PROCEEDINGS

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RADIO CLUB *of* AMERICA

Vol. I No. 6 October, 1920

R.C.A. SPECIAL NOTICES

The coming of the Fall season brings a new interest in amateur radio. This year the art is actively turning toward continuous wave transmission. Your Lecture Committee is securing a series of papers which will acquaint the membership with the very latest developments in this newer field as fast as they are available for publication.

PERSONAL NOTES

Mr. T. Johnson, Jr., one of our active members and directors for many years, recently resigned as Expert Radio Aide, Bureau of Steam Engineering, Washington, D. C., to take up Radio work with the General Electric Company, Schenectady, N. Y. Mr. Johnson served during the war in charge of Naval Aircraft Radio development and his achievements along this line have done much to further this new branch of Radio.

Mr. E. V. Amy, our Treasurer, has also shifted the scene of his radio activities. He was formerly Research Engineer at the Radio Corporation Laboratory, City College, until his recent transfer to the Woolworth Building to take up new engineering duties, for the same Company.

At the Board of Directors meeting to be held this month the five additional directors will be elected, as authorized by the recent amendment to the Club Constitution. We hope to announce the list of names in the next Proceedings.

Office of the Editor—319 West 94th St., N. Y. City.

Walter S. Lemmon, Editor
Ernest V. Amy
Austin Lescarboura
Lester Spangenberg

Bulb Oscillators For Radio Transmission

By L. A. Hazeltine

Professor of Electrical Engineering, Stevens Institute of Technology

Presented at meeting of the Radio Club of America, Columbia University, April 30, 1920

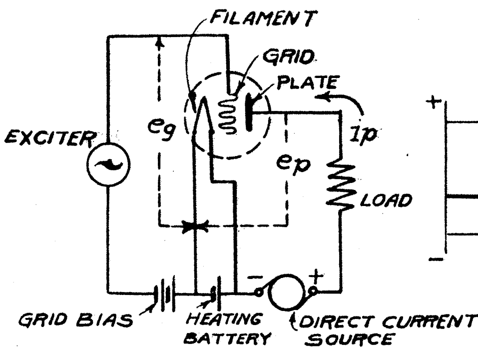
Valves as Rectifiers and as Oscillators

The unilateral conductivity of certain vacuous or gaseous conductors permits their employment as **electric valves** to alternately open and close an electric circuit, analogously to the use of mechanical valves to alternately interrupt and permit the flow of air or steam. The simplest use of a valve is to convert an alternating or intermittent flow into a continuous flow; for this will be accomplished automatically by a valve which permits a flow only in one direction. Thus automatic valves are used in reciprocating air compressors to give a continuous discharge of air, although the motion of the piston is alternating; and similarly electric **rectifiers** (such as the arc rectifier, the Tungar rectifier, the Fleming valve, etc.) act as automatic valves to convert an alternating current into a direct current.

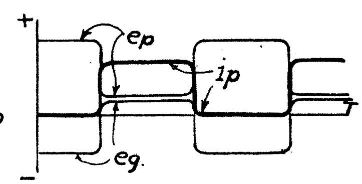
The reverse operation, the conversion of a continuous flow into an alternating flow, can be automatically accomplished only by a valve which is inherently unstable; otherwise a positive (non-automatic) control of the valve is required, either by an independent means having the desired frequency or by the alternating flow produced. The mouth-piece of a wind musical instrument and the ordinary arc oscillator are examples of mechanical and electric valves which produce oscillations by their inherent instability. Bulbs having considerable gas, of either the two-electrode or the three-electrode types, may be electrically unstable and so can act in this manner as electric oscillators, as has been found with some audions without the normal feed-back; also the dynatron, a particular form of three-electrode bulb, acts as an oscillator by reason of instability. Oscillators having a positive valve control, however, are those in which we are here particularly interested, especially **self-excited oscillators** whose valve action is controlled by the alternating flow produced, as exemplified by the steam engine and by the ordinary three-electrode bulb oscillator (audion, pliotron, etc.). In the steam engine the valves, which admit steam to alternate ends of the cylinder and so convert the continuous flow in the steam line into the alternating motion of the piston, are themselves controlled by this motion. Similarly in the three-electrode bulb oscillator the grid whose varying potential periodically interrupts the plate current and so converts the direct-current power supplied to the plate circuit into alternating-current power, is itself controlled in potential by this alternating current. Instead of this electrostatic valve control, self-excited oscillators may have electromagnetic valve control, which has been practically applied in various ways.

Electrostatically Controlled Oscillator

This paper will refer specifically to the electrostatically controlled oscillator, employing a bulb with three electrodes: the cathode, in the form of a filament heated to incandescence; the anode, often in the form of a plate; and the control electrode, usually in the form of a grid interposed between the filament and the plate. Electrons emitted by the filament by virtue of its temperature leave the immediate neighborhood of the filament at a rate depending on the combined effect of the plate potential and the grid potential, and constitute the "space current". In all ordinary bulbs the effect of a given potential at the grid exceeds by several times the effect of an equal potential at the plate, but this is not essential. In other words, the "amplification constant" of the bulb (defined as the quotient of the change in plate potential required to cause a given small change in space current, divided by the change in grid potential to give an equal effect) is usually above 5, but could be less than unity without prohibiting oscillation. When the grid is negative it tends to prevent ence to the separately excited oscillator of Fig. 1a. The "exciter" may be an alternating current generator having a rectangular voltage wave or it may be a periodically operated reversing switch connected to a battery. In combination with the "grid bias" it causes the grid potential to be alternately slightly positive and highly negative, as represented by the wave e_g,

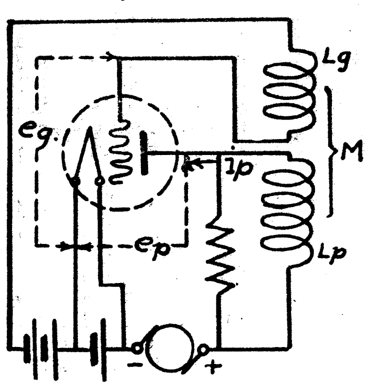


-FIG. 1a.-

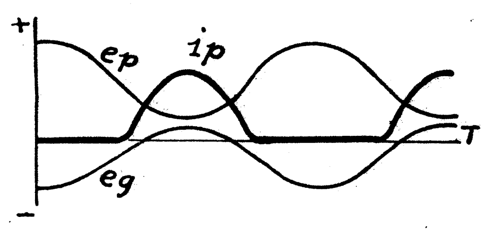


-FIG. 1b.-

electrons from leaving the filament, and if sufficiently negative will reduce the space current to zero, thus opening the electric circuits through the bulb. On the other hand, when the grid is positive, it will tend to draw more electrons from the filament, thus raising the space current and providing relatively low-resistance paths through the bulb. When the grid is negative, practically no electrons reach it, though electrons may pass through it to the plate; and even when the grid is positive, fewer electrons usually reach it than reach the Fig. 1b. The highly negative grid potential interrupts the plate current entirely, while the slightly positive grid potential permits the plate current to flow readily, as indicated by the wave i_p. The grid current (not shown) will vary similarly to the plate current, but will be smaller. The plate potential (in this figure) will be equal to the voltage of the "direct-current source" when the plate current is zero, and will fall to a low value when the plate current flows (that is, when most of the



-FIG. 2a.-

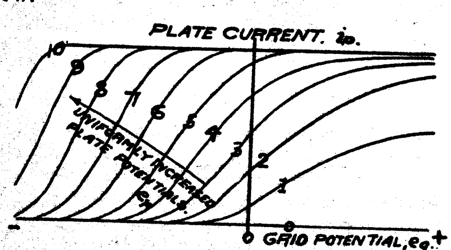


-FIG. 2b.-

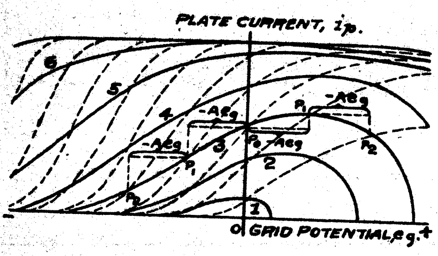
plate, on account of its smaller surface. Thus the space current is made up of the plate current and the grid current, the latter normally being zero or relatively small.

The physical action in a bulb oscillator may be most simply examined by refer- voltage of the source is used in the "load"), as indicated by the wave e_p. Evidently the variations in plate potential are in the opposite sense to the variations in grid potential; this condition is essential to the production of alternating-current power and must be arranged for in self-excited oscillators by proper polarity connections.

Conditions in Fig. 1 are simple and ideal. Each of the operating currents and voltages has only two different values during a cycle—the open-circuit value and the closed-circuit value. The internal losses in the bulb will be small, for current flows only when the corresponding potential is low.



-FIG. 3.-

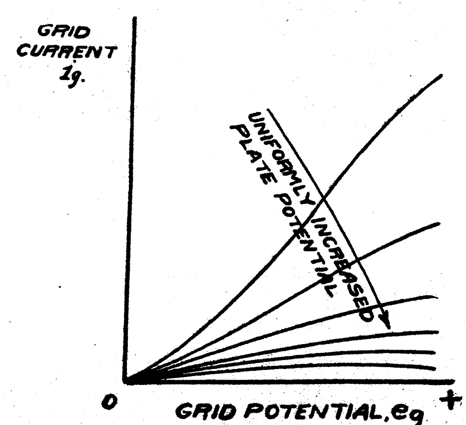


-FIG. 4.-

Let us try to obtain the results of Fig. 1 in a self-excited oscillator by connecting the primary of a transformer across the load and the secondary in the grid circuit, as in Fig. 2a. If it were possible to have a transformer without exciting current, so that it would transform voltage but would not affect the currents in the circuits, and if all inductive and capacity effects were absent, then the waves of Fig. 1b could theoretically be obtained, though even then the frequency would be indeterminate. As a matter of fact, the transformer must take exciting current and the circuit parts must have capacity; so the simple results attained by positive valve control in Fig. 1 cannot now occur. Instead, we shall have the following conditions to satisfy: first, the variation in grid potential must be in phase with the variation in plate potential, due to assumed close coupling of the transformer coils; secondly, the current must vary in phase with the two potentials, since these determine the current by their combined action; and thirdly, the relation of plate current to plate potential must be that fixed by the impedance of the plate circuit external to the bulb. The last two conditions together show that the external plate circuit must act like a **pure resistance**, inasmuch as its current and voltage must be in phase. Therefore an oscillation can occur only at that frequency which will make the capacity and inductance associated with the plate circuit resonant with one another and hence non-inductive in their combination. Usually in practice, the capacity and inductance are effectively in parallel and are sharply tuned, causing the plate potential, and thence the grid potential, to be almost free from harmonics, as represented by the sine wave curves e_p and e_g, Fig. 2b. The plate current will then be zero while the grid is highly negative and will roughly follow the potentials during the remainder of the cycle, as represented by the wave i_p of the same figure. The grid current will vary in the same general way, but with a longer zero interval.

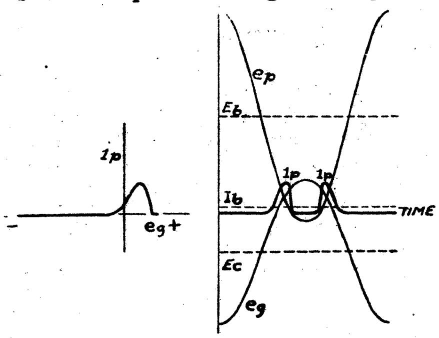
Thus it is seen that the ordinary self-excited oscillator cannot have sharp opening and closing of the circuits through the bulb; but instead the valve action serves to gradually change the resistance of the plate circuit. Such valve action is analogous to the slow opening and closing of the valves of a steam engine, resulting in "wire-drawing", or gradual throttling, and is undesirable for the same reason—loss in energy in the resistance (friction) interposed. Later in this paper will be shown (Fig. 11) a circuit devised and used by the author for giving sharp valve action in bulbs. As is well known the corresponding result in steam engines is one of the main advantages of the Corliss valve.

For simplicity's sake, the load resistance has been shown in Fig. 1 and 2 directly in the plate circuit and so will carry both direct and alternating currents having the same order of magnitude. In practice, oscillators are arranged, by the use of transformers or sharply tuned circuits or both (Fig. 9 and 10), to have a path of low resistance for the direct plate current and of suitably high effective resistance for the alternating plate current. The oscil-



-FIG. 5.-

lator can then serve to convert the direct-current power of the plate generator or battery into alternating-current power with an efficiency that compares favorably with that of other electrical converting apparatus of like power rating. The grid-bias



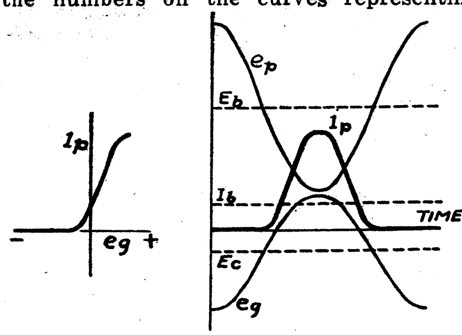
-FIG. 6a.- -FIG. 6b-

-REPRESENTING UNDERLOAD-

battery shown in Fig. 1 and 2 is a sink, not a source, of power, and is usually replaced by a resistance (R_c, Fig. 9 and 10) in which the grid direct current will cause a like voltage drop. The plate generator and this bias resistance are shunted by condensers to afford low-impedance paths for the alternating parts of the plate and grid currents respectively.

Characteristic Curves

The details of the action of a bulb oscillator may be determined as described below from the characteristic curves, in which the plate and grid currents are plotted against the grid potential for constant values of the plate potential. Fig. 3 shows a family of "mutual characteristic curves" of plate current and grid potential, the numbers on the curves representing



-FIG. 7a.- -FIG. 7b-

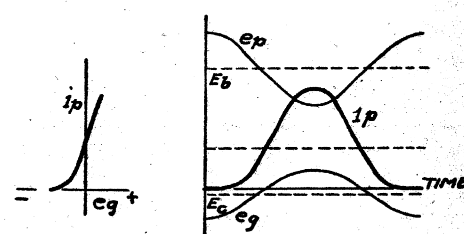
REPRESENTING NORMAL LOAD.

the relative plate potentials, which are constant for each curve. The "grid characteristic curves" of Fig. 5 are less important but are needed for a complete analysis; the grid current is plotted against grid potential for various constant plate potentials.

It is convenient to plot curves showing the relation between the plate current and the grid potential, taking into account such variations in plate potential as occur during oscillation. These are called derived characteristics. Under ordinary conditions the changes in plate potential bear a constant ratio to the changes in grid potential, represented by (**n**) in the equation below (which is not, of course, the usual amplification constant):—

$$-\frac{\delta e_p}{\delta e_g} = \mathbf{n} = \text{constant},$$

δe_p and δe_g normally having opposite signs in order that power shall be **given out** from the plate circuit. The derived characteristic curves for this condition are shown by the full lines of Fig. 4, which are obtained from the normal characteristic curves reproduced from Fig. 3 and shown dotted. To plot one of these curves— say $P_2P_1P_0$—the increment δe_p in plate potential between the successive dotted curves is divided by



-FIG. 8a.- -FIG. 8b.-

-REPRESENTING OVERLOAD-

the constant **n**, to give the corresponding decrement ($-\delta e_g$) in grid potential. Then starting from any point on one of the dotted curves, lay off δe_g horizontally, and draw a vertical line to the succeeding dotted curve. This gives one point on the new derived curve. In a similar manner other points on the new curve may be obtained. There will evidently be a different family of such derived characteristic curves for every value of **n**.

Derived **grid characteristic** curves may be constructed by a similar process from the normal family of curves in Fig. 5.

In Fig. 6a, 7a and 8a are shown derived mutual characteristic curves, which are fixed for a given bulb by the alternating and direct components of the plate and grid potentials. Assuming sinusoidal variation of these potentials, their waves may be plotted as e_p and e_g, Fig. 6b, 7b and 8b, and thence the waves of plate current, i_p, may be plotted by reference to the characteristic curves. Similarly the wave of grid current could be plotted, if desired, by reference to derived grid characteristic curves. From these waves the losses and output of the oscillator may be determined.

Thus by assuming various values for the potentials and plotting first the appropriate characteristic curves and then the waves, the behavior of an oscillator under all possible adjustments and loads may be examined. Usually such a process is far too laborious for a general numerical investigation, but is useful for a qualitative study.

As a matter of fact, the curves of Fig. 6, 7 and 8 have been so chosen as to represent underload, normal load and overload, respectively, of a bulb oscillator with fixed supply voltage $\mathbf{E}_b$, fixed grid bias resistance $\mathbf{R}_c$, and fixed ratio **n** of alternating plate voltage to alternating grid voltage. With the light-load conditions of Fig. 6 (corresponding to a low antenna resistance in Fig. 9 and 10), the alternating and direct components of plate current are relatively small, while the alternating components of the potentials are high. The minimum of plate potential is then slightly negative, causing all of the space current to flow to the grid for an interval and giving a sharp dip to zero in the plate current curve. This does not harm the bulb, but the output is much below that attainable from the bulb. With the normal-load conditions of Fig. 7, the potentials vary over narrower ranges and never permit an excessive grid current; so the plate current has little or no dip and is higher than before. With the heavy-load conditions of Fig. 8 (corresponding to a high antenna resistance in Fig. 9 and 10), the potentials vary over still narrower ranges and the minimum plate potential is much higher. This greatly increases the loss at the plate and will overheat the bulb, though the power output is not greatly different from that in Fig. 7.

The direct voltage (bias) and the alternating voltage (excitation) of the grid circuit are chosen with a view to giving high output and high efficiency, but are not highly critical in adjustment. The best ratio (**n**) of alternating plate voltage to alternating grid voltage has sometimes been considered to be equal to half the amplification constant of the bulb, this corsponding to an external (load) resistance in the plate circuit equal to the internal resistance*. But considerably higher grid voltages may be desirable.

On the whole, the proper load, bias voltage, and excitation voltage of a bulb oscillator, as well as the heating current and the plate generator vlotage, are best determined by direct test. These quantities are all constants of the bulb and do not depend on the wave-length or other characteristics of the load. When no data of the oscillating circuit is available, the r.m.s. value of the plate alternating voltage ($\mathbf{E}_p$) may be assumed one half of the plate generator voltage ($\mathbf{E}_b$) and the efficiency may be assumed 50%; the bias resistance ($\mathbf{R}_c$) and grid alternating voltage ($\mathbf{E}_g$) should be made adjustable, the probable values being assumed, using Table II as a guide.

Circuit Design

When the various bulb adjustments have been decided on, and when the constants of the load are known for a specific case, we may proceed with the design of oscillator circuits. The numerical calculations in a radio-frequency circuit are simpler than in a low-frequency circuit because the reactances are usually so high in comparison with the resistances that the latter may be neglected in computing impedances, except when the reactances are cancelled by tuning. Thus, with resistance neglected, the impedance of a coil is $\omega\mathbf{L}$, that of a condenser is $(1/\omega\mathbf{C})$. That of a coil and condenser is series and tuned to resonance is **r**. Here the symbols having the meanings indicated in Table I and are expressed either in standard units or in the more convenient radio units.

Let us calculate, for example, the proper circuit constants for a 300-meter radio transmitting set using for oscillators two type T pliotrons (Navy designation CG-1162, Signal Corps designation VT-14), and a 20-ohm (0.20 kilohm) 0.0005-microfarad (0.5-millimicrofarad) antenna, first with the connections of Fig. 9 and secondly with those of Fig. 10. A test of a bulb of this type operated below normal rating to increase the life, gave at a heating current of 1.7 amperes the optimum values of Table II, corresponding approximately to the condition of Fig. 7. The last three items of this table are needed in the radio-frequency calculations and are copied in Table III, together with the antenna data. The lower part of this table gives the calculations for the circuit of Fig. 9, employing the "convenient radio-frequency units" throughout. Similar calculations for the circuit of Fig. 10 are given in Table IV. (In this latter case $\mathbf{M}_p$ signifies the mutual inductance between the portion of the coil included in the plate circuit and the portion included in the antenna circuit.)

For simplicity's sake in the above calculations, no account has been taken of the inherent capacities of the various parts. This can best be done by reducing such capacities to the equivalent values in

*The relation between these resistances is determined wholly by the voltage ratio, (**n**); for any change in the external plate resistance would be followed by a corresponding change in the internal resistance, the latter not behaving as a constant in a self-excited oscillator under varying load.

TABLE I. Notation

Symbol	Quantity	Standard Unit	Convenient Radio Unit	
			for low power	for high power
E	Voltage	Volt	Volt	Kilovolt
I	Current	Ampere	Milliampere	Ampere
P	Power	Watt	Milliwatt	Kilowatt
r	Resistance	Ohm	Kilohm	
C	Capacity	Farad	Millimicrofarad	
L	Self-inductance	Henry	Millihenry	
M	Mutual Inductance	Henry	Millihenry	
ω	Angular Frequency $2\pi \times$ Frequency	Radian per second	Radian per microsecond	

TABLE II. Bulb Test Data

Plate supply voltage	E_b	252 volts
Plate current (direct)	I_b	21.3 milliamperes
Grid bias voltage	E_c	44.5 volts
Grid bias resistance	R_c	15.66 kilohms
Plate alternating voltage	E_p	122 volts
Grid alternating voltage	E_g	84 volts
Useful power output	P	3220 milliwatts

TABLE III. Calculations for Fig. 9.

Bulb Data (2 bulbs)	Antenna Data
$P = 6440$ mw. $E_p = 122$ volts $E_g = 84$ volts	$\lambda = 300$ meters $C = 0.5$ millimicrofarads $r = 0.02$ kilohms
$\omega = \frac{1885}{\lambda}$	$\omega = \frac{1885}{300} = 6.28$ rad/μsec.
$\omega L = \frac{1}{\omega C}$	$L = \frac{1}{(6.28)^2 \times 0.5} = 0.0507$ mh.
$P = I^2 r$	$I = \sqrt{\frac{6440}{0.02}} = 568$ ma.
$E_p = I\omega M_p$	$M_p = \frac{122}{6.28 \times 568} = 0.0342$ mh.
$E_g = I\omega M_g$	$M_g = \frac{84}{6.28 \times 568} = 0.0235$ mh.

the main oscillating circuit, by multiplying each by the square of the corresponding ratio of voltages. Such capacities usually amount to a few hundreths of a millimicrofarad and so are appreciable. For example, let us assume in Fig. 9 and Table III the following capacities:

Plate and connections,	0.03	0.05 mμf.
Plate coil,	0.02	
Grid and connections	0.02	0.035 mμf.
Grid coil,	0.015	
Antenna coil,	0.02 mμf.	

Then the total effective capacity to be added to the antenna capacity is

$$0.05\times\frac{M_p^2}{L^2}+0.035\times\frac{M_g^2}{L^2}+0.02=0.05 \text{ m}\mu\text{f.};$$

so that instead of 0.5 mμf. we should have used (0.5+0.05=0.55 mμf.)

For the coil design we may employ the empirical formula,

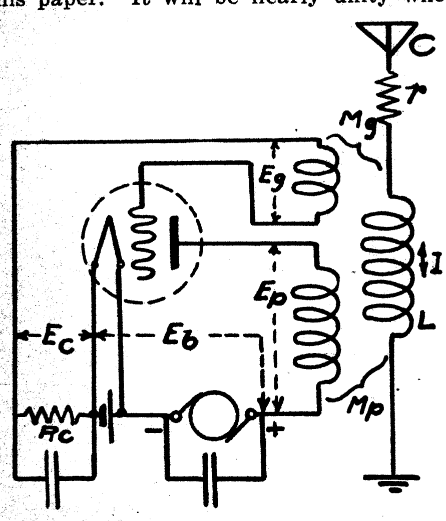
$$L=\frac{0.0008\ a^2N^2}{6a+9b+10c}\text{mh.},$$

where **N** is the number of turns and **a**, **b** and **c** expressed in inches are respectively the mean radius, the axial length and the radial depth of the winding section. (In single-layer coils (**c**) is then zero.) The mutual inductances are given in terms of the self-inductance and the coefficient of coupling **k** by the usual formula,

$$M_{12}=k\sqrt{L_1L_2}.$$

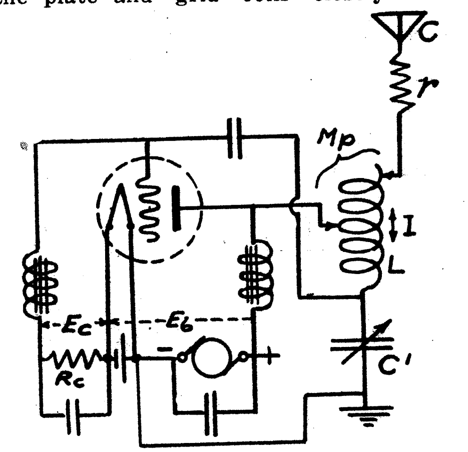
The calculation of **k** is beyond the scope of this paper. It will be nearly unity when, as with M_p in Fig. 10, the two coils have a large portion in common. For two like single-layer coils placed end-to-end in contact, **k** will be given approximately by the formula,

$$k=\frac{a}{a+3b}.$$



-FIG. 9-

In Fig. 9 care should be taken to couple the plate and grid coils closely to the antenna coil and less closely to one another, to prevent a short-wave oscillation in which the antenna does not take part; and where the values of **L** and M_p come out nearly alike (as in the example) it is convenient to connect the plate and the antenna to taps on the same coil, as in Fig. 10.



-FIG. 10-

Symmetrical Oscillators for High Outputs.

As explained previously in connection with Fig. 1 and 2, high efficiency of a bulb oscillator requires that the plate current should flow only during the time while the plate potential is low; and this result can be attained with the usual bulb circuits only by limiting the plate current to a small portion of the cycle. The plate current must have a high maximum value, therefore requiring a high filament temperature, and will be rich in harmonics. The ideal condition would be that of Fig. 1, where the plate potential and plate current are substantially constant for half of each cycle, the plate current being zero for the other half. This condition has been attained by the author with the symmetrical circuit arrangement of Fig. 11a.

In Fig. 11a the plate coil L_p and the grid coil L_g are coupled as usual to produce an oscillation which is transformed to the load essentially as in Fig. 9. Taps from the centers of these coils lead to the filament through the impedance coil **Z** and plate generator and through the resistance R_c, respectively. The impedance coil **Z** is designed to choke out practically all alternating plate current and to pass only a non-pulsating direct current. If the grids of the two bulbs are so highly negative for alternate half cycles as to reduce the corresponding plate currents to zero, then the constant current of the generator will flow to one plate for one half cycle and to the other plate for the next half cycle, giving a rectangular plate current

R_c will be so high compared with the internal resistance of the grid circuit in this half cycle that the grid potential will remain very low; moreover, the grid potential will then be nearly constant, as it varies only slowly with the grid current. In the other half cycle, when the grid is negative, no grid current flows and the grid potential will be negative by the half voltage of coil L_g plus the nearly equal voltage drop in R_c. Hence the grid potential will vary as represented by the wave

TABLE IV. Calculations for Fig. 10.

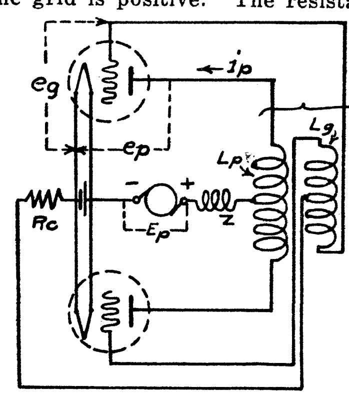
Same Data as in Table III	
$\omega = \frac{1885}{\lambda}$	$\omega = \frac{1885}{300} = 6.28$ rad/µsec.
$P = I^2 r$	$I = \sqrt{\frac{6440}{0.02}} = 568$ ma.
$E_p = I\omega M_p$	$M_p = \frac{122}{6.28 \times 568} = 0.0342$ mh.
$E_g = \frac{I}{\omega C'}$	$C' = \frac{568}{6.28 \times 84} = 1.076$ mµf.
$\omega L = \frac{1}{\omega C} + \frac{1}{\omega C'}$	$L = \frac{1}{6.28^2}\left(\frac{1}{0.5} + \frac{1}{1.076}\right) = 0.0743$ mh.

wave as indicated by i_p, Fig. 11b.

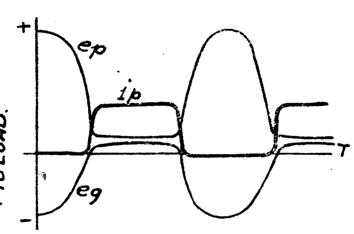
Each grid circuit, including the common resistance R_c, will receive half the alternating voltage of coil L_g, and will permit current to flow during the half cycle in which the grid is positive. The resistance

e_g Fig. 11b, consisting approximately of a straight line and a half sinusoid. The voltage across R_c will consist of half sinusoids and will be of double frequency.

The plate potential, during the half cycle of positive grid will be low and near-



-FIG. 11a.-



-FIG. 11b.-

ly constant, since it has to produce a constant current with the aid of a nearly constant grid potential; during this interval most of the half voltage of coil L_p and most of the generator voltage E_b will appear across the impedance coil **Z**. In the other half cycle, when the grid is negative and the plate current is zero, the plate will be positive by the half voltage of coil L_p plus the voltage across **Z** plus the generator voltage. Hence the plate potential will vary as represented by the wave e_p, Fig. 11b, consisting (like the grid potential) approximately of a straight line and a half sinusoid. The voltage across **Z** will consist of half sinusoids with a displaced axis and will be of double frequency.

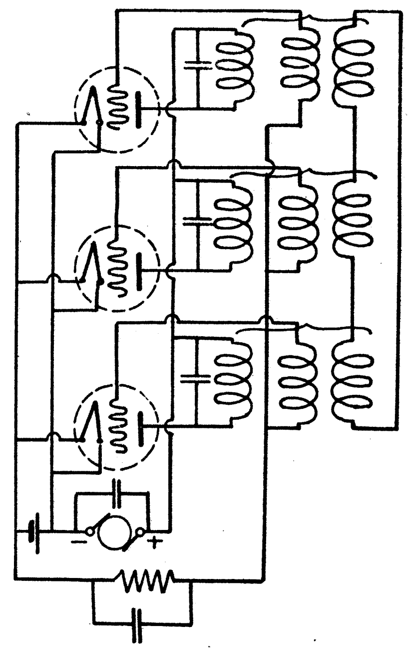
Conditions in Fig. 11 are complicated when the bulb and coil capacities are appreciable, as would occur especially at short waves. Instead of the single coil **Z**, it might then be desirable to use two coupled coils directly adjacent to the plates, thus eliminating the double-frequency potential of the coil L_p.

The arrangement of Fig. 11 is most useful for high-power bulbs, in which the plate potential during the flow of plate current is a small fraction of the direct supply voltage, and in which the output is limited by plate heating; for here the lowering of the plate loss would be relatively great and would make possible much higher outputs per bulb. It is doubtful whether this arrangement would result in any great improvement when applied to low-power bulbs operating on short waves, as in most amateurs' stations.

Polyphase Oscillators.

It is well known that two or more bulb oscillators having approximately the same frequency will tend to pull into synchronism when coupled. If three coils, one supplied from each of three oscillators, are connected together to constitute a closed circuit, the three oscillators will be coupled and brought into synchronism. The vector sum of the alternating voltages of these three coils must be zero; so in general the voltages will be in polyphase relation.

The above principle has been applied by the author to produce three-phase oscillations with the connections of Fig. 12. The three oscillators are alike throughout and produce equal alternating voltages in the three synchronizing coils at the right of the figure. These voltages then combine to form a three-phase equilateral triangle. It is found that the frequencies of the separate oscillators may differ greatly without preventing their being pulled into synchronism when the circuit through the synchronizing coils is closed; for a correcting current will flow through the local circuit of these coils to satisfy the electrical relations required in each oscillator circuit. The same action takes place in case loads of unlike phase angle are connected across different phases since the plate current and plate potential of each bulb must be in phase.



-FIG. 12.-

It does not seem unlikely that polyphase bulb oscillators may be useful in supplying power to a number of suitably spaced antennas for sharply directive radiation.