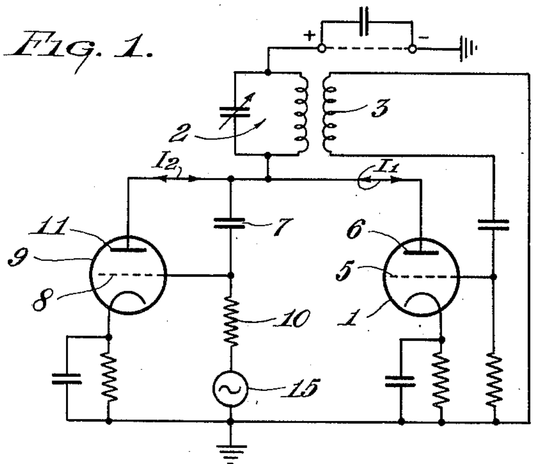
Jan. 30, 1951 G. HEPP 2,539,952

FREQUENCY MODULATION

Filed April 27, 1946 2 Sheets-Sheet 1

FIG. 1.



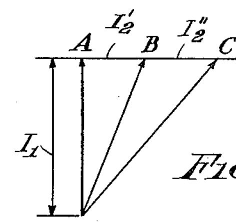


FIG. 2.

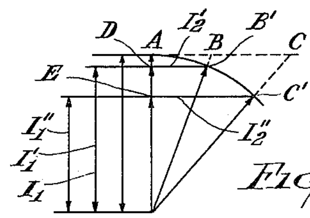
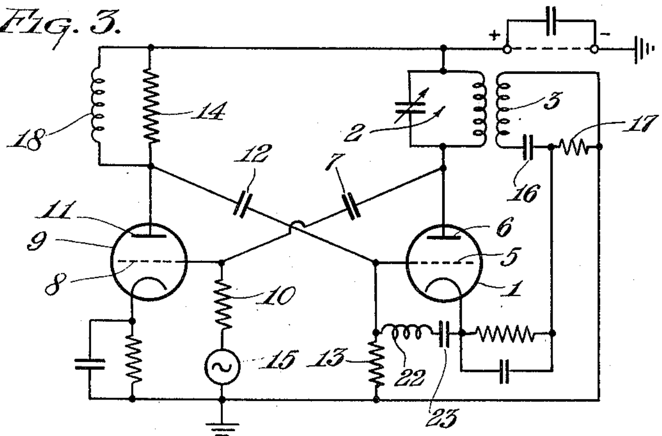


FIG. 4.

FIG. 3.



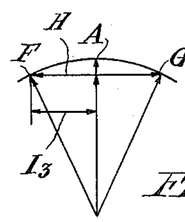
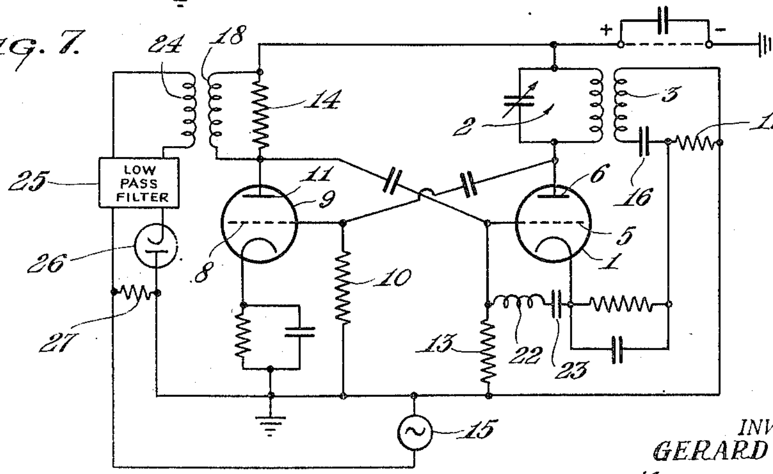


FIG. 5.

FIG. 7.



INVENTOR.
GERARD HEPP.

BY Fred M Vogel

AGENT.

Jan. 30, 1951 G. HEPP 2,539,952

FREQUENCY MODULATION

Filed April 27, 1946 2 Sheets-Sheet 2

Fig. 6.

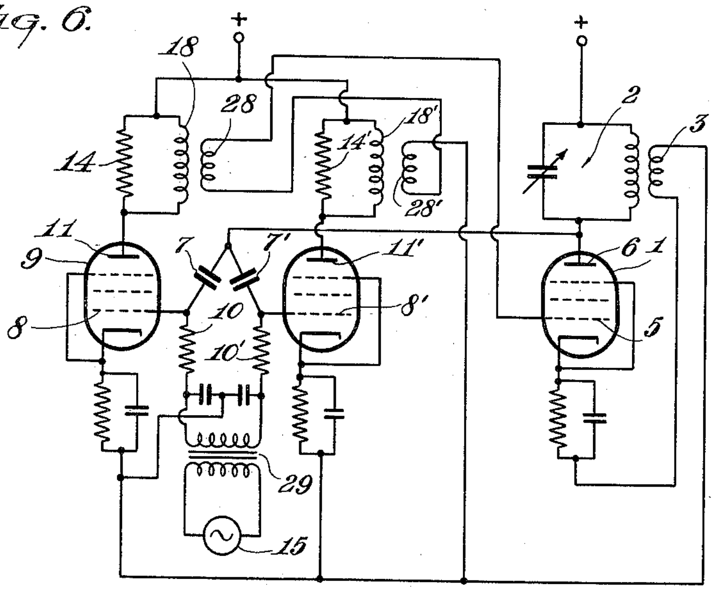
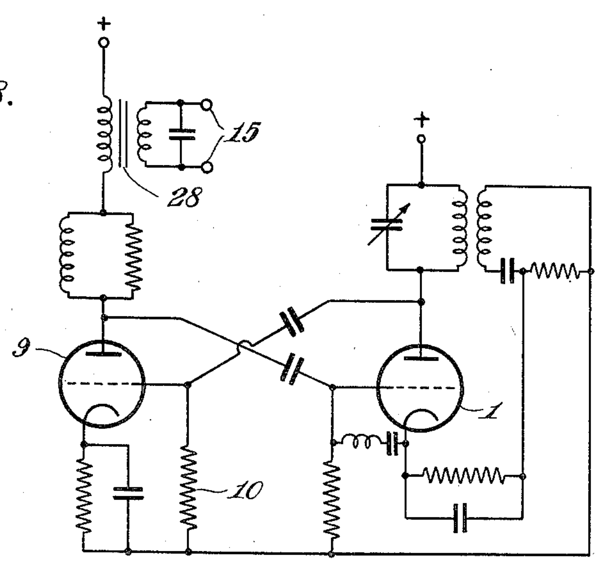


Fig. 8.



INVENTOR.
GERARD HEPP.
BY Fred M. Vogel
AGENT.

Patented Jan. 30, 1951 2,539,952

UNITED STATES PATENT OFFICE

2,539,952

FREQUENCY MODULATION

Gerard Hepp, Eindhoven, Netherlands, assignor, by mesne assignments, to Hartford National Bank and Trust Company, Hartford, Conn., as trustee

Application April 27, 1946, Serial No. 665,391
In the Netherlands July 11, 1942

Section 1, Public Law 690, August 8, 1946
Patent expires July 11, 1962

10 Claims. (Cl. 332—18)

1

It is common practice in frequency-modulating electric oscillations to employ a circuit arrangement commonly known as a "reactance tube circuit" which comprises a discharge tube which is operated in such manner that its anode current is about 90° out of phase with respect to its anode voltage, so that it behaves as an apparent inductance or capacity. This tube is usually connected in parallel with the tuning circuit of the oscillator and the value of the L or C thus connected in parallel with the circuit is controlled by control of the characteristic of the reactance tube, which results in corresponding variations in the frequency of the oscillations.

This circuit arrangement has the drawback that the reactance tube as presently used is connected in parallel with the tuning circuit whose capacity is low especially at the high frequencies Consequently, small variations in the tube have relatively such a great influence on the frequency that the stability is seriously affected. Moreover, variations of the internal resistance of the reactance tube effect a degree of amplitude modulation.

According to the invention the above-mentioned disadvantages are eliminated by applying the anode voltage of the reactance tube, which is about 90° out of phase with respect to that of the oscillator tube, to the control grid of the latter. To this end the last-mentioned tube may be provided with a special control grid, or the above-mentioned phase-shifted voltage and the feed back voltage on the oscillator may jointly be applied to one grid, or one of these two voltages may be injected in the cathode lead of the oscillator tube.

According to the invention the anode-cathode capacity of a reactance tube is isolated from the resonant circuit of the oscillator, which prevents said capacity from affecting the frequency of the oscillations produced by said oscillator, and in addition offers certain other advantages which will appear as the specification progresses.

The invention will now be described more fully with reference to the accompanying drawing in which:

Fig. 1 shows a known frequency modulation circuit,

Fig. 2 is a vector diagram explaining the operation of the circuit of Fig. 1,

Figs. 3, 6, 7 and 8 show frequency modulation circuits according to the invention, and

Figs. 4 and 5 are vector diagrams explaining the operation of the circuit of Fig. 3.

In the accompanying drawing Fig. 1 represents the above-mentioned well-known arrangement for frequency modulation comprising a reactance tube.

2

An oscillator tube 1 has in its anode circuit a resonant circuit 2, which through a feedback coil 3 acts in such a phase upon the control grid 5 of the tube as to generate oscillations. The anode 6 is directly connected galvanically to the anode 11 and through a small condenser 7 to the control grid 8 of a reactance tube 9. The grid 8 is connected to earth through a resistance 10 in series with a source 15 of modulation voltages.

Since the reactance of the condenser 7 for the operating frequency is high relatively to the resistance 10, the voltage applied to the grid 8 will lead the anode voltage by about 90°, so that the tube 9 substantially exhibits the property of a capacitive reactance. The value of this capacity depends on the slope of the characteristic curve of tube 9, and this is affected by the modulation voltage delivered at 15. Since the anode 11 is connected to one terminal and the cathode of the tube 9 is connected for high-frequencies to the other terminal of the resonant circuit 2, the tube 9 lies in parallel with the circuit 2, which involves the drawbacks already referred to above.

According to the invention the above-mentioned disadvantages are eliminated by a circuit arrangement by means of which two currents are induced simultaneously in the circuit 2, which currents will hereinafter be referred to as I_1, and I_2 respectively, the former of which is independent of the modulation, whereas the other current, which is displaced in phase by 90° with respect to the first current, varies linearly with the modulation. In the diagram shown in Fig. 1 the current I_1 is supplied by the oscillator tube 1, whereas the leading current I_2 displaced in phase by 90° is supplied by the tube 9. When the reactance tube is operating on a substantially quadratic part of its characteristic curve then I_2 will depend linearly on the modulation voltage.

In this case the vector diagram for two different modulation voltages, corresponding to currents I_2', and I_2'' respectively will be that shown in Fig. 2.

The vector OA invariably represents the current I_1, whereas the vectors AB and AC respectively represent the currents I_2' and I_2'' respectively. The vectorial sum of the two currents which in the first-mentioned case is represented by OB in the second case by OC flows in circuit 2.

A circuit arrangement according to the invention, in which substantially the same current variation in circuit 2 can be obtained, without the tube 9 being connected in parallel with this circuit, is represented in Fig. 3 of the drawing.

This circuit arrangement is different from that shown in Fig. 1 inasmuch as the anode **11** of the reactance tube is not connected to the anode **6** and to one terminal of the circuit **2**, instead is connected through a blocking condenser **12** to the control grid **5** of the tube **1**, which is grounded through a resistance **13**. In this case the feed back voltage is made operative in the cathode lead of the tube **1** but may obviously also be applied in another manner between control grid and cathode. The supply to the tube **9** is applied through the resistance **7**.

Between the grid and cathode of the oscillator tube there is connected a series circuit comprising an inductance **22** and a blocking condenser **23**, which inductance has such a value as to compensate the undesired effect of the grid-cathode capacity.

For very much the same purpose an inductance **18** is connected in parallel with the anode resistance **14** and a reactance tube, which in the literal meaning of this term is no longer a reactance tube and for this reason will be called modulation tube hereinafter, the said inductance **18** neutralizing the anode capacity of this tube.

The voltage of the anode **11**, which leads in phase by about 90° relatively to that of the anode **6**, is now impressed on the control grid **5** of the oscillator tube through the blocking condenser **12**. In this respect it should be noted that the same result can also be achieved by bringing about the phase displacement by the network **12—13** instead of by the network **7—10**. This may be achieved by giving the condenser **7** a high value and the condenser **12** a small value, instead of conversely. It has been found that this method yields advantages in practice.

Consequently the vectorial sum of the voltage leading in phase by 90° and of the feed-back voltage, which is about 180° out of phase relatively to the voltage of the anode **6**, is operative between the grid **5** and the cathode. The current thus supplied by the tube **1** to the circuit **2** will be the vectorial sum of the two currents I and I_2 separately supplied by the tubes **1** and **9** in Fig. 1, so that in the case of modulation the current in this circuit will react in exactly the same manner as in the circuit shown in Fig. 1. In effect a capacity whose value is determined by the modulation is consequently connected in parallel with the circuit **2**.

Hence the vector diagram shown in Fig. 2 also applies to Fig. 3, at least as long as the current I_1 remains uneffected by the modulation voltages, which may for instance be achieved by preventing the limitation (which, of course, is necessary in each oscillator) from taking place in the current of the oscillator tube. This can be accomplished, for instance, by connecting a bounding element in parallel with the tuning circuit, or by giving the anode voltage of the tube such a small value as to limit the circuit voltage to a sufficient degree. In limiting the tube current, however, the vector sum of the tube current will be bounded, for instance, by the length OA, resulting in the diagram shown in Fig. 4. Herein I_2, corresponding to $DB'<AB$ in Fig. 2 and similarly

$$I_{2''}=EC'<AC$$

in Fig. 2. $E_{1'}$ which initially had a value OA, now falls, however, to OD and OE respectively, which means amplitude modulation is present and, of course, is undesirable.

In the following paragraphs several circuit arrangements by means of which amplitude modulation is substantially completely eliminated will be described.

Such a circuit arrangement may, for instance, be based on the principle of impressing still a third voltage on the control grid of the tube **1**, which by itself would produce a current I_3 in the tube in phase opposition relatively to I_2 and whose value correspondends to the average value of I_2. This is vectorially represented in the diagram shown in Fig. 5. For comparison with Fig. 4 it is assumed that the value EC′ corresponds to the maximum value of I_2. In Fig. 5 when the vector I_3 is represented by $HF=\frac{1}{2}EC'$ (in value) then the value of I_1 between maximum and zero modulation appears to vary solely between the limiting values OA and OH.

A simple method of realizing this principle is shown in Fig. 3. In fact, the circuit of the reaction coil **3** comprises a phase-shifting element **16, 17**, and the value of the feed back voltage is slightly increased in such manner that the resulting feed back voltage produces a current in the tube, which is the vectorial sum of the currents I_1 and I_3.

Another circuit arrangement, in which the drawback does not occur, is obtained by making use of two pushpull connected modulation tubes jointly acting upon one oscillator tube. In this case the vector sum I_1+I_2 will move symmetrically about the vector I_1, exactly as illustrated in Fig. 5. Fig. 6 represents an executional example thereof. The anode **6** of the oscillator tube is connected through two condensers **7** and **7′** respectively to the grids **8** and **8′** respectively of two pushpull connected modulation tubes **9** and **9′** respectively. The modulation voltage originating from the supply **15** is impressed in pushpull on the two grids **8** and **8′** through the intermediary of a transformer **29** and the two resistances **10** and **10′** yieldingly, in combination with the condensers **7** and **7′**, the phase-displacement desired for the oscillator voltage. Two tubes **9, 9′** are coupled to series connected coils **28** and **28′** respectively which are located between the grid **5** and the cathode of the oscillator tube and are coupled to coils **18, 18′** in the anode circuits of tubes **9, 9′**. The operation of the circuit arrangement will be readily understood by those skilled in the art.

With the two above connecting methods, both of which are based in the pushpull principle, one achieves elimination of the above error and at the same time and more particularly the well known advantages of stability accruing from this principle, since the average out phase component of the voltage is equal to zero.

The invention lends itself particularly for use in combination with that disclosed in co-pending U. S. application Serial No. 667,446, filed May 4, 1946, now Patent No. 2,530,611, dated November 21, 1950. In this case a part of the current flowing in the reactance tube, which is amplitude-modulated by the signal, is fed back in phase opposition to the tube after detection. One example of this application is given in Fig. 7 which, except for the addition set out hereinafter, corresponds to that shown in Fig. 3.

The inductance **18** in the anode circuits of the modulation tube **9** is inductively coupled to a coil **24**. The currents induced therein pass through a low-pass filter **25** and are rectified by a diode **26**. Thus across the output resistance **27** of this diode oscillations corresponding to the low-frequency modulation voltages impressed at **15** occur and are rendered in phase-opposition by correctly poling the diode **26**. The resistance **27** now lies in series with the modulation supply **15** between cathode and grid of the tube **9**. The use of this method of negative feed back is extremely simple in arrangements according to the invention, since in the latter the current passing through the modulation tube is isolated from the anode circuit of the oscillator so that no special steps need be taken for separating this current for negative feed back purposes.

Furthermore the invention is particularly suitable for use jointly with that disclosed in co-pending application No. 667,446 previously mentioned according to which the modulation voltage is not applied as a variable grid voltage to the modulation tube, and thus has a controlling effect on the slope of the tube as has been customarily heretofore, but instead is injected in the anode circuit of the modulation tube.

Fig. 8 represents an executional example thereof, which substantially corresponds to the circuit arrangement shown in Fig. 3, but the modulation voltages are applied by means of a transformer **28** to the anode circuit of tube **9**, instead of being applied to the grid thereof.

What I claim is:

1. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and the cathode of said tube, means interposed between the grid and the cathode of said tube to couple said grid in feedback relationship to said anode, means to derive a voltage of said carrier frequency in phase quadrature with the voltage generated in said resonant circuit, means to amplitude-modulate said quadrature voltage, means to inject said modulated quadrature voltage in the grid-cathode path of said electron discharge tube, and means coupled to said resonant circuit to derive a potential in phase quadrature with the resultant voltage in said resonant circuit and to inject said potential in the grid-cathode path of said discharge tube.

2. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, means interposed between the grid and the cathode of said oscillator tube to couple said grid in feedback relationship to said anode, means to derive a voltage of carrier frequency in phase quadrature with the voltage generated in said resonant circuit, means comprising a modulator tube having an anode, a control grid and a cathode to amplitude-modulate said quadrature voltage, means to couple the anode of said modulator tube to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube to produce a frequency-modulated wave in said resonant circuit, and means coupled to said resonant circuit to derive a potential in phase quadrature with the resultant voltage in said resonant circuit and to inject said potential in the grid-cathode path of said oscillator tube.

3. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, means interposed between the grid and the cathode of said oscillator tube to couple said grid in feedback relationship to said anode, means to derive a voltage of carrier frequency in phase quadrature with the voltage generated in said resonant circuit, a modulator tube having an anode, a control grid and a cathode, means to apply operating potentials to said tubes, means to modulate the anode potential of said modulator tube to amplitude-modulate said quadrature voltage, means to couple the anode of said modulator tube to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube, and means interposed between the grid and cathode of said oscillator tube and coupled to said resonant circuit to inject a potential in phase quadrature with the resultant voltage in said resonant circuit in the grid-cathode path of said oscillator tube.

4. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, means interposed between the grid and the cathode of said oscillator tube to couple said grid in feedback relationship to said anode, means to derive a voltage of carrier frequency in phase quadrature with the voltage generated in said resonant circuit, a modulator tube having an anode, a control grid and a cathode, means to apply operating potentials to said tubes, means to modulate the anode potential of said modulator tube to amplitude-modulate said quadrature voltage, means to derive a direct potential proportional to the amplitude of said modulated quadrature voltage, means to apply said direct potential to said modulator tube in phase opposition to said modulating means, means to couple the anode of said modulator tube to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube, and means interposed between the grid and cathode of said oscillator tube and coupled to said resonant circuit to inject a potential in phase quadrature with the resultant voltage in said resonant circuit into the grid-cathode path of said oscillator tube.

5. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, means to derive a voltage of carrier frequency in phase quadrature with the voltage generated in said resonant circuit, means comprising a modulator tube having an anode, a control grid and a cathode to amplitude-modulate said quadrature voltage, means to couple the anode of said modulator tube to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube, and means interposed between the grid and the cathode of said oscillator tube and coupled to said resonant circuit to inject a potential in phase quadrature with the resultant voltage in said resonant circuit into the grid-cathode path of said oscillator tube.

6. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, means interposed between the grid and the cathode of said oscillator tube to couple said grid in feedback relationship to said anode, means to derive a voltage of carrier frequency in phase quadrature with the voltage

generated in said resonant circuit, means comprising a pair of push-pull modulator tubes to amplitude-modulate said quadrature voltage, each of said modulator tubes having an anode, a control grid and a cathode, and means to couple the anodes of said modulator tubes in opposition to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube.

7. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, means to derive a voltage of carrier frequency in phase quadrature with the voltage generated in said resonant circuit, a modulator tube having an anode, a control grid and a cathode, means to apply said quadrature voltage to the control grid of said modulator tube, means to apply modulating potentials to the control grid of said modulator tube to amplitude-modulate said quadrature voltage, means to couple the anode of said modulator tube to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube, and phase shifting means interposed between the grid and the cathode of said oscillator tube and coupled to said resonant circuit to inject a potential in phase quadrature with the resultant voltage in said resonant circuit in the grid-cathode path of said oscillator tube.

8. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, a capacitor and an inductor connected in series and coupling the cathode to the control grid of said oscillator tube, means comprising a second capacitor to derive a voltage of carrier frequency in phase quadrature with the voltage generated in said resonant circuit, a modulator tube having an anode, a control grid and a cathode, means to apply said quadrature voltage to the control grid of said modulator tube, a second inductor interposed in between the anode and cathode of said modulator tube, means to apply modulating potentials to the control grid of said modulator tube to amplitude-modulate said quadrature voltage, a third capacitor coupling the anode of said modulator tube to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube, and phase shifting means comprising a fourth capacitor and a resistor interposed between the grid and the cathode of said oscillator tube and inductively coupled to said resonant circuit to inject a potential in phase quadrature with the resultant voltage in said resonant circuit in the grid-cathode path of said oscillator tube.

9. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, means to derive a voltage of carrier frequency in phase quadrature with the voltage generated in said resonant circuit, a modulator tube having an anode, a control grid and a cathode, means to apply said quadrature voltage to the control grid of said modulator tube, means to apply modulating potentials to the control grid of said modulator tube to amplitude-modulate said quadrature voltage, means coupled to the anode of said modulator tube to produce a voltage proportional to the amplitude of said modulated quadrature voltage, rectifying means to produce a direct potential proportional to said voltage, means to apply said direct potential in phase opposition to said modulating potentials to provide negative feedback control of said modulator tube, means to couple the anode of said modulator tube to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube, and phase shifting means interposed between the grid and the cathode of said oscillator tube and coupled to said resonant circuit to inject a potential in phase quadrature with the resultant voltage in said resonant circuit in the grid-cathode path of said oscillator tube.

10. A circuit arrangement for frequency modulating a carrier wave, comprising an electron discharge oscillator tube having an anode, a control grid and a cathode, a resonant circuit interposed between the anode and cathode of said oscillator tube, a capacitor and an inductor connected in series and coupling the cathode to the control grid of said oscillator tube, means comprising a second capacitor to derive a voltage of carrier frequency in phase quadrature with the voltage generated in said resonant circuit, a modulator tube having an anode, a control grid and a cathode, means to apply said quadrature voltage to the control grid of said modulator tube, means to apply modulating potentials to the control grid of said modulator tube to amplitude-modulate said quadrature voltage, a transformer having the primary winding thereof interposed in between the anode and cathode of said modulator tube and a secondary winding, a low pass filter coupled to said secondary winding, a rectifier connected to said low pass filter, a load resistor coupled to said rectifier across which is developed a direct potential proportional to the amplitude of the lower frequencies of said modulating potentials, means to connect said load resistor in series with said modulating means to provide negative feedback control of said modulator tube at said lower modulating frequencies, a third capacitor coupling the anode of said modulator tube to the control grid of said oscillator tube to inject said modulated quadrature voltage in the grid-cathode path of said oscillator tube, and phase shifting means comprising a fourth capacitor and a resistor interposed between the grid and the cathode of said oscillator tube and inductively coupled to said resonant circuit to inject a potential in phase quadrature with the resultant voltage in said resonant circuit in the grid-cathode path of said oscillator tube.

GERARD HEPP.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,278,429	Crosby	Apr. 7, 1942
2,298,438	Usselman	Oct. 13, 1942
2,350,171	Lawrence	May 30, 1944
2,351,368	Roberts	June 13, 1944
2,356,483	Travis	Aug. 22, 1944
2,394,427	Clark et al.	Feb. 5, 1946
2,408,192	Bell et al.	Sept. 24, 1946
2,419,527	Bartelink	Apr. 29, 1947