June 7, 1949. B. D. LOUGHLIN 2,472,598

ULTRA HIGH FREQUENCY OSCILLATION GENERATOR

Filed March 1, 1945

FIG. 1

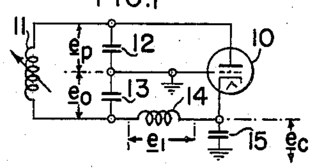
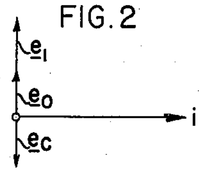


FIG. 2



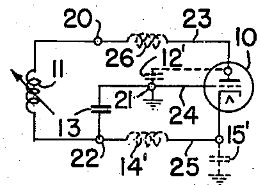


FIG. 3

FIG. 4a

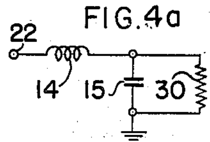


FIG. 4b

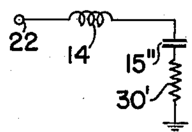


FIG. 5

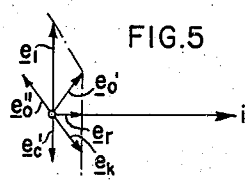


FIG. 6

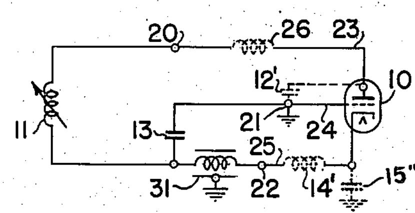
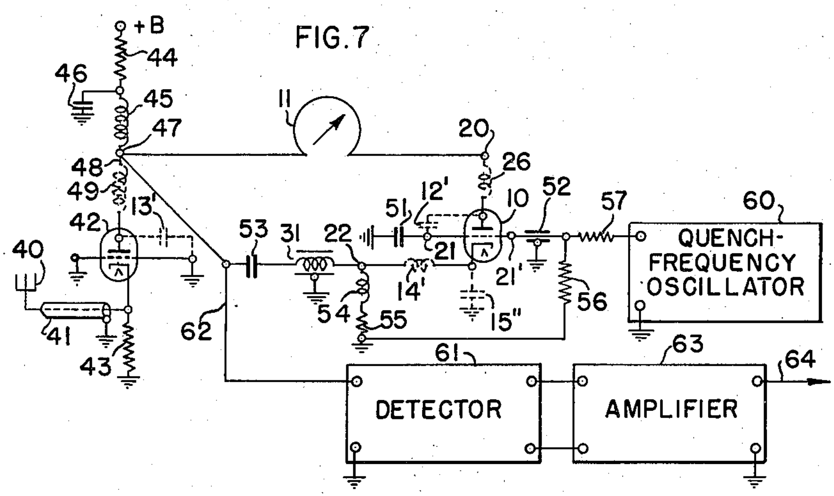


FIG. 7



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Patented June 7, 1949 **2,472,598**

UNITED STATES PATENT OFFICE

2,472,598

ULTRA HIGH FREQUENCY OSCILLATION GENERATOR

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Application March 1, 1945, Serial No. 580,375

12 Claims. (Cl. 250—36)

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This invention is directed to ultra-high-frequency oscillation generators. While being subject to a variety of applications, the invention is especially suited for use in a wave-signal receiver of the superregenerative type and will be particularly described in that connection.

As is well understood in the art, a superregenerative receiver essentially comprises a regenerative circuit which has positive and negative values of conductance during alternate operating intervals. The conductance variations are usually controlled by a periodic quench voltage of relatively low frequency and for stable operation the circuit conductance, integrated over a period of time long with reference to the period of the quench voltage, has a positive value. During negative-conductance intervals, transient oscillations are produced in the regenerative circuit which build up exponentially during each such interval and attain a maximum amplitude determined by the amplitude of the signal which initiates the oscillations. The initiating signal may be a received signal or, in the absence of received signals, may be supplied by the noise signals inherent in the regenerative circuit. In either case, the oscillations generated in one negative-conductance interval are suppressed or damped during the next succeeding interval of positive conductance. Thus, the receiver may be considered as an oscillation generator having an interrupted, as distinguished from a continuous, operation and producing transient oscillations which vary in accordance with the exciting signal. Such a recever has two outstanding characteristics: (1) the regenerative circuit has an exceedingly high gain so that received signals are amplified to an unusually high degree, and (2) in the usual installation the receiver radiates an output signal termed "a quiescent signal" in the absence of received signals.

When receivers of the type under consideration are to be operated at ultra-high frequencies, certain difficulties are encountered in their construction. For example, conventional oscillatory circuits which have been utilized in prior art arrangements do not permit optimum operation to be realized. This results from the fact that inherent circuit reactances, such as interelectrode capacitances and electrode-lead inductances, represent appreciable reactances at ultra-high frequencies which have a pronounced effect on the operating characteristics of the oscillator and, in the usual case, impair its operating characteristics.

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Also, in some installations it is desirable to prevent the receiver from transmitting its quiescent signal during operating intervals when no signals are being received. To obtain this result, it has been proposed that a radio-frequency amplifier or buffer stage be interposed between the regenerative circuit and its receiving antenna. At the frequencies involved, a very practical buffer stage for this purpose is the cathode-input or grounded-grid amplifier, wherein the input and output circuits are effectively shielded without the necessity of elaborate neutralizing circuits. In the prior arrangements such a buffer stage has been coupled capacitively or inductively to the regenerative circuit. However, the inherent reactances of the output circuit of the buffer stage in these arrangements reflect undesirable reactance components into the regenerative circuit and difficulty has been experienced in providing efficient coupling between the buffer and regenerative circuits.

It is an object of the present invention, therefore, to provide an improved ultra-high-frequency oscillation generator which substantially avoids the above-mentioned limitations of prior art arrangements.

It is another object of the invention to provide an improved ultra-high-frequency oscillation generator which makes effective use of its inherent circuit reactances.

It is a further object of the invention to provide an improved ultra-high-frequency oscillation generator especially adapted to be included in a superregenerative receiver in cascade with a buffer stage.

An ultra-high-frequency oscillation generator, in accordance with the present invention, comprises an electron-discharge device having anode and cathode electrodes and an intermediate control electrode maintained at a fixed reference potential. The generator includes resonant-circuit means having a voltage-divider tap coupled to the control electrode of the electron-discharge device and a phase-shifting network including at least one element which is serially connected with the resonant-circuit means between the anode and cathode electrodes of the electron-discharge device. The phase-shifting network, in conjunction with the resonant-circuit means, provides input and output circuits for the electron-discharge device effective to feed back energy from the output circuit to the input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of the resonant-circuit means.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

In the drawing, Fig. 1 is a schematic circuit diagram of the alternating current circuits of an oscillation generator in accordance with the invention; Fig. 2 is a vector diagram utilized in explaining the operation of the Fig. 1 arrangement; Fig. 3 represents a modification of the Fig. 1 arrangement; Figs. 4*a* and 4*b* are schematic circuit diagrams, while Fig. 5 is a vector diagram, utilized in describing a particular operating characteristic of the oscillation generators of Figs. 1 and 3; Fig. 6 is a further modification of the Fig. 1 arrangement; and Fig. 7 represents a complete superregenerative receiver including an oscillation generator in accordance with the invention.

Referring now more particularly to Fig. 1, there are represented the alternating current circuits of an oscillation generator, adjustably tuned for operation over a desired range of ultra-high frequencies. This generator comprises an electron-discharge device, specifically a triode vacuum tube **10**, having anode and cathode electrodes and an intermediate control electrode which is grounded so as to be maintained at a fixed reference potential. Tube **10** is selected of such construction as to have a control-electrode lead of negligible inductance. A resonant-circuit means including a capacitive-type voltage divider having a tap coupled to the control electrode of tube **10** constitutes the frequency-determining circuit of the generator. This resonant-circuit means includes a variable inductor **11** tuned by series-connected condensers **12** and **13**. The common terminals of condensers **12** and **13** are directly connected to the control electrode of tube **10**.

The generator also comprises a phase-shifting network including at least one reactance element of a first type serially connected with resonant circuit **11**, **12**, **13** between the anode and cathode electrodes of tube **10** and at least one reactance element of a second type effectively connected between the control electrode and one of the anode and cathode electrodes of tube **10**. As illustrated, this phase-shifting network comprises an inductor **14** coupling one terminal of the frequency-determining circuit with the cathode of tube **10** and a condenser **15** connected between the control electrode and cathode of tube **10**. This phase-shifting network is series-resonant at a frequency substantially different from the operating frequency of the generator and, in conjunction with the frequency-determining circuit thereof, provides input and output circuits for tube **10** effective to feed back energy from the output circuit to the input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of the frequency-determining circuit. The output circuit, coupled between the anode and cathode electrodes of tube **10**, includes resonant circuit **11**, **12**, **13**, while the input circuit, coupled between the cathode and control electrodes, includes condenser **13** in common with the output circuit for feeding back energy from the output to the input circuit.

In considering the operation of the described arrangement, let it be assumed that the circuit is oscillating, producing circulating currents in resonant circuit **11**, **12**, **13**. The resulting voltage e_p established across condenser **12** at any instant is in phase opposition to the voltage e_o established across condenser **13** and utilized as the feed-back voltage. The feed-back voltage produces a current flow in phase-shifting network **14**, **15** which is represented by vector i of Fig. 2. The phase-shifting network is series-resonant at a frequency much less than the operating frequency of the generator so that a voltage e_l of relatively large magnitude and leading the current through the phase-shifting network by 90 degrees is produced across inductor **14**. A smaller voltage e_c which lags the current by 90 degrees is established across condenser **15**. The vector sum of the voltages e_l and e_c represents the driving voltage e_o of the phase-shifting network. Thus, it will be seen that the voltage e_c between the cathode of tube **10** and ground, or effectively between the cathode and control electrodes of the tube, is in phase opposition to the driving voltage e_o and, hence, is in phase with the voltage e_p. Therefore, the voltage variations of the anode and cathode electrodes, referred to the grounded control electrode, are in phase, which is the proper phase relation required to support sustained oscillations at a frequency corresponding substantially to the resonant frequency of the circuit **11**, **12**, **13**.

The described oscillation generator is particularly suited to take advantage of the inherent reactances associated with vacuum tube **10**. These reactances include the self-inductances of the electrode leads conventionally utilized for making circuit connections to the tube and the inherent interelectrode capacitances. The circuit arrangement of Fig. 3 is a modification of the Fig. 1 generator demonstrating the manner in which such inherent reactances may be conveniently utilized.

In Fig. 3 the terminals **20**, **21** and **22** are intended to designate the terminal prongs which are coupled by way of electrode leads **23**, **24** and **25** to the anode, control electrode, and cathode, respectively, of tube **10**. In this embodiment of the invention, the inductive reactance of the described resonant-circuit means includes variable inductor **11** as well as an inductor **26**, represented in broken-line construction since it consists of the self-inductance of the anode-electrode lead **23**. The tuning capacitance of the resonant-circuit means again includes condenser **13** serially connected with a condenser **12'**, shown in broken-line construction since it comprises the anode-control electrode capacitance of tube **10**. In like manner, the inductor **14'** of the phase-shifting network is provided by the self-inductance of the cathode-electrode lead **25**, while the condenser **15'** consists of the interelectrode capacitance of the control electrode and cathode of tube **10**. This circuit will be seen to be the full electrical equivalent of that of Fig. 1 and its operation will be evident from the foregoing description. The advantage of the Fig. 3 arrangement resides in its effective use of the inherent circuit reactances which otherwise may materially impair the operating efficiency of the circuit. While inductor 14' has been represented as the inherent inductance of cathode lead 25, an external inductance may also be included in the cathode circuit, supplementing the inherent inductance thereof, where the inherent inductance is insufficient to provide the desired resonant frequency of the phase-shifting network.

The description thus far has taken into consideration only the inductive and capacitive reactances of the input circuit of tube 10. It will be appreciated that the tube has a predetermined input conductance, that is, the conductance between its cathode and control electrodes. Where the input conductance constitutes an appreciable impedance element of the input circuit, the phase-shifting network 14, 15 has the form represented schematically in Fig. 4a, where the resistance 30 represents the input conductance. In accordance with well-known transformation theories, the circuit of Fig. 4a may be reconstructed as illustrated in Fig. 4b where the condenser 15'' and resistor 30' replace elements 15 and 30 of Fig. 4a. Through appropriate selection of elements 15'' and 30', the characteristics of the schematic circuits of Figs. 4a and 4b are identical.

The phase relations of the voltages established in the generator circuit, where the phase-shifting network is as represented in Fig. 4b, are illustrated by the vector diagram of Fig. 5. Current flow through the phase-shifting network produces voltage e_l across inductor 14, voltage e_c' across condenser 15'', and voltage e_r across resistor 30', the latter being in phase with the current i flowing through the network. The addition of voltage vectors e_c' and e_r shows the voltage e_k established between the cathode and control electrodes to have a phase angle with reference to vector e_l which is different from 180 degrees. The driving voltage e_o' of the phase-shifting network may be determined by the vector addition of the vectors e_l and e_k. It will be apparent that since the cathode-control-electrode voltage e_k should preferably be in phase opposition to the driving voltage of the phase-shifting network, it is desirable to introduce an additional phase displacement to compensate for the effect of the input conductance of tube 10. To this end, a time-delay network 31 is included in the phase-shifting network of the generator, as illustrated in Fig. 6. In this representation, time-delay network 31 is interposed between inductor 14' and the feed-back condenser 13. The circuit of Fig. 6 is otherwise the same as that of Fig. 3 and corresponding components are identified by the same reference characters. The required time-delay network 31 may readily be constructed by enclosing a coil, such as a signal choke, within a grounded metal foil. This construction effectively constitutes a transmission-line section and is proportioned to effect the desired time delay in the phase-shifting network so that the voltage e_k of Fig. 5 ultimately established between the control electrode and cathode of tube 10 is out of phase with the driving voltage e_o'' of the phase-shifting network.

Referring now to Fig. 7, there is represented a complete signal-translating system, specifically, a superregenerative receiver, including an oscillation generator in accordance with the present invention. The receiver comprises an antenna system 40 coupled by means of a coaxial transmission-line section 41 to the input circuit of a repeater or grounded grid-amplifying stage. This stage is provided by a vacuum tube 42 having an anode, an intermediate control electrode maintained at ground potential, and a cathode. The input circuit of tube 42 includes a cathode resistor 43, connected between the cathode electrode of tube 42 and ground, to which the antenna system is coupled. A source of space current, indicated +B, is coupled to the anode electrode of tube 42 through a resistor 44, a radio-frequency signal choke 45 by-passed to ground by a condenser 46, terminal prong 47 of the tube and its anode-electrode lead 48. Inductor 49, shown in broken-line construction, represents the self-inductance of lead 48.

The regenerative circuit, conventionally included in a superregenerative receiver as pointed out above, is in the form of an oscillation generator of the type represented in Fig. 6 and corresponding components thereof are identified by the same reference characters. The inductive reactance of the resonant-circuit means includes the variable inductor 11 provided by a single turn of metallic ribbon which may be tuned in a well-known manner by a tuning plunger adjustable into and out of the plane of the inductor. Inductor 11 is directly coupled between anode terminal 20 of tube 10 and anode terminal 47 of tube 42. Hence, the inductive reactance of the resonant-circuit means also includes the self-inductances of the anode-electrode leads of the oscillator tube 10 and repeater tube 42. The tuning capacitance of the resonant-circuit means comprises the condensers 12' and 13', shown in broken-line construction since they comprise the anode-control electrode capacitances of tubes 10 and 42, respectively.

Tube 10, in the arrangement under consideration, is provided with a pair of terminals 21, 21' individually coupled with its control electrode. Terminal 21 is grounded through a condenser 51 representing a short circuit at any desired operating frequency of the oscillation generator and terminal 21' is similarly grounded through a condenser 52. Condenser 52 consists of a grounded metal foil surrounding the lead coupled to terminal 21' so that the control electrode may be grounded for radio-frequency signals while having a required direct current path. The direct current paths of tube 10 are completed by a radio-frequency choke 54 and bias resistor 55 coupled to the cathode of tube 10, as well as a grid resistor 56. A blocking condenser 53 is included in the phase-shifting network of the oscillation generator.

A quench-frequency oscillator 60, coupled to the input circuit of tube 10 through an isolating resistor 57, supplies quench voltage for varying the conductance of the oscillation generator circuit in a manner to provide superregeneration. While oscillator 60 may be of any conventional design and construction, it preferably supplies a quench voltage of sinusoidal wave form having a frequency that is low with reference to the operating frequency of tube 10 but high with reference to the highest modulation component of a received signal to be translated. Condenser 52 in the input circuit of tube 10, while grounding the control electrode thereof at the operating frequency of the receiver, presents a high impedance to the quench voltage.

A detector 61 is coupled to the resonant-circuit means of tube 10 through a conductor 62 to derive an output signal therefrom by detecting the generated transient oscillations. An amplifier 63, coupled to the output circuit of detector 61, supplies the output signal of the receiver to a suitable utilizing device (not shown), as indicated by the arrow 64.

The operation of the receiver of Fig. 7 is generally the same as that of any conventional superregenerative receiver and will be understood by those skilled in the art. The circuit arrangement, however, differs from those of the prior art in that there is a direct coupling between the repeater or buffer stage 42 and the regenerative circuit of tube 10. This avoids the necessity of complex coupling circuits and through the utilization of a grounded grid tube 42, wherein the input and output circuits are effectively shielded, the arrangement is prevented from transmitting its quiescent signal in the absence of received signals. Additionally, the inherent impedances of tube 10 and those of the output circuit of tube 42 are employed as elements of the frequency-determining circuit of tube 10.

In each of the several modifications of the invention, the phase-shifting network is utilized for coupling the resonant-circuit means to the cathode of the oscillator tube. However, it will be understood that the phase-shifting network may, if desired, couple the resonant-circuit means to the anode electrode of the oscillator tube.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An ultra-high-frequency oscillation generator comprising, an electron-discharge device inculding anode and cathode electrodes and an intermediate control electrode maintained at a fixed reference potential, resonant-circuit means having a voltage-divider tap coupled to said control electrode, and a phase-shifting network including at least one element serially connected with said resonant-circuit means between said anode and cathode electrodes and providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

2. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including anode and cathode electrodes and an intermediate control electrode maintained at a fixed reference potential, resonant-circuit means having a voltage-divider tap coupled to said control electrode, and a phase-shifting network series-resonant at a frequency substantially different from the operating frequency of said generator and including at least one element serially connected with said resonant-circuit means between said anode and cathode electrodes and providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

3. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including anode and cathode electrodes and an intermediate control electrode maintained at a fixed reference potential, resonant-circuit means including a capacitive voltage divider having a tap coupled to said control electrode, and a phase-shifting network series-resonant at a frequency substantially less than the operating frequency of said generator and including at least one element serially connected with said resonant-circuit means between said anode and cathode electrodes and providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

4. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including anode and cathode electrodes and an intermediate control electrode maintained at a fixed reference potential, resonant-circuit means having a voltage-divider tap coupled to said control electrode, and a phase-shifting network including a reactance element of a first type serially connected with said resonant-circuit means between said anode and cathode electrodes and a reactance element of a second type effectively connected between said control electrode and one of said anode and cathode electrodes, said phase-shifting network providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

5. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including anode and cathode electrodes and an intermediate control electrode maintained at a fixed reference potential, resonant-circuit means including a capacitive voltage divider having a tap coupled to said control electrode, and a phase-shifting network including an inductor serially connected with said resonant-circuit means between said anode and cathode electrodes and a condenser effectively connected between said control electrode and one of said anode and cathode electrodes, said phase-shifting network providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

6. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including anode and cathode electrodes and an intermediate control electrode maintained at a fixed reference potential, resonant-circuit means having a capacitive voltage-divider tap coupled to said control electrode, and a phase-shifting network including an inductor serially connected with said resonant-circuit means between said anode and cathode electrodes and a condenser effectively connected between said control electrode and said cathode electrode, said phase-shifting network providing in conjunction with said resonant-circuit means input and output

circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

7. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including an anode, a cathode and an intermediate control electrode maintained at a fixed reference potential and having electrode leads for making circuit connections thereto, resonant-circuit means connected between said anode and cathode electrodes so as to have an inductive reactance including the self-inductance of at least one of said electrode leads and a capacitive reactance including the interelectrode capacitance between said control electrode and at least one of said anode and cathode electrodes, said resonant-circuit means having a voltage-divided tap coupled to said control electrode, and a phase-shifting network including at least one element serially connected with said resonant-circuit means between said anode and cathode electrodes and providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

8. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including an anode, a cathode, and an intermediate control electrode maintained at a fixed reference potential and having electrode leads for making circuit connections thereto, resonant-circuit means connected between said anode and cathode electrodes and having a voltage-divider tap connected to said control electrode, and a phase-shifting network including the self-inductance of the electrode lead and the interelectrode capacitance to said control electrode of one of said anode and cathode electrodes and providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

9. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including an anode, a cathode, and an intermediate control electrode maintained at a fixed reference potential and having electrode leads for making circuit connections thereto, resonant-circuit means connected between said anode and cathode electrodes so as to have an inductive reactance including the self-inductance of said anode-electrode lead and a capacitive reactance including the interelectrode capacitance of said anode and control electrodes and having a voltage-divider tap connected to said control electrode, and a phase-shifting network including the self-inductance of said cathode-electrode lead and the interelectrode capacitance of said cathode and control electrodes and providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

10. An ultra-high-frequency oscillation generator comprising, an electron-discharge device including an anode, a cathode, and an intermediate control electrode maintained at a fixed reference potential and having a predetermined control electrode-cathode conductance, resonant-circuit means having a voltage-divider tap coupled to said control electrode, and a phase-shifting network having at least one element serially connected with said resonant-circuit means between said anode and cathode electrodes and including a time-delay network for compensating said control electrode-cathode conductance, said phase-shifting network providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

11. In a signal-translating system including a repeater having an anode, an intermediate control electrode maintained at ground potential, a cathode, and electrode leads for making circuit connections thereto, an ultra-high-frequency oscillation generator comprising, an electron-discharge device including an anode, a cathode, and an intermediate control electrode maintained at ground potential and having electrode leads for making circuit connections thereto, resonant-circuit means having an inductive reactance coupled between said anode electrodes of said repeater and said electron-discharge device so as to include the self-inductance of said anode-electrode leads thereof and having a capacitive reactance including the anode-control electrode capacitance of said electron-discharge device in series with the corresponding capacitance of said repeater so that said control electrode of said electron-discharge device is effectively connected to a voltage-divider tap of said resonant-circuit means, and a phase-shifting network including at least one element serially connected with said resonant-circuit means between said anode and cathode electrodes of said electron-discharge device and providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

12. In a signal-translating system including a repeater having an anode, an intermediate control electrode maintained at ground potential, a cathode, and electrode leads for making circuit connections thereto, an oscillation generator for operation over a predetermined range of ultra-high frequencies comprising, an electron-discharge device including an anode, a cathode, and an intermediate control electrode maintained at ground potential and having electrode leads for making circuit connections thereto, tunable resonant-circuit means having a variable inductor coupled between said anode electrodes of said repeater and said electron-discharge device so as to include the self-inductance of said anode-electrode leads thereof and having a capacitive reactance including the anode-control electrode capacitance of said electron-discharge device in series with the corresponding capacitance of said

repeater so that said control electrode of said electron-discharge device is effectively connected to a voltage-divider tap of said resonant-circuit means, and a phase-shifting network including at least one element serially connected with said resonant-circuit means between said anode and cathode electrodes of said electron-discharge device and providing in conjunction with said resonant-circuit means input and output circuits for said electron-discharge device effective to feed back energy from said output circuit to said input circuit with such phase as to support sustained oscillations at an operating frequency corresponding substantially to the resonant frequency of said resonant-circuit means.

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