Feb. 6, 1945. E. H. LANGE 2,369,055

THERMIONIC DEVICE FOR CONVERTING FREQUENCY-MODULATION INTO AMPLITUDE-MODULATION

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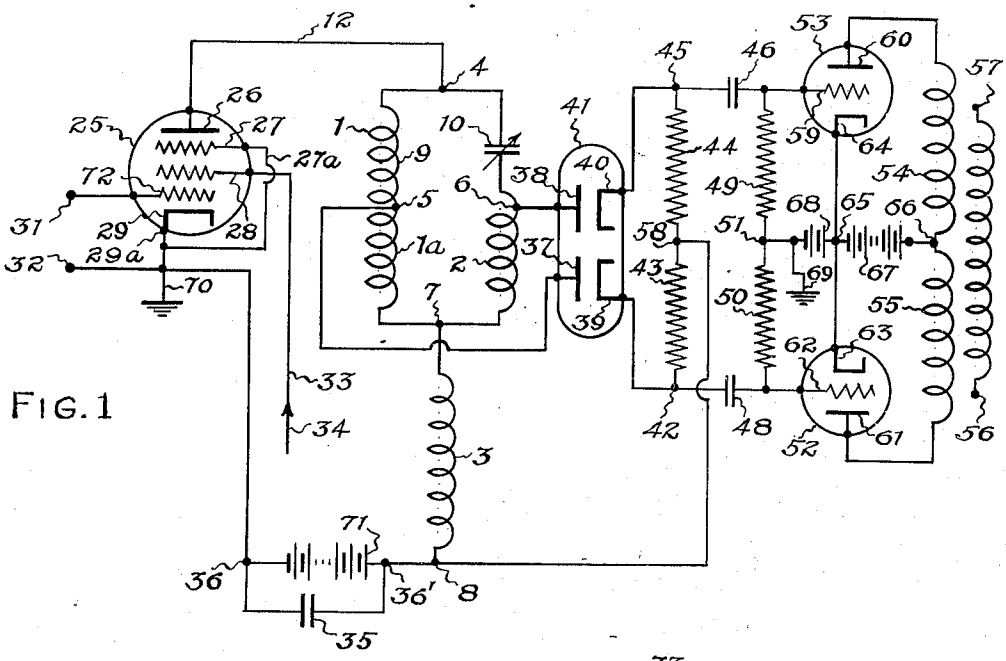


FIG. 1

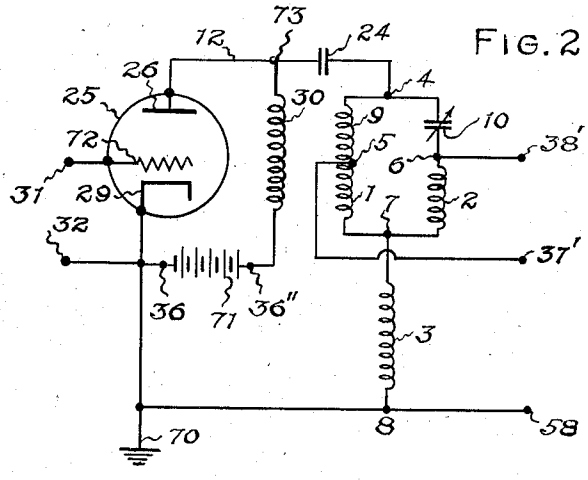


FIG. 2

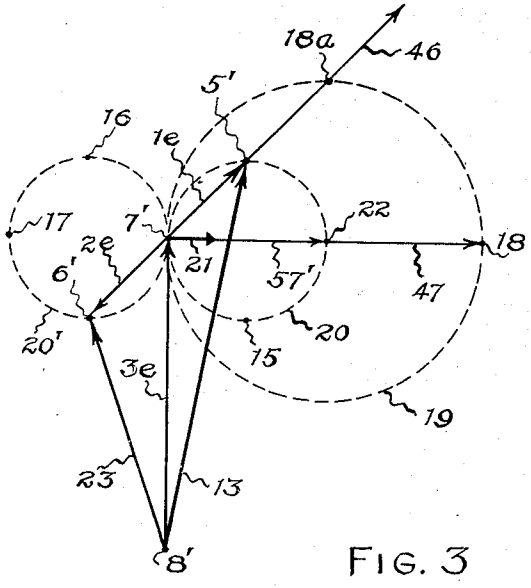


FIG. 3

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THERMIONIC DEVICE FOR CONVERTING FREQUENCY-MODULATION INTO AMPLITUDE-MODULATION

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9 Claims. (Cl. 250—20)

This invention pertains to a device for utilizing the signal-intelligence contained in a frequency-modulated alternating current, by converting the amount of such frequency changes into corresponding voltage magnitudes, and providing modification of said voltage magnitudes responsive to the rate of frequency change of the applied frequency-modulated alternating currents.

The principal object of this invention is to accomplish this desired function by providing a simple form of apparatus, having both a high degree of sensitivity, and economy of necessary component parts.

Another object of this invention is to provide a device of the character stated, having a direct proportionality between the voltage magnitude produced and the frequency deviation from the resonant or centre frequency, of the applied frequencies, and for a very substantial range of frequency deviations from the centre frequency; also to provide a device in which the polarity of the voltage produced is opposite for sub-resonant frequencies in relation to super-resonant frequencies, so that the produced voltage is zero for the centre or resonant frequency, and varies in a substantially straight line relation with the frequency deviation.

Still another object of this invention is to provide a balanced type of output circuit, and in relation to the input circuit, and adapted to use with a push-pull type amplifier.

These objects, and others, and important features of this invention are hereinafter further pointed out in the specification and appended claims, and will be better understood by reference to the drawing.

Referring to the drawing, Fig. 1 illustrates the device of this invention, connected to a conventional form of saturation-operated thermionic tube, on the input side, and to a push-pull type amplifier on the output side, and having the saturation-operated thermionic tube anode energized through the input circuit of the device.

Fig. 2, illustrates a modification of Fig. 1, adapted to connection on the output side to the same connections as are illustrated in Fig. 1, and having the anode of the saturation-operated thermionic tube separately energized through a separate choke-coil, and having the input circuit of the device of this invention conductively insulated from said anode by a stopping-condenser.

Fig. 3, illustrates a vector diagram, illustrating in a simplified form the principle of operation of the device, and certain important vector relations.

Referring to Figs. 1 and 2, at 25 is a thermionic tube, having an anode 26, a cathode 29, a control-grid 72, a suppressor-grid 27 connected to the cathode 29 by connection 27a to terminal 29a, and a screen-grid 28 connected to the lead wire 33. The cathode terminal 29a is connected to ground by the connection 70. The terminals 31 and 32, are connected respectively to the control-grid 72 and the ground connection 70. The anode 26 is energized through the connection 12, and from the source of continuous voltage 71, connected between the terminals 36 and 36', the positive terminal of said source being at 36', and the negative terminal 36 being connected to the ground connection 70. At 35, Fig. 1, is a by-pass condenser, permitting the alternating current component of current to anode 26, to pass to cathode 29 by a direct low-impedance path. Continuous positive potential is supplied to the lead wire 33 to the screen-grid 28, the unidirectional flow of current being as shown by the arrow 34; this can be provided for example by connection of the lead 33 to a positive terminal of the source 71, or by other suitable means. For the purpose of this invention, it is understood that a frequency-modulated alternating voltage is impressed across the terminals 31—32, and that the thermionic tube 25 operates as a saturated device, such that frequency-modulated alternating currents of constant amplitude are provided in the external anode-cathode circuit 12—29a, independent of any amplitude-modulation which may also exist in the alternating voltage impressed across 31—32. It will be understood that this can be accomplished by other thermionic means than the saturation of a thermionic tube such as 25, and that the present invention is not concerned with the specific apparatus for providing a frequency-modulated alternating current of constant amplitude.

Connected between the terminal 4 and the terminal 8, is the input circuit of the device of this invention. This consists of the series parallel circuit 8—7—4, in which a two-branch parallel resonant circuit is provided between 7—4, and a high impedance choke-coil between 7—8, consisting principally of inductive reactance, when traversed by alternating currents. One branch of the parallel resonant circuit consists of the inductance coil 1, the other branch consists of the capacitance 10 in series with the inductance coil 2, connected together at the terminal 6, and bridged across the terminals 4—7. At 7, is a common junction of a terminal of the choke-coil 3, the inductance 1 and inductance 2. The in-

ductance 1, is divided into two parts by the connection 5, thus providing the two portions 9 and 1a of the inductance 1.

At 41 is a thermionic double-diode, having a first anode 37 and a first cathode 39, and a second anode 38 and second cathode 40. The terminal 6 of the inductance 2, is connected as shown to the anode 38, and the connection 5 upon the inductance 1, is connected as shown to the anode 37. Connected across the cathodes 39 and 40, are the resistances 43 and 44, which are of equal magnitude, the resistances being connected in series and having the common connection 58, so that the connection or terminal 58 is at the half-resistance point upon the total resistance between the cathodes 39 and 40, or between 42 and 45, the latter terminals being connected respectively to the cathodes 39 and 40 by leads of negligible resistance. The terminal 58 is connected to the terminal 8 of the choke-coil 3, as shown. Connected between the terminal 45 and the ground connection 69, is the condenser 46 in series with the resistance 49, and similarly connected between the terminal 42 and ground connection 69, is the condenser 48 in series with the resistance 50. The condensers 46 and 48 have equal capacitance, and likewise the resistances 49 and 50 are of equal value, and have their common connection 51 connected to the ground connection 69. At 53 and 52 are thermionic tubes of a push-pull amplifier, having respective anodes 60 and 61 connected respectively to primary windings 54 and 55 of a transformer, as shown, and respective cathodes 64 and 63 connected to a common terminal 65, the terminal 65 being connected to a common terminal 66 of the windings 54 and 55, through a source of continuous voltage 67 having its positive terminal at 66, and negative terminal at 65. At 56 and 57, are terminals of a secondary winding of said transformer. The common terminal 65 of the cathodes 63 and 64, is connected to the common connection 51 of the resistances 49 and 50, through a source of continuous voltage, for purposes of providing a bias voltage, the continuous voltage source 68 having its positive terminal connected to 65, and negative terminal connected to 51. The grid 59 of tube 53 is connected to the resistance 49 as shown, and the grid 62 of tube 52 is connected to the resistance 50 as shown.

In Fig. 2, the source of continuous voltage 71, between the terminals 36 and 36'', is separately connected to the anode 26, through a choke-coil 30 connected between terminal 36'' and lead wire 12, which is connected to the anode 26. Connections of series-parallel circuit between 8—7—4, to the double-diode are otherwise identical with Fig. 1, the terminal 38' which is connected to 6, being connected to anode 38, the terminal 37' which is connected to 5, being connected to anode 37, and the terminal 58 which is connected to 8, being connected to the common connection 58 of the resistances 49, 50. The terminal 4, is insulated from conductive connection to the anode 26 by the condenser 24, which serves as a stopping condenser for the steady potential of the source 71, and otherwise has a negligible impedance in relation to the impedances of the parallel circuit 4—7, or choke-coil 3.

It will be noted that in neither Fig. 1 nor the modification of Fig. 2, is there any difference of potential across diode 38—40, or across diode 37—39, of the double-diode 41, occasioned by the presence of the continuous voltage source 71. In Fig. 1, when no alternating current is traversing the circuit 4—7—8, the diode elements 38, 39, 40, and 37, are each at the same positive potential of the source 71. In Fig. 2, under similar conditions, the diode elements 38, 40, 39, and 37, are each at ground potential.

For purposes of simplicity, heater elements commonly used to elevate the temperature of the various cathodes illustrated, to attain electronic emission, are not shown in the drawing.

The inductances 1 and 2, are understood to be such as to have a very high reactance-resistance ratio for the frequency range in which they are to be used, so that the resonant circuit 4—7 is sharply resonant to the centre frequency of the frequency-band to be employed. At exact resonance, the parallel circuit 4—7 acts as a pure resistance of high value; the inductive reactance of the choke-coil 3 should be of at least this order of magnitude, and preferably higher.

The operation of the device can best be understood by reference to a vector diagram, as shown in Fig. 3. At 21, is a current vector, representing the constant magnitude alternating current applied to the circuit 4—7—8, and of variable frequency, above and below the centre or resonant frequency of the parallel circuit 4—7. The alternating current vector 21, is taken as a reference vector, while various alternating voltages vary both in phase and magnitude as the frequency is varied. A conventional counter-clockwise rotation of vectors is employed, to illustrate and identify lagging and leading vectors. Thus, the total alternating current 21 flows through the choke-coil 3, and because the choke-coil 3 is essentially pure reactance to this current, the alternating voltage 3e across 3 leads the current 21 by substantially 90 degrees in phase, that is, the alternating current 21 lags the positive direction of the voltage vector 3e, by 90 degrees, the points 7' and 8' defining respectively the tip and end of the vector 3e. When the applied frequency is exactly at the centre or unmodulated frequency, and the parallel circuit 4—7 is exactly tuned for this frequency, an alternating voltage 47 is developed across 4—7, indicated by the vector 47 having a tip at 18, and end at 7', exactly in phase with the current 21. As the frequency is varied, the tip of 47 traces around a circle such as 19. For positive frequency deviations from centre frequency, that is, for frequencies above resonance, indicated by the lower half of the circle 19, the voltage vector 47 traces along the lower half circle 19, lagging the current 21, and for frequencies below resonance, that is negative frequency deviations, the voltage vector 47 is positioned somewhere in the upper half of circle 19, that is, leading the current 21. The voltage employed upon the anode 37 is the vector sum of the voltage 3e across the choke-coil 3, together with a part of the voltage across the coil 1, that is a part of the vector 47, in whatever phase position this vector happens to be, in relation to the existing frequency. This part of the voltage of coil 1, is the part across 1a, between 5 and 7, the coil 1 being divided into two parts 9 and 1a by the connection 5. Thus, for the particular sub-resonant frequency illustrated, the tip of vector 47 will be at the position 18a. If half of the total voltage of coil 1 is employed, between 5 and 7, as illustrated, then this voltage is as shown at 1e, upon the circle 20, having half the diameter of 19. The inductance of coil 2, is proportioned in relation to 1a, so as to have the same magnitude of alternating voltage at resonance across 6—7 as there is across

5—7. The alternating voltages across 5—7, and 6—7, are in substantially opposite phase with reference to the point 7, that is, when one of these voltages is directed toward the junction 7 the other is directed away from the junction 7. As the frequency changes, the voltage across coil 2 traces around the circle 20', of equal diameter, and opposite to circle 20. For the sub-resonant frequency illustrated, when the alternating voltage across 1a is as shown by vector 1e, the corresponding alternating voltage across the coil 2 is as shown by the vector 2e. At 46, is shown the vector voltage across the condenser 10. The unidirectional or rectified current passing the anode-cathode 38—40, is dependent upon the magnitude of the resultant voltage applied across 6—58, and likewise the magnitude of unidirectional current passing the anode-cathode 37—39 is dependent upon the magnitude of the resultant voltage applied across 5—58. Thus, for the particular sub-resonant frequency illustrated, the voltage across 5—58 is the vector sum of 3e and 1e, or vector 13; the voltage across 6—58 is the vector sum of 3e and 2e, or the vector 23. In this instance, the unidirectional current flowing from 42 to 58, will be greater than the unidirectional current flowing from 45 to 58, and there will exist a resultant voltage across the terminals 42—45, directed from 42 to 45. For zero deviation of frequency, that is, at the exact resonant frequency, the point 5' will coincide with point 22 at the tip of the vector 57', which is the half-diameter of 47, and likewise the point 6' will coincide with 17. In this condition, the resultant vectors 23 and 13 will be of equal magnitude, and there will be no resultant voltage between the terminals 42—45. Similarly, for super-resonant frequencies, when the vector 1e has traversed the circle 20 to point 15, the corresponding vector 2e will have traversed the circle 20' to point 16; the vector 23 will now be greater than the vector 13, and the resultant voltage across terminals 42—45 as a consequence of rectified current will be directed from 45 to 42. It will be noted that the frequency deviations usually employed, are but a small percentage of the actual centre frequency; thus in this usage only a part of the circles 20 and 20' is employed, on either side of resonance, and likewise the vector 3e is then substantially constant in magnitude during such small frequency changes.

There is thus provided by this device, an apparatus of but few necesasry component parts, and having a very high conversion sensitivity, as is also evident from the vector diagram. For example, a difference of the resultant voltages 13 and 23 equal to about one half the total voltage 3e across the choke-coil 3, is attained by the relatively small frequency deviation required to de-phase the voltage 1e by 45 degrees from resonant position. To accomplish a fifty percent change in voltage across the choke-coil directly by a change in frequency would require a fifty percent change in carrier frequency, with a constant alternating current through the choke-coil, whereas this same result is attainable by a frequency deviation of one percent of the centre or resonant frequency. The sensitivity is thus fifty times as great as that of the choke-coil 3 in producing a voltage difference, and is equivalent to that of a choke-coil of fifty times the self-inductance of coil 3. The above magnitudes are given for purposes of illustration only, of the sensitivity of conversion in relation to the circuit elements, and are not to be understood as limitations, or otherwise than a specific example given for the better understanding of the operation of the device. In general, the inductance of the choke-coil 3, is of the same order of magnitude as the resistance at resonance of the parallel resonant circuit. If the reactance-resistance ratio of the resonant circuit elements is designated by Q, the resistance at resonance of the parallel resonant circuit is of the general order of magnitude of Q times the inductive reactance at the centre frequency, of the coil 1. However, the choke-coil 3 is of this same order of magnitude; the sensitivity is therefore equivalent to that of an inductance coil Q times as large in inductance as choke-coil 3, or Q^2 times as large as coil 1 of the resonant circuit, in either instance, having the same alternating current magnitude passing through, and for the same frequency-deviation.

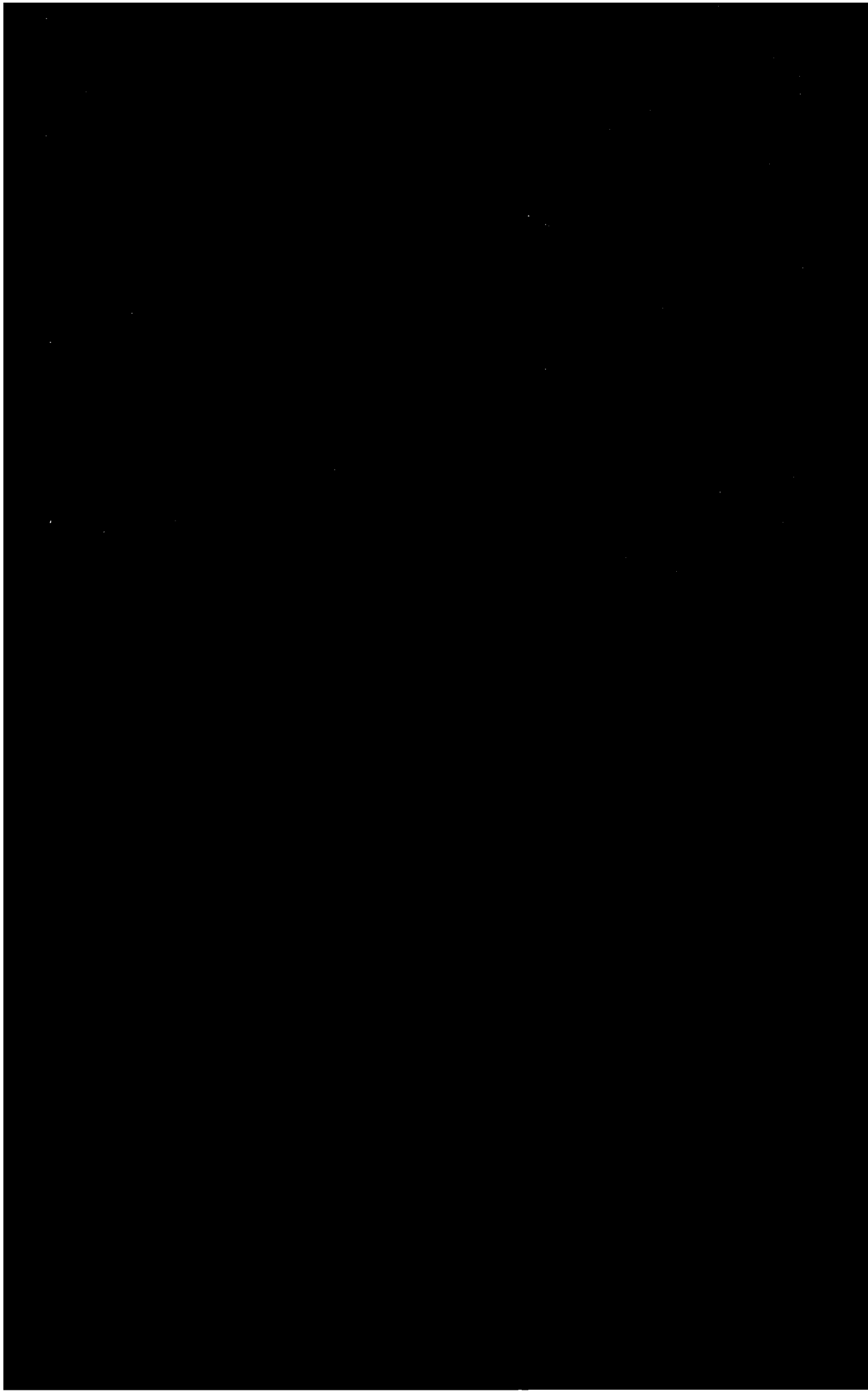
For purposes of illustration, coils 1 and 2, of the resonant circuit, are shown as separate coils, without mutual inductance between them. A single coil can also be used, the connections 5 and 7 upon a single coil being then chosen with reference to the end-terminals 4 and 6, so that the alternating voltage developed between 6—7 is the same at resonance as that developed between 5—7

An important feature of this device is the means provided by the circuit for symmetrical loading, caused by the diode circuits. Since some power is necessarily taken from the input circuit for establishing voltage across 43 and 44, this power is reflected as some additional loss, reducing the effective Q-values of the resonant input circuit. The device disclosed provides a balanced arrangement, with a minimum of undesired asymmetry of reaction of the diode loads upon the phase-determining resonant circuit.

Having thus described several illustrative embodiments of my invention, it will be evident that changes can be made in the form and arrangement of parts without departing from the spirit of my invention, as set forth in the appended claims, and I do not therefore limit the scope of the invention to such particular embodiments, or otherwise than by the terms of the appended claims.

What is claimed is:

1. The combination with an alternating current limiting apparatus having a thermionic tube with cathode, anode and control-grid, frequency-modulated alternating voltages impressed across the control-grid and cathode, and a source of continuous voltage connected across the cathode and anode, of a converter device for converting constant-amplitude frequency-modulated alternating currents into amplitude-modulated alternating voltages, said device having a choke-inductance connected in series with a two-branch parallel resonant circuit, connected in series between said source of continuous voltage and said anode, said parallel resonant circuit having one branch consisting of a first inductance, the other branch consisting of a second inductance in series with a condenser, one terminal of each of said inductances being connected to a common junction; said device having a double-diode with a first anode and first cathode, and a second anode and second cathode, a resistance connected between said first and second cathodes, a connection between the half-resistance point of said resistance and the terminal of said choke-inductance opposite said junction, a connection between the first anode and an intermediate point upon



opposite said junction, a connection from the first anode to a terminal upon said first inductance, and a connection from said second anode to the terminal of said second inductance opposite said junction; said device having connections to a thermionic tube, including connections from a cathode of said tube to an anode of said tube, through a continuous-voltage source, and through said input circuit.

7. A device for converting frequency-modulated alternating currents into amplitude-modulated alternating voltages, said device having an input circuit comprising a two-branch parallel resonance circuit in series with a choke-coil, said parallel resonance circuit consisting of an inductance coil and a capacitance shunted across said inductance coil, with a first terminal at a common connection of the inductance coil and said capacitance, and a second terminal at a point intermediate the terminals of said inductance coil, a terminal of said series-connected choke-coil being connected to said second terminal, a third terminal upon said inductance coil, and a fourth terminal upon said inductance coil, said third and fourth terminals being upon opposite sides of said second terminal, and so spaced that equal alternating voltages exist at resonance between the third and second terminal and between the fourth and second terminal; said device having an output circuit including a thermionic double-diode with a first anode and first cathode, and a second anode and second cathode, two equal resistances connected between the first and second cathodes, in series relation, a connection from the common mid-point of said resistances to the terminal of said choke-coil opposite said second terminal, a connection from the first anode to said third terminal, and a connection from said second anode to said fourth terminal, whereby a frequency-modulated constant-amplitude alternating current applied through said input circuit establishes voltage between said cathodes, directly proportional to frequency deviation from resonance frequency of said parallel circuit, and whereby the polarity of said established voltage for sub-resonant frequencies is opposite to the polarity for super-resonant frequencies.

8. A device for converting frequency-modulated alternating currents into amplitude-modulated voltages, said device having an input-circuit through which frequency-modulated alternating currents are applied, comprising a two-branch parallel resonant circuit in series with a choke-coil, said parallel resonant circuit having one branch consisting of a first inductance, and the other branch consisting of a second inductance in series with a first condenser, a terminal of said first inductance and of said second inductance being connected to a terminal of said choke-coil to form a common junction; said device having an output-circuit including a first thermionic diode-means connected between the terminal of said choke-coil opposite said junction and the terminal of said second inductance opposite said junction, through a first resistance, and having a second thermionic diode-means connected between the terminal of said choke-coil opposite said junction and a terminal upon said first inductance, through a second resistance equal to said first resistance, a circuit connected across said first resistance including a second condenser, and a circuit connected across said second resistance including a third condenser, whereby differential-voltage is established across said first and second resistances in series, proportional to frequency-deviation from resonant frequency, and of opposite polarity for sub-resonant frequencies in relation to polarity for super-resonant frequencies.

9. A frequency-demodulator device, said device having an input-circuit for impressing frequency-modulated alternating currents, comprising a two-branch parallel resonant circuit in series with a conductive impedance, said parallel resonant circuit having one branch containing a first inductance coil, the other branch containing a second inductance coil in series with a condenser, and said conductive impedance having a high ratio of reactance to resistance at the centre frequency of said alternating currents, a terminal of said first inductance coil and of said second inductance coil being connected to a terminal of said conductive impedance, to form a common junction; said device having an output-circuit including a first diode means connected between the terminal of said impedance opposite said junction and the terminal of said second inductance coil opposite said junction, through a first resistance, and a second diode means connected between said terminal of said impedance opposite said junction and a terminal upon said first inductance coil, through a second resistance equal to said first resistance, whereby differential rectified-voltage is established across said first and second resistances in series.

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