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ELECTRICAL WAVE PRODUCTION

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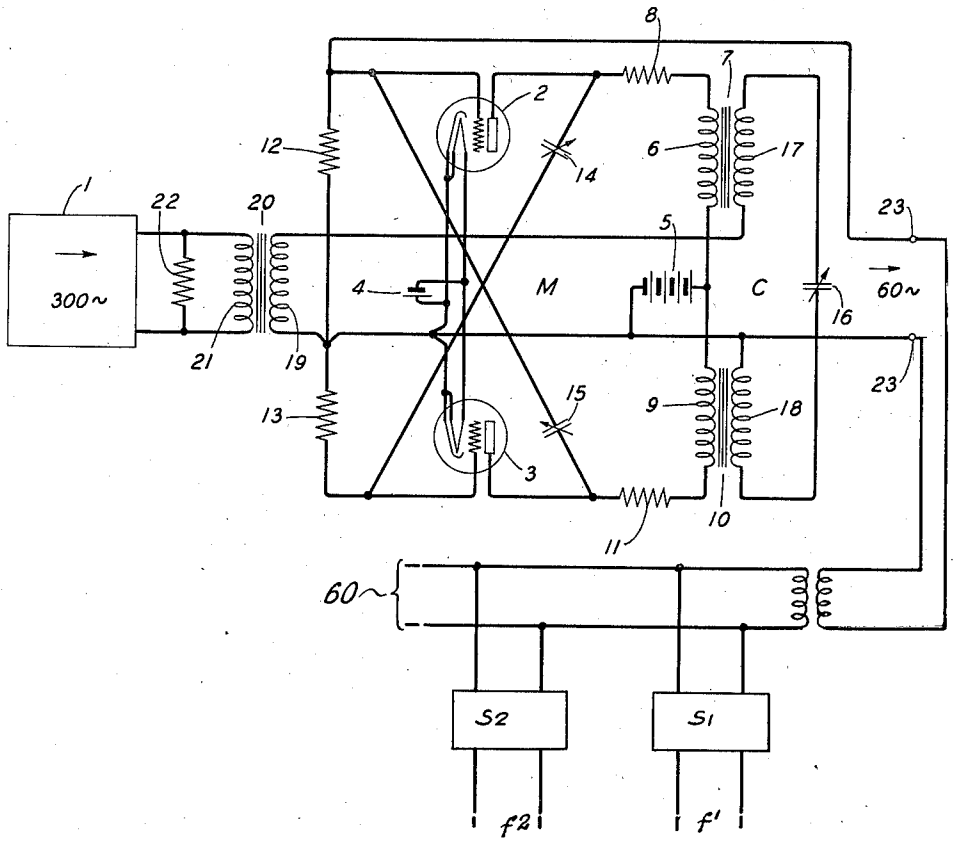

INVENTOR
C. H. RUMPEL
BY H. A. Burgess
ATTORNEY

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ELECTRICAL WAVE PRODUCTION

Carl H. Rumpel, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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The invention relates to the production of electrical waves and particularly to the production of electrical waves of desired frequency by converting from a wave of another frequency.

An object of the invention is to produce an electrical wave whose frequency bears a definite relation to the frequency of a given wave.

Another and a more specific object is to generate a wave whose frequency is a desired submultiple of a given frequency.

One type of frequency conversion circuit in the prior art is the so-called "multivibrator". A multivibrator is an arrangement of electric discharge devices operating as a distorted wave oscillator to produce a discontinuous wave, the frequency of which may be adjusted to have any value within wide limits. In its simplest form, as devised by Abraham and Bloch, it comprises a two-stage resistance-capacity coupled vacuum tube amplifier in which the output of the last tube is coupled to the input of the first tube. The time constants of the circuit elements are selected so that the multivibrator oscillates at a fundamental frequency which is approximately that of the frequency desired. When the multivibrator is used as a step-up frequency converter, the fundamental component of the output frequency is determined by and maintains a constant phase relation with a low frequency control oscillation injected into the plate or grid circuits of the tubes. When the multivibrator is used as a step-down frequency converter, the frequency of the injected control oscillations coincides with an harmonic of the multivibrator.

In accordance with the invention, I have combined a frequency conversion circuit of the above type with a circuit including induction coils of the saturable core type to produce a frequency converter which has exceptional stability in operation.

A more complete understanding of the invention together with its various objects and features will be had from the following detailed description thereof when read in connection with the accompanying drawing, the single figure of which shows schematically a step-down frequency converter representing one embodiment of the invention.

The circuit of the invention will be described as applied to the production of a stable low frequency alternating current wave from an alternating current wave having a constant higher frequency which is equal to a harmonic of the low frequency wave.

The circuit, as shown in the drawing, comprises three main elements: a source 1 of alternating current control waves of the harmonic frequency, a multivibrator M having a natural oscillation frequency approximately equal to the desired low frequency and a coupling circuit C therebetween adapted to oscillate freely at the desired fundamental low frequency. The source of control waves 1 of constant frequency may be, for example, a vacuum tube oscillator controlled by a tuning fork or piezoelectric crystal.

The multivibrator M comprises the two three-electrode amplifying vacuum tubes 2 and 3. The cathodes of the tubes 2 and 3 are preferably, as shown, of the heater type arranged to be heated in parallel from a source of current 4 of proper voltage which, for simplicity, is shown as a direct current battery but may be a source of alternating current supplied from commercial electric lighting mains in the well-known manner. Space current is supplied by the common plate battery 5 to the plates of the multivibrator tubes 2 and 3, respectively, through one winding 6 of the transformer 7 and high resistance 8 in series, and through one winding 9 of transformer 10 and the high resistance 11 in series, which resistances and windings are connected in series between the plates of the two tubes. A series resistance 12 is connected in the grid-cathode circuit of tube 2 and a series resistance 13 is connected in the grid-cathode circuit of tube 3. The plate of tube 2 is connected to the grid of tube 3 by the variable condenser 14, and the plate of tube 3 is connected to the grid of tube 2 by the variable condenser 15. The values of the resistances and condensers in the multivibrator circuit, as just described, primarily determine the natural frequency of vibration of the circuit.

The resonant circuit C coupling the source of control oscillations 1 to the multivibrator M comprises the variable condenser 16, the winding 17 of transformer 7, the winding 18 of transformer 10 and the secondary winding 19 of input transformer 20 in series. The terminals of the primary winding 21 of the transformer 20 are connected to the source 1 of control oscillations across the impedance matching resistance 22.

The transformers 7, 10 and 20 are provided with magnetic cores, preferably of chrome-permalloy laminations, though cores of other magnetic materials such as silicon steel may be used. The output (terminals 23) of the frequency conversion circuit is shown, in this particular case, connected across the grid and cathode of the multivibrator tube 2. For purposes, however, where a more sinusoidal than a square

wave shape is desired, the output terminals could be connected across condenser 16 or transformer 7 or 10. A utilization circuit, which may include an amplifying vacuum tube (not shown on the drawing), may be connected across terminals 23 by any suitable means, such as a transformer as indicated.

The operation of the frequency conversion system described above in producing an alternating current wave of a stable frequency of say 60 cycles per second from a given standard wave of say 300 cycles per second will now be described.

The values of the resistances and condensers in the multivibrator circuit M are initially adjusted so that the multivibrator oscillates at a fundamental frequency which is approximately equal to the desired frequency (60 cycles).

In the multivibrator circuit, as described, the plate circuit of the tube 2 is resistance-capacity coupled to the grid circuit of tube 3 through resistances 8 and 13 and the condenser 14. The plate circuit of tube 3 is, in turn, resistance-capacity coupled to the input of the tube 2 through resistances 11 and 12 and condenser 15. The circuit may be considered as that of an ordinary oscillator except that the feed-back has been increased to a maximum and there is no inductance-capacity tuned circuit to determine the frequency of oscillation.

The high feed-back results in oscillations of comparatively large amplitude in which the grids of the tubes are driven alternately very positive and negative as follows:

Since the output of one tube is coupled to the input of the other, a continuous amplification path is produced. Thus, any small potential occurring at random, or definitely applied by external means, in the continuous amplification path (the plate or grid circuit of tube 2 or 3) will be successively amplified by one tube and then the other such that the same impulse may pass through the same tube several times. In so doing, the impulse will become amplified so much that one of the tubes "blocks". Under this condition, the "blocked" tube, say tube 2, has zero plate current because the potential of its grid has, by the amplified impulse, been driven extremely negative. Condenser 14 draws charging current through resistance 13 maintaining the grid of tube 3 positive and the internal impedance of tube 3 a minimum, causing the plate potential of tube 3 to drop far below the potential of battery 5. Condenser 15, therefore, is discharged from battery potential to the potential of the plate. This discharge causes a current through resistance 12 maintaining the grid of tube 2 at its extreme negative value.

Eventually, condensers 14 and 15 approach being fully charged and discharged respectively, and the grid of tube 2 becomes less negative and the grid of tube 3 less positive. Suppose, at approximately this instant, a small positive potential is applied externally to the grid of tube 2 which is sufficient to re-establish an increment of plate current. The tube 2 is then no longer "blocked" and the circular amplification path is again established. The positive potential applied to the grid of tube 2 will then be immediately amplified and the grids of tubes 2 and 3 will be driven extremely positive and negative respectively. The exact reverse of the original "blocked" condition is then reached, that is, tube 3 is now blocked instead of tube 2. Tubes 2 and 3 and their associated condensers, coils and resistances have effectively exchanged conditions. Condensers 14 and 15 go through discharge and charge cycles, respectively, and the grids of tubes 2 and 3 are maintained at positive and negative potentials, respectively, by the currents through resistances 12 and 13. Eventually, a condition exists where a small positive potential applied to the grid of tube 3 will be sufficient to unblock that tube. With tube 3 unblocked, the continuous amplification path is again restored and the chain of events leading to the blocking of the tube 2 and then tube 3 is continuously repeated as described above.

From the above, it is seen that each cycle may be started by the injection of a pulse of the proper polarity and sufficient amplitude at certain instants, or that each cycle may be started by a random pulse, such as noise, etc. It follows, therefore, that cycles started by noise or other random impulses would have a very approximate starting time. For this reason, a multivibrator operating without a control frequency is not very stable and the frequency generated thereby is subject to change with changes in tubes, line voltage, etc. On the other hand, a multivibrator operating under a controlled frequency becomes very stable. A more specific explanation of this stabilizing action is as follows:

A substantially constant frequency (300 cycles per second in this case) supplied by source 1, is injected into the continuous amplification path of tubes 2 and 3 through transformers 7 and 10 connected in the plate circuits of these tubes. When a tube is highly blocked (the grid extremely negative), a large applied voltage is required to unblock it, so for a 300 cycle wave controlling a 60 cycle multivibrator most of the individual cycles will have no effect. But, at the moment when the condensers become fully charged and discharged, as previously explained, the tube becomes less highly blocked so that one of the individual waves of the 300 cycles supplies the required stimulus at just the critical moment to fix accurately the time of shift.

From the above discussion, it may be seen that if the controlling frequency of the multivibrator is too high, the shift will occur too early, say at every fourth instead of every fifth cycle of the 300 cycle wave. This is because the control frequency is so high that the blocked tube can be unblocked earlier in the cycle. Thus, if the control frequency to a multivibrator is gradually raised, the multivibrator will suddenly start oscillating at a frequency one step higher. If, however, the particular wave which provides the shift stimulus is made to have an amplitude greater than the other waves, it is seen the time of shift would be made all the more precise. The possibility of the shift taking place at, say, every fourth instead of every fifth wave, would then be considerably lessened. A circuit for increasing the stability of a multivibrator by this method is described below.

The 300 cycle control frequency from the source 1 is impressed upon the resonant circuit C by the transformer 20. The values of the circuit elements in resonant circuit C comprising the secondary winding 19 of transformer 20, the winding 18 of transformer 10, the winding 17 of transformer 7 and the condenser 19 in series, is adjusted so that the circuit is adapted to have a free period of oscillation of approximately the desired submultiple frequency (60 cycles per second), providing these oscillations are not of sufficient amplitude to produce saturation effects in the cores of the windings. The size of the mag-

netic cores for the transformers 10 and 7 is made such that they are adapted to be saturated by the space currents of the associated vacuum tube circuits which currents are larger than those due to the free oscillations of the circuit C. The multivibrator M being tuned to the desired frequency (60 cycles per second) will act "in step" as described above with the 300 cycle control frequency from the source 1, and the plate currents of tubes 2 and 3 will produce saturation in the cores of the coupling transformers 7 and 10 at the proper instant to maintain the circuit C oscillating at a constant frequency of 60 cycles per second.

The core saturation just described has the effect of aiding both the charge and discharge of condenser 16 such that the resistance of the circuit is neutralized and the circuit becomes self-oscillating. This resistance neutralization is caused by the introduction of negative resistance by the core saturation. This negative resistance cancels the positive resistance of the circuit and the circuit becomes self-oscillating. Negative resistance, however, is only a mathematical explanation of the above phenomena. What physically happens, since there is actually no such physical thing as negative resistance, is briefly as follows:

When the core of a coil saturates, the current through the coil suddenly rises because the coil no longer has appreciable inductance. This added flow of current causes the condenser 16 to be charged to a value higher than it would have been without saturation. Also, on the discharge, the saturation effect causes the condenser 16 to be discharged more than it would without the saturation in the coil. This added stimulus to the condenser 16 is, if the circuit positive resistance is low, sufficient to overcome the losses occurring in the positive resistance. The effect of the positive resistance is, therefore, nullified by this so-called negative resistance phenomena and the circuit maintains self-oscillation.

The governing frequency supplied to the multivibrator M from the resonant circuit C through the transformers 7 and 10 will, therefore, be composed of the constant 60 cycles per second frequency generated by the circuit C in step with the 300 cycle frequency supplied by the source 1. The effect of supplying the 60 cycle oscillations to the multivibrator is to make the critical wave, as described above, of higher amplitude than the others so that the multivibrator will remain "in step" more easily. The result is that the stability of the multivibrator M is approximately equal to that of a multivibrator operating with a 1 to 1 ratio between its governing and operating frequencies or, in this case, with a 60 cycle stabilizing frequency.

Since the saturating effects in the transformers of the resonant circuit C are mainly supplied by the multivibrator instead of by the 300 cycle power source, the latter source may be small in size (a few milliwatts). The frequency conversion circuit, as described, is self-starting due to the self-starting properties of the multivibrator. Almost any standard vacuum tube coupling transformers of the proper ratio may be used since they are connected in the circuit with direct current flowing through them to enhance the saturating effect.

It will be seen, from the above description, that the frequency conversion circuit of the invention comprises in effect two frequency conversion circuits employing a single source of waves of the primary frequency to be converted, the two circuits mutually controlling each other to produce waves of stable frequency harmonically related to the frequency of the primary waves.

The circuit arrangement above described was built for use in connection with an electric clock synchronizing system, where the entire system was operated from a common power supply subject to large voltage variations. Such a circuit requires a high degree of stability because, when the power supply voltage varies, it causes changes in the magnitude of the multivibrator governing voltage, all filament supply voltages and plate voltages. The circuit was found to be perfectly stable with changes from one-half to double normal values of condensers 14, 15, 19 and resistances 8, 11, 12 and 13 and for power supply voltages varying from 70 to 140 volts.

In the circuit of the invention, described above, the submultiple frequency (60 cycles per second) is picked off from the output circuit of the multivibrator M by a circuit connected to the output terminals 23. It is apparent that any desired harmonic f_1, f_2 of the fundamental frequency may be also picked off from the output of the multivibrator by employing selective circuits of suitable design, for example, an anti-resonant circuit s_1, s_2, as indicated, comprising inductive and capacitive elements of suitable values.

Although the invention has been specifically described for the case where the frequency converter operates to produce a low frequency wave from a higher frequency wave, it is applicable as well to a system for producing a higher frequency wave from a low frequency wave, in which case the control waves produced by the source 1 should be of a frequency having a subharmonic relation to the desired higher frequency wave, and the resonant circuit C and the multivibrator M should be tuned to the latter frequency.

Screen grid amplifying tubes may be substituted for the ordinary three-electrode tubes illustrated in the circuit of the invention. Various other modifications of the circuit shown and described within the scope of the invention will occur to persons skilled in the art. The invention is only to be limited by the scope of the appended claims.

What is claimed is:

1. A frequency converter comprising a passive oscillating circuit adapted to oscillate freely at a desired frequency, said circuit including at least one induction coil provided with a magnetic core adapted to be saturated by a current larger than that due to the free oscillations of said circuit, a source of primary waves of a frequency harmonically related to said desired frequency and coupled to said passive circuit, an active oscillating circuit adapted to oscillate freely at the same frequency as said passive oscillating circuit, the two oscillating circuits being coupled together to interact on each other, and a circuit for selecting from the output of one of said oscillating circuits a wave of a converted frequency.

2. A frequency converting system comprising a passive circuit tuned to oscillate at a desired frequency, said circuit including induction coils each provided with a magnetic core adapted to be saturated by a current larger than that due to the free oscillations of said circuit, means for producing saturation in said coils such as to aid in the production of oscillations of said passive circuit at said desired frequency, comprising a multivibrator circuit having a natural oscillation frequency approximately equal to that of said passive oscillating circuit and a source of con-

trol waves of a frequency harmonically related to said desired frequency both coupled to said passive circuit, the coupling between said passive circuit and said multivibrator circuit transmitting to the latter circuit waves of said desired frequency and of harmonically related frequencies to control its oscillation at said desired frequency, and means for selecting from the output of one of the coupled oscillating circuits a wave of a converted frequency.

3. A frequency reducing system comprising a source of alternating current waves of a given frequency, a passive oscillating circuit adapted to oscillate freely at a fundamental frequency which is a desired submultiple of said given frequency, and coupled to said source, said passive circuit including at least one induction coil having a magnetic core adapted to be saturated by current larger than that due to the free oscillations of said passive circuit, a multivibrator having a natural oscillation frequency approximately equal to said submultiple frequency also coupled to said passive circuit, said source and said multivibrator cooperating to produce saturation current in each induction coil and thus to control oscillation of said passive circuit at said submultiple frequency, the coupling between said source and said multivibrator transmitting to the latter waves of both said given and said submultiple frequency to control oscillation of said multivibrator at said submultiple frequency, and means for selecting from the output of said multivibrator waves of said submultiple frequency.

4. The system of claim 3, in which each induction coil comprises a winding of a transformer, said transformer having another winding in circuit with said multivibrator so that said transformer inductively couples said passive circuit to said multivibrator.

5. A frequency reducing system comprising a source of primary waves of a given frequency, a resonant circuit coupled thereto and adapted to oscillate freely at a fundamental frequency which is a desired submultiple of said given frequency, a multivibrator circuit having a natural oscillation frequency approximately equal to said desired submultiple frequency, two transformers coupling said resonant circuit to said multivibrator circuit, each transformer being provided with a magnetic core adapted to be saturated by current stronger than that due to the free oscillations of said resonant circuit and which current is supplied almost entirely by said source and said multivibrator circuit, said transformers transmitting to said multivibrator circuit waves both of said given frequency and of said submultiple frequency to control the latter at said submultiple frequency, and means for selecting from said multivibrator circuit waves of said submultiple frequency.

6. The system of claim 5, in which said multivibrator circuit comprises two electric discharge tubes each having a cathode, an anode and a control electrode, a cathode-anode and a cathode-control electrode circuit for each tube, a resistance in each cathode-anode and cathode-control electrode circuit, the anode of each tube being connected to the control electrode of the other tube by a capacitive element and one winding of each transformer being connected respectively in the cathode-anode circuit of a different one of said tubes, and said resonant circuit comprises another winding of one of said transformers in series with another winding of the other transformer.

CARL H. RUMPEL.