April 9, 1946.

E. K. STODOLA

2,397,992

ELECTRICAL NETWORK

Filed Nov. 17, 1942

5 Sheets-Sheet 1

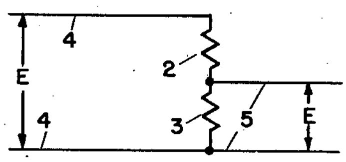


FIG-1

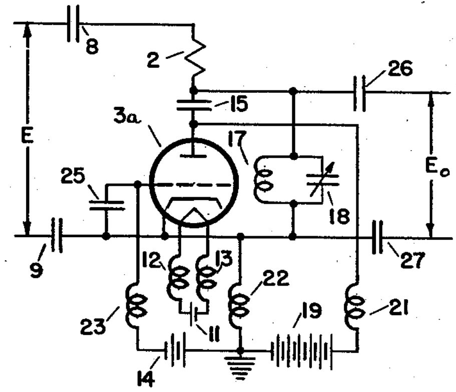


FIG-3

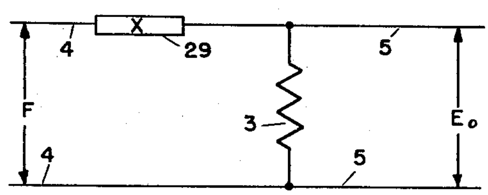
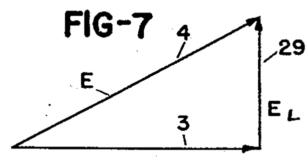


FIG-5

FIG-7



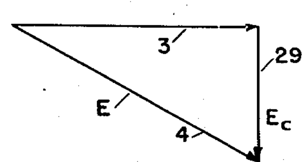


FIG-8

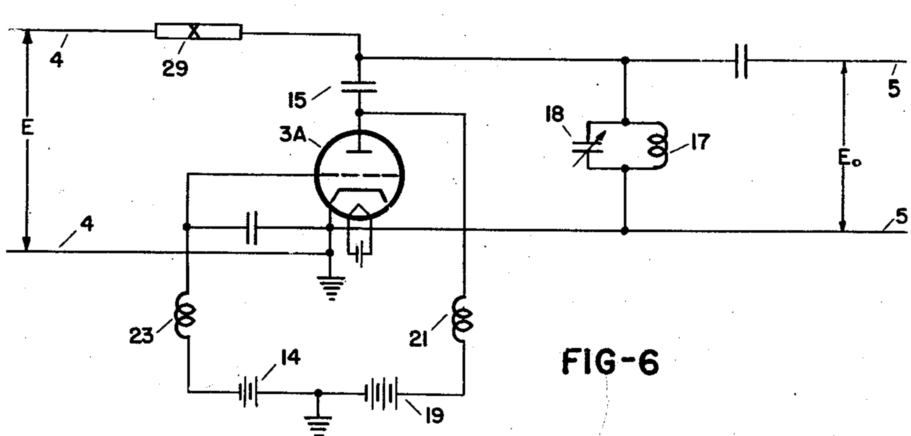


FIG-6

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FIG-2

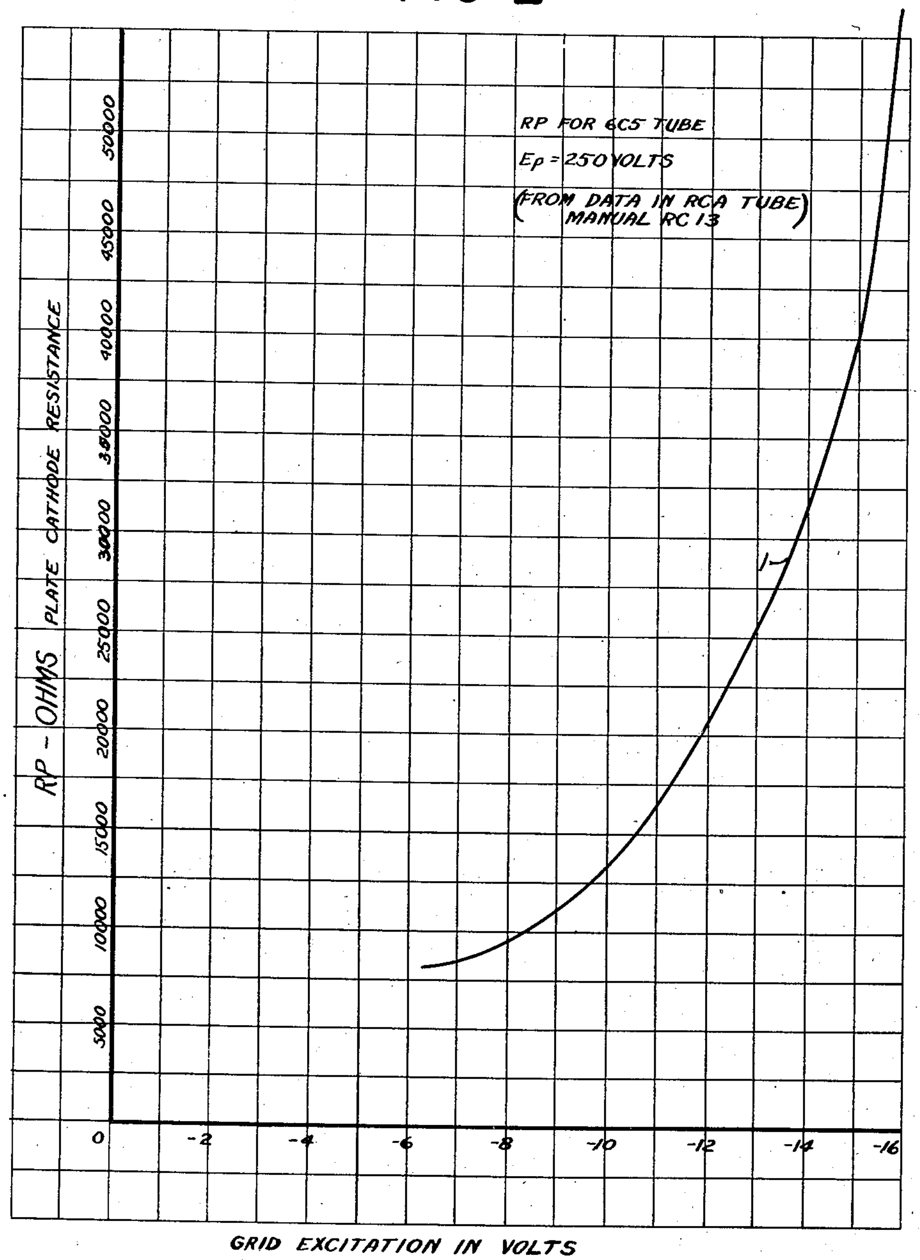

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FIG-4

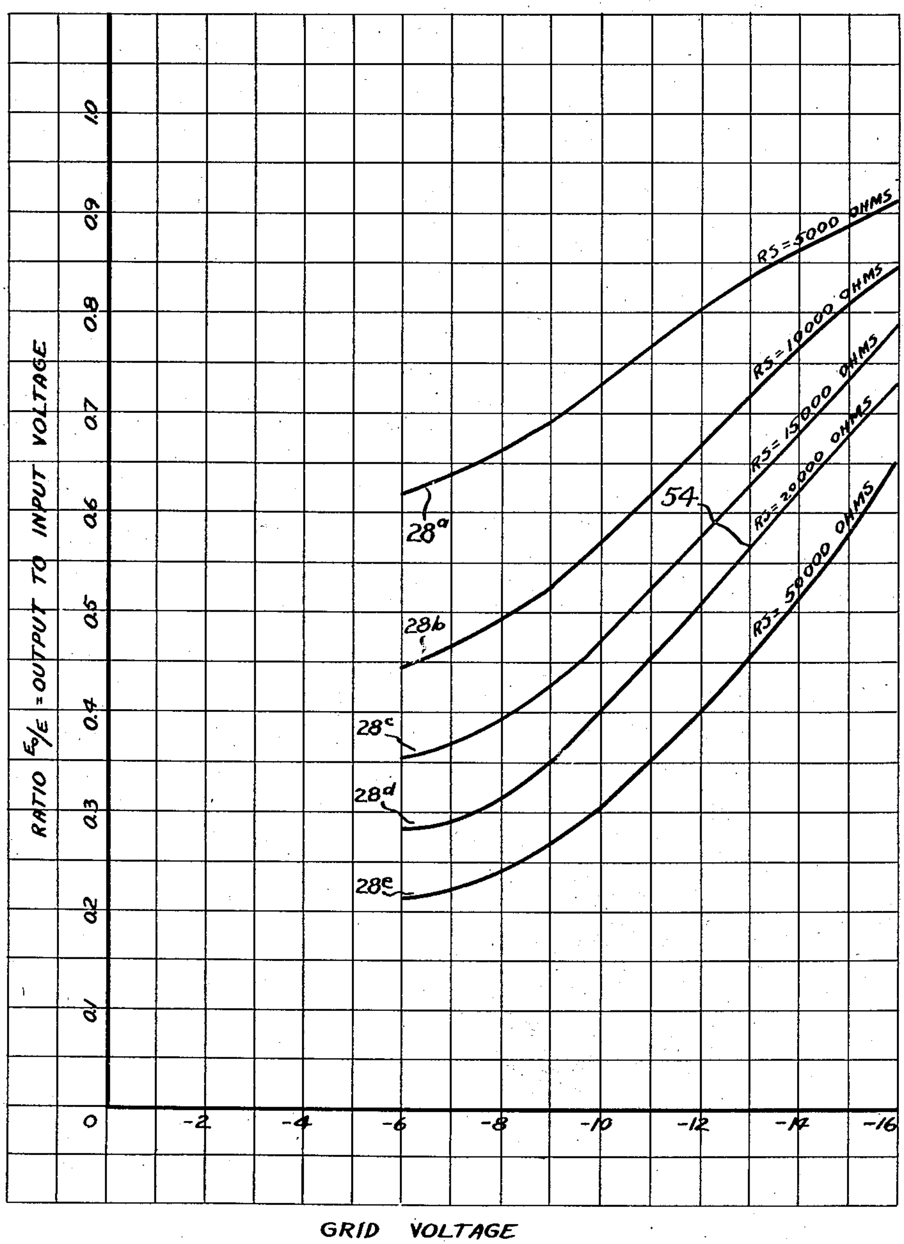

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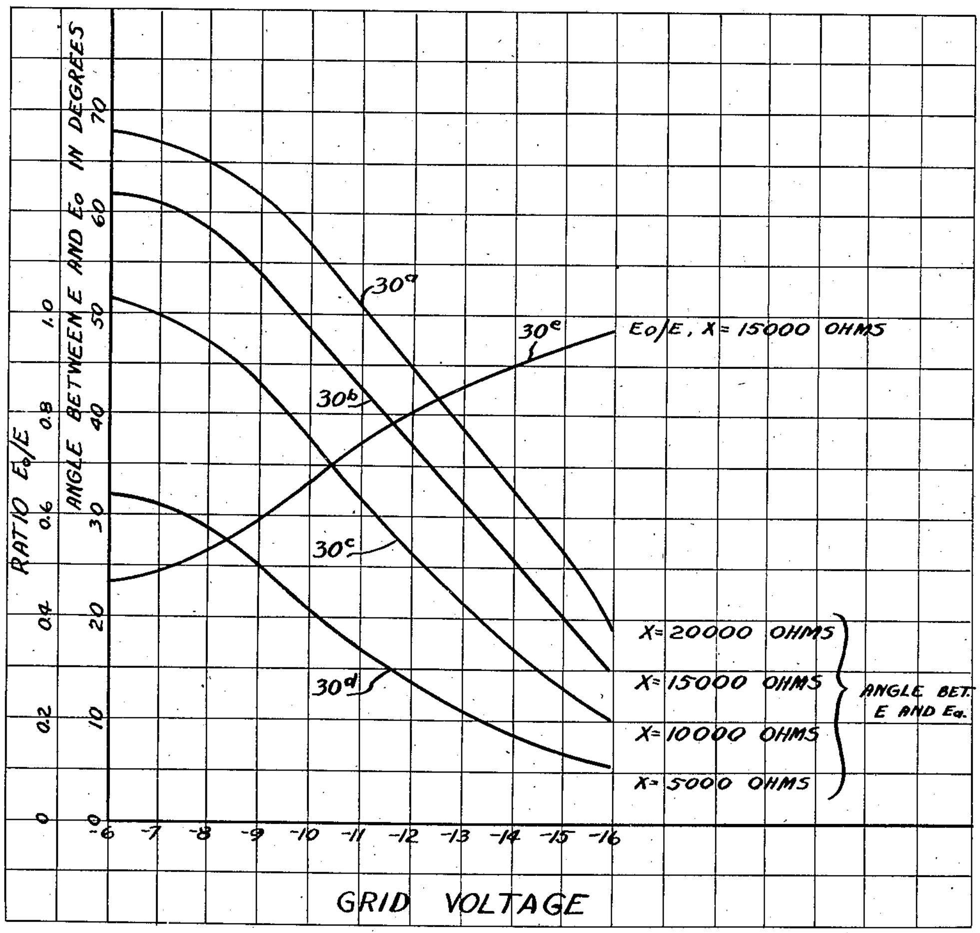
FIG-9



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ELECTRICAL NETWORK

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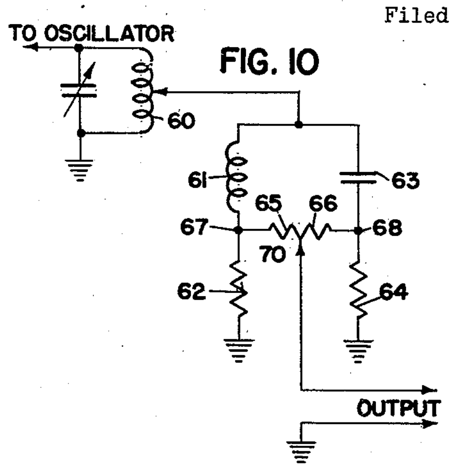
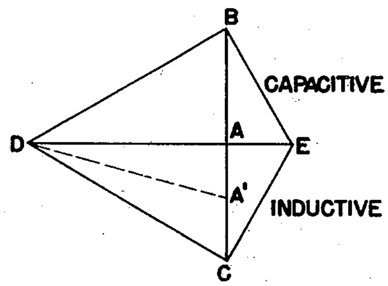


FIG. 10

FIG. 11



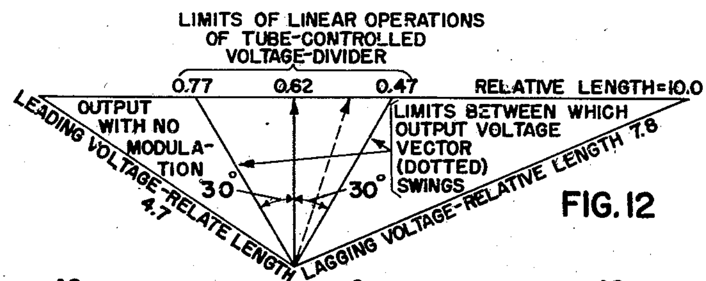


FIG. 12

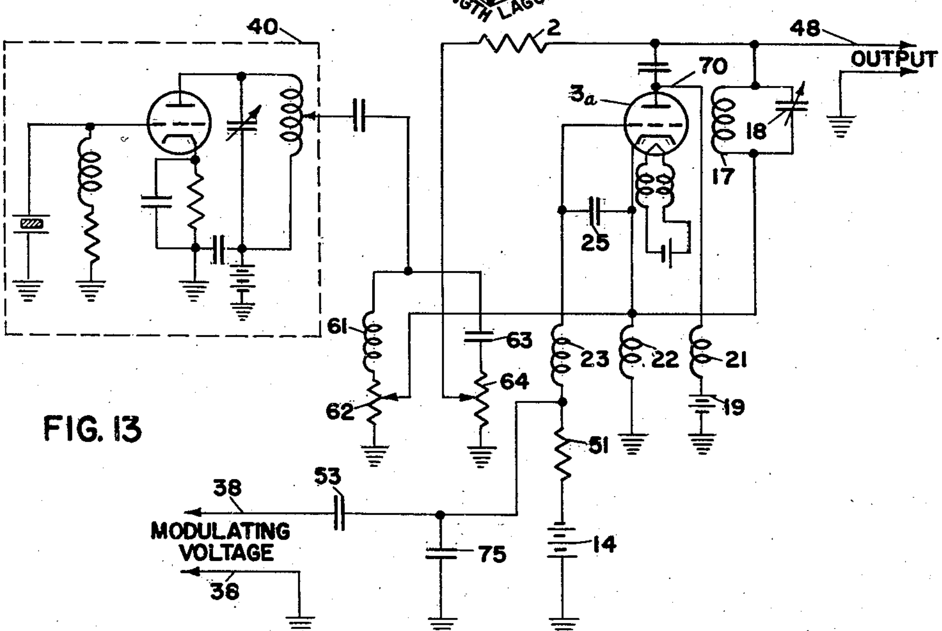


FIG. 13

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UNITED STATES PATENT OFFICE

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ELECTRICAL NETWORK

Edwin K. Stodola, Neptune, N. J.

Application November 17, 1942, Serial No. 465,921
13 Claims. (Cl. 179—171.5)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

This invention relates to electrical networks, particularly those which are suitable for modulation of carrier waves.

One object of my invention is to provide a resistance or impedance network, that may be controlled to function as a voltage-divider by modulating an electron tube, or other non-linear impedance, in the network, so that the output potential between two predetermined points of the network will vary as a linear function of the modulating force applied to the electron tube or have a non-linear function different from that of the impedance.

Another object of my invention is to provide a resistance or impedance network including an electron tube, with the characteristics of the network elements so related to the characteristics of the electron tube, that modulation of the tube by an external force will provide a resultant output voltage, between two predetermined points of the network, that shall vary as a linear function of the modulating force that is applied to the tube.

Another object of my invention is to provide an impedance network, including an electron tube, with the characteristics of the network so related to the characteristics of the tube, that the phase angle of an output voltage between two predetermined points of the network may be controlled and caused to vary substantially as a linear function of a modulating force applied to the electron tube.

Another object of my invention is to provide a phase shifting network, including an electron tube, with the characteristics of the network so related to the characteristics of the tube that the output voltage of the network may be shifted angularly with respect to a basic applied voltage, by the effect of, and in proportion to the amplitude of, an external modulating control voltage applied to the tube.

Another object of my invention is to provide a modulation system, wherein a carrier voltage is controlled by a voltage dividing network, including an electron tube that is controlled by an external modulating voltage to vary the phase relation between an output voltage and the carrier as a linear function of the amplitude of the modulating voltage applied to the electron tube.

Another object of my invention is to set up an impedance network, including an electron tube whose plate-cathode impedance is not a linear function of the grid voltage, so the voltage between two predetermined points of the network will be a linear function of the effective voltage on the grid of the electron tube.

In a radio system in which a carrier voltage is to be controlled to establish phase or frequency modulation, it is desirable to establish a direct or linear relationship between the modulating control voltage and the resulting modulation effect.

To establish such relationship I provide a voltage dividing network, from which an output voltage may be derived that is a direct linear function of a modulating control voltage that is applied to an electron control tube in the network. The plate-cathode impedance of a standard commercial triode, and hence the voltage drop across the triode, does not vary in direct proportion to the varying potential of the grid. In order to procure a voltage drop across the tube, that shall be relatively a linear function of the grid voltage, I provide a resistor or impedance element, of proper characteristics and constants, in series with the tube to constitute a voltage dividing circuit, across which a fixed voltage, such as the carrier voltage, may be applied. With a resistor of proper value connected in series with the triode, when the plate-cathode impedance is varied by varying the grid voltage, the ratio of the plate-cathode voltage drop to the total voltage drop across the circuit, including the tube and the fixed resistor, may be made to follow substantially as a direct or linear function of the modulating voltage applied to the grid of the tube through a substantial part of the relationship.

The voltage drop across the tube, in such voltage dividing circuit, may then be utilized as a control voltage that bears a direct or linear relationship to the modulating voltage which is applied to the grid.

Where the impedance device that is connected in series with the tube is purely resistive, the voltage drop across the tube will be in phase with the voltage drop across the resistor. Where the impedance device is partly or entirely reactive, however, the voltage drop across the tube will be angularly displaced with respect to the total voltage across the circuit including the impedance and the tube and the angular displacement will be varied when the impedance of the tube is varied by the modulating voltage that is applied to the grid.

The voltage dividing circuit may thus be employed to provide a plate-cathode voltage drop, the value of which is a substantially direct or linear function of the modulating voltage applied to the grid, or to provide a voltage that is phase-displaced from a base voltage, in accordance with the effective excitation of the grid of the tube by the external modulating voltage.

The manner in which the voltage dividing circuit is employed to establish such phase or frequency modulation is illustrated in the accompanying drawings, in which

Figure 1 is an equivalent diagram of a voltage dividing circuit, as shown in Figure 3;

Figure 2 is a graph, illustrating the relationship between the grid voltage and the plate cathode resistance of a triode at present available on the market;

Figure 3 is a diagram of a voltage dividing circuit, in which a resistor is connected in a series with a triode, to establish a direct linear proportionality between the voltage drop across the triode and the total applied voltage across the triode and the resistor;

Figure 4 is a family of curves, showing the relationship between the grid voltage and the ratio between the tube voltage drop and total applied voltage across the tube and resistor;

Figure 5 is an equivalent diagram of the voltage dividing circuit, with a reactor in series with the tube;

Figure 6 is a diagram of a circuit showing the tube and the reactor in series to constitute a voltage dividing circuit;

Figure 7 is voltage vector triangle for the voltage dividing circuit of Fig. 6 when the reactor is inductive;

Figure 8 is a similar triangle of the voltages when the reactor is capacitive;

Figure 9 is a graph showing a family of curves directed to the relationship of the phase angle between the voltage across the tube and the total applied voltage, as controlled by the excitation of the grid, in the circuit of Fig. 6;

Figure 10 is a simple schematic diagram of a circuit network for establishing a voltage triangle of particular construction, wherefrom a voltage is derived to energize a voltage dividing circuit;

Figure 11 is a voltage diagram of a symmetrical layout as in Fig. 10;

Figure 12 shows a non-symmetrical voltage triangle of the system of Fig. 13; and

Figure 13 is a detailed circuit diagram of a phase modulation system embodying the features of Fig. 10.

In Fig. 2 is illustrated a simple graph 1, showing the relationship between the excitation voltage on the grid of an electron tube, such as a triode, and the resistance of the cathode to plate of the tube.

In the present invention, the electron tube is utilized as a variable resistance device to control the voltage disposition in a voltage divider circuit, such as is illustrated schematically and simply in Fig. 1.

As shown in Fig. 1, the voltage divider circuit includes two resistors, 2 and 3, connected in series and energized from an input circuit 4. An output circuit 5 is connected across the terminals of the resistor 3, and that circuit 5 is energized in accordance with the potential drop across the resistor 3.

If the two resistors, 2 and 3, are of fixed values, the voltage drop across each resistor will maintain the same proportion relative to the voltage drop across the other resistor, when the applied voltage 4 is varied.

If, however, the voltage 4 that is applied to the voltage dividing circuit, is kept constant, and the resistors varied, the voltage drop across the two resistors 2 and 3 will vary according to the values of those resistors. The ratio of the output voltage of circuit 5 to the input voltage of circuit 4 will vary according to the ratio of the resistance of resistor 3 to the sum of the resistors 2 and 3.

Where the resistance 2 is kept at constant value and the resistor 3 is made variable, the drop in potential across resistor 3 will not vary directly in proportion to the change of resistance of the resistor 3, but will vary instead according to the ratio of the resistor 3 to the total resistance of the voltage dividing circuit.

Thus, for example where an electron tube is used to constitute the resistor 3 in the circuit in Fig. 1, the voltage drop across the cathode-plate of the tube will have the same ratio to the applied voltage E from the input circuit 4, as the tube resistance will have to the total resistance of the voltage dividing circuit.

As indicated in Fig. 2, the cathode-plate resistance of the tube varies with the grid excitation.

When an electron tube is employed as a resistor element in the voltage dividing circuit, the circuit arrangement becomes such as is shown in the diagram of Fig. 3. The input circuit 4 is shown connected to the voltage dividing circuit, which includes the resistor 2 and the triode 3a, through coupling condensers 8 and 9 of low impedance to the impressed frequency.

The triode 3a is shown as a typical heater-type triode, in which the heater element is shown as energized from a source of heating energy, as a battery 11, connected to the heater element through two R. F. chokes 12 and 13. The cathode is connected to one conductor of the input circuit 4 through the condenser 9. The grid is provided with a biasing potential derived from a source indicated as a battery 14, that is connected to the grid through an R. F. choke 23.

In order to balance out the inter-electrode capacitance of the triode a parallel shunt, including an inductance 17 and a capacitance 18, is connected across the tube 3a. The constants of the shunt elements 17 and 18 are such, that, at the operating radio frequency, the tube capacity and the shunt are resonant to said frequency and constitute a non-reactive circuit, with the shunt resistance being very high compared to the tube plate-cathode resistance. The plate voltage for the triode is provided by a source indicated as a battery 19. The negative terminal of battery 19 is grounded, and the positive terminal is connected through an R. F. choke 21 to the plate of the triode 3a. The cathode D. C. return path is provided by an R. F. choke 22. The grid biasing battery 14 is grounded at the positive terminal. The plate of the tube is connected to the resistor 2 through a condenser 15 having negligible impedance at the operating radio frequency to prevent short circuiting of the plate battery 19 by the impedance element 17 of the parallel shunt.

The grid electrode of the triode 3a is shown provided with a by-pass condenser 25 to the cathode, to provide a low resistance path to any appreciable radio frequency voltage between the grid and the cathode while, at the same time, permitting the application of a direct current biasing voltage between the cathode and the grid.

The two condensers 8 and 9 in the input circuit, and two similar condensers 26 and 27 in the output circuit, connected to the terminals of the triode, are provided to isolate the direct current voltage within the voltage divider assembly of Fig. 3, when that assembly is connected to the rest of a circuit. These condensers all have a negligible reactance to the impressed frequency.

In the arrangement shown in Fig. 3, as the grid voltage is varied, the resistance of the tube varies. The ratio of the output voltage, representing the drop across the tube, to the input voltage, as applied to the voltage dividing circuit, depends upon the value of the resistor 2, and the relationship of that value to the resistance characteristics of the tube 3*a*.

Since the resistance of the tube 3*a* between the cathode and the anode, will vary with the excitation of the grid, the ratio of the output voltage to the input voltage will also vary with the grid excitation.

One of the primary objects of my invention is to provide a voltage dividing circuit including a triode or other form of electron tube, with such circuit characteristics that a voltage derived from the voltage divider shall be a linear function over a substantial region of the grid voltage applied to the tube.

In Fig. 4, several curves 28*a* to 28*e* are shown, representing the relationship between the ratio of output voltage to input voltage, and the corresponding grid excitation, for different values of resistance in the series resistor 2 connected to the tube 3*a* in Fig. 3.

The value of the resistor 2, corresponding to each curve 28*a* to 28*e* is shown at the upper end of each curve. The middle curve 28*c* corresponding to a resistance value of 15,000 ohms in series with the tube, shows a linear relationship between the ratio of output voltage to input voltage Eo/E and the direct current grid voltage, between values of $Eo/E=0.795$ and $Eo/E=0.47$. Thus with a resistor 2 having a certain fixed value of resistance in series with the triode 3*a*, an output to input voltage ratio may be established that will bear a linear relationship to the grid voltage over a substantial range.

In the present instance, in the circuit shown in Fig. 3, the resistor 2 has a resistance value of 15,000 ohms, and the triode 3*a* is the tube known commercially as the "6C5." The middle curve 28*c* in Fig. 4 illustrates the linear relationship between the grid voltage and the ratio of the output voltage to the input voltage of the voltage divider circuit. According to that curve, as the grid voltage is varied between ten volts and sixteen volts, a direct linear relationship will be established between the grid voltage and the ratio of the voltage across the plate and cathode electrodes of the triode, to the input voltage, across the circuit including the resistor 2 and the triode 3*a* in series.

Thus, with a circuit including a tube, and a resistor having the proper resistance value corresponding to the characteristics of the tube, a direct linear voltage relationship may be established between the grid excitation of the tube 3*a* and an output voltage of the network circuit over an extended range of the relationship, where the input voltage is held constant.

While in the above circuit a tube has been used as a non-linear resistance, it is evident that any other known type of element, which has a non-linear relation between its resistance or impedance and the controlling function applied thereto, can be used. In addition, all or part of resistance 2 in Figures 1 and 3 can be constituted by the internal resistance of the source of voltage E.

By making the impressed voltage E, in Fig. 3, a source of carrier potential and placing a source of modulating potential in series with battery 14, the output Eo will be an amplitude modulated carrier which will bear a linear relationship to the modulating voltage over a range depending upon the constants of the circuit.

Tube controlled phase shifter

It is well known that when an alternating voltage is applied to a circuit including a resistor and an impedance device in series, the voltage drop across the impedance device is angularly displaced from the voltage drop across the resistor, and that each such voltage drop is displaced from the applied voltage. Such circuit arrangement is shown, for example, in Fig. 5, in which the applied voltage from an input circuit 4, similar to that of Fig. 2, is applied to a circuit including the resistor 3 and an impedance device 29. The circuit is similar to that shown in Fig. 2, except that the impedance device 29 is inductive or reactive, as distinguished from the non-inductive resistor 2 in the circuit in Fig. 2.

Fig. 6 illustrates a circuit similar to that shown in Fig. 3, except that device 29 connected in series with the triode 3*a*, is an impedance instead of the non-inductive resistor 2 of Fig. 3.

In Figs. 7 and 8, are shown vector voltage diagrams of the voltage dividing circuit shown in Fig. 5, depending upon whether the reactor 29 is inductive or capacitive. If the reactor 29 is inductive, the relationship between the applied voltage and the voltage drop across the reactor 29 and across the resistor 3 will be as shown in Fig. 7. If the impedance 29 is purely capacitive, the relationship between the voltage drop across the reactor 29 and the voltage drop across the resistor 2 is reversed with respect to the applied voltage as shown in Fig. 8.

In each case, the base line represents the voltage drop across the resistor 3, and the perpendicular line El or Ec represents the voltage drop across the impedance device 29, the direction being dependent upon whether the impedance device is inductive or capacitive.

If the value of the impedance 29 is kept constant and the value of the resistance is varied, while the applied voltage is constant, the drop of potential across the resistor 3 will vary, as well as the drop of potential across the reactor 29, in such manner as to vary the angle between the applied voltage and the voltage across the resistor.

Another important purpose of the present invention is to provide a system wherein the phase angle of the output voltage with respect to the input voltage will be a linear function of the voltage applied to the grid of the triode 3*a* in the system illustratively shown in Fig. 6. The phase angle between the applied input voltage from circuit 4, and the output voltage across the triode 3*a* will be the angle whose tangent is represented by the fraction, of which the numerator is the potential drop across reactor 29 and the denominator is the potential drop across the resistor, or triode 3*a*, of Fig. 6.

In Fig. 9, several curves 30*a* to 30*d* are drawn, showing the relationship between the grid excitation voltage, of the electron tube 3*a* in Fig. 6, and the phase angle between the applied voltage E and the output voltage Eo, the latter corresponding to the potential drop across the triode.

The curve 30*b*, corresponding to the case where a reactor is used having 15,000 ohms reactance, shows a linear relationship between the grid voltage and the phase angle between the applied voltage and the output voltage for the range of values of the phase angle between 15° and 55°. Thus, by use of proper circuit constants in a voltage dividing system such as shown in Fig. 6, a triode may be employed as a variable resistor, and an output voltage derived across the triode, whose angular relationship to the input voltage will be a linear function of the amplitude of the modulation voltage applied to the tube over a substantial range of that voltage.

It should be noted that considering amplitudes only, the variation of Eo/E with respect to variation in grid voltage is not a linear relationship. Curve 30*e*, in Fig. 9, shows the amplitude variation when reactance 29 has a value of 15,000 ohms. If this is considered undesirable it can be eliminated by conventional amplitude limiting or automatic volume control methods.

As is the case with Figs. 1 and 3, any other type of non-linear impedance can be used instead of tube 3*a* in Figs. 5 and 6. Also all or part of reactance 29 can be constituted by the internal reactance of voltage source E.

If source E in Fig. 6 is a source of carrier voltage and a source of modulating voltage is inserted in series with grid battery 14, the output Eo will be a phase modulated wave wherein the phase shift in degrees, will bear a linear relationship to the modulating voltage. The amplitude modulation can be eliminated by methods above referred to.

Although in the above described circuits the linear relationships are functions of the grid voltage, the circuits can be arranged to make said relationships a function of the voltage impressed on another electrode or combinations of electrodes.

Another phase modulation method

In Figs. 10 to 13, inclusive, I have illustrated another arrangement for establishing phase modulation on a carrier voltage of high frequency.

A basic diagram of the system is shown in Fig. 10, which includes an oscillator (not shown) feeding a tank circuit 60, or an equivalent source of high-frequency carrier current, and a bridge network including one circuit with an inductor 61 and a resistor 62 in series, and a second circuit parallel to the first circuit and including a capacitor 63 and a resistor 64 in series. The two parallel circuits thus constituted are grounded to complete the parallel connection of the two circuits. A voltage dividing circuit shown schematically as including two resistors 65 and 66, is connected between the two parallel circuits and is energized by the potential difference between the two terminal sections of the voltage dividing circuit, at points 67 and 68. The juncture point 70 between the two resistors 65 and 66 of the voltage dividing circuit will have a potential difference relative to ground, that will depend upon the relationship between the resistance values of the resistor 65 and the resistor 66.

If the resistor 66 be varied in accordance with some modulating voltage, the potential of the juncture point 70 will be varied, and the potential difference between the juncture point 70 and ground will then provide the output voltage whose phase-angular relationship with respect to the initial source voltage may be caused to vary in accordance with the amplitude of the modulating voltage.

In Fig. 11 is shown a vector diagram of the various voltages as distributed in the network of Fig. 10.

The entire carrier voltage as applied to the network is represented by the vector line D—E. The potential of the point B, corresponding to point 68 below the condenser 63, and the potential of the point C, corresponding to point 67 below the inductor 61, are on opposite sides of the applied voltage D—E, and the potential difference between the points B and C represents the voltage that is applied to the voltage-dividing circuit including the resistors 65 and 66. The potential of the juncture point A, representing potential of point 70 between resistors 65 and 66, corresponds to the point of intersection between the applied voltage vector D—E and the potential difference line B—C. That point of intersection, indicated as A, represents the point 70 of floating potential, that shifts above or below the line D—E, on the line B—C as a locus.

If the resistance of the resistor 66 were increased, with a resultant shift of the potential of the point 70 to the position indicated by the point A′ on the line B—C, the output voltage of the modulating network would then be represented by broken line D—A′, and the amount of phase-displacement would be represented by the angle between the line D—E and the broken line D—A′.

In the basic circuit of the simple diagram shown in Fig. 11, the constants and values of the elements in the two parallel circuits are chosen so the current values in the two main branches will be relatively high compared to the small cross-current that will flow through the voltage dividing circuit including the resistors 65 and 66 so that variation of the cross-current has a negligible effect on the fixed phase shifts produced by the phase shifting elements. As the voltage drop across the variable resistor 66 is modified by the modulating voltage, to change the ratio of the voltage C—A to voltage C—B, the phase or angular position of voltage D—A′ will be shifted, and phase modulation of the output voltage will result.

If the ratio of voltage C—A to C—B is a linear function of the modulating voltage, then linear phase modulation is obtainable between the applied modulating voltage and the output voltage, as shown by the angular shift of the broken line D—A′, in Fig. 11, from the original solid line D—A, up to about 30 degrees phase shift.

For the sake of illustration, the vector diagram in Fig. 11 has been shown symmetrical. In a circuit arrangement such as in Fig. 13, however, where the voltage dividing circuit includes a triode, it may be desirable to have the initial voltage line D—A perpendicular to the locus line B—C at a point that is not at the middle of the line B—C.

If the characteristics of the network are such, that at the quiescent point the juncture 70 is so located that the voltage represented by the line B—A is not equal to the voltage represented by the line C—A, then the elements represented by voltage lines D—B and D—C should be so proportioned that the line B—C joining these two points will be perpendicular to the output voltage line D—A, so that for a 30 degree phase shift of output voltage in either direction, the operation of the voltage divider will not depart from a linear characteristic.

The detailed diagram in Fig. 13 illustrates the various elements that are included in the circuit to establish the phase-modulated output voltage. The elements in the bridge network correspond to those in Fig. 10, and the elements in the voltage dividing circuit correspond to those already identified in Fig. 3.

The triode 3a in Fig. 13 corresponds to the resistor 66, in Fig. 10, and resistor 2 corresponds to resistor 65. The combination of resistor 2 and tube 3a and the other elements shown are the same as similarly numbered elements in Fig. 3. Choke 22 functions to keep the cathode at a high R. F. potential with respect to ground. Fig. 13 shows, in addition a modulating network for the grid voltage of 3a wherein voltage applied to lead 38 is coupled through condenser 53 across resistor 51 in series with grid-biasing battery 14. Modulation voltage applied to leads 38 will vary the grid bias and, hence, the voltage drop in tube 3a. This voltage variation will result in phase modulation as above explained in connection with Figs. 10 to 12. Condenser 75 has a high impedance to the modulating voltage but serves to by-pass any carrier voltage from the source of oscillations 40. As the modulating voltage varies, the grid potential changes the resistance of the triode 3a, and the potential of the floating potential point 70 as in Fig. 13, is correspondingly shifted between the limits indicated by the two thirty degree angles of the vector diagram of Fig. 12. The unsymmetrical arrangement of voltages illustrated is necessitated by the fact that the center of linear operation for the tube controlled voltage divider chosen occurs at a voltage ratio of 0.62.

A slight improvement in linearity at phase shifts greater than 30 degrees can be obtained by using a voltage divider network having a slightly non-linear characteristic and setting the quiescent point so that the angle between the output vector and the vector for the controllable voltage across the controllable voltage divider is not a right angle.

The phase modulators above described can be used as components of conventional frequency modulation systems. It has been pointed out by Armstrong and others that pure frequency modulation is equivalent to phase modulation in which the maximum phase shift for a given modulating voltage is inversely proportional to the modulating frequency. Hence, any device which produces phase modulation will produce frequency modulation by making the modulating voltage inversely proportional to the modulating frequency. Of course, at any single modulating frequency there is no distinction between the two. Hence, in this invention reference has been made to phase modulation with the understanding that by properly correcting the modulating voltage the same devices and methods will produce frequency modulation. In the claims the expression "wave-length modulation" will be used as a generic designation of both phase and frequency modulation systems.

The specific circuits and their constants above described are to be considered as illustrative of the principles of the invention. Numerous modifications can be made without departing from the spirit of the invention as set forth in the appended claims.

I claim:

1. A phase modulation system for a source of carrier voltage comprising a pair of branches connected in parallel across said source, one branch comprising an inductor and a resistor in series, the other branch comprising a capacitor and a resistor in series, a third branch connected between the junction of said inductor and resistor and the junction of said capacitor and resistor, said third branch comprising an impedance connected in series with the anode-cathode path of a grid-controlled electron tube, means to vary the voltage on said grid over a predetermined range, and an output circuit having one terminal connected to the junction of said anode-cathode path and said impedance and a second terminal connected to one side of said carrier voltage source, the resistance of said anode-cathode path over said range of grid voltage variation being a non-linear function of voltage variation on said grid, the magnitude of said impedance being so related to the average resistance of said anode-cathode path over said range that the ratio of the magnitude of a given characteristic of the voltage across said anode-cathode path with respect to the magnitude of a like characteristic of the voltage across said third branch is a substantially linear function of said grid voltage variation.

2. A phase modulation system for a source of carrier voltage comprising a pair of branches connected in parallel across said source, one branch comprising an inductor and a resistor in series, the other branch comprising a capacitor and a resistor in series, a third branch connected between the junction of said inductor and resistor and the junction of said capacitor and resistor, said third branch comprising a resistor connected in series with the anode-cathode path of a grid-controlled electron tube, means to vary the voltage on said grid over a predetermined range, an output circuit having one terminal connected to the junction of said anode-cathode path and said resistor and a second terminal connected to one side of said carrier voltage source, the resistance of said anode-cathode path over said range of grid voltage variation being a non-linear function of voltage variation on said grid, the resistance of said resistor being so related to the average resistance of said anode-cathode path over said range that the ratio of the voltage drop across said anode-cathode path with respect to the voltage across said third branch is a substantially linear function of said grid voltage variation.

3. A wave-length modulation system for a constant frequency carrier source comprising a pair of parallel branches connected across the terminals of said source, one branch including a fixed inductance in series with a fixed resistance, the other branch including a fixed capacitance in series with a second fixed resistance, a third branch connected between intermediate points on said pair of branches, an output circuit connected between an intermediate point on said third branch and one terminal of said source, and modulating means to vary the impedance of said third branch.

4. A modulation system as set forth in claim 3, wherein both resistances are equal, and the inductive reactance equals the capacitative reactance at the frequency of said source.

5. A modulation system as set forth in claim 3, wherein said inductance and capacitance each have one terminal connected to each other.

6. A modulation system as set forth in claim 3, wherein the relative impedances of said branches are such that the current in the third branch is relatively small compared to the currents in the other branches.

7. A modulation system as set forth in claim 3, wherein said third branch comprises a fixed resistance in series with the space-current path of an electron tube, and wherein said modulating

means varies the impedance of said space-current path.

8. A modulation system as set forth in claim 3, wherein said third branch comprises a fixed resistance in series with the anode-cathode path of an electron tube, wherein said modulating means varies the impedance of said path, and a parallel resonant circuit connected across said path and tuned to the frequency of said source.

9. A substantially linear amplitude-modulation network for a source of carrier voltage comprising a pair of predominantly-resistive elements connected in series between the terminals of said source, one element being a resistance, the other element being the space-current path of an electron tube having control means to vary the resistance of said space-current path, a source of modulation voltage variable over a predetermined range, said control means being connected solely to said modulation-voltage source, an output circuit connected solely across said space-current path, the resistance of said path being a non-linear function of said modulation voltage over the range of variation thereof, the magnitude of said resistance being so related to the average resistance of said space-current path that the output-voltage amplitude is a substantially linear function of said modulation-voltage variation.

10. A substantially linear amplitude-modulation network for a source of carrier voltage comprising a pair of predominantly-resistive elements connected in series between the terminals of said source, one element being a resistance, the other element being the space-current path of an electron tube having control means to vary the resistance of said space-current path, a source of modulation voltage variable over a predetermined range, said control means being connected solely to said modulation-voltage source, an output circuit connected solely across one of said elements, the resistance of said path being a non-linear function of said modulation voltage over the range of variation thereof, the magnitude of said resistance being so related to the average resistance of said space-current path that the ratio of the output-voltage amplitude with respect to the voltage amplitude of said carrier-voltage source is a substantially linear function of said modulation-voltage variation.

11. A modulation network as set forth in claim 10, wherein the impedance of said output circuit is high compared to the impedance of said space-current path.

12. A modulation network as set forth in claim 10, wherein said output circuit together with the capacity of said space-current path is parallel-resonant to the frequency of said source.

13. A modulation network as set forth in claim 10, wherein the capacity of said space-current path is neutralized.

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