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A. E. HARPER

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SYNCHRONOUS CONTROL OF OSCILLATORS

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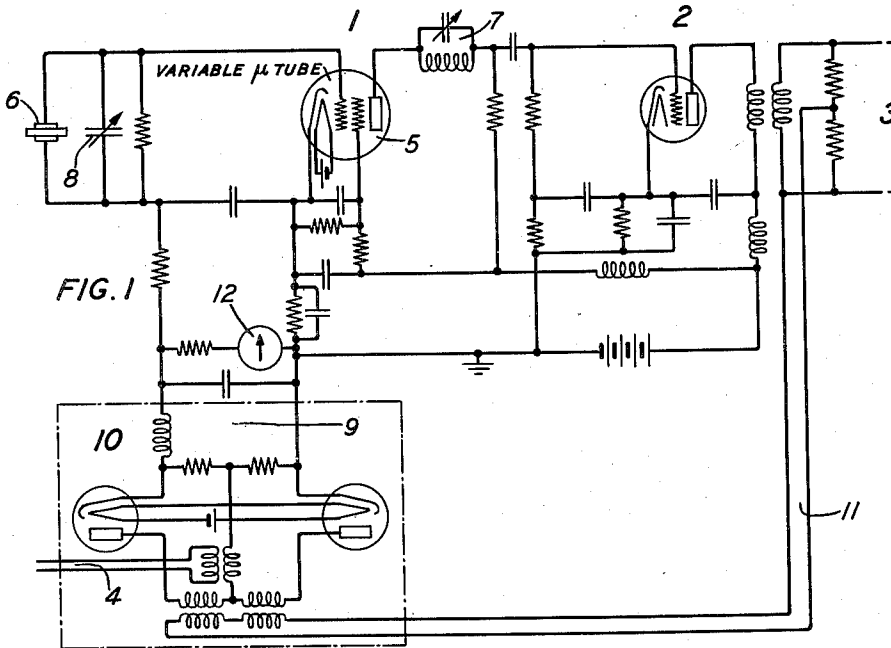


FIG. 2

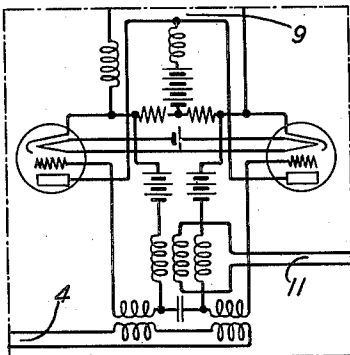
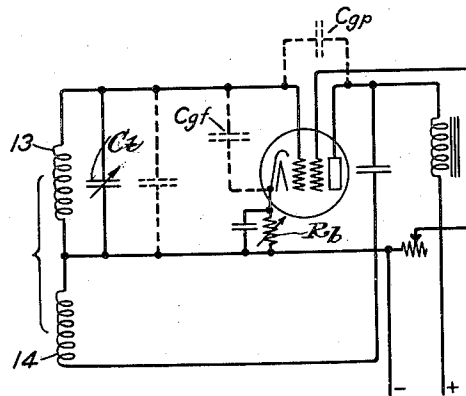


FIG. 3



INVENTOR
A. E. HARPER
BY *Guy T. Morris*

ATTORNEY

UNITED STATES PATENT OFFICE

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SYNCHRONOUS CONTROL OF OSCILLATORS

Augustus E. Harper, Rockville Centre, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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4 Claims. (Cl. 250—36)

This invention relates to the synchronous control of oscillators and to an oscillator adaptable for use in the synchronizing system of the invention as well as having utility for general applications.

The invention has expression in quite widely variant forms. Treated as an oscillator, per se, the invention inheres in the use of a so-called variable-mu tube to replace the more conventional type of vacuum tube in vacuum tube oscillator circuits. The variable-mu principle, as implying a more linear characteristic of the tube, and recognizing that the conditions for the initiation of oscillations and the character and amplitude of the oscillation products depend on this characteristic, means generally that a variable-mu tube oscillator has certain outstanding advantages over oscillators using other types of tubes as making possible a more accurate predetermination of the above criteria. It is an object of the invention to achieve this result in the electrical and mechanical design of vacuum tube oscillators.

According to another aspect of the invention and which is generic to the variable-mu tube and all other known types of vacuum tubes employing an anode, cathode and a control element, the tube is conceived as presenting a capacitance to a potential impressed between the control element and cathode, which is valued as a function of the potential impressed between the control electrode and the cathode. In this manner a tube may be treated as a capacitor whose capacitance may be varied electrically, as distinguished from mechanical capacitance varying means of the prior art. It is therefore an object of the invention to achieve a variation of capacitance wholly by electrical means with the attendant positiveness, simplicity, and reproducibility inherent in this sort of function.

A particular application of the above electrically variable capacitance feature of the invention is in a synchronizing system in which the variable potential to be reflected in a change in capacitance is caused to be a measure of an incipient difference in frequencies of the controlling and controlled waves and in which the variable capacitance is an element of the frequency determining circuit of the oscillator which produces the controlled wave. In the carrying out of this synchronizing principle the two waves concerned are combined in any desired or convenient type of modulating device. One of the modulation products when the two component frequencies are the same but differ only in phase as initiating a relative change in frequency, is a direct potential

the value of which is a direct function of the difference of phase. This potential is impressed between the control element and cathode of the controlled oscillator to achieve a compensatory variation of the frequency of the wave generated thereby so as to effectively lock together the frequencies of the two waves. If the controlled oscillator has piezoelectric crystal stabilization the imputed variable capacitance may be thought of as replacing or adding to the capacitance of the conventional trimming condenser placed in simple relation to the piezoelectric crystal to effect a small change in the frequency of the generated waves. If the controlled oscillator does not have piezoelectric crystal stabilization but is, rather, a vacuum tube oscillator whose frequency is principally determined by the electrical constants of the circuit, a similar change of frequency may be achieved since the input capacitance of the tube, in any except a very approximate analysis of the circuit functions, may be treated as a component part of the reactance of the frequency determining network, its relative effect depending on the relative values of the constants of associated circuit elements.

According to the aspect of the invention as presented in the next above paragraph it is an object of the invention to utilize the characteristics of a vacuum tube whereby its input capacitance is a function of the impressed potential to synchronize the frequencies of waves from two wave sources one of which utilizes said tube and therefore to constrain one wave source to generate oscillations having the frequency of the wave from another source without the interposition of mechanical means to achieve the frequency change in the controlled source.

In operation, the frequency of the controlled source (hereinafter to be denominated oscillator) is adjusted manually while coupled with the controlling wave circuit until a condition of synchronism is evident by the use of a critically positioned milliammeter as in accordance with conventional synchronizing practice, whereafter the two frequencies should keep in step. In the event that the frequency of the wave from the controlled oscillator should tend to drift away from this synchronous relation, its phase relative to the phase of the controlling wave will correspondingly change, thereby producing or increasing the control potential, which will then bring the controlled oscillator back into synchronism. This arrangement, therefore, not only holds the frequencies in synchronism but also holds the phase of the controlled oscillator at a

predetermined value relative to the phase of the controlling wave. While the choice of tube for this synchronizing function is not limited, the characteristics of a variable-mu tube which serve to distinguish this type of tube generally from its prototypes, commend it especially for use in this connection.

Other objects of the invention will appear more fully hereafter in connection with the following detailed description of the invention as illustrated by the accompanying drawing in which:

Fig. 1 illustrates a synchronizing system of the invention, including the variable-mu tube oscillator also of the invention;

Fig. 2 illustrates a form of the push-pull modulator alternative to that enclosed in dashed line boundaries in Fig. 1; and

Fig. 3 is a partially symbolic representation of the controlled oscillator of Fig. 1.

In the synchronizing system of Fig. 1, which is characterized by a novel means for coercing the frequency of the wave from the controlled oscillator to cause it to conform with that of the controlling wave, the purpose generally is to conform the frequency of the wave from controlled oscillator 1 to the frequency of the controlling wave which is incident on the system, and indirectly on the controlled oscillator itself, through circuit 4. The frequency of the wave here incident, and correspondingly the current or wave itself, will sometimes be described by the word "controlling" and sometimes by the word "standard". The controlled oscillator, or more accurately the output circuit 3 in which the eventual controlled frequency energy appears after amplification if desired by amplifier 2 might well be used with a local broadcast station constrained to use a frequency having a very definite relationship, perhaps representing equality of frequencies, with a distant source associated with the incoming circuit 4, although there is intended to be no limitation as to the use to which the controlled frequency is put so far as concerns this invention.

The controlled oscillator 1 has no limitation as to circuit or structure except only that it employs an electric discharge tube 5 in the operation of which its mutual conductance is a function of this grid potential. This tube is illustrated as a so-called "variable-mu" tube, constituting an example of a tube having this function, although conventional tubes having the usual anode, cathode and controlling electrode, would do substantially as well. The theory on which this function is based, which function is a very important feature in the operation of the synchronizing system of the invention as a whole, will be analyzed later, in connection with the symbolic showing of the controlled oscillator circuit in Fig. 3. As used herein this tube characteristic supplies a variable capacitance requisite to determining an adequate frequency change or control in conformity with changes in relative frequency, or tendency thereto, of the controlled and controlling waves.

In the specific controlled oscillator illustrated a piezoelectric crystal 6 is used to stabilize the frequency. As is customary in the art of piezoelectric crystal oscillators, the crystal is connected effectively between the controlling electrode and cathode and cooperates, by its equivalent reactance, with the equivalent reactance of the output tuned circuit 7 and the inter-electrode capacitances to constitute the circuit as a whole an equivalent Hartley type oscillator. The con-

denser 8 may be used, as is illustrated, in close relation to the crystal, although it does not have to be in shunt to it, to make possible a slight change in the generated frequency although, of course, the crystal is the primary frequency determining element. A condenser used in this way is sometimes denominated a "trimming condenser". The effect of the variable mutual conductance of the tube, as a function of the variable grid (controlling electrode) potential, is reflected in a correspondingly variable tube input capacitance, as will be shown in the subsequent analysis. This capacitance accordingly is in such a position as to serve as the capacitance of a "trimming condenser" to replace the condenser 8 or as a secondary "trimming condenser" to provide the component of frequency change required for synchronizing or other purposes, this not being inconsistent with the use of a primary "trimming condenser" to initially adjust the frequency within the range of synchronizing control. The function of the tube just described is not inconsistent with, or exclusive of its conventional function in an oscillator circuit, of regeneratively repeating and amplifying the wave impressed on its input. In fact, the oscillator circuit as a whole is conventional as to its continuity although it is believed that applicant is the first one to have used a variable-mu tube, instead of alternative types of tubes, in such a circuit. A variable-mu tube and its characteristics are described in a paper by Ballantine and Snow in the December, 1930 number of the Proceedings of the Institute of Radio Engineers, as well as in British Patent 376,737, complete accepted July 6, 1932.

The amplifier 2 is not an essential element of the system of the invention although useful here as in other systems where it is conventionally used after a prime source of oscillations and especially after a crystal stabilized oscillator. The amplifier here illustrated is entirely conventional and is merely typical of a considerable choice of amplifiers, including also the coupling to the oscillator, that could be made. It is not believed that a more detailed description is merited.

The variable direct potential by which the variation of tube capacitance is achieved is impressed on the controlling electrode of the controlled oscillator tube by circuit 9. This potential is made to reflect an incipient relative change of the two significant frequencies by being made an output product of the combination or intermodulation of the controlling wave and the controlled wave in balanced modulator 10. This modulator comprises two tubes, here of the two-element type, in push-pull relation. The controlling wave is impressed in the same phase on the cold electrodes in the two tubes through circuit 4 and the controlled wave is impressed differentially on the same electrodes through circuit 11 connected to the output circuit 3 of the amplifier 2. The use of two tubes here has the advantage of the use of two tubes generally in modulating circuits, as pertaining to the elimination by balancing of certain undesired components and the accentuation of other components. However, the principle of operation of the modulator, or combining device, for the present considered purpose does not necessitate the use of two tubes in push-pull relation as shown, however practically desirable this alternative may be. Neither does it require the use of the two-element tubes disclosed as distinguished

from three-element tubes. Nor do the two impressing wave circuits have to be related to the tubes and to the output circuit 9 exactly as shown. In fact, in the alternative circuit of Fig. 2, the relations of the two impressing wave circuits have been interchanged as compared with the relation shown in Fig. 1. Likewise, this circuit of Fig. 2 illustrates how the principle may be adapted to the use of three-element tubes. The prior art contains many disclosures of specific modulators, especially balanced modulators, which could be used alternatively. For example, Affel 1,450,966, April 10, 1923, discloses, by the modulator M, a push-pull or balanced modulator utilizing three-element tubes wherein the output wave is taken from the circuits including the anode elements of the tubes. The Affel circuit generally is suggestive of that of applicant's to the extent that it likewise develops a synchronizing variable direct potential component from the modulating operation and uses it to achieve the same ultimate result although it does not coerce the controlled oscillator by electrically varying a capacitance as in the operation of applicant's circuit.

The milliammeter or the like 12 is so positioned as to be made use of in determining when the two frequencies are approximately the same as measured by the character of the modulator output. For example, the controlled frequency may be adjusted manually by trimming condenser 8 until approximate synchronization is indicated by the condition of steady reading of this milliammeter 12 whereafter the synchronizing principle should be effective to further maintain the equality relationship of the frequencies. When the frequencies are the same, the beat frequency product of the modulation which would otherwise be a measure of the difference between the two frequencies, would take the form of a direct potential. As the two frequencies tend to vary relatively this potential correspondingly cyclically tends to vary through a cycle measuring a unit difference of relative frequency. Accordingly, at this epoch, namely, at the initiation of the relative change of frequency, the only reflection is a relative change of phase which is measured by a correspondingly variable direct potential, the value of which may be obtained from a reading of the meter 12. When the controlling wave has taken control of the frequency of the local source it maintains it by reason of the coercive effect of this direct potential, which effect varies proportionally as the tendency toward a relative change of frequency and therefore obeys the basic law to which a stable frequency system, including a synchronizing system of this kind, must be subjected.

It is evident that the synchronizing system of the invention is highly sensitive to the extent that it employs electric frequency varying means as compared with the mechanical means of Fig. 1 of the Affel patent and of other alternative systems, in the prior art and that it, like the Affel system, is inherently quickly responsive to a relative change of frequency on account of its responsiveness, immediately, to the change of phase which initiates such change of frequency, the maximum coercive force coming into play before the frequencies have differed by as much as a cycle. As electrically varying a frequency by variation of a capacitance, instead of by a variation of inductance as in Fig. 2 of Affel, or by other types of variation illustrated by the prior art, other practical advantages are ob-

tained in the simple, positive, control of the frequency of the wave from vacuum tube oscillator. Although this type of control is particularly adaptable in the instance of a piezoelectric crystal stabilized oscillator as illustrated, the principle is equally applicable to vacuum tube oscillators not characterized by the use of stabilizing crystals or the like, provided that the generated frequency is a function of the reactance of a frequency determining circuit element, for in all such cases the input tube capacity may be made effectively a part of a frequency determining element and therefore will exert a frequency determining effect.

Fig. 3 illustrates, partially symbolically, a controlled oscillator like that of Fig. 1 although somewhat generalized. Therein the crystal 6 of Fig. 1 has been replaced by its analogous inductance 13 and, to illustrate how the principle may be effective in a circuit more closely conforming with the conventional Hartley oscillator circuit than a crystal stabilized Hartley oscillator circuit, the output circuit inductance 14 which may be taken as symbolizing the effective inductance of the circuit 7 of Fig. 1 is illustrated as directly coupled with the input inductance 13 alternatively to the coupling through the inter-electrode capacitance of the tube as assumed in the case of the oscillator of Fig. 1 and as would ordinarily be required in crystal stabilized oscillator circuits. The circuit otherwise is substantially the same as that of the oscillator of Fig. 1. Since it is the purpose of this Fig. 3 to analytically demonstrate the effectiveness of an electric discharge device as a variable capacitance, and since this analysis will require a consideration of certain geometrical tube reactances, that is, inter-electrode reactances, the showing is purposely made a little unconventional in order to indicate all of the elements to be made use of in the analysis. The elements indicated by dash lines represent these geometrical reactances of the tube. For the purposes of the analysis the constants of the equations will be listed below with their definitions, these quantities as occurring in the equations being also used in Fig. 3 to represent the structures having these characteristics:

- C_t = a tuning condenser for determining the oscillation frequency of the circuit,
- C_{gp} = the grid-plate (controlling electrode anode) capacitance, either internal or external to the tube,
- C_{gf} = the grid-filament (controlling electrode cathode) capacitance of the tube,
- C_g = effective capacitance between grid and filament resulting from the capacitances C_{gp} , C_{gf} and the tube constants as will be presently shown,
- R = the external output impedance,
- R_o = the internal plate-filament resistance, and
- R_b = the grid biasing resistor for varying the mutual conductance

$$\frac{\mu}{R_o}$$

As in accordance with well-known tube theory:

$$C_g = C_{gf} + \left(\frac{\mu R}{R + R_o} + 1 \right) C_{gp}$$

This equation reduces to:

$$C_g = C_{gf} + C_{gp} + \frac{\mu R C_{gp}}{R + R_o}$$

Therefore the effective capacitance of the tube, namely, C_g , which capacity is introduced in parallel with the resonant frequency determining circuit constituted by inductance 13 and condenser C_t is determined by the geometrical grid-filament and grid-plate capacitances of the tube plus a factor which is a function of the amplification

$$\frac{\mu R}{R + R_0}$$

of the tube and included circuits. This demonstrates that a vacuum tube and circuit, the amplification of which may be varied, may be used as a correspondingly variable capacitance.

Since the resultant capacity C_g is a function of the geometrical tube capacities C_{gp} and C_{gt} , it is apparent that if these capacities are purposely minimized by special tube design as in shield grid tubes etc., the available variable C_g may not be sufficient for control purposes. In such cases it will be necessary to artificially increase the capacity C_{gp} by means of a small external condenser, connected between the grid and the plate. To further simplify, let it be assumed that R is small as compared with R_0 as it could easily be in practice. The variable amplification factor

$$\frac{\mu R}{R + R_0}$$

becomes approximately

$$\frac{\mu R}{R_0}$$

and since

$$\frac{\mu}{R_0}$$

the mutual conductance of the tube, is a function of the grid voltage in the conventional types of vacuum tubes having a plate, grid and filament, and also having additionally if desired shielding and space charge electrodes, and especially in a so-called variable-mu tube, the effective input capacitance of the tube is a function of the grid potential. The initial mutual conductance, and hence the input capacitance, may be adjusted by a corresponding adjustment of the grid biasing resistance R_b which adjustment might be treated as supplemental to the corresponding adjustment of the condenser C_t to slightly vary the frequency. The variation of frequency in the carrying out of the synchronizing control function is accomplished by the subsequent variations of grid potential as a function of the variation of relative frequency as has been explained.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illus-

trated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. An oscillation generating system comprising in combination, an electric discharge device having an anode, a cathode and a controlling electrode and which is characterized by having a mutual conductance, hence a capacitance between cathode and controlling electrode, which is a function of the potential impressed between said cathode and controlling electrode, feedback means connected to said device for producing oscillations, a resonant frequency determining circuit comprising the effective condenser constituted by the cathode and controlling electrode of said device, the capacitance of which varies, as recited, with the variations of potential impressed therebetween, and means impressing a variable potential between said cathode and controlling electrode to correspondingly vary said capacitance and hence the frequency of the generated oscillations.

2. A synchronizing system comprising the circuit recited in claim 1 together with a controlling wave source, and means responsive to a variation of relative frequency of the waves from said source and generator for establishing the variable potential impressed between the controlling electrode and cathode of said device whereby the frequency of the generated waves is constrained to at all times equal the frequency of the controlling wave.

3. In a synchronizing system in combination, a controlled oscillator comprising an electric discharge device having an anode, a cathode, a control electrode and a resonant frequency determining circuit, in the operation of which the mutual conductance and hence the input capacitance is a function of the difference of potential between the control electrode and cathode, said input capacitance effectively constituting an element of said frequency determining circuit, a controlling wave source, means for intermodulating the waves from said oscillator and said source, means for deriving from said intermodulating means the difference frequency modulation product, which becomes a direct potential varying with the difference in phase of the two wave when the difference in frequency is less than one cycle, and means for impressing said difference frequency product between said control electrode and cathode, whereby a tendency toward a relative change of the two frequencies from equality give rise to a corresponding force tending to compensatorily vary the frequency of the controlled oscillator so as to perpetuate the initial condition of frequency equality.

4. The synchronizing system specified in claim 3 in which the electric discharge device is a variable-mu tube.

AUGUSTUS E. HARPER.