 at a time which is approximately one-half a baud, or signal impulse, later than the received signal reversal detected by the receiving tubes 25 and 26. This process is

known herein as the first signal scanning, and the means for producing the scanning impulses and the manner in which their timing is controlled will be discussed in detail in a subsequent portion of the specification. Suffice it to say that these impulses are generated at a rate which is substantially equal to twice the highest dot signal reversal frequency.

Each scanning impulse produces an impulse of short duration in the primary winding 55 of the transformer 56. Depending upon which of the first pick-up tubes is conducting, the polarity of the impulse which is induced in the secondary winding 58 of the coupling transformer will operate one or the other of a pair of storing relays 59 and 60. The input circuits of these tubes are connected to the secondary winding 58 of the coupling transformer in a conventional manner as shown. These tubes should possess high amplification factors and may be of the 6Z7 type or their equivalents. The tubes are equipped with feed-back or inverse biasing circuits by means of which their sustained operation in response to the short impulses derived from the winding 58 is secured. These circuits may be described by assuming that the tube 59 is conducting and the tube 60 is non-conducting. If, in these circumstances, an impulse is induced in the winding 58 of the coupling transformer 56 of such a character that the lower terminal of this winding is positive with respect to the upper terminal, the grid of tube 60 will be biased positively with respect to its associated cathode, thereby rendering this tube conducting. The negative potential which is applied at the same time to the grid of the storing tube 59 is effective to render this tube non-conducting. Consequently, the potential which is applied to the anode of this tube is raised to some high positive value approaching the full potential of the space current source 61. This high positive potential is connected by means of a feed-back resistance 62 to the grid of the tube 60 which has just been rendered conducting. These circuits are so designed that the positive feed-back potential is supplied to the tube last operated before the operating potential derived from the short transformer impulse has been removed. Thus, it is seen that the tube which is non-conducting furnishes a biasing potential to the conducting tube to maintain these conditions. Hence, it becomes possible to operate the storing tubes alternately in response to impulses of very short duration and of opposite polarity.

The output circuits of the storing tubes 59 and 60 include respectively resistances 63 and 64, the terminals of which are connected through resistances 65 to the terminals of the input circuits of a pair of tubes 66 and 67 which are referred to herein as second pick-up tubes. These tubes may also be of the 6Z7 type or their equivalents. The anodes of the second pick-up tubes are connected to the terminals of a primary winding 68 of a coupling transformer 69. In a manner similar to that described for the first pick-up tubes, space current for the second pick-up tubes is supplied over conductors 70 by the periodic impression thereon of a series of locally generated impulses which are known as the second scanning impulses. These impulses are also generated by means which will be described in greater detail in a subsequent portion of the specification. The frequency of the second scanning impulses is substantially equal to twice the highest signal reversal frequency. The timing of one of

the second scanning impulses with reference to one of the first scanning impulses is approximately one-half a baud, or signal impulse, later. Each of the second scanning impulses is employed to generate an impulse in the primary winding 68 so that there is produced by induction in the secondary winding 71 a series of impulses corresponding in number and polarity to the signals which were originally received from the line W. The impulses which are induced in the secondary winding 71 are utilized to control the operation of a pair of transmitting tubes 72 and 73.

These tubes are of the gaseous arc discharge type similar to the receiving tubes 25 and 26. They are also provided with delayed feed-back circuits similar to those described in connection with the receiving tubes. However, in the case of the transmitting tubes, the amount of the positive feed-back to the grid of the non-conductive tube is slightly less than the potential necessary to reduce the fixed negative bias to the critical firing potential of the tube. Hence, in the absence of an external positive potential applied to the grid, the non-conductive tube will not be operated by means of the biasing potentials. This method of operation is necessary because the impulses derived from the secondary winding 71 of the transformer 69 are of relatively short duration and are spaced in time from one another. Hence, there are no available signal-derived potentials to maintain stable operating conditions of the tubes between signal reversals as in the case of the receiving tubes. It should be noted that there is no delay in the response of the transmitting tubes for the reason that the impulses impressed upon the input circuits have extremely steep wave fronts.

The output circuits of the transmitting tubes include, in addition to the network of inductances and resistances similar to those employed with the receiving tubes, another network comprising a condenser 74 and a resistance 75 connected in series between the respective anodes of the transmitting tubes. The anode of the tube 73 is connected to ground. The anode of the tube 72 is connected through an inductance 76 to the apex 77 of a network of terminating impedances 78. One terminal of the terminating network is connected to the line E and the other terminal through an artificial line 79 to ground. As the transmitting tubes 72 and 73 are operated in accordance with the signals which are to be sent into the succeeding section of the line, the polarity of the potential applied to the apex 77 is alternately reversed, according to the character of the signal being transmitted. The elements 74, 75 and 76 comprise what is known in the art as an anti-noise set which has for its purpose the suppression of currents which may cause interference with lines in the vicinity of the line E. Such a device is well known and its connection in the circuit is conventional and will not be described in any further detail.

The apparatus which is employed to generate the scanning impulses for the repeater will be described by having reference particularly to Figs. 5 and 6 of the drawings. As previously described, two series of scanning impulses are used and are furnished at a frequency which is substantially twice the highest signal reversal frequency. These impulses are generated by electronic means which for convenience comprise two electronic oscillators operating at relatively high frequencies with reference to the desired frequency and differing from one another in an amount equal

to the desired frequency. The outputs of the oscillators are combined and the difference, or beat, frequency is utilized. Two such independent frequencies are required and one oscillator is arranged so that it is operated in conjunction with each of two other oscillators. Once adjusted, the frequency of the common oscillator remains fixed but the frequencies of the other two oscillators are susceptible of mutually independent variations in order to provide the desired regenerating action of the repeater. If the two other oscillators are arranged to normally operate at the same frequency whereby the two beat frequencies produced are substantially the same, there is a marked tendency for these two oscillators to lock together and operate at the same frequency. It is necessary to prevent such an occurrence since the frequency variation of one of these oscillators must be independent of that of the other. To obviate the locking tendency by shielding the wiring, which is the medium by which the undesired coupling is effected, is unnecessarily expensive. A better way is to adjust the frequencies of the oscillators so that one beat frequency is produced at twice the highest telegraph signaling frequency and the other beat frequency is produced at substantially the highest telegraph signaling frequency. Since the latter beat frequency is unusable in this form, it is doubled by means of a frequency doubler.

One of the local sources of oscillations provided includes an electron discharge device 80 which is arranged so as to have a negative resistance characteristic. This device is provided with an electrode 81 which is connected so that a secondary emission of electrons therefrom is produced. A source of potential 82 is connected to a series arrangement of a plurality of resistances 83, 84 and 85. These resistances comprise a voltage divider to which connections to the electrodes of the tube 80 are made. A shunted arrangement of a condenser 86 and an inductance 87 is connected between the electrode 81 and an intermediate point on the voltage divider. The apparatus of this circuit is to control the frequency of the oscillations in a well known manner and is commonly referred to as a tank circuit. The output circuit of the oscillation generator 80 is coupled electrostatically by means of a condenser 88 to a parallel arrangement of a pair of resistances 89 and 90. From these resistances are derived the input circuits for a pair of vacuum tubes 91 and 92 which may be of the 6C8G type or other equivalents. The output circuits of the amplifying tubes 91 and 92 are also connected in parallel to the primary windings 93 and 94, respectively, of transformers 95 and 96.

There is also provided a second oscillator tube 97 the output of which is amplified by means of vacuum tubes 98 and 99 in substantially the same manner as that described in connection with the oscillator 80. The amplified output of the oscillator 97 is impressed upon the primary windings 100 and 101 of transformers 102 and 103, respectively.

There is provided a third oscillator 104, the output of which is amplified by means of vacuum tubes 105 and 106 in substantially the same manner as that described for the other two oscillators. Similarly, the amplified output of the oscillator 104 is impressed upon the multiple connection of windings 107 and 108, respectively, of the transformers 109 and 110.

The condenser elements of the tank circuits 86-87, 111 and 112 are variable and are ar-

ranged to be controlled by a common frequency adjusting control (not shown). The oscillator 97 is the common oscillator previously referred to, and oscillators 80 and 104 are the variable frequency oscillators. The circuit constants of the three tanks are chosen so that, with the common frequency adjusting control set at one extreme position, the oscillations generated by the oscillator 80 have a frequency of substantially 614.5 cycles per second, those generated by the oscillator 97 substantially 585 cycles per second and those generated by the oscillator 104 substantially 644 cycles per second. Thus, it is seen that the beat frequency derived from oscillators 80 and 97 is the difference between these respective frequencies which is 29.5 cycles per second. Similarly, the beat frequency derived from oscillators 97 and 104 is 59 cycles per second or exactly twice the first beat frequency which is subsequently doubled and utilized together with the second beat frequency at times when the telegraph signaling is effected at approximately 29.5 cycles per second. The movement of the frequency adjusting control to its other extreme position decreases the frequency of the oscillators 80 and 97 and increases that of the oscillator 104, so that the respective frequencies become substantially 605, 500 and 710 cycles per second. Now, it will be seen that the beat frequency derived from the oscillators 80 and 97 is 105 cycles per second and that derived from the oscillators 97 and 104 is 210 cycles per second. Again, it will be observed that the two-to-one relation exists between the two beat frequencies. The same relation holds for all positions of the frequency adjusting control between the two described extremes. These frequencies are selected initially in accordance with the telegraph signaling frequency. The values given herein are intended only as illustrations and are not contemplated as limiting the scope of the invention in any manner. Also, it will be understood by those skilled in the art that, by taking the necessary precautions against coupling, the oscillator 80 may be operated at substantially the same frequency as the oscillator 104 without departing from the scope of the invention.

Each of the transformers associated with the output circuits of the frequency amplifiers is provided with a plurality of secondary windings, the purpose of which will become apparent from subsequent portions of the specification. Secondary winding 113 of transformer 95 is connected in series relation with secondary winding 114 of transformer 102. The terminals of this series connection, when properly poled, are connected respectively to the grid and cathode of an amplifier tube 115. Similarly secondary winding 116 of transformer 95 is arranged in series connection with secondary winding 117 of transformer 102 and the properly poled terminals of this connection are connected respectively to the grid and cathode of a vacuum tube 118. The respective anodes of the tubes 115 and 118 are connected to the terminals of a winding 119 of transformer 120. The midpoint of this transformer winding is connected to the positive terminal of a source of direct current potential 121. The negative terminal of this source of potential is connected through a resistance 122 to the cathodes of the amplifier tubes 115 and 118. Thus, it is seen that these tubes are connected in a push-pull arrangement. Also, it is seen that the input circuits of this push-pull amplifier are derived from transformer windings in such a

manner that a combination of the frequencies generated by the oscillators 89 and 97 is impressed upon the amplifier. By such an arrangement there appears in the primary winding 119 of the output transformer 120 two potentials having the frequencies of the oscillators 89 and 97, respectively. These potentials are reproduced by induction in the secondary winding 123 of the transformer 120 and are demodulated by means of a full wave rectifier tube 124 in order to produce a series of uni-directional impulses of varying amplitude having an envelope which varies in frequency in accordance with the difference, or beat, frequency produced by the combination of the frequencies generated by the oscillators 89 and 97. This series of impulses is passed through a filter network 125 which comprises a plurality of inductive and capacitive reactances connected as shown and which has for its function the filtering out of the high frequencies produced by the oscillators. Thus, the potentials which are applied to the primary winding 126 of a transformer 127 are alternating in character, have a sinusoidal wave form and a frequency which is the beat, or difference, frequency derived from the oscillators 89 and 97, and which is equal to the signal reversal frequency.

These potentials are reproduced by induction in the secondary winding 128 of this transformer and are applied to a frequency doubling arrangement by being impressed upon the input circuits of a pair of vacuum tubes 129 and 130. These tubes may be of the 6E6 type or their equivalents and are biased so as to having non-linear amplifying characteristics. The output circuits of the amplifier tubes 129 and 130 are connected to the primary winding 131 of a transformer 132 in a multiple, or push-push connection as shown. Thus, there appears in the primary winding the second harmonic of the amplifier input frequency and there is derived from the secondary winding of the transformer 132 a sine wave potential having twice the signal reversal frequency. Before the manner in which this alternating current potential is employed in the repeater is described it may be well to discuss briefly the generation of the second alternating current frequency.

In view of the foregoing description the detailed circuits which are involved in the generation of this second alternating current potential will not be described fully since they are precisely similar to those already described. The respective outputs of the oscillators 97 and 104 are combined by means of the secondary windings of transformers 103 and 110 and applied to the input circuits of a pair of push-pull amplifier tubes 133 and 134. The connections of these tubes to the secondary transformer windings are similar to the connections described in detail for the input circuits of the push-pull amplifier tubes 115 and 118. The combination potential of the two oscillators 97 and 104 is demodulated by a rectifier tube 135 and the high frequency components of the resultant wave are filtered out by means of the filter 136. The beat frequency alternating current potential is impressed upon the input circuits of a pair of amplifier tubes 137 and 138 by means of a coupling transformer 139. Because of the difference between the frequencies of oscillation of the oscillators 97 and 104 previously described, there is impressed upon the primary winding 140 of the transformer 141 an alternating current po-

tential having a sinusoidal form and a frequency substantially equal to twice the signal reversal frequency.

The sinusoidal alternating current voltage of approximately twice the telegraph signal reversal frequency which appears in the secondary winding 142 of the transformer 132 is applied by means of conductors 143 to the input circuits of a pair of gaseous arc-discharge tubes 144 and 145 (see Fig. 3). Each of these tubes is provided with a feed-back circuit which is somewhat similar to the feed-back circuits associated with the receiving tubes but which has a somewhat different timing characteristic. The feed-back circuit which is associated with the tube 144 comprises a resistance 146 in series with a condenser 147, which combination is connected between the anode of the tube and the negative terminal of the source of potential 148. A voltage divider is connected in shunt with the condenser and comprises resistances 149 and 150 and the upper half of the secondary winding 142 of the transformer 132. A connection is made to the grid of the tube 144 from the junction of resistances 149 and 150 whereby the desired positive potential is applied to the grid. As soon as the tube 144 is rendered non-conducting, the anode is raised to substantially the full positive potential of the battery 148. Consequently, the condenser 147 begins to charge through the resistance 146 at a rate which is determined by the value of this resistance. As is well known, the potential of the condenser when plotted against time rises substantially according to an exponential curve until ultimately the potential across the condenser reaches a maximum steady state value. A portion of this voltage is selected by means of the voltage divider and applied to the grid of the tube 144 and is just capable when acting by itself in concert with the fixed negative bias to initiate conduction in the tube. The tube 145 is also provided with a similar feed-back circuit and the action of these tubes in response to the exciting potentials applied to the conductors 143 is identical with the action of the receiving tubes previously described. In this case, however, it will be observed that the positive bias which is applied to the tubes after they become extinguished is gradually built up rather than being applied instantaneously after a predetermined delay as in the case of the receiving tubes. This type of operation is equally as good as that obtained with the feed-back circuits previously described.

The output circuits of these tubes also include apparatus similar to that previously described, and in addition there is included in each of these circuits, in series with the anodes of the respective tubes, primary windings 151 and 152 of transformers 153 and 154, respectively. Since these tubes are driven under the control of potentials having a frequency twice the highest signal reversal frequency, there will appear across the terminals of a pair of resistors 155 and 156 an alternating current potential of twice the signal reversal frequency. This potential is applied to the input circuits of a pair of vacuum tubes 157 and 158 which may be of the 6Z7 type or their equivalents. In each of the circuits for space current of these tubes there is included one-half of the primary winding 159 of a transformer 160 and the secondary winding 161 of the transformer 29.

For the description of the function of the tubes 157 and 158, let us assume initially that the signals which are being repeated from the line W into the line E are perfect ones requiring no cor-

rection by the repeater. This, of course, is an ideal condition not practically realizable in practice, but it is believed that the invention may be better understood if this ideal situation is assumed to exist. It will be remembered that as the receiving tubes 25 and 26 are operated alternately in response to received signal reversals, a surge of current or a transient effect is produced in the primary winding 28 of the transformer 29 due to the action of the commutating condenser 32. These surges are all of the same polarity and therefore produce by induction a series of unidirectional impulses in the secondary winding 161 of this transformer. These impulses are of short duration and serve as the source of space current for the tubes 157 and 158. The timing of these impulses under the ideal conditions assumed is such that they occur at the precise moment that a reversal of the input potentials applied to these tubes is occurring. Hence, for example, the impedance of the tube 157 is at this time being increased and the impedance of the tube 158 is being decreased. Consequently, the impulse which is generated in the transformer winding 161 will produce in the secondary winding 162 of the transformer 160 a transient which comprises a half cycle of one polarity followed by a half cycle of the opposite polarity. This transient voltage is impressed upon a pair of conductors 163 which lead to the correcting circuits, the operation and function of which will be described presently.

Once every other cycle of the alternating current frequency, which is employed to drive the tubes 144 and 145, there is generated an impulse in the winding 164 of the transformer 154. These impulses therefore occur at a rate which is substantially equal to twice the signal reversal frequency, and are impressed upon conductors 57. This series of impulses comprise the first scanning impulses previously referred to and are connected to the repeater in the anode circuits of the first pick-up tubes 50 and 51. The timing of these impulses is such that the received signals which are employed to condition the first pick-up tubes are passed at the proper time to the storage tubes 59 and 60. There is also generated in the secondary winding 165 of the transformer 153, a series of short impulses which is 180° out of phase with the series of first scanning impulses or, in terms of the telegraph signals, differ in time by one-half a baud. The impulses generated in the winding 165 are employed for a purpose which will be described more fully in a subsequent portion of the description.

The alternating current potentials which are generated in the secondary winding 166 of the transformer 141 (see Fig. 6) are connected by means of conductors 167 to the input circuits of a pair of gaseous arc-discharge tubes 168 and 169 (see Fig. 4). The input and output circuits of these tubes are substantially similar to those provided for the tubes 144 and 145 of Fig. 3. Likewise, they are operated at a frequency which is twice that of the highest signal reversal frequency. The transformer 170 is connected with its primary winding 171 in the output circuit of the tube 168 so that there is generated in the secondary winding 172 a series of impulses having substantially twice the signal reversal frequency. These impulses are connected to conductors 70 and are employed to provide space current for the second pick-up tubes 66 and 67. These impulses are the so-called second scanning impulses previously referred to and control the timing of the

retransmitted signals. There is connected to the anode of the tube 169 the primary winding 173 of a transformer 174, the secondary winding 175 of which is utilized for a testing purpose to be described.

The alternating current potentials of twice the signal reversal frequency which appear in the output circuits of the tubes 168 and 169 are connected to the terminals of a series arrangement of a pair of resistances 177 and 178. From these resistances are derived the input circuits of a pair of amplifier tubes 179 and 180. These tubes may also be of the 6Z7 type or their equivalents. The output circuits of these tubes are connected to the terminals of a primary winding 181 of a transformer 182. Space current for the tubes is supplied over conductor 183 by the secondary winding 165 of the transformer 153. Thus, at a frequency approximately equal to twice the signal reversal frequency, there is completed a circuit for the flow of space current in either or both of the tubes 179 and 180. If it is assumed that the ideal conditions still obtain, there will be generated in the secondary winding 184 of the transformer 182 a series of transient potentials comprising one half cycle of one polarity followed immediately by one half cycle of the opposite polarity. These transient potentials are connected by means of conductors 185 to the frequency control circuits of Fig. 6 to which reference is now made.

The impulses which are generated in the secondary winding 162 in the transformer 160 are applied by means of conductors 163 to the input circuit of an amplifier tube 186. This tube may be of the 6E6 type or its equivalent. The amplified impulses are impressed upon the primary winding 187 of a coupling transformer 188, the secondary winding 189 of which is shunted by a resistance 190 for the purpose of regulating the amplitude of the impulses induced therein. The induced impulses, if they are of sufficient magnitude, are impressed upon an integrating network 191 by means of a discharge device 192 which may be a neon tube. If the impulses are generated under the ideal conditions assumed, the voltage thereof will be insufficient to break down the neon tube 192. It will be seen that this is of no material significance since the impulses, being closely spaced in time with respect to one another and also being of opposite polarity, would therefore cancel one another if they were admitted to the integrating network. Consequently, in the ideal situation assumed there is no corrective action exerted upon the phasing frequency generator.

There is a similar arrangement of apparatus to correct the transmitting frequency generator and includes an amplifier tube 193, the input of which is connected by means of conductors 185 to the secondary winding 184 of the transformer 182. The amplified impulses are impressed upon another integrating network 194 by means of a transformer 195 and a neon tube 196.

Before proceeding with the description of the operation of the apparatus described up to this point under actual operating conditions, it is believed that a theoretical consideration of the apparatus employed for altering the frequencies of the two generators used in the system may lead to a better understanding of the operation of the specific apparatus employed to control these frequencies. For this purpose reference will be made to Fig. 7. There is shown schematically an oscillator 197 which is provided with a primary source of energy comprising the tank T and two sec-

ondary sources of energy comprising respectively the tanks T_L and T_C . The primary tank T is capable of sustaining oscillations when acting alone at a frequency which is determined by the resonant frequency of the condenser 198 and the inductance 199 comprising this tank circuit. The secondary tank circuit T_L also comprises a condenser and an inductance and is tuned for resonance at a point which is a predetermined amount above the resonant frequency of the primary tank T . Similarly, the secondary tank T_C is tuned for resonance by the same predetermined amount below the resonant frequency of the primary tank. The two secondary tanks are included respectively in the output circuits of vacuum tubes 200 and 201. Both of these tubes are excited at the oscillator frequency by means of coils 202 and 203 which are coupled to the inductance 199 of the primary tank circuit T . There are also provided in the input circuits of the tubes biasing arrangements whereby the tube impedances may be varied in any desired manner, for example the switches 204 and 205 in their upper positions bias the grids of the two tubes equally. It may be seen that this is accomplished by connecting the two-unit battery 206 between the grid and cathode of the tube 200. Likewise, the one-unit battery 207 is connected in series with another one-unit battery 208 between the cathode and grid of the tube 201. When the switches 204 and 205 are placed in their lower positions, the battery 207 is connected in series with the battery 206, thereby furnishing three units of biasing potential to the tube 200. Also, with the switches in their lower positions it may be seen that the tube 201 is biased only by the potential of the one-unit battery 208. The output circuits of the tubes 200 and 201 are combined and coupled by means of resistances 209 and 210 to the output circuit of the oscillator 197. Therefore, in addition to the energy which is supplied by the primary source T , the oscillator is furnished with energy from the two secondary sources including the tanks T_L and T_C .

The operation of the frequency control circuits will be described with reference to Figs. 8 and 9. Fig. 8 is a vector diagram which shows graphically the relations existing between some of the voltages and currents present in the circuits of Fig. 7 at a time when a state of equilibrium exists. In order to simplify the diagram as much as possible, it is assumed that only a fractional part of the output voltage of the oscillator is employed to excite the vacuum tubes 200 and 201. It is further assumed that this exciting voltage when amplified by the amplification factor of the tubes is equal to the output voltage of the oscillator. This voltage may then be considered as the driving voltage necessary to produce a current flow in the output circuits of the vacuum tubes. Consequently, this driving voltage is represented in Fig. 8 as the vector E_r and is used as the reference vector for all others shown in this diagram. Considering first the output circuit of the tube 200, it may be seen that, since the tank T_L is tuned for resonance at a frequency higher than the frequency of the driving voltage in the circuit, it acts as an inductance. Consequently, the current flowing in the output circuit of the tube is lagging with respect to the driving voltage E_r and is represented in the diagram by the vector I_1 . It is assumed that the resistance which is present in the output circuit of the tube 200 is represented by the impedance of the tube. Obviously, other resistances may be inserted in the circuit without changing the fundamental operating character-

istics thereof. Since the impedance of the tube is all resistance, the voltage drop across the tube is in phase with the current. This voltage drop is not shown in the diagram but the reaction voltage of the tube which is equal in magnitude and opposite in phase to the voltage drop is represented by the vector $I_1 R_{T_L}$. The constants of the tank T_L are so chosen that the inductance predominates over the resistance. Consequently, the voltage drop E_1 across the tank T_L leads the current I_1 by an angle which approaches 90° . Also, the reaction voltage of the tank is equal to the voltage drop across the tank and is opposite to it in phase, and is represented by the vector $I_1 T_L$. The total reaction in the circuit is obtained by adding the vectors $I_1 R_{T_L}$ and $I_1 T_L$, and is represented by the vector $-E_r$ which, it will be observed, is equal and opposite in phase to the driving voltage E_r .

A similar analysis can be made of the output circuit of the tube 201 in which is included the tank T_C which acts as a capacity since it is tuned for resonance at a frequency below that of the oscillator 197. Since both of the secondary tanks are detuned by the same amount from the oscillator, the effects produced in the circuits are equal. Therefore, the current flowing in the output circuit of the tube 201 may be represented by the vector I_2 which may be seen to lead the driving voltage E_r by the same angle as the vector I_1 lags in this voltage. The reaction voltage of the tube 201 is represented by the vector $I_2 R_{T_C}$ and is equal and opposite in phase to the voltage drop (not shown) across the tube which is in phase with the current I_2 . Similarly, the voltage drop E_2 across the tank T_C lags the current I_2 by an angle which approaches 90° . The reaction voltage of the tank T_C is represented by the vector $I_2 T_C$ which is equal to E_2 and opposite in phase. The sum of the reaction voltages $I_2 R_{T_C}$ and $I_2 T_C$ is equal to the driving voltage E_r and opposite thereto in phase and is represented by the vector $-E_r$.

Since the voltages developed across the secondary tanks are combined and added to the output voltage of the oscillator, this feed-back voltage may be represented by the vector E_{FB} which is the vector sum of the voltages E_1 and E_2 . It may be seen that this feed-back voltage is in phase with the oscillator voltage E_r . Therefore, they are combined additively to produce a voltage which may be represented by the vector E_0 which is the voltage applied to the load circuit supplied by the oscillator. Under these conditions, with the feed-back voltage in phase with the oscillator output voltage, a state of equilibrium exists and so long as the circuit constants are unchanged and the tubes maintained with equal biases on their grids, the oscillator will continue to operate at a fixed frequency.

If the switches 204 and 205 are placed in their lower positions to increase the positive bias on the tube 200 and simultaneously decrease the positive bias on the tube 201, there will be produced changes in the output circuit of these tubes which will be analyzed by having reference to Fig. 9. The driving voltage vector E_r is again used for reference. Since the positive bias of the tube 200 has been increased, the impedance of the tube is decreased. No change is made in the impedance of the tank circuit T_L which acts as an inductance. Consequently, this element of the circuit exerts a greater control over the phase of the current flowing in the circuit with respect to

the voltage and this current I_1 now lags the voltage E_r by a greater angle than in the previous case. There is also an increase in the magnitude of the current because of the decreased total impedance of the circuit. The increase in the magnitude of the current and the decrease in the impedance of the tube combine to produce a tube reaction voltage which is slightly less than in the previous case. This reaction voltage is represented by the vector $I_1 R'_T$. Also, because of the increase in the magnitude of the current, the reaction voltage of the tank T_L which is represented by the vector $I_1 T_L$ is increased. It may be seen that the sum of these two reaction voltages is again equal and opposite in phase to the driving voltage E_r . It will also be observed that the voltage drop across the tank T_L represented by the vector E'_1 is also increased. In the circuit of the tube 201 the reverse conditions are present, that is, the current I_2 is smaller and more nearly in phase with the voltage E_r . Also, the tube reaction voltage $I_2 R'_T$ is slightly increased and changed in phase. In addition, the reaction voltage of the tank T_c is decreased as shown by the vector $I_2 T_c$. Again it will be observed that the summation of the vectors $I_2 R'_T$ and $I_2 T_c$ is equal and opposite in phase to the voltage E_r . Now it may be seen that the voltages E'_1 and E'_2 developed across the respective tanks T_L and T_c when combined produce a feed-back voltage E'_{FB} which leads in phase with respect to the oscillator voltage E_r . Consequently, the voltage which is supplied to produce oscillation is the vector sum of the voltages E_r and E'_{FB} and is represented by the vector E'_0 . Also this voltage is seen to lead the voltage E_r of the primary tank T and therefore the frequency of oscillation is increased.

While the unsymmetrical bias conditions are maintained on the tubes 200 and 201, the oscillator frequency will increase until a second state of equilibrium is obtained. Since the tubes are being excited at the oscillator frequency, the higher the frequency becomes the more nearly the resonant frequency of the tank T_L is approached and the greater the deviation from the resonant frequency of the tank T_c becomes. It will be obvious that, as the frequency increases, the current flowing in the output circuit of the tube 200 decreases and the current in the output circuit of the tube 201 increases. The reason for this is that the impedance of the tank T_L increases with an increase in frequency while that of the tank T_c decreases. It is evident that ultimately the frequency will reach a point at which a balance is restored between the two output circuits, at which point the currents flowing in these circuits will again be equal in magnitude and will lag and lead, respectively, the driving voltage by the same angles. These are the conditions which are represented by the vector diagram of Fig. 8 and it has been demonstrated that the feed-back voltage under these conditions is in phase with the oscillator voltage and stable conditions exist.

It is believed that it will be obvious to those skilled in the art that an increase in the positive biasing of the tube 201 and a corresponding decrease in the positive biasing of the tube 200 will be effective to produce a feed-back voltage which is lagging with respect to the oscillator voltage. This condition will result in a decrease in the oscillator frequency until a new frequency is reached at which stable conditions again will exist. Thus it is evident that such a system provides an almost instantaneous effect upon the oscil-

lator in response to a change in the biasing of the vacuum tubes employed.

Having reference again to Figs. 5 and 6, there is shown a vacuum tube 211 which is provided with an input circuit connected between its grid and cathode which includes a portion of a potentiometer 212 and the integrating network 191. The potentiometer 212 is connected across the terminals of a secondary winding 213 of the transformer 96. Consequently, the tube 211 is driven at a frequency which is equal to that of the oscillator 80. The integrating network 191 serves as the means for altering the bias applied to the grid of the tube 211 in a manner which will be disclosed presently. The output circuit of this tube is connected across the terminals of the battery 82 and includes a resistance 214, a tank circuit 215, and the space discharge path of the tube 211. The resistance 214 is shunted by a condenser 216, the purpose of which is to bypass the high frequency currents around the resistance. There is also connected across the terminals of the battery 82 a voltage divider including the resistance 214 and resistances 217 and 218 and a portion of a potentiometer 219 which is connected to another secondary winding 220 of the transformer 96.

There is also provided in the phasing frequency corrector another vacuum tube 221 which is provided with an input circuit connected between its grid and cathode and which includes the resistance 218 and a portion of the potentiometer 219. The output circuit of this tube is connected across the terminals of the battery 82 and includes a resistance 222, a tank circuit 223 and the space discharge path of the tube. The resistance 222 is shunted by a condenser 224 for the purpose of providing a low impedance path for the high frequency currents.

The tank circuit 215 constitutes a secondary tank circuit which is tuned for resonance at a frequency which is higher than that of the primary tank circuit 86—87 of the oscillator 80. The tank circuit 223 forms the other secondary tank circuit and is tuned for resonance at a frequency which is lower than that of the primary tank circuit associated with the oscillator 80. Hence, as far as the alternating currents are concerned the tank circuit 215 acts as an inductance and the tank circuit 223 acts as a capacity. These two secondary tank circuits are connected respectively through resistances 225 and 226 and are connected through a direct current blocking condenser 227 to the primary tank circuit 86—87.

The correcting action of the phasing frequency corrector circuits outlined above will be described by assuming that conditions of equilibrium obtain and the oscillator 80 is operating at a given frequency. If now one or more correcting impulses are impressed upon the integrating network 191 from the transformer 160 of Fig. 3 and these impulses are of the same polarity, the grid bias of the tube 211 is changed. If the impulses are of such a nature that the grid of the tube 211 is more positively biased, the tube will pass more current. An increase in the current flowing in the plate circuit of the tube 211 decreases the positive potential of the point 228. Since this point is connected through the resistance 217 to the grid of the tube 221, the grid of this tube is made less positive with respect to its cathode, thereby reducing the current flowing in its output circuit. The increase of current flowing in the inductive tank circuit 215 and the decrease of the current flowing in the capacitive tank circuit

223 with the attendant phase shifts of these currents with respect to the driving voltage results in the feed-back to the primary tank circuit 86—87 of the oscillator 80 of energy leading in phase with respect to the primary tank circuit energy to produce an increase in the frequency of the alternating current generated by the oscillator in accordance with the theory of operation outlined hereinbefore. As previously described, this increase in frequency produces changes in the phasing frequency corrector circuits of such a nature that equilibrium is again established to maintain the frequency at this new point.

Obviously an increase in the frequency generated by the oscillator 80 will produce an increase in the phasing frequency which is derived from the combination of the outputs of oscillators 80 and 97 because the frequency of the latter generator remains constant.

The correcting impulses which are to be used to control the frequency of the transmitting frequency generator are applied to the integrating network 194. This network serves to vary the bias of a vacuum tube 229. The input circuit for this tube includes a portion of the potentiometer 230 which is connected to a secondary winding 231 of the transformer 109 and also the integrating network 194. The output circuit of this tube is connected across the terminals of the battery 82 and includes a resistance 232, a secondary tank circuit 233 which is arranged to act as an inductance and the space discharge path of the tube. The resistance 232 is shunted by a condenser 234 for the purpose of providing a low impedance path for the high frequency currents. A tube 235 is also included in the transmitting frequency corrector and is provided with an input circuit including a portion of the potentiometer 236 which is connected across another secondary winding 237 of the transformer 109. The output circuit of this tube includes a resistance 238 connected in series with a secondary tank circuit 239 which is arranged to act as a capacity. The resistance 238 is shunted by a condenser 240 to bypass the high frequency currents.

The impedance of the tube 229 is altered in accordance with the correcting impulses which are applied to the integrating network 194 by the transformer 182. The grid of the tube 235 is oppositely biased in a manner similar to the biasing of the tube 221. The energy components derived from the secondary tank circuits 233 and 239 are combined and connected through the direct current blocking condenser 241 to the primary tank circuit 112 associated with the oscillator 104. The control of the frequency of this oscillator is effected in substantially the same manner as that of the oscillator 80. Consequently, any change in the frequency of the oscillator 104 results in a change in the frequency of the transmitting frequency generator.

So long as the signals which are being received from the line W are not subjected to influences which produce phase shifts, the phasing frequency generator and the transmitting frequency generator are maintained constant both as to frequency and their mutual phase relationship. However, such ideal conditions are not easily realizable in practice. Therefore, the operation of the operation of the repeater will be described under conditions which are met in operating the system over line wires which are subject to interference.

For the consideration of one phase of the operation of the repeater, assume that the periodic

device which is employed to time the transmission of the signals from the remote station connected to the line W is maintained constant. Under these conditions, the only phase shifts which may be present in the signals that are received from this line by the apparatus herein disclosed are those which are produced by interference effects, such as the introduction into the signals of extraneous currents. Suppose that the arrival time of a given signal is later than its immediate predecessor, which was a perfectly timed signal. At the time of the reversal produced by the late-arriving signal, an impulse is generated in the secondary winding 161 of the transformer 29. This impulse is employed by the phase comparator comprising the tubes 157 and 158 and their associated circuits to generate a correcting impulse in the secondary winding 162 of the transformer 160. Since the impulse generated in the winding 161 occurs at a time which is later than normally, the phase comparator tube 157 will be conditioned for the conduction of space current. The amplitude of the correcting impulse is sufficient, when amplified, to break down the neon lamp 192. The polarity of the correcting impulse generated in the transformer winding 162 is such that an impulse of negative polarity is applied through the neon lamp 192 to the integrating network 191. As previously described, such a condition tends to produce a change in the frequency of oscillation of the oscillator 80 of such a nature that the frequency of the phasing frequency generator tends to be decreased. In actual practice, the system is best arranged to require a succession of a small number of like impulses to be generated before a change in the frequency of the generator is produced. However, it is thought that the operation may be better understood if it is assumed that this change in frequency is made substantially instantaneously so that the next half cycle of the phasing frequency is slightly delayed. When it does occur, the tube 145 is rendered conducting and the surge of space current through the winding 152 of the transformer 154 generates the first scanning impulse in the winding 164. This impulse is generated at a time which is approximately one-half a baud, or signal impulse, later than the arrival time of the signal. In accordance with the polarity of the received signal, the first scanning impulse which is impressed by conductors 57 upon the anode circuits of the first pickup tubes 50 and 51 results in the operation of one of the storing tubes 59 or 60. At a time, equal to the time delay of the received signal less than one-half a baud, after the operation of the storing tubes, the signal is passed to the transmitting tubes 72 and 73 for transmission over the line E. In other words, there is no change made in the spacing of the retransmitted signals, even though a change has occurred in the received signals and a corresponding change has been made in the phasing frequency generator.

One-half cycle of the phasing frequency later than the generation of the first scanning impulse, the tube 144 is rendered conducting to generate in the winding 165 of the transformer 153 a comparison impulse which is employed by the phase comparator including tubes 179 and 180 for the purpose of comparing the phase relations of the phasing frequency and transmitting frequency generators. Since a slight change has been made in the frequency of the phasing frequency generator prior to the comparison, a small

phase difference will be detected and a correcting impulse generated in the secondary winding 184 of the transformer 182. This correcting impulse is utilized to apply an impulse to the integrating network 194 of such a polarity (in this case negative) that a tendency is produced to decrease the frequency of the transmitting frequency generator. However, the integrating network is arranged so that one such impulse is virtually ineffective to produce any change in the frequency of the transmitting frequency generator. Consequently, when one late-arriving signal is retransmitted over the line E, there is no difference in the timing interval between it and its predecessor than in any of the previously transmitted signals.

The reason for such an arrangement will be apparent when it is considered that the arrival time of the following signal may be early with respect to the signal just considered, or nearly even with respect to a perfectly timed signal. In either case, a discrepancy between the phase of the early arriving signal and the phasing frequency generator will be detected by the phase comparator including the tubes 157 and 158 and an appropriate correcting impulse applied to the phasing frequency corrector to increase the frequency of the phasing frequency generator. Thus, it is seen that so long as the frequency of the originally transmitted signals is unchanged, phase differences occurring in the individual signals as they are received at the repeater are continually operating to correct the phasing frequency generator so that it may be kept in step with each individual signal. At the same time, substantially no change is made in the frequency of the transmitting frequency generator, with the result that the retransmitted signals are unchanged as to their spacing from one another in point of time.

Suppose now that the frequency of the originally transmitted signals begins to drift in one sense or the other, say the tendency is for the frequency to decrease. Then, aside from the effects of fortuitous disturbances on the received signals, each signal will arrive later than its predecessor. Hence, the operation of the phasing frequency corrector effects a decrease in the frequency of the phasing frequency generator. Consequently, there is a succession of like correcting impulses generated in the winding 184 of the transformer 182, which produces an accumulation of impulses in the integrating network 194 which, after a period of time, becomes effective to alter the frequency of the transmitting frequency generator. This change, however, is of such a gradual nature that a slow change is made in the frequency of the retransmitted signals. Therefore, there is a minimum of distortion of a phase shifting character produced in the retransmitted signals.

In operating a synchronous telegraph system of the multiplex type, it is the practice at times when no signals are being transmitted to periodically reverse the polarity of the potential which is applied to the line circuit. These reversals occur at a frequency which is substantially less than that of the highest telegraph signal reversals and are for the purpose of maintaining synchronism between the terminal apparatus. These synchronizing reversals are also effective to maintain synchronism between the terminal apparatus and the equipment of any repeaters included between the two terminals which employ periodic timing mechanisms. One such repeater

is that in which the present invention is embodied.

Instead of the relatively low frequency synchronizing alternating current which is transmitted, it is necessary at other times to transmit alternating current signals having a frequency substantially equal to the telegraph signaling frequency. For example, when the system is being lined up, it is the practice for each repeater station to transmit alternating current at signaling frequency to the next repeater station or to a terminal station in order that the attendant at the remote station may balance his artificial line while he is receiving at his station the signal frequency alternating current. It sometimes becomes necessary to make such a line-up at times when telegraph signals are being received from the opposite end of the circuit. In any event, it is necessary to prevent either the telegraph signals or the synchronizing reversals being received from the opposite direction from being transmitted to the station at which the line-up is being made.

In the regenerative repeater disclosed herein there are two sources of alternating current, but each has a frequency which is twice that of the highest signal reversal frequency. In order to utilize the alternating current derived from one of these local sources, it thus becomes necessary to halve the generated frequency in order to transmit alternating current at the telegraph signaling frequency. This is accomplished by utilizing the operating characteristics of the transmitting apparatus including the gas discharge tubes and the delayed action positive feedback circuits with which these tubes are provided.

Having reference again to Fig. 4, the manner in which one of the local sources of oscillations is employed to operate the transmitting tubes 72 and 73 will be described. When it is desired to transmit to the remote station connected to the line E alternating current at signalling frequency, a switch 242 is moved to the left. It may be seen that by this operation the secondary winding 71 of transformer 69 is short-circuited, thereby preventing any of the signals received from the line W from affecting the operation of the transmitting tubes and at the same time the input circuits of the transmitting tubes are connected in multiple. Also, the connection from the mid-point of the secondary winding 71 to the common cathode circuit is connected to include the secondary winding 175 of the transformer 174. There is induced in the winding 175 a series of unidirectional impulses at a frequency equal to twice the telegraph signaling frequency. The winding is connected so that this series of impulses periodically renders the grids of both of the transmitting tubes 72 and 73 positive with respect to their associated cathodes.

The operation of the transmitting tubes to transmit signal frequency alternating current to the line E will be described by assuming that the tube 72 is conductive and the tube 73 is non-conductive. The space current of the tube 72 flowing through the common cathode resistance applies a fixed negative bias to the grid of the tube 73 as described. Also, a predetermined time after the extinction of the arc in the tube 73 a positive bias is also impressed upon the grid of this tube by means of the delayed action network. In accordance with the foregoing description of these circuits this time is approximately equivalent to one-half of the baud time. Both of the

transmitting tubes are provided with such networks, the operation of which has been described previously. As described, the combination of the negative and positive biases is insufficient to operate the tubes. Therefore, until one of the impulses is generated in the secondary winding 175 of the transformer 174, the transmitting tube 73 remains unoperated. However, when the next impulse is generated by the transformer 174 and positive potential with respect to the cathodes is applied to the grids of the transmitting tubes, the tube 72 which is already operated is unaffected, but a discharge is initiated in the unoperated tube 73. It should be noted that the impulses which are applied to the input circuits of these tubes are of relatively short duration, somewhat less than one-half a signal baud. Consequently, it is after the termination of the impulse that the delay network operates to apply positive feed-back potential to the tube 72 which was extinguished by the operation of the tube 73. However, it is important to understand that the magnitude of the impulse is insufficient to re-operate the tube 72 without the aid of the positive feed-back potential. Therefore, so long as the time delay introduced by the network is greater than the time duration of the impulse, only one tube will be operated by one impulse.

Thus, it is seen that the succession of unidirectional impulses applied simultaneously to the input circuits of the transmitting tubes produces the alternate operation of these two tubes. Therefore, the signals which appear in the input circuits of the transmitting tubes and which are transmitted over the line E have a frequency which is exactly one-half of that of the impulses impressed upon the input circuits of the tubes.

The foregoing description of the frequency divider circuits employed in the regenerative repeater is concerned only with the fundamental or essential elements. Reference has been made to a series of unidirectional impulses employed to operate the transmitting tubes 72 and 73 in the manner described. Actually there are applied to the multiplied input circuits of these tubes other potentials which are inactive as far as these circuits are concerned, and therefore have no effect upon the operation of the transmitting tubes. These other potentials are unidirectional impulses of opposite polarity to those utilized by the tubes and are spaced 180 electrical degrees therefrom. It will be apparent that the inactive, as well as the active, series of unidirectional impulses is derived from the secondary winding 175 of the transformer 174 when it is considered that the tubes 168 and 169 are operated alternately and instantaneously in response to a sinusoidal alternating current potential. Therefore, there is produced in the output circuits of these tubes a substantially square-topped alternating current. At the beginning of each of the alternate half-cycles of the output alternating current there is produced by induction in the secondary winding 175 of the transformer 174 a transient voltage of one polarity and of relatively short duration. Also, at the end of each of these alternate half-cycles there is produced in the transformer secondary winding a transient voltage of the opposite polarity and of relatively short duration. The transient voltages developed in the winding 175 are impressed upon the multiplied input circuits of the transmitting tubes 72 and 73. It will be obvious to those skilled in the art that only those impulses which render the grids positive with respect to their associated cathodes are effective in

these circuits. The other series of impulses which render the grids negative with respect to the cathodes does not affect the operation of the transmitting tubes in any way.

Thus, it should be apparent that the impression of alternating current impulses of the character described upon the input circuits of the transmitting tubes connected in parallel will result in the production in the output circuits of these tubes of an alternating current having a frequency which is the second subharmonic of the alternating current applied to the input circuits.

The frequency divider connected and adjusted as described utilizes a series of relatively short impulses for its successful operation. If, instead of adjusting the delay networks connected to these tubes so that the positive feed-back potentials are applied to the grids of the tubes with a time delay equal substantially to one-half a baud, they are adjusted to produce a time delay equal to slightly more than one-half a baud, say three-quarters of a baud, each of the impulses may comprise a complete half cycle of the alternating current applied to the input circuits of the tubes. Such an arrangement will permit the operation of the transmitting tubes 72 and 73 in response to an alternating current input having substantially any constant wave form to produce in the output circuit of the tubes an alternating current having a frequency which is exactly half of the frequency of the input alternating current. Such an arrangement would permit the elimination of the tubes 168 and 169 and their associated apparatus. In this case, the alternating current which is applied to the grids of these tubes by means of conductors 167 would be utilized in place of the impulses derived from the secondary winding 175 of transformer 174.

It will be apparent to those skilled in the art that, by suitably adjusting the delay networks to produce a time delay in the impression of the positive feed-back potential equal to slightly less than the time required for one half cycle of the desired alternating current, other sub-multiples of an alternating current may be obtained. For example, the delay can be made equal to slightly less than two bauds. In this case, the first positive impulse operates one of the transmitting tubes, say the tube 73. The second positive impulse which is spaced in time one baud from the first impulse is ineffective since the positive feed-back potential is absent at the time. However, this biasing potential is present by the time that the third positive impulse is impressed upon the input circuits of the tubes and causes the operation of the tube 72. Thus, it is seen that once every fourth half cycle of the input alternating current, there is produced one half cycle of the output alternating current, or in other words, the input alternating current is divided by four.

The frequency divider disclosed herein is susceptible of use with any thermionic device arranged to operate as a trigger device. Such operation is an inherent characteristic of the gaseous arc discharge tubes employed in the present repeater. However, other thermionic tubes in which the anode current is at all times under the control of the grid element may be arranged to operate as trigger tubes by connecting them in accordance with the instant disclosure. For example, the two tubes 59 and 60 of Fig. 3 connected as shown with inverse biasing circuits may also be provided with the delayed action positive feed-back circuits with which the gas-filled tubes shown herein are provided. When

thermionic vacuum tubes, preferably tubes having high amplification factors, are connected in this manner, their operation in response to critical potentials is substantially similar to the operation of gaseous arc discharge tubes. In this case, it may be desirable to suppress those impulses which render the grids negative with respect to the cathodes, such as by shunting the transformer winding 175 with a suitably poled rectifier. Therefore, it is apparent that the frequency divider apparatus shown and described in detail is not necessarily limited to the actual apparatus and connections shown. Instead, it is susceptible of a much broader use in accordance with the foregoing outline of other modifications thereof.

The repeater circuits described herein may be duplicated and connected between the lines E and W in the reverse manner to those disclosed in order that westbound signals traversing the circuit between the two remote stations may be regenerated also. In that case, the westbound receiver 243 is connected as shown to the terminating impedance 73 associated with the line E. Connections are made from the receiver 243 to the westbound regenerator 244 and thence to the westbound transmitter 45. This transmitter, in turn is connected to the apex of the terminating impedance 24 associated with the line W. Both eastbound and westbound repeaters function independently so that full duplex operation of the system is effected.

While the invention has been disclosed in what, at present, is considered a preferred embodiment, it is not contemplated that the invention be limited to the specific instrumentalities illustrated. For example, the types of tubes employed herein have been designated so as to enable one skilled in the art to practice the invention. However, it is obvious that other types of tubes may be employed, together with correspondingly different values of impedances, potentials, and so forth, without departing from the spirit of the invention. Accordingly, the scope of the invention is defined in the appended claims.

What is claimed is:

1. In combination, an electronic oscillator, a source of primary periodic energy to determine the normal frequency of said oscillator, two auxiliary resonant generators respectively producing periodic energies one of which leads and the other of which lags the phase of said primary periodic energy by equal angles each of less than one-half wave length relative to said primary energy, means for combining said auxiliary periodic energies to supply supplementary energy to said oscillator in phase with said primary periodic energy, and means for oppositely changing the phase angles of said auxiliary energies to displace in phase said supplementary energy with respect to said primary energy.

2. In a frequency control system, a primary generator of wave energy, two secondary resonant generators of wave energies, one leading and the other lagging the phase of said primary wave energy by less than one-half wave length of said primary energy, a utilization circuit, means for combining said secondary energies with said primary energy to supply said utilization circuit, the combination of said secondary energies being normally in phase with said primary energy, means for exciting said secondary generators from said utilization circuit, means for oppositely varying the phase of said secondary wave energies to cause a succession of like phase variations of the energy

supplied to said utilization circuit, and means for causing the combination of said secondary energies to be restored in phase with said primary energy and thereby stabilize the system at a new frequency.

3. In a system for varying the frequency of a generator between predetermined limits, an oscillation generator including an electron discharge tube having input and output circuits, a first impedance which increases with frequency within said limits coupling the input and output circuits, a second impedance which decreases with frequency within said limits connected in multiple with said first impedance, two control circuits each including one of said impedances, an impedance which is independent of frequency included in each of said control circuits, means for causing alternating currents derived from said generator to flow in said control circuits, and frequency-varying means to oppositely alter said frequency-independent impedances.

4. In a frequency control system, an oscillation generator including an electron discharge tube having input and output circuits, a reactive network having an inductive characteristic at the normal generator frequency, another reactive network having a capacitive characteristic at the normal generator frequency, the total impedance of said networks having a substantially constant value throughout a range of frequencies varying a predetermined amount above and below the normal generator frequency, two parallel circuits each including one of said networks to couple said input and output circuits and thereby furnish energy to said generator, means for causing alternating currents derived from said generator to flow in said networks, and means for varying said currents to vary the frequency of said generator by causing a phase shift of the energy furnished to said generator by said parallel circuits.

5. In a frequency control system, an oscillation generator including an electron discharge tube having input and output circuits, a primary tank circuit comprising inductance and capacitance tuned for resonance at a normal frequency coupling said input and output circuits, an inductive secondary tank circuit comprising inductance and capacitance tuned for resonance at a frequency which is a predetermined amount higher than said normal frequency, a capacitive secondary tank circuit comprising inductance and capacitance tuned for resonance at a frequency which is said predetermined amount lower than said normal frequency, said secondary tank circuits each being connected in multiple with said primary tank circuit, means for causing alternating currents derived from said generator to flow in said secondary tank circuits, the current in the respective circuits normally being of equal magnitude, and means for varying the relative magnitudes of said currents.

6. In a frequency control system, an oscillation generator including an electron discharge tube having input and output circuits, two auxiliary circuits including respectively inductive and capacitive reactance elements, two feed-back circuits each including one of said reactance elements coupling said output circuits, means for normally causing alternating currents having the frequency of said generator to flow in said auxiliary circuits, said currents being normally equal and thereby producing in said feed-back circuits equal energies which differ in phase by equal but opposite angles with respect to said generator, and means for unbalancing said alternating cur-

rents to correspondingly unbalance said feed-back energies and thereby cause said generator to operate at a new frequency which is effective to restore the balance between said alternating currents.

HAROLD F. WILDER.
ALBERT W. BREYFOGEL.

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