Aug. 6, 1935. R. V. L. HARTLEY 2,010,665

FREQUENCY CHANGING DEVICE

Filed Jan. 15, 1935

FIG. 1

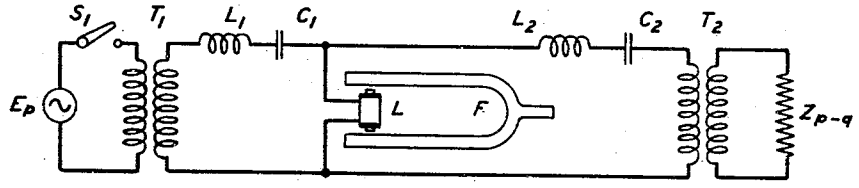



FIG. 2

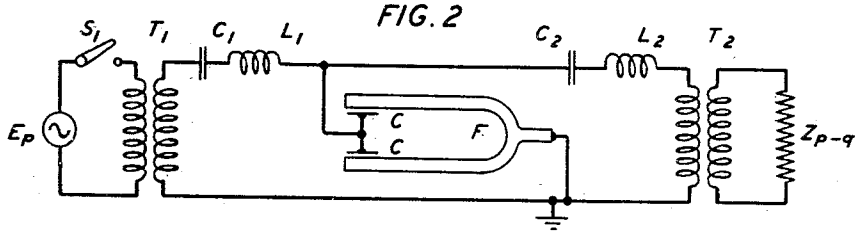



FIG. 3

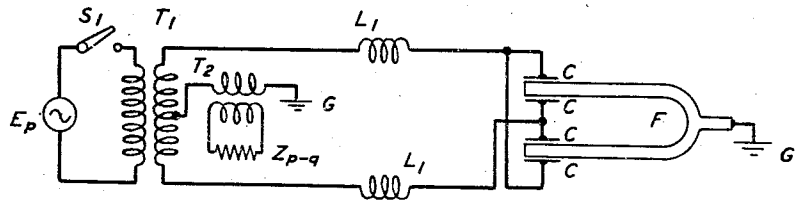



FIG. 4

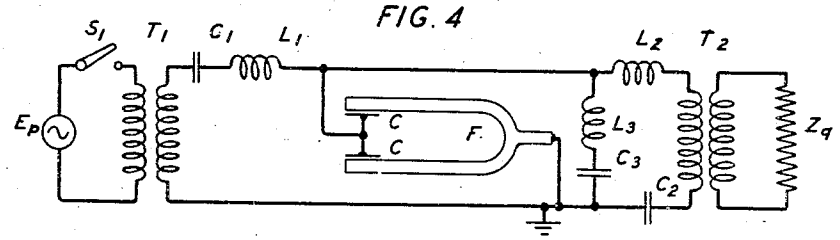
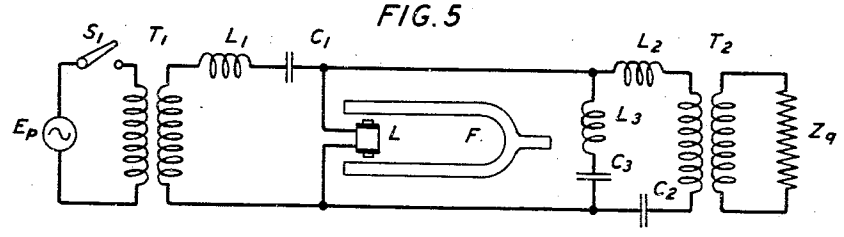



FIG. 5




INVENTOR
R.V.L. HARTLEY
BY G H Stevenson
ATTORNEY

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# UNITED STATES PATENT OFFICE

2,010,665

## FREQUENCY CHANGING DEVICE

Ralph V. L. Hartley, South Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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5 Claims. (Cl. 172—281)

This invention relates to frequency convertors and more particularly to arrangements for producing currents of reduced frequency with respect to that of the energy source.

In accordance with the invention, frequency conversion is effected through the agency of a reactance device included in an electric circuit, the reactance of the said device being variable with the current or voltage in the circuit by virtue of a mechanical motion of its parts. In the systems of the invention the variable reactance may comprise an iron cored inductance coil, the inductance of which is varied by the motion of an armature mounted on a tuned reed or tuning fork or may consist of an air condenser, one plate of which is capable of vibration at a fixed frequency.

By the proper tuning of the electrical circuit and the mechanical vibrators, it has been found possible to produce currents of a frequency lower than that of the impressed exciting current and related thereto by the frequency of the mechanical vibrator. In one arrangement of the invention the current of reduced frequency has a frequency equal to the difference between the frequency of the exciting current and the resonance frequency of the mechanical vibrator. In a modified form currents of two frequencies are produced, the sum of which is equal to twice the impressed frequency.

The nature of the invention and its mode of operation will be more fully understood from the following detailed description and by reference to the attached drawing of which:

Fig. 1 shows in schematic arrangement one embodiment of the invention;

Figs. 2 and 3 inclusive, illustrate alternative arrangements of the invention operating on the same principle as that of Fig. 1, and

Figs. 4 and 5 show alternative arrangements of a modified form of the invention.

Referring to Fig. 1, $E_p$ is a source of sinusoidal electromotive force of frequency $p$ cycles per second which is connected to the system through a switch $S_1$. $T_1$ is an input transformer through which the electromotive force is impressed on the electromechanical system. $C_1$ and $L_1$ are a condenser and inductance respectively, which are of such magnitude that, through resonance with the effective inductance of the system, they permit a large current of frequency $p$ to flow, but substantially suppress any flow of current components of other frequencies. $C_2$ and $L_2$ are respectively a condenser and an inductance adjusted to resonate the output system to a frequency $p—q$, permitting a large current component of frequency $p—q$ to flow into the output transformer $T_2$ and substantially suppressing all other frequency components in the output transformer $T_2$. In the tuning of these circuits the leakage inductance of the transformers should be taken into account. This may be done by modifying the values of $L_1$ and $L_2$. The impedance $Z_{p-q}$ represents the impedance of the system to which power at frequency $p—q$ is delivered. L is an iron core coil placed between the arms of a tuning fork F and of such a length that, except for thin air-gaps, the magnetic path consists of the iron core and the tuning fork F. The tuning fork F has a natural resonant frequency of $q$ cycles per second.

When the generator $E_p$ is connected into the system by closing switch $S_1$, a transient response is excited (as in all dynamic systems) having frequency components at the impressed frequency and at the resonant frequencies of the system. There will be a current component of frequency $p$ in the $C_1$, $L_1$, $T_1$ mesh, a current component of frequency $p—q$ in the $C_2$, $L_2$, $T_2$ mesh, and a mechanical vibration, of frequency $q$, of the tuning fork F.

In a linear system the transient components at other than the impressed frequency would have no energy source to sustain them, consequently they would quickly be damped out, the system settling down to sinusoidal oscillations at the impressed frequency ($p$). Here the magnetic coupling of the electric and the mechanical system is non-linear, due to the fact that the mechanical force on the fork F, produced by the flux across the air-gap, is proportional to the square of the flux. This non-linearity affects the electrical system through the changing of the width of the air-gap as the fork vibrates, thereby changing the inductance.

Modulation takes place as the result of this non-linearity. The current components of frequency $p$ and $p—q$ interact to produce their difference frequency $q$. This frequency component in the flux produces a corresponding mechanical force across the air-gaps which reenforces the mechanical vibrations. Simultaneously the mechanical motion produces a component of frequency $q$ in the flux due to the variation in the magnetic path. This component modulates with the flux component of frequency $p$ to produce the difference frequency $p—q$, thus reenforcing the current component of frequency $p—q$. Because of this process of mutual reenforcement with energy drawn from the generator and transferred by

modulation, the transient disturbances of frequency $q$ and $p—q$ do not die out but will, if the losses are sufficiently small and the impressed force sufficiently large, built up and stabilize to steady oscillations.

The arrangement thus operates as a frequency changer delivering to the load a current of a frequency equal to the difference between that of the source and the resonance frequency of the vibrating element. These frequencies may be so related that the output is at a sub-harmonic of the supply frequency, but this relationship is not necessary. The tuning of the electrical circuits should be such as to produce electrical resonances at the frequencies indicated, but exact tuning is not necessary. It is necessary only that the impedances be low to currents of the respective frequencies.

Fig. 2 shows a modification in which the electromechanical coupling is electrostatic instead of magnetic. C represent plates of parallel plate condensers. The other plate of each of these condensers is an arm of the tuning fork F. The circuit resonances are obtained by means of a suitable choice of inductances and capacities $L_1$, $L_2$, $C_1$ and $C_2$ as before. The non-linearity is of essentially the same type as in the system of Fig. 1 since the mechanical force on the fork is proportional to the square of the charge on the condenser and the capacity reactance is varied by the variation in the spacing between the condenser plates when the fork vibrates.

A balanced form of the electrostatically coupled system is shown in Fig. 3. The input transformer $T_1$ has a mid-tap in the secondary winding. This mid-tap is connected through the primary winding of an output transformer $T_2$ to ground G. The tuning fork F has plates C mounted on both sides of each arm and is itself grounded at G. The condensers C between the arms of the fork are connected through an inductance $L_1$ to one side of the input transformer. The condensers C, on the outside of the arms of the tuning fork, are connected through an inductance $L_1$ to the other side of the input transformer. The modulation by which the oscillations at frequencies $p—q$ and $q$ are sustained takes place as in the circuit of Fig. 2. The advantage of this form of the circuit is in a more complete separation of the electrical components. It is evident from the symmetry that no component of current of frequency $p$ will be present in the mid-branch; thus the impressed frequency component is balanced out of the output much more readily than it can be suppressed by means of tuned circuits as in the previously described systems. When the arms of a fork vibrate they always move in opposite directions. Thus, when the motion of the arms of the fork F increases the capacity of the outside condensers C it decreases the capacity of the inside condensers C, making the modulation products flow in the mid-branch, through the output transformer $T_2$. From the symmetry it is evident that the current component of frequency $p—q$ will divide and flow in equal magnitudes both directions from the mid-tap in the secondary of the input transformer thus balancing out the primary of the input system. By a suitable choice of the inductances $L_1$ and the input and output transformers $T_1$ and $T_2$ the system may be resonated to both the frequency components $p$ and $p—q$.

In Fig. 4 is shown a different form of an electrostatically coupled device. The input network, consisting of a source of sinusoidal electromotive force of frequency $p$, $E_p$, an input transformer $T_1$, and a tuning inductance $L_1$ and capacity $C_1$, is as before. The condenser plates C are mounted to form condensers with the arms of a tuning fork F. In series with the primary of the output transformer $T_2$ is a condenser $C_2$ and inductance $L_2$. The power delivered to the terminating network (represented by $Z_q$) is at a frequency $q$. Shunted across the output transformer $T_2$ and the condenser $C_2$, is an inductance $L_3$ in series with a condenser $C_3$.

The resonant frequency of the tuning fork is, in this case, $2p$. By means of a suitable choice of $L_3$ and $C_3$ the system is given an electrical resonance at a frequency $2p—q$ and by means of $C_2$ the system is given an electrical resonance at frequency $q$. Current components of other frequencies are substantially suppressed in the output transformer $T_2$ by virtue of the selectivity of the circuits.

Because of the mechanical force on the tuning fork, from the electrical system, being proportional to the square of the charge on the condenser there will be a mechanical force component of frequency $2p$, which will sustain mechanical vibration of the fork at that frequency. This varying condenser, as in the previous cases, is a non-linear reactance. When the generator electromotive force $E_p$ is impressed the fork F will start vibrating at a frequency $2p$ and there will be transient current components at the resonant frequencies $2p—q$ and $q$. The component $2p—q$ will modulate in the condenser producing a component $q$ (the difference component between $2p$ and $2p—q$) which will reenforce the transient component at that frequency. Simultaneous, the component of frequency $q$ will modulate in the condenser, producing a difference frequency component $2p—q$ which will reenforce the transient current component at that frequency. This process of mutual reenforcement will sustain these two components of current with energy drawn from the condenser, which, of course, obtains it from the source $E_p$.

In the modification illustrated in Fig. 5, the electromechanical coupling is magnetic by means of iron core coil L. The input is tuned, as in the other examples of magnetic coupling, by means of a condenser $C_1$ and inductance $L_1$. The remainder of the system is the same as that of Fig. 4 and the operation is essentially the same.

What is claimed is:

1. A frequency changer adapted to produce sustained oscillations of a lower frequency when excited by oscillations of a single fixed frequency comprising a circuit tuned to a desired low frequency, a second circuit including a wave source of fixed higher frequency, a variable reactance device common to both of said circuits comprising an electrical reactance element and mechanical means for varying the reactance of said element responsively to variations of electrical energy therein, and means including said variable reactance device for selectively absorbing energy at a frequency corresponding to a lower side frequency resulting from the modulation of currents of said desired low frequency and currents from said wave source, whereby oscillations of said low frequency are made self-sustaining.

2. A system in accordance with claim 1 in which the said mechanical means comprises a mechanical vibrator tuned to a frequency equal to the difference of the wave source frequency and the desired low frequency.

3. A system in accordance with claim 1 in

which the said mechanical means comprises a mechanical vibrator tuned to a frequency equal to twice the wave source frequency and in which the selective energy absorbing means comprises an electric circuit including the said variable reactance device tuned to a frequency equal to the difference of the frequency of said vibrator and the desired low frequency.

4. A frequency changer adapted to produce sustained oscillations of a lower frequency when excited by oscillations of a single fixed frequency comprising a load circuit tuned to a desired low frequency, a second circuit including a wave source of fixed higher frequency, a coil common to both of said circuits, and a mechanically tuned armature in the field of said coil, said armature being tuned to a frequency equal to the difference of said wave source frequency and said desired low frequency.

5. A frequency changer adapted to produce sustained oscillations of a lower frequency when excited by oscillations of a single fixed frequency comprising a load circuit tuned to a desired low frequency, a second circuit including a wave source of fixed higher frequency, a coil common to both of said circuits, a mechanically tuned armature in the field of said coil having a resonance frequency of twice the wave source frequency, and a third circuit including said coil tuned to a frequency equal to the difference of the resonance frequency of said armature and the said desired low frequency.

RALPH V. L. HARTLEY.