

Dec. 25, 1923.

1,478,638

H. G. CORDES

ELECTRIC OSCILLATOR

Filed May 10, 1917

4 Sheets-Sheet 1

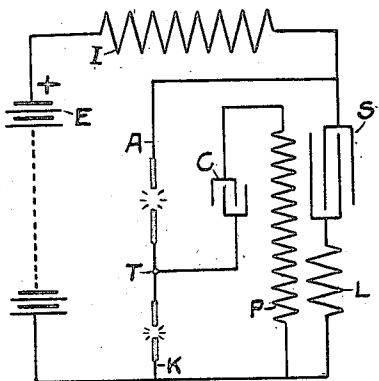


FIG. 1.

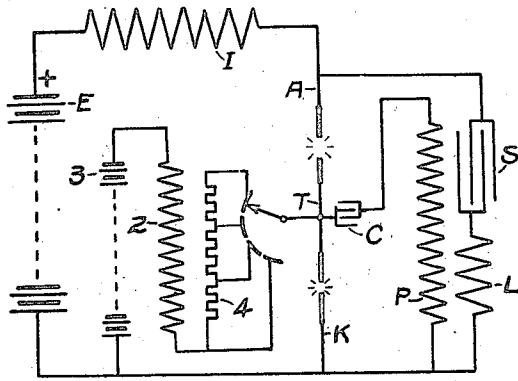


FIG. 2.

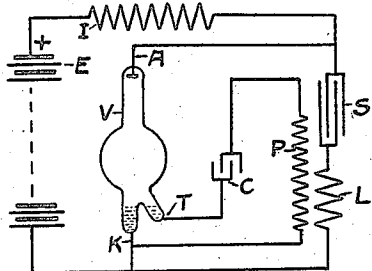


FIG. 3.

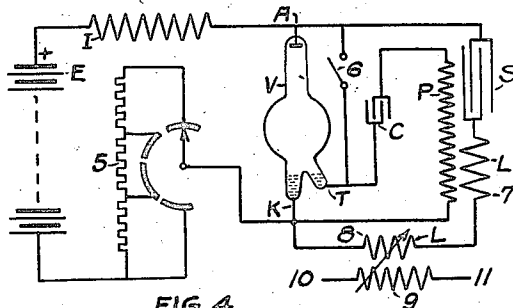


FIG. 4.

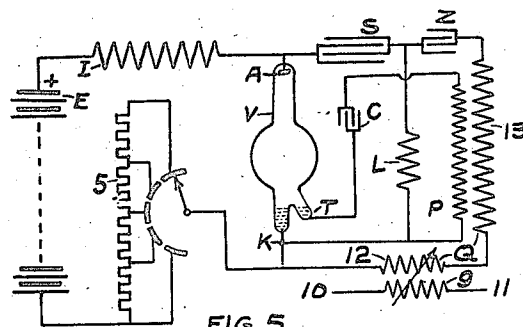


FIG. 5.

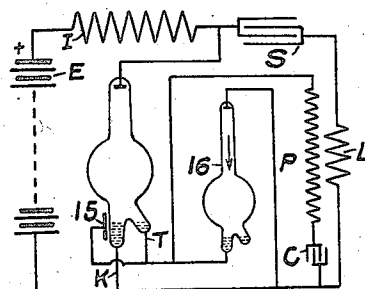


FIG. 7.

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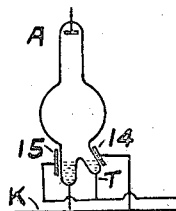


FIG. 6.

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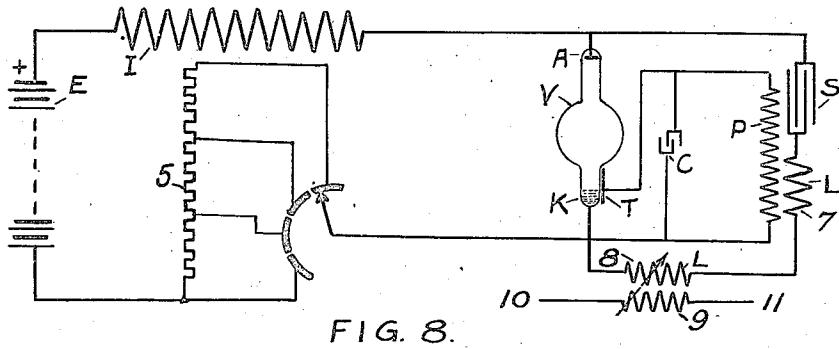


FIG. 8.

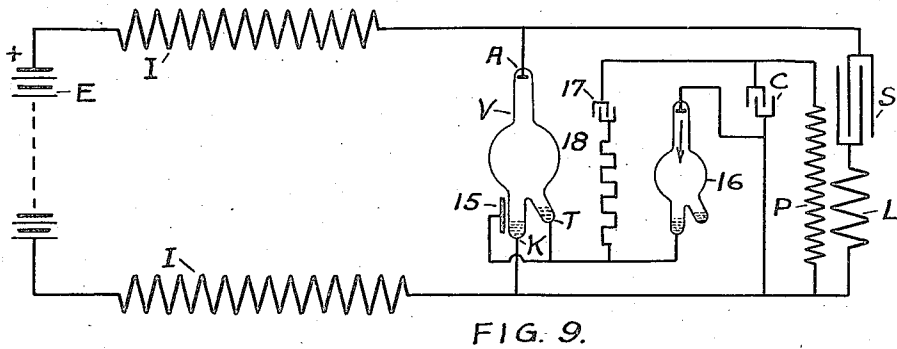


FIG. 9.

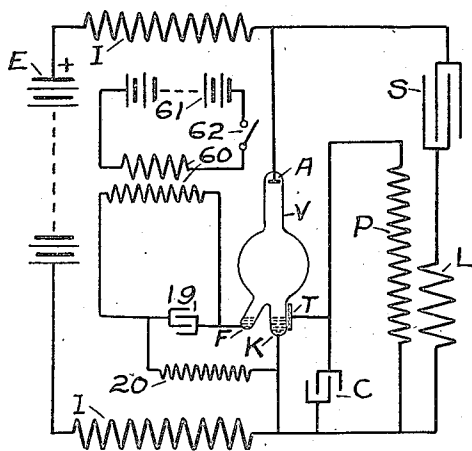


FIG. 10.

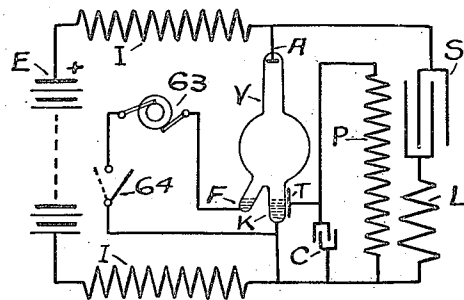


FIG. 11.

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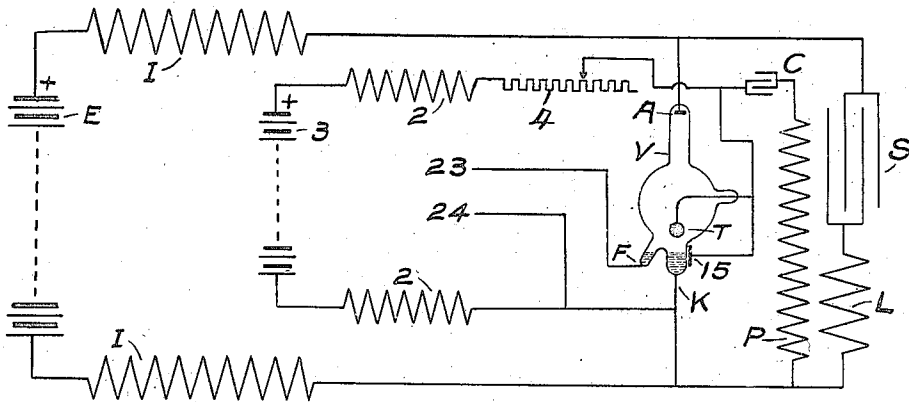


FIG. 12

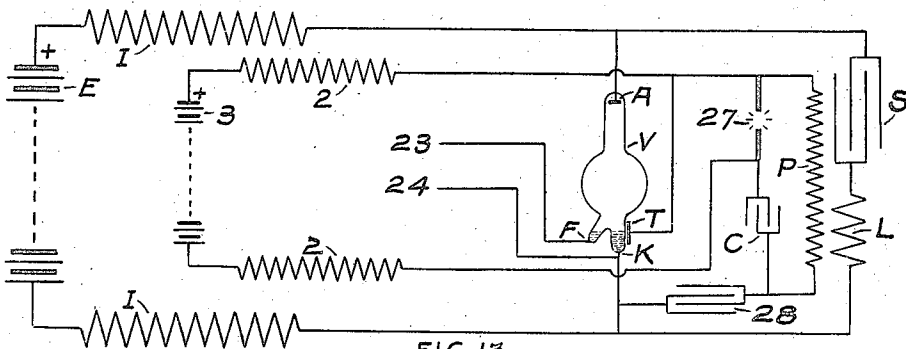


FIG. 13.

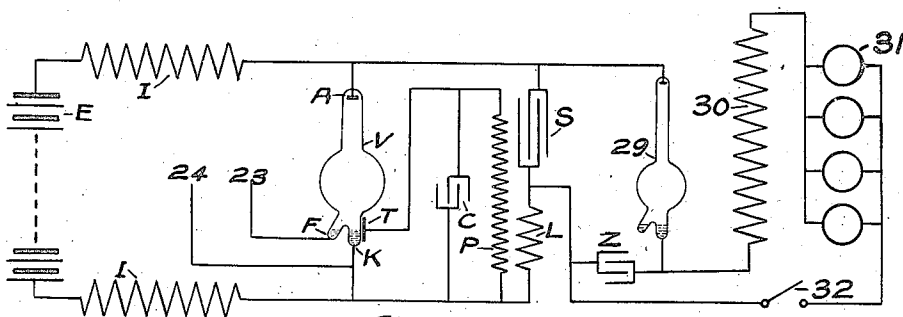


FIG. 14.

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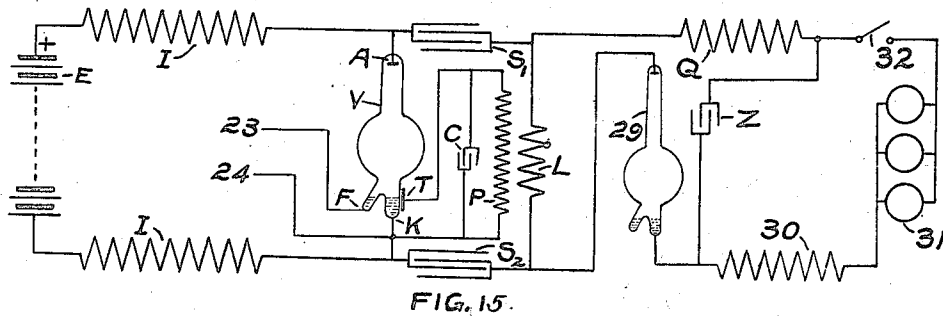


FIG. 15.

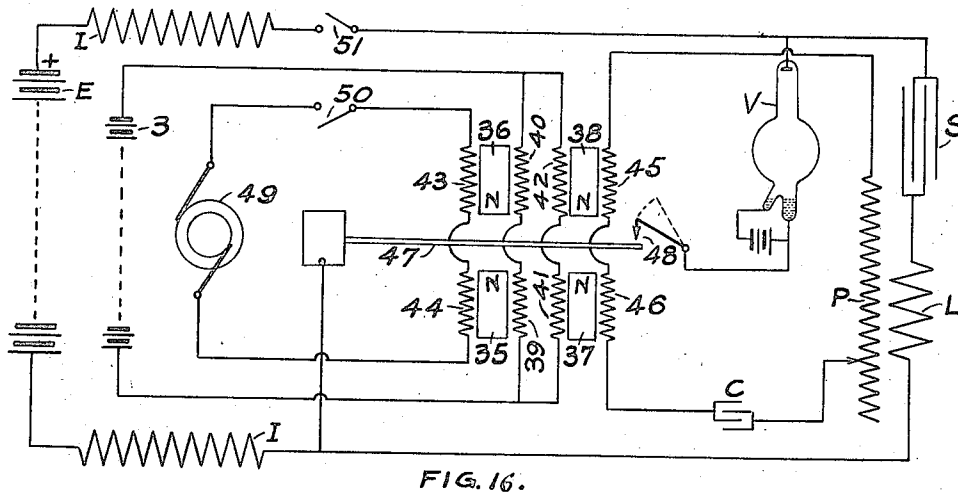


FIG. 16.

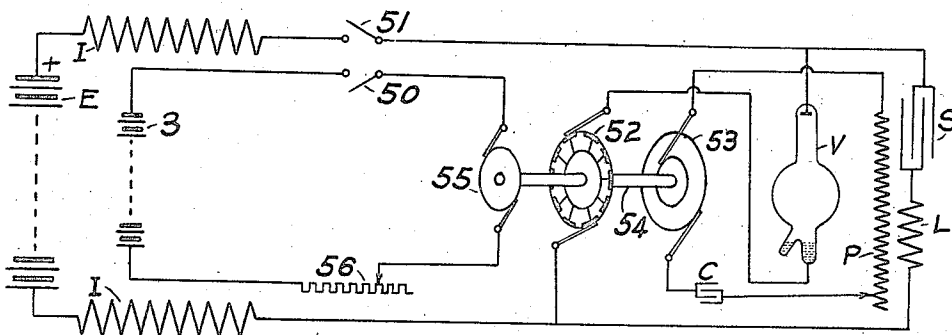


FIG. 17.

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Patented Dec. 25, 1923.

1,478,638

UNITED STATES PATENT OFFICE.

HENRY G. CORDES, OF BREMERTON, WASHINGTON.

ELECTRIC OSCILLATOR.

Application filed May 10, 1917. Serial No. 167,809.

To all whom it may concern:

Be it known that I, HENRY G. CORDES, a citizen of the United States, residing at Bremerton, in the county of Kitsap and State of Washington, have invented new and useful Improvements in an Electric Oscillator.

My invention relates to improvements in arrangements for starting, sustaining, utilizing and studying a particular class of oscillations of a direct current arc oscillator. As to common subject-matter this application is a continuation in part of application 43,436.

The object of my invention is to attain greater efficiency in converting direct current into oscillating current energy, to permit the efficient use of a lower potential direct current in a radio transmitter, to secure greater stability of the apparatus, to adapt an arc oscillator to the production of variable frequency oscillations for radio telephony and to efficiently transform the potential of direct current energy by means of oscillating current.

These improvements are attained by applying a principle well known in the production of oscillations in mechanical devices to the production of electrical oscillations.

My invention can be best explained by considering the direct current arc oscillator as the basis of my improvements. My improvements pertain to class 2 oscillations which are defined by the committee on standardization for 1915 of the Institute of Radio Engineers as those oscillations in which the amplitude of the oscillation circuit current is at least equal to the direct current, but in which the direction of the current thru the arc is never reversed. In other words, in this class of oscillations the arc acts as an electric check valve.

A class 2 oscillation involves three circuits and two time intervals. The circuits will be referred to as the direct current charging circuit, the direct current arc circuit and the discharge circuit. The time intervals will be referred to as the primed and unprimed intervals. During the primed interval current flows through the arc and during the unprimed interval no current flows through the arc. The direct current arc and discharge circuits are only closed during the primed interval. With the usual large inductance in series with the direct current source the direct current amplitude varies a little

and consists of an oscillating current of comparatively small amplitude superposed upon a direct current. The discharge circuit consists of a capacitance discharging through an inductance; the inductance may be either in series with the arc or in series with the capacitance across the direct current line.

The potential of the capacitance varies practically as a linear function of the time during the unprimed interval or period while the potential varies as a sinusoidal function of the time during the primed period of each cycle. Similarly, the graph of the current is also a straight line and a damped sine wave. Oscillations having the characteristics above described will be referred to by the general term "linear-sinusoidal oscillations."

During the primed period electromagnetic energy is stored in the direct current arc-circuit inductance while during the unprimed period the discharge circuit capacitance is charged simultaneously with the discharge of this energy and the energy due to the flow of direct current during the unprimed period.

The drawings forming part of this specification and the following explanations of the figures of the drawings will disclose my improvements.

Fig. 1 shows a class 2 arc oscillator and an additional arc in series, to which is connected my characteristic circuit arrangement. Fig. 2 is a modification of Fig. 1. Fig. 3 shows an arrangement in which the arc is placed in a vacuum and oscillations are difficult to start. Figures 4 and 5 show arrangements to facilitate starting. Figures 6, 7, 8 and 9 show modifications of parts of Figures 4 and 5. Figures 10 and 11 show a practical arrangement for starting which is an essential feature of my improvement. Figures 12 and 13 show arrangements for varying the frequency of the oscillations. Figures 14 and 15 show a direct current potential transformer. Figures 16 and 17 show electro-mechanical arrangements for producing linear-sinusoidal oscillations of low frequency.

A more detailed description of the figures of the drawings will now be given. Similar letters and numerals in the different figures refer to similar parts.

In Fig. 1 consider the anode T and cathode K of the arc T—K short circuited. Then the direct current source E, the inductance

I, the arc A—T, the capacitance S and inductance L constitute an arc oscillator of the prior art. Assume that class 2 oscillations are flowing in the circuits. The frequency of the discharges in the discharge circuit A—T—K—L—S depends upon the circuit constants and upon the amplitude of the direct current for a given condition of the arc.

Make the natural period of inductance P and capacitance C equal to the period of the class 2 oscillations and couple P to L. Sinusoidal oscillating current will then be induced in the T—K—P—C circuit. Now separate T and K to a distance less than that between A and T and thus form the arc T—K. The potential of S, which reignited the arc A—T in the production of class 2 oscillations, is not able to reignite the arcs A—T and T—K in series. P is large compared to L and S is large compared to C. The current in T—K—P—C is small and the potential is high compared to the discharge circuit A—T—K—L—S. The oscillations in the T—K—P—C circuit serve as a pilot spark for reignition or closing of the discharge circuit. The frequency of the discharges in the discharge circuit therefore depends upon the natural period of the T—K—P—C circuit. The circuit T—K—P—C will be referred to as the "priming circuit."

I will hereinafter refer to class 2 oscillations as a particular type of linear-sinusoidal oscillations in which the arc has two electrodes or terminals and a drooping voltage characteristic and reignition depends upon the potential of the capacitance (S) of the discharge circuit. The presence of the priming circuit will render the frequency of the linear-sinusoidal oscillations more independent of fluctuations in the amplitude of the direct current.

Fig. 2 is a modification of Fig. 1. An auxiliary direct current arc circuit 3—2—4—T—K is added. This auxiliary direct current arc circuit and the priming circuit, which becomes a discharge circuit, produce class 2 oscillations. The auxiliary arc circuit prevents inverse current through the arc T—K and also provides for two sources of energy supply to the priming circuit, viz; from L to P and from the auxiliary direct current arc circuit to the priming circuit.

The frequency of the priming circuit can be varied by changing the amplitude of the auxiliary direct current by means of the rheostat 4 and this will change the frequency of the linear-sinusoidal oscillations in L—S. The large ratio of P to C will render the frequency of the class 2 oscillations in the priming circuit comparatively constant.

In Fig. 3, E, I, L, S, P and C have the same relations as in Fig. 1. The two arcs of

Fig. 1 are here replaced by the mercury arc valve V. It is well known that with a given voltage between A and K current will not flow from A to K, but if a spark passes from T to K then the path from A to K becomes conductive due to ionization by collision of the vapor.

It is obvious that if an oscillating current of proper frequency flows in the priming circuit T—K—P—C that linear-sinusoidal oscillations will result in L and S, the arc being primed at the proper instant during each cycle by the priming circuit in which there is assumed to be enough voltage to spark from T to K and K to T during each cycle as is the case in the discharge of a condenser across a spark-gap in series with inductance.

The arc is unprimed as it is in a class 2 arc oscillator. If linear-sinusoidal oscillations are assumed to exist in L and S, then the oscillating current in the priming circuit would be sustained by a transfer of energy from L to P.

This arrangement will therefore not operate because linear-sinusoidal oscillations can not be produced unless oscillating current flows in the priming circuit and oscillating current cannot flow in the priming circuit unless there are linear-sinusoidal oscillations in L and S from which the priming circuit can receive its energy.

In a number of mechanical devices analogous conditions exist. For example, the pendulum of a clock will not swing unless the escapement operates, but the escapement will not operate unless the pendulum swings. Another example is the gas engine; the piston will not oscillate unless the ignition system operates and the ignition system will not operate unless the piston oscillates. In order to make the clock operate it is necessary to give the pendulum an initial swing. Similarly, to make the gas engine operate it is necessary to start the piston to oscillate by auxiliary means. The piston and slide valve operating mechanism also constitute such a combination of two interdependent mechanisms. The escapement, ignition system and slide valve mechanism are trigger arrangements whose failure to operate will stop the flow of energy from the source.

Fig. 4 shows an auxiliary arrangement to make Figure 3 operate. In this figure L is divided into two sections, 7 and 8. P is coupled to section 7. The inductances, 8 and 9, constitute an oscillation transformer of variable coupling. The terminals, 10 and 11, are connected to a source of alternating current or sustained oscillations, thus making 9 the primary of the oscillation transformer. A rheostat 5 is placed in series with the direct current circuit.

To operate this arrangement close switch 6 and short circuit T—K by tilting the valve

V. The current will be limited by 5. Open T—K and 6, the valve being primed. Impress an alternating current, having a frequency equal to the natural frequency of the priming circuit on 10 and 11. This will induce constant amplitude oscillations in the discharge circuit A—K—L—S after the starting transient has disappeared. The maximum amplitude of the oscillating current in the discharge circuit must remain less than the direct current amplitude or the valve will become unprimed. Close and open T—K by tilting the valve; if enough energy is transferred from L to P to maintain an oscillating current across the gap T—K in the priming circuit then the coupling of the oscillation transformer is increased until the maximum amplitude of the oscillating current in the discharge circuit is greater than the amplitude of the direct current and the result will be linear-sinusoidal oscillations in L and S. The linear-sinusoidal oscillations are initiated the instant that the resultant current thru V becomes zero. Resistance is now gradually removed from the direct current circuit by means of 5 and at the same time the coupling of the oscillation transformer is gradually decreased so that the amplitude of the linear-sinusoidal oscillations remains practically constant while the energy supply is gradually transferred from the alternating current circuit to the direct current circuit. This constitutes one method of starting linear-sinusoidal oscillations.

If the current in the priming circuit is too weak to sustain the linear-sinusoidal oscillations then only a series of linear-sinusoidal oscillations of decreasing frequency will take place in L—S when the maximum amplitude of the oscillating current in L—S—V becomes large enough to unprime the valve provided the potential induced in 8 by the alternating current flowing thru 9 is small compared to the potential required to produce a spark from A to K and provided the value of the potential of source E and the resistance 5 are less than the critical value for stability. This series of linear-sinusoidal oscillations is the result of the dissipation of the electromagnetic energy stored by the direct current in the inductance I. It is known that if both the potential of source E and the resistance 5 be made large enough that oscillations will take place in Fig. 4 when the priming circuit P—C is omitted; the object of adding the priming circuit being to produce oscillations from a source of lower potential, reduce the loss of energy dissipated in 5 and secure oscillations of more constant frequency.

Fig. 5 is similar to Fig. 4, except an intermediate oscillatory circuit L—Q—Z is introduced. This circuit is conductively coupled to the discharge circuit. Both the

priming circuit and the alternating current starting circuit are coupled to the intermediate circuit.

To operate this arrangement impress alternating current of a frequency equal to or slightly greater than the natural frequency of the intermediate circuit on the oscillation transformer 9—12, which will induce oscillations in the latter circuit. Close and open T—K. If enough energy is transferred from inductance part 13 of Q to P an alternating current arc will be established between T and K. This will prime the valve at proper intervals to allow direct current energy to be transferred to the discharge circuit as linear-sinusoidal oscillations. Energy is transferred from the latter to the intermediate circuit which then becomes the secondary oscillatory circuit. The secondary circuit transfers energy to the priming circuit which is thus indirectly coupled to the discharge circuit.

Two practical difficulties arise in the arrangements of Figures 4 and 5; a suitable starting circuit cannot readily be provided except in a laboratory and, secondly, if the valve V has a vacuum and gas suitable for the efficient production of radio frequency oscillating current, then it is found that the priming gap T—K deionizes so rapidly that it constitutes a high effective resistance in the priming circuit, which renders it difficult to transfer enough energy from L to P to sustain the oscillatory current in the priming circuit.

The latter difficulty will be dealt with first. The function of the starting band on a mercury vapor lamp is well known. The presence of a starting band or positive pole near the cathode while being positively charged with respect to the cathode reduces the potential required between the anode and the cathode for the main discharge to be initiated. For convenience in explaining my invention this phenomenon will be considered due to an arc-priming discharge in a discharge circuit comprising the band, the capacitance between the band and the rarefied gas, the rarefied gas which becomes ionized, the cathode, and, the capacitance between the cathode and the band; this circuit has negligible inductance hence the discharge is of short duration and the maximum instantaneous current is large thus producing maximum ionization to initiate the main discharge with the minimum expenditure of energy.

Fig. 6 shows the valve V with two starting bands, 14 and 15, adjacent to the priming electrode T and cathode K. This reduces the potential required to maintain an alternating current arc between T and K.

Fig. 7 is a modification of Fig. 6 and involves a change in the priming circuit. Here, only one starting band 15 is used, and

a valve 16 is introduced. In this arrangement the oscillating current thru P—C will spark from T to K, but not from K to T; because the voltage drop thru valve 16 in the direction of the arrow is less than the potential required to spark from K to T. The gap T—K thus becomes a uni-directional current spark gap and 16 is a by-pass for inverse current thru T—K.

Figure 8 shows another modification of the valves and priming circuit of Fig. 4. Increasing the potential between the priming terminal T and cathode K to a sufficiently high value, increasing positively on T with respect to K, will decrease the potential required between anode A and cathode K to initiate a discharge from A to K. In this arrangement the valve is primed with displacement current flowing thru the wall of V from T thru the gas in V to K while in the preceding figures the valve is primed with conductive current flowing from T to K. Fig. 8 is electrically equivalent to Fig. 4 with the addition to Fig. 4 of a capacitance connected in parallel with P. The capacitance between T and K is considered part of the capacitance C while the capacitance between T and the gas in V will be referred to as limitary capacitance because it limits the extent to which C can be discharged thru the gas in V. The damping of the circuit P—C decreases as the ratio of the limitary capacitance to the capacitance C decreases. The limitary capacitance is a capacitance connected in parallel with C when the gas is ionized. The limitary capacitance is analogous to the stopping or blocking condenser in series with a detector connected in parallel with the condenser of the secondary oscillatory circuit of a radio receiving circuit except as to comparative sizes. In this arrangement the oscillating current in P—C does not prime the valve; the valve is primed by a discharge in the circuit C—T—K in which the inductance is very small or negligible and the capacitance is the limitary capacitance and C in series. The auxiliary oscillatory circuit P—C will be referred to as the stabilizing circuit to distinguish it from the arc-priming discharge circuit C—T—K. The current in C—T—K is large, but the natural period of C—T—K is short, compared with circuit P—C. The priming discharge takes place when the positive charge on the terminal T pole of S is increasing; it only partially discharges C, that is, C discharges thru C—T—K until the charge of the limitary capacitance attains practically the same potential as the charge on C.

The priming circuit P—C in Figures 1 to 7 functions both as a stabilizing circuit and as an arc-priming circuit. The arrangement of Fig. 8 functions better as a stabilizer because the effective resistance of circuit P—C is less;

a separate arc-priming circuit is better because for a given amount of priming energy a large priming current flowing for a short interval of time is more efficacious in initiating the main discharge than a smaller priming current flowing for a longer interval of time. The priming energy required to initiate a discharge from A to K can be made small if the frequency of the linear-sinusoidal oscillations is so chosen that the potential of S is nearly high enough to cause a spark from A to K at the instant of each cycle when the priming discharge takes place. The stabilizing circuit inductance P is coupled to L in such a way that the priming terminal pole of C and the anode pole of S are simultaneously positively charged at a same instant of each cycle as the valve is being unprimed by means of the oscillation transformer 8—9.

Fig. 9 shows a modification of Figures 7 and 8. The condenser 17 is small compared with C. P and C determine largely the period of the stabilizing circuit as in Fig. 8. During one half of a cycle the condenser 17 is in parallel with C by current flowing thru the valve 16; during the second half cycle 17 discharges across the gap T—K and primes the valve V. When 17 discharges across T—K oscillations will take place thru C and 17; during one half cycle they will pass thru C—17—T—K and during the other half cycle thru C—16—17. These local oscillations are of much higher frequency than those in P—C and are objectionable. To overcome this difficulty make the inductance in the path of all current passing thru 17 as low as possible and introduce a resistance 18, if necessary, to make the current thru 17 non-oscillatory at the frequency of the local oscillations.

The valves or arcs shown in Figure 1 to 9 have a common characteristic feature. In Fig. 1 assume S charged to a potential which is high enough to spark across A—T, but not high enough to spark across A—T and T—K in series when the gas in T—K is not ionized. By impressing an E. M. F. across T—K from an auxiliary source whose positive pole is connected to T so that a spark passes from T to K the gas in T—K becomes ionized which allows the condenser S to discharge. Similarly in Fig. 3 if S is charged to a potential insufficient to discharge across A—K a spark from T to K from an auxiliary source of high potential will allow S to discharge. Fig. 8 also illustrates this feature. With a given potential impressed on A—K no discharge takes place, but by allowing sufficient displacement current to flow from the upper part of T to increase the ionization of the gas an auxiliary current will initiate an arc discharge of S by reducing the potential required to spark from A to K.

The common characteristic feature described above consists in a (third) terminal in addition to the usual anode and cathode of an arc. Under given conditions a small expenditure of energy between this third terminal and the cathode will allow a comparatively large amount of energy to discharge from A to K. In Fig. 1 the third terminal consists of an additional anode and cathode, in Fig. 3 it consists of an additional anode and in Fig. 8 it consists of one pole of a capacitance while the opposite pole is rarefied gas which becomes a conductor when it is ionized. These arrangements are well known, but no general term has been applied to them. I will refer to them as "three-terminal" arcs, or "three-terminal" arc valves when used for producing linear-sinusoidal oscillations, to distinguish them from "two-terminal" arcs as used in a class 2 arc oscillator.

The difficulty of starting linear-sinusoidal oscillations will now be further considered. Class 2 oscillations are started by means of class 1 oscillations which require an arc of drooping volt-ampere characteristic. The latter type of arc is inefficient due to the large average voltage drop across the arc and difficulty in overcoming sluggish deionization of the gas of the arc. An arc in a vacuum, like the mercury vapor arc, has a slightly drooping volt-ampere characteristic; class 1 oscillations which are sufficiently vigorous to lead to class 2 oscillations cannot be produced unless the effective resistance of the discharge circuit is very low; furthermore class 2 oscillations produced from a low potential source could not persist due to the high potential required to reignite the arc. If an automatic priming circuit is introduced then the oscillations can be made to persist.

It is desirable, however, to withdraw energy from the discharge circuit while starting; or in other words, to start under load. The objection to the method of starting shown in Figures 4 and 5 has been noted.

Fig. 10 shows a more practicable method of starting linear-sinusoidal oscillations. The stabilizing circuit is that shown in Fig. 8. The valve V differs from that of Fig. 8 in that it has a fourth terminal F which is also a priming terminal. Inductance 20 and a condenser 19 are connected in series between F and K. The condenser 19 is charged by means of the secondary of the transformer or induction coil 60 to a potential just high enough to discharge condenser 19 across the gap F—K. The primary of 60 is connected in series with a source 61 of direct current and a quick-break switch 62 which opens the primary circuit of 60 and thereby charges 19 to the potential required to produce one train of oscillations in the starting priming

circuit 19—F—K—20. The natural time period of the starting priming circuit must be practically equal to the natural period of the stabilizing circuit P—C. The starting circuit oscillations produce linear-sinusoidal oscillations in L and S, which induce oscillations in P—C; if the latter attain a sufficiently high amplitude the oscillations in the two interdependent circuits, viz, the stabilizing circuit and discharge circuit, will become self-sustaining. The damped train of oscillations in the starting oscillatory circuit must persist until the inertia of the direct current circuit has been sufficiently overcome in order to render the interdependent circuits self-sustaining. Since it is desirable to have the inductance I large it is necessary that the damping of the starting oscillations be low and their initial amplitude be high.

Figure 11 is similar to Fig. 10 except that an auxiliary source 63 of sustained alternating current is used for starting as in Figures 4 and 5. In this arrangement sustained alternating current passes between the terminal F and cathode K when the quick make-and-break switch 64 is closed and opened. Any convenient source of alternating current of sufficiently high potential to sustain an arc of proper current strength between F and K may be used. The frequency of the alternating current generated by 63 must practically equal the resonant frequency of the automatic stabilizing circuit. The alternating current arc between F and K should be maintained only long enough for oscillations in the interdependent circuits to reach self-sustaining amplitudes.

Fig. 12 shows an arrangement in which class 2 oscillations are produced in the priming circuit as in Fig. 2. A four-terminal arc is shown instead of the two arcs of Fig. 2. The capacity area 15 primes the priming terminal T which then primes the valve V with conductive current. The starting oscillations impressed on F—K produce simultaneously oscillations in L—S and in P—C. In this arrangement as in Fig. 2 the existence of oscillations in P—C does not depend upon oscillations in L—S and the coupling between P and L can be made zero if desired, provided the auxiliary direct current circuit furnishes enough energy for the priming circuit. The current varying device 4 acts similarly as in Fig. 2. The priming terminal T may be placed over the cathode as shown.

Fig. 13 is a modification of Figures 8 and 12. The auxiliary direct current circuit is conductively insulated from the principal direct current circuit by means of condenser 28, which is large compared to C. The two-terminal arc 27 is of the usual class 2 arc oscillator type. The coupling between L

and P can be made zero if the potential of the auxiliary direct current source 3 be made sufficiently high. To operate this arrangement impress a starting alternating current on F—K, separate the electrodes of 27 and then discontinue the starting current.

Fig. 14 shows an arrangement which constitutes a static direct current potential transformer. Secondary oscillatory and direct current circuits are added to the arrangements of Figures 10 and 11. The voltage of S rises higher than that of E. With the switch 32 open the voltage of the secondary condenser Z will become practically equal to the maximum voltage of S by current passing thru the check valve 29. Close 32 and the potential of Z will cause current to flow thru the comparatively large inductance 30 and thru the energy consuming device 31. S—29—Z constitutes the secondary oscillatory circuit. E—I—29—30—31—32—L constitutes the secondary high potential direct current circuit. The inductance of 30 should be greater than the inductance of I.

Fig. 15 is Fig. 14 modified by a different connection between the low and high potential direct current circuits. The secondary inductance Q has been introduced into the secondary circuits; this will increase the potential of Z. The valve 29 has also been connected to the cathode instead of to the anode of the valve; this allows the condenser S to be divided into two series condensers S_1 and S_2 . The latter condensers conductively insulate the low and high potential direct current circuits, but electrostatically couple them. L—29—Z—Q constitutes the secondary oscillatory circuit and L—29—30—31—32—Q is the secondary direct current circuit.

Fig. 16 shows an electro-mechanical arrangement for producing linear-sinusoidal oscillations of low frequencies. A vibrating iron reed 47 is placed between electro-magnets 35, 36, 37 and 38 as shown; 39 and 44 are the windings on 35, similarly 40 and 43 are on 36, 41 and 46 are on 37, and 42 and 45 are on 38. The windings 39, 40, 41 and 42 are so wound that N is the north poles of the magnets. The windings 43 and 44 are so wound that while 43 is neutralizing 40 the winding 44 is assisting the winding 39. An alternating current of proper maximum amplitude passed thru 43 and 44 will cause the reed 47 to vibrate in synchronism with the frequency of the alternating current. The windings 45 and 46 bear the same relations to windings 41 and 42 as 43 and 44 bear to 39 and 40.

To operate this arrangement let the alternator 49 produce current of a frequency equal to the natural frequency of the circuit 45—46—P—C. Close switch 50 and the reed will vibrate and alternately close and

open contact 48. An arc valve V is introduced in series with contact 48 across the direct current line to act as a check valve. Close switch 51 and open switch 50 practically simultaneously.

Linear-sinusoidal oscillations are thus produced in L and S from which energy is transferred to the 45—46—P—C circuit, and the latter circuit then performs the function of the alternating current circuit which was used for starting the oscillations. The valve V prevents inverse discharge. The relative duration of broken and closed contact of 48 can be adjusted to suit.

Fig. 17 shows another electro-mechanical arrangement similar to Fig. 16. Two motors 53 and 55 have a common shaft 54 on which is mounted a revolving contact maker 52 which is insulated from the shaft. 55 is a direct current motor and 53 is a single phase synchronous motor. The inductance of the winding of 53, the inductance P and capacitance C constitute an oscillatory circuit which determines the frequency at which 52 closes and breaks the discharge circuit. The arc valve V prevents inverse current thru 52. This arrangement is operated by closing switch 50 which brings the motor 55 up to proper speed. Then open 50 and close 51 simultaneously. The linear-sinusoidal oscillations in L will induce sinusoidal oscillations in the synchronous motor actuating circuit P—53—C. If the amplitude in the latter circuit is sufficiently high the two interdependent oscillatory circuits coupled by L and P become self-sustaining. Instead of opening 50, resistance 56 may be introduced into the starting circuit and the synchronous motor actuating circuit in conjunction with the starting circuit operate the revolving contact maker. The brushes of the contact maker should be made adjustable for angular displacement with respect to the poles of the synchronous motor.

Figures 16 and 17 illustrate arrangements which do not require the ignition or priming of an arc to close the discharge circuit in producing linear-sinusoidal oscillations. The expressions "three-terminal" and "four-terminal" arc must therefore be replaced by a more general term. The function of the arc is replaced in Figures 16 and 17 by a make-and-break switch and a check valve. A device by which one circuit closes, another circuit is called a relay. A device for discharging a Leyden jar is called a discharger. The expression "unidirectional current relay-discharger" will therefore be used to refer to a device by means of which one circuit can discharge the capacitance of another circuit, prevent a reverse oscillatory discharge thru the discharger and open the latter circuit. The three- or four-terminal arc is a particular form of a unidirectional current relay-discharger. The

discharger of a class 2 oscillatory circuit does not involve any relay function. The three circuits of a linear-sinusoidal oscillator will be referred to as the direct current capacitor charging circuit, the direct current discharger circuit and the sinusoidal capacitance discharge circuit; the last two circuits being closed thru the discharger.

Certain features which are common to the linear-sinusoidal oscillatory circuits shown will be noted. Resistances have not been shown in either the direct current line or in the discharge circuit. It is understood that resistances or other energy consuming devices are introduced to limit the amplitudes of the current where necessary as is done in class 2 oscillatory circuits or other analogous circuits.

The coupling of priming circuit or stabilizing circuit to discharge circuit has been shown as an inductive coupling. Direct coupling or other form of coupling can be used instead. The coupling between the interdependent circuits should always be a step-up oscillation transformer when the potential of E is low. During each cycle there is transfer of energy from L to P and retransfer of energy from P to L; the retransfer of energy should be made as small as possible in order to maintain the frequency constant and independent of direct current fluctuations. This can be effected by a change in coefficient of coupling, change in stabilizing circuit current amplitude and the ratio of the natural period of L-S to P-C. To operate two oscillators in parallel from the same source of direct current the inductance I must be considered as part of the oscillator. Means for creating a magnetic field between the anode and cathode of the arc and means for cooling the electrodes are not required as in class 2 arc oscillators except at very high frequencies.

Thermionic current oscillators have circuit arrangements which are analogous to my arrangements, but the valve is radically different. An incandescent cathode, an anode and a control electrode or terminal constitute the essential elements of the valve. The cathode tends to continually ionize the space between anode and cathode while the control terminal either increases or decreases this ionizing effect depending on the polarity of this terminal with respect to the cathode. This type of valve has a rising volt-ampere characteristic and the cathode is an incandescent filament which is fragile.

Valves in which the incandescent filament has been replaced by an arc have also been used with the arrangements of thermionic current oscillators. In the latter the function of the control circuit is the same as in thermionic current oscillators. For convenience I will refer to this class of valves as

"control" valves in order to distinguish them from the valves of my arrangement, which I will designate "discharge" valves. The current thru a control valve follows at every instant the potential of the control terminal with respect to the cathode; the variations of the former are a repetition of the variations of the latter. The current thru a discharge valve requires only to be started; after it has started it is independent of the potential of the priming terminal with respect to the cathode. The priming terminal acts as a trigger and cannot control the discharge after it has been started. The current thru a discharge valve produces its own ionization while in a control valve the ionization is produced by auxiliary means. The opening of the stabilizing circuit stops the linear-sinusoidal oscillations and flow of direct current while opening the control circuit stops the oscillations but does not stop the flow of direct current thru the valve. The control valve oscillator generally produces class 1 oscillations, but if the amplitude of the potential of the control circuit is high enough linear-sinusoidal oscillations will result. The analogy between the arrangements of control valve oscillators and my circuit arrangements will suggest many obvious modifications to the latter.

The Marconi and Franklin method described in British Patent #7610 of 1913 shows an arrangement for producing linear-sinusoidal oscillations by means of a three-terminal arc. The primary circuit is separately excited by a priming circuit whose natural period is less than the natural period of the discharge circuit, but the arc is primed at intervals whose durations is greater than the natural period of the discharge circuit. The natural frequency of the auxiliary or priming circuit is not the same as the frequency of the priming discharges which particularly distinguishes the arrangement from my arrangements. The combined stabilizing circuit P-C and priming discharge circuit C-T-K, Fig. 8, is further distinguished by the presence of a limitary capacitance and by the fact that C is only partially discharged during each cycle of the linear-sinusoidal oscillations.

The arrangement used with the Chaffee gap illustrated in the Proceedings of the Institute of Radio Engineers, vol. 4, page 343, is a linear-sinusoidal oscillator in which the antenna circuit may be compared in some respects to the stabilizing circuit of my arrangements. The current in the antenna circuit which is a main oscillatory circuit reacts upon the discharge circuit and determines the time intervals between discharges but this reaction takes place only once in two or more cycles of the antenna current. This results in sustained oscillations of vari-

able amplitude in the antenna circuit. In this arrangement the linear-sinusoidal oscillations are started by means of a transient current which initially ionizes the gas in the gap or valve.

The static direct current transformer of Figures 14 and 15 may be considered analogous to a class 2 arc oscillator used as a radio transmitter and a receiving antenna which constitutes an intermediate oscillatory circuit. The rectifier and telephone receiver connected to the antenna circuit is analogous to the secondary oscillatory and direct current circuits.

The illustrations have shown only the elements of my invention and not the details of construction which are understood to be similar to class 2 arc oscillators, thermionic current oscillators and other analogous arrangements and devices. I do not wish to be limited to the particular arrangements or devices illustrated and described except as required by my claims.

I claim:

1. In a linear-sinusoidal oscillator comprising a direct current capacitance charging circuit, a direct current discharger circuit, a sinusoidal discharge circuit and a unidirectional current relay-discharger therefor, an auxiliary oscillating current relay-discharger actuating circuit coupled to said discharge circuit for actuating said relay-discharger of said oscillator.

2. In a linear-sinusoidal arc oscillator comprising a direct current capacitance-charging circuit, a direct current arc circuit, a sinusoidal discharge circuit and a unidirectional current relay-discharger therefor having a priming terminal and a cathode, an auxiliary oscillating current stabilizing circuit coupled to said discharge circuit and connected to the priming terminal and to the cathode of said relay-discharger.

3. In a linear-sinusoidal oscillator comprising a direct current capacitance-charging circuit, a direct current discharger circuit, a sinusoidal discharge circuit and a unidirectional current relay-discharger therefor, an oscillating current relay-discharger-actuating circuit coupled to said discharge circuit and auxiliary means transiently operative for producing currents in said circuits.

4. In a linear-sinusoidal arc oscillator comprising a direct current capacitance-charging circuit, a direct current discharger circuit, a sinusoidal discharge circuit and an arc having a priming terminal and a cathode, an auxiliary oscillating current stabilizing circuit coupled to said discharge circuit and connected to said priming terminal and to the cathode of the arc of said oscillator and auxiliary means transiently operative for producing currents in said circuits.

5. In a linear-sinusoidal oscillator having a unidirectional current relay-discharger and a discharge circuit, an oscillating current relay-discharger actuating circuit coupled to the discharge circuit of said oscillator and auxiliary means for transiently actuating said relay-discharger of said oscillator.

6. In means for generating linear-sinusoidal oscillations the combination of a discharge circuit, a unidirectional current relay discharger comprising rarefied gas in said discharge circuit, means for starting linear-sinusoidal oscillations comprising a source of transient current and means for sustaining said oscillations comprising a source of sustained alternating current.

7. In a linear-sinusoidal arc oscillator having an arc and a discharge circuit, arc terminals consisting of an anode, a cathode and a priming terminal and an auxiliary oscillating current stabilizing circuit coupled to the discharge circuit of said oscillator and connected to the priming terminal and cathode of said arc.

8. In a linear-sinusoidal arc oscillator, arc terminals comprising an anode, a cathode and a priming terminal, said priming terminal consisting of a capacity area which with the cathode constitutes a capacitance, and an oscillating current stabilizing circuit connected to said terminal and to said cathode.

9. In a linear-sinusoidal arc oscillator, a main discharge circuit, an auxiliary arc-priming discharge circuit comprising an arc and an oscillating current stabilizing circuit coupled to said main discharge circuit and to said arc-priming discharge circuit.

10. The combination of an arc consisting of an anode, an ionized gas and a cathode in series; an arc circuit comprising a source of direct current, an inductance and said arc in series; a discharge circuit comprising a capacitance, an inductance and said arc in series; a charging circuit comprising said source of direct current, said inductances and said capacitance in series; an auxiliary oscillatory circuit comprising an auxiliary inductance and a second capacitance; a third capacitance and said ionized gas in series connected in parallel with said second capacitance; and, means for producing current in said auxiliary oscillatory circuit.

11. The combination of a circuit comprising a source of direct current, an inductance and an ionized arc-vapor conductor in series; a circuit comprising a capacitance, an inductance and said conductor in series; a circuit comprising said source of direct current, said inductances and said capacitance in series; and, an auxiliary sustained oscillating current circuit coupled to, and excited by, one of said circuits and disposed to increase the ionization of said arc-vapor conductor.

12. The method of making capacitance discharge current and oscillating current interdependent which consists in initiating each cycle of said discharge current by means of said oscillating current and exciting said oscillating current by means of said discharge current during each cycle of said currents.

13. The method of initiating a series of linear-sinusoidal oscillations which consists in passing a direct current thru an electrical check valve comprising arc vapor and superposing upon said current flowing thru said valve a transient current of such amplitude that the resultant current flowing thru said valve becomes zero.

14. The method of starting and sustaining linear-sinusoidal oscillations which consists in starting linear-sinusoidal oscillations with a transient current superposed upon a direct current and sustaining said oscillations with a sustained alternating current.

15. The method of perpetuating a series of linear-sinusoidal oscillations which consists in initiating each primed period of a series of linear-sinusoidal oscillations with an auxiliary oscillating current of constant amplitude, said initiation being effected during each cycle of said auxiliary oscillating current.

16. The method of producing constant amplitude linear-sinusoidal oscillations which consists in simultaneously partially discharging an inductance and charging a capacitance with direct current energy and with the energy of said partial discharge, discharging said capacitance thru an ionized gas, initially ionizing said gas during each cycle of said oscillations by means of an auxiliary oscillating current whose natural frequency is equal to the frequency of said oscillations and sustaining said auxiliary oscillating current by means of said oscillations.

17. The method of initiating each discharge of a series of capacitance arc discharges thru a unidirectional current relay-discharger at the resonant frequency of an auxiliary alternating current circuit which consists in charging a capacitance with energy from a direct current source, discharging said capacitance thru a unidirectional current relay-discharger and initiating each of said discharges by producing a priming discharge at the resonant frequency of an auxiliary alternating current circuit.

18. The method of keeping the time interval constant between the discharges of a capacitance thru a unidirectional current discharger which consists in charging a capacitance, discharging said capacitance by initiating a flow of current thru a unidirectional current discharger with a constant amplitude oscillating current and sustaining

said oscillating current by means of said capacitance discharges.

19. The method of controlling the time interval between arc discharges thru rarefied gas of a capacitance by means comprising an auxiliary capacitance which consists in charging said capacitance with direct current energy, discharging said capacitance thru rarefied gas, initiating each of said discharges by partially discharging an auxiliary capacitance thru said gas, and controlling the time interval between said initiatory auxiliary capacitance discharges by varying the frequency of an oscillating current.

20. A generator of linear-sinusoidal oscillations comprising a main discharge circuit, an oscillating current stabilizing circuit comprising inductance P and capacitance C and means for partially discharging said capacitance C to initiate each cycle of said linear-sinusoidal oscillations in said main discharge circuit, said partial discharge of capacitance C taking place in a circuit the natural frequency of which is higher than the natural frequency of said stabilizing circuit.

21. In means for producing linear-sinusoidal oscillations the combination of a discharge circuit, a unidirectional current relay-discharger in said discharge circuit comprising arc vapor, an auxiliary oscillating current circuit and means for actuating said relay-discharger at the natural frequency of said auxiliary oscillating current circuit.

22. In a generator of linear-sinusoidal oscillations the combination of a discharge circuit, a unidirectional current relay-discharger therefor comprising rarefied gas, a stabilizing circuit comprising inductance and capacitance the natural frequency of which determines the frequency of said oscillations and means for transferring energy from said stabilizing circuit to said relay-discharger during each cycle of the oscillations of said stabilizing circuit.

23. In means for producing linear-sinusoidal oscillations the combination of a stabilizing circuit comprising inductance and capacitance, a conductor comprising rarefied gas and an auxiliary discharge circuit comprising said capacitance, said rarefied gas and a limitary capacitance in series; said limitary capacitance constituting means for limiting the supply of energy to said auxiliary discharge circuit; the natural frequency of said stabilizing circuit determining the frequency of said oscillations.

24. In means for producing linear-sinusoidal oscillations the combination of a main discharge circuit, a unidirectional current relay-discharger comprising an anode, a cathode and rarefied gas, a stabilizing circuit comprising inductance and capacitance, and an auxiliary discharge circuit compris-

ing said rarefied gas; said auxiliary discharge circuit comprising means for partially discharging said capacitance during each cycle of said oscillations.

5 25. In a generator of linear-sinusoidal oscillations the combination of a source of direct current, a rarefied gas container, means for establishing a direct current arc thru the rarefied gas in said container and means for
10 unpriming the arc by reducing said direct current thru said arc to zero for an instant in order to start a train of said linear-sinusoidal oscillations.

26. The method of stabilizing linear-sinusoidal oscillations produced by means comprising a rarefied gas which consists in ini-

tiating each cycle of linear-sinusoidal oscillations with an oscillating current and at the frequency of said current.

27. The method of reducing the potential 20 of a direct current source required to sustain linear-sinusoidal oscillations produced by means comprising arc discharges thru rarefied gas which consists in initiating each
25 cycle of linear-sinusoidal oscillations by reducing the potential required to initiate an arc discharge once per cycle of said oscillations with oscillating current energy.

HENRY G. CORDES.

Witnesses:

T. M. LIBBY,
R. NIGHTINGALE.