SETTING OF CIRCUITS FOR HIGH FREQUENCY, HIGH EFFICIENCY OSCILLATORS

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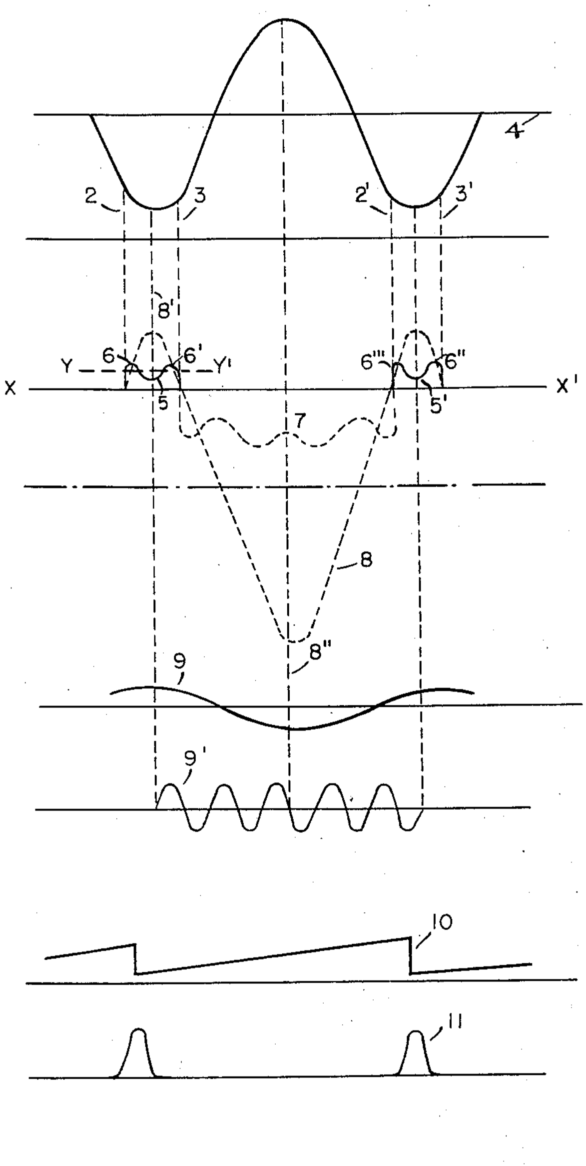

FIG. 1A.

FIG. 1B.

FIG. 1C.

FIG. 1D.

FIG. 1E.

FIG. 1F.

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My invention relates to improved circuits designed for high frequency oscillators and amplifiers, intended for considerably increasing the efficiency and the output power obtainable from the said circuits, and characterized particularly by a new process of control of the grid in the said tubes.

Various processes have already been devised in order to obtain the said improvements. For instance oscillating circuits have been already realized in which the output is limited to a very small fraction of the duration of a cycle (the said circuits being called "Class C" circuits) but it is well known that in such circuits the A. C. plate voltage cannot be increased beyond certain limits for fear of causing a deformation of the plate current liable to lower the proportion of the fundamental, which is the useful component. In order to make the plate voltage at every moment larger than (or at least equal to) the grid voltage, it has already been suggested to change the shape (initially sinusoidal) of the high frequency plate voltage, so as to reduce its crest amplitude while maintaining the same amplitude of the fundamental. To that effect, various processes are already known which mainly consist in introducing in the plate circuit the third harmonic, so as to give it a proper phase and amplitude with reference to the fundamental.

While the introduction of a circuit (which could be called "damping circuit") in series with the oscillating plate circuit makes possible a small reduction of the voltage drop in the tube and a longer duration of flow of the current, thus allowing to obtain a better efficiency this latter yet remains rather poor, because the power dissipated by the grid is very important. On the other hand, the series connection of two oscillating plate circuits meets with practical difficulties, due to the fact that the phase of the voltage in the circuit of the harmonic is not easy to define with precision and it depends on the load.

In a general way all the systems belonging to the "class C" type offer very serious difficulties. The first one is due to the very high value of the voltage amplitude which has to be applied to the grid, wherefrom are likely to result important drawbacks, for instance a failure in the insulation between grid and plate or between the grid and the ground, with important electrostatic effects on the grid connections. The second source of difficulty results from the very large grid current which comes out when the grid is positive while the plate voltage is very low. The third source of difficulty lies in the considerable relative importance of the instantaneous output current of the tube, which necessitates a very large electronic emission, and consequently the use of cathodes absorbing large amounts of current.

My invention provides for the overcoming of all those difficulties, in supplying to the grid a complex periodic voltage by an improved application of the technical principles described in several prior patent applications (third addition filed June 15, 1937, to French Patent 819,199 of June 19, 1936, and French Patent 840,915 of January 5, 1938).

The technical means outlined in the above patents consist in generating a voltage of a desired shape, by a synthetic operation carried out on the components of the said desired voltage.

According to the present invention, a complex voltage, synthesized for example by the techniques described in the aforementioned French patents, is applied to the grid (or grids) of the tube (or tubes); and the said synthesized complex grid voltage varies in conformity with the following sequence of conditions:

(*a*) The applied grid voltage remains, during the largest fraction of its cycle, at a value negative enough to prevent any production of plate current.

(*b*) The applied grid voltage suddenly assumes a positive value, at the very moment when an output current is desired.

(*c*) The grid voltage remains at a relatively low positive value, relatively low, when the plate voltage is minimum (in order to avoid any useless flow of grid current of too high an intensity).

(*d*) The applied grid voltage rises to a higher positive value when the plate voltage increases again, and

(*e*) The applied grid voltage then falls abruptly to a negative value in order to cut off the plate current at the proper time.

Thanks to the above operating conditions, the power dissipated by the grid is reduced to a minimum, the relative duration of action of the triode is brought down to a very low value (generally expressed in angle and called its "opening angle") and the efficiency obtained is excellent.

My invention applies particularly to constant power oscillators (working in frequency modulator systems) or in connection with some treatments involved in high frequency industrial heating operations, in which the efficiencies can attain extremely high values, for instance 90 to 95%.

For a better understanding of the invention various curves have been included in Fig. 1.

An oscillating triode belonging to the "Class C" type can be employed, for example, to convert direct current to alternating current. Figure 1*a* illustrates a D. C. voltage **4** which must be converted by such an oscillating triode into an alternating current, and the numeral **1** designates the alternating voltage of the load or output circuit. In order to realize the said conversion with a high efficiency, the triode must obviously realize during a short fraction of the cycle, a true commutation; and it is necessary therefore that the conductibility of the tube be shifted abruptly from zero to as high a value as possible at time **2** (the voltage drop in the tube must be exceedingly reduced between times **2** and **3**) the said conductibility returning abruptly to an as low as possible value at time **3**.

During the following cycle the same successive changes must be repeated integrally at times **2′** and **3′**.

For securing a very abrupt conduction and cutting of the triode, one should apply to the grid a voltage which varies very suddenly at the opportune time. If the grid is fed with an alternating voltage having the same frequency as the load circuit, use must be made of an extremely high amplitude.

In Fig. 1*b* has been shown the variation curve of that voltage as a function of the time. The drawbacks of that system so frequently used can be readily understood. At first the very high negative voltage, in comparison with the voltage applied to the grid at time **8″**, threatens to injure the insulation. Moreover, the high positive grid voltage at time **8′** results in extremely large grid current, the more dangerous at that time as the lower is the corresponding instantaneous voltage of the plate.

According to my invention, the sinusoidal voltage **8** shown in dotted lines is replaced as a grid supply by a periodic complex voltage designated **6—5—6′—7** etc. in Fig. 1*b*, this latter voltage resulting from the superposition on the fundamental frequency **1** of one or several harmonic frequencies of appropriate rank, amplitude and phase. As can be seen in Fig. 1*b*, the slope of the composite waveform in the zone of progressive control of the triode, extending between zero triode current and triode saturation current (i. e. between the straight lines X′X and Y′Y) is practically the same as the slope of the sinusoid **8**. On the other hand, the total voltage amplitude between grid and cathode is relatively very low; and particularly the negative maximum value 7 is much smaller in magnitude than the negative maximum value of the sinusoid **8**. This reduction of maximum negative grid voltage is of the highest importance in maintaining the life of the triode. Moreover, at the time of passage of the plate voltage through its minimum (e. g. between times **2** and **3**) the curve of the grid voltage does not rise beyond all measure (as would be the case at time **8′** if a conventional grid voltage such as that illustrated at **8** were employed) but, to the contrary, the grid voltage actually falls to a minimum **5**. By referring to the characteristic curves of the triodes, it will be seen that a given current is obtainable with a lower grid voltage when the plate voltage decreases. It has already been seen that grid current commences to appear for a less positive value of the voltage. Thus, when the composite grid voltage of the present invention is employed, one is able to limit grid current to a relatively very low value for the whole duration of the unblocking of the grid (as shown at points **6, 5, 6′**) and the power dissipated in control of the grid is thus maintained at a very low value. In distinction to ordinary "Class C" oscillators, for which it is generally admitted that nearly ⅛ of the power supplied must be lost for operating the grid, a circuit constructed in accordance with the present invention permits the same result to be secured with a much lower amount of power (approximately ¼ of that previously required). The relative duration of action of the triode, which the usual circuits had not allowed to bring down under 70°, can now be considerably reduced (down to 15 to 20° for instance), and it becomes possible to use without any inconvenience tubes offering a very low internal drop of voltage (the cathode of which may be indirectly heated, provided with a very large surface, and most convenient for the very large outputs).

The periodical curve given as an example in Fig. 1*b* (points **6, 5, 6′, 7, 6″, 5′, 6″**) results from the superposition of a fundamental frequency with one or several harmonics of an appropriate order (which in the case of the figure is the sole harmonic **5**). The harmonic or harmonics actually superposed on the said fundamental must obviously be chosen in conformity with the "opening angle" to be adopted. The said angle should be chosen as small as possible for a given saturation current of the triode.

On the Figs. 1*c* and 1*d* the fundamental frequency has been designated **9** and the 5th harmonic of said fundamental has been designated **9′**. By addition of the two curves **9** and **9′**, the desired complex grid voltage curve has been obtained as shown in **6—5—6′—7**. It is obvious that the relative phases of the two frequencies **9** and **9′** must be determined with very high precision. The exact superposition of the two frequencies must be made with all the necessary accuracy and the resultant voltage must then be amplified up to the desired amount, by an application of the technical means already described in various occasions, particularly in the above mentioned French patents and applications. The grid circuit of the oscillator includes several series connected oscillating circuits tuned to the selected harmonic frequencies to be superimposed. For producing in the said harmonics the desired voltages having the proper amplitudes and phases, use is preferably made of such circuits as the "cathodyne" or other counter-reaction circuits under the lead of a special "master circuit" in conformity with the technique already developed in the above patents.

In order to generate the above said harmonics (to be later amplified to a proper degree and with a properly selected phase), my invention provides a very convenient means of operation. It consists in connecting with the main frequency a relaxation oscillator circuit producing a sawtooth voltage such as the one designated **10** in Fig. 1*e*. By means of that variable voltage, and by using a transformer which gives the derivative of the current, a periodic pulse is generated, such as shown at **11** in Fig. 1*f*; and therefore are finally extracted, by means of appropriate filters, the various harmonics needed.

The carrying out of my invention is illustrated by means of a sole instance and a few figures only, but its application is in no way limited to such a case and such a particular device. Other appropriate means may indeed be called to secure the control voltage of the grid of the tube provided that a shape be obtained for that voltage which reproduces with a sufficient approximation the shape of the complex grid waveform curve shown in Fig. 1*b*.

My invention, moreover, does not exclusively apply to high vacuum tubes, but it can also find application, under certain conditions, to circuits involving the use of gas tubes.

What I claim is:

1. The method of operating an electronic tube including applying to said electronic tube a control voltage of predetermined frequency for generating in its output circuit pulses of current of predetermined duration and of said predetermined frequency, comprising the steps of applying a negative bias to such control electrode sufficient normally to maintain said tube substantially beyond cut-off, applying to said control electrode a signal composed of a first sinusoidal voltage at said predetermined frequency and a further sinusoidal harmonic of said predetermined voltage which is so phase relative to said first sinusoidal voltage that a trough of said harmonic concurs in time with a crest of said first sinusoidal voltage.

2. A method in accordance with claim 1, wherein said harmonic voltage is an odd harmonic of said predetermined voltage.

3. A class C oscillator comprising an electronic tube including a control electrode, a voltage source so connected to said control electrode and of such value as to maintain said tube substantially at cut-off, an oscillatory circuit network connected to the out-put of said tube, a network coupling said oscillatory network to said control electrode whereby a fundamental sinusoidal voltage is applied to said control electrode in phase opposition to the output voltage of said tube, a network adapted to generate a sinusoidal voltage at an harmonic of said fundamental voltage and a network for applying said harmonic to said control electrode in such phase that a trough of said harmonic voltage coincides with the crests of said fundamental voltage.

4. A class C oscillator comprising an electronic tube including a control electrode, a voltage source so connected to said control electrode and of such value as to maintain said tube substantially at cut-off, an oscillatory circuit network connected to the out-put of said tube, a network coupling said oscillatory network to said control electrode whereby a fundamental sinusoidal voltage is applied to said control electrode in phase opposition to the output voltage of said tube, a relaxation oscillator adapted to generate a saw-tooth voltage at a harmonic of said fundamental voltage, a network for transforming said saw-tooth voltage to a sinusoidal voltage, and a network for applying said harmonic sinusoidal voltage to said con-

trol electrode whereby a trough of said harmonic voltage coincides with the crests of said fundamental voltage.

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