July 22, 1947. H. M. HUGE 2,424,236

FREQUENCY CHANGER

Filed May 6, 1943

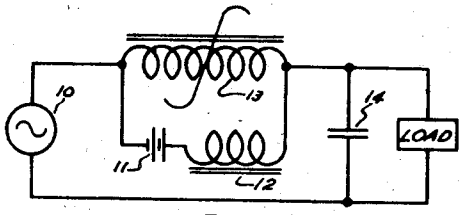


FIG. 1

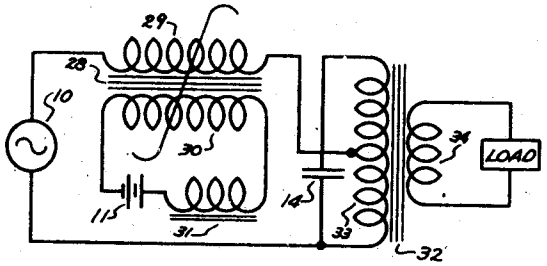


FIG. 2

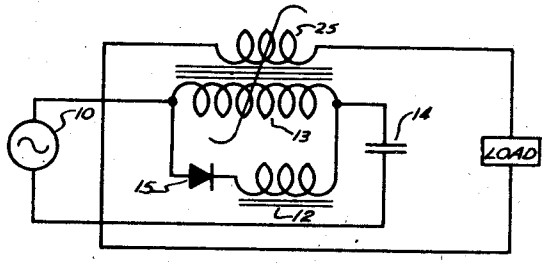


FIG. 3

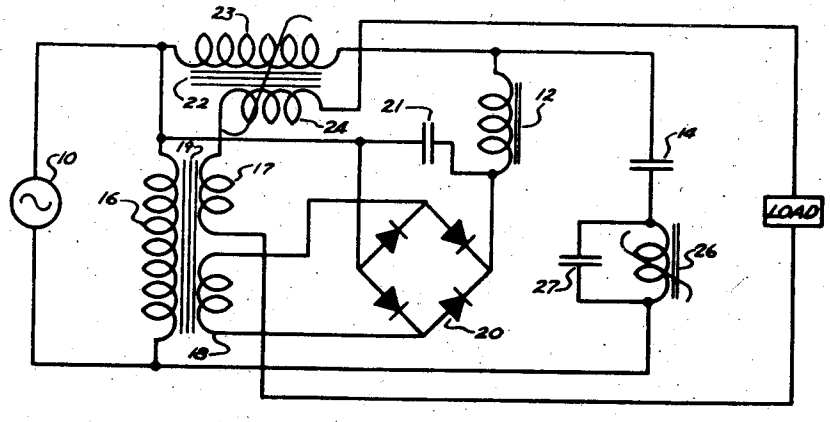


FIG. 4

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FREQUENCY CHANGER

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18 Claims. (Cl. 172—281)

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This invention relates to frequency changers and in particular to a magnetic frequency divider which does not require a starting transient.

The invention makes use of the saturation of a ferromagnetic core to divide the frequency of an alternating current source, and comprises a biased saturable inductance in series with a capacitor in a self-starting circuit. By my invention I am able to reduce the number of elements required in a self-starting frequency divider and at the same time obtain maximum efficiency, greatly improved stability with fluctuations of input voltage and load, and excellent regulation of the output voltage. In my frequency changer the oscillations are stabilized by controlling the phase relationship between the subharmonic and input frequency voltages across the saturable inductance, and in this manner the correct value of negative resistance necessary under any load condition is produced while maintaining a substantially constant subharmonic voltage across the load. Another feature of my invention provides automatic adjustment of the biasing current to greatly extend the usable range of input voltage over which the frequency changer will operate.

It is an object of this invention to divide the frequency of an alternating current source by magnetic means.

Another object of this invention is to provide a magnetic frequency reducer which is self-starting without a starting transient.

A further object of this invention is to generate even subharmonics of an alternating current source in a static frequency changer.

An additional object of this invention is to energize the biasing rectifier with voltage from the saturable inductance for which it provides the bias.

Another object of this invention is to energize the biasing rectifier in a frequency divider with a combination of voltage from the alternating current source and voltage from the saturable inductance for which it provides the bias.

It is also an object of this invention to supply a load with a substantially constant subharmonic voltage in spite of variations of the alternating supply voltage or load variations.

A further object of this invention is to stabilize the operation of a magnetic frequency reducer over a wide range of input voltage and load.

Another object of this invention is to utilize a linear inductance to increase the operating range and stability of a frequency changer.

Another object of this invention is to provide a frequency reducer having a high efficiency.

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Another object of this invention is to provide a frequency reducer which is self-starting under normal loads and self-protecting against overloads.

Another object of my invention is to provide automatic adjustment of the biasing current supplied to the saturable inductance to compensate for input voltage variation.

Further objects and a better understanding of my invention may be had by referring to the following specifications and claims, in connection with the accompanying drawings in which

Figure 1 is a circuit diagram of an embodiment of my invention including a direct current source to bias the saturable inductance,

Figure 2 is a modification of the circuit of Figure 1; in which the direct current circuit is insulated from the alternating current circuit, and an alternative method of stabilization is shown.

Figure 3 is another modification of the circuit of Figure 1, using a half-wave rectifier to supply the biasing current and showing an alternative method of connecting load.

Figure 4 is a circuit diagram of a preferred embodiment of my invention, showing the bias supplied by a full-wave rectifier and including provision for introducing harmonics in the output voltage.

In general my invention provides new and improved means for stabilizing subharmonic oscillations under wide variations of load and input voltage, for increasing the efficiency of conversion and for initiating the oscillations.

Referring now to Figure 1, there is shown the circuit diagram of a frequency changer made in accordance with my invention and comprising a capacitor 14, a saturable inductance 13, and a filter inductance 12. The circuit is energized by alternating current source 10 and direct current source 11 and supplies voltage of the new frequency to the load shown connected across capacitor 14.

Direct current from source 11 flows through inductance 12 and inductance 13 and is blocked from source 10 by the D. C. resistance of the load.

I prefer to construct the magnetic circuit of inductance 12 with a suitable air gap to avoid excessive magnetization of the core by the direct current flowing through the winding. Saturable inductance 13 is normally constructed with a closed magnetic circuit, thus it has a non-linear magnetization characteristic and may be referred to as a non-linear inductance.

The superposition of the direct current from source 11 and the alternating current from source

10 produces an asymmetrical flux condition in inductance 13 and produces in cooperation with capacitor 14, a negative resistance at the subharmonic frequency, and when this negative resistance exceeds the positive circuit resistance, subharmonic oscillations start spontaneously. The subharmonic oscillations are produced most readily at a frequency which is one half the frequency of source 10, and the operation described in these specifications is primarily applicable to frequency halving, but other even subharmonic frequencies, such as one-fourth or one-sixth the source frequency can be obtained by altering the circuit constants. Generally the wave shape of the voltages produced at these lower frequencies is not as good as that of the voltage produced at half the source frequency.

I prefer to construct inductance 12 with an impedance value which produces an appreciable subharmonic current flow through it. In this way inductance 12 can be used to stabilize the oscillations over a wide range of input voltages from source 10. The value of inductance 12 is set to provide optimum tuning of the circuit to both the subharmonic frequency and the frequency of source 10. The stabilization can be accomplished alternatively by providing the magnetic circuit of inductance 13 with a suitable air gap in part or all of the lamination stack, thus reducing its maximum impedance value. Even with this air gap, however, inductance 13 has a non-linear characteristic. In the alternating current circuit, inductance 12 is in parallel with inductance 13 and increasing the exciting current of inductance 13 produces an effect similar to that produced by increasing the exciting current of inductance 12.

In the operation of the frequency changer of my invention, I am able to obtain a highly desirable load-carrying characteristic, depending on the cooperation of stabilizing inductance 12 with capacitor 14 and saturable inductance 13. When a light resistive load is applied in the circuit of Figure 1, the voltage across capacitor 14 drops slightly, and as the load resistance is decreased, the load voltage drops very slowly until peak load is approached. As the load resistance is diminished below the value which draws peak power, the subharmonic output voltage falls rapidly although no instability or shift in frequency occurs at any value of load. At a relatively low value of load resistance the subharmonic oscillations cease, but a slight increase in load resistance above this value causes the oscillations to restart.

I have found that by controlling the phase shift between the subharmonic and fundamental voltages across saturable inductance 13 I can maintain a negative resistance equal to the positive resistance which changes with load. I make use of this discovery by proportioning saturable inductance 13, linear inductance 12, and capacitor 14 to produce a phase shift between fundamental and subharmonic voltages to produce the necessarily large changes in negative resistance without large changes in the magnitude of the voltage across the saturable inductance. This feature of the invention gives my frequency changer a highly desirable characteristic so that normal variations in load do not produce large changes in output voltage.

In the circuit of Figure 2, primary winding 33 of transformer 32 is connected in parallel with capacitor 14 and saturable inductance 28 is provided with two windings, winding 29 connected

to alternating current source 10 and winding 30 connected to direct current source 11.

The operation of the frequency changer of Figure 2 is similar to that of the frequency changer of Figure 1. The direct current supply is isolated from the alternating current supply, however, and the load is isolated from both the D. C. and A. C. sources. Furthermore, the circuit of Figure 1 is not adapted to supply a load having low direct current resistance, whereas no such restrictions need be placed on the character of the load in Figure 2.

Inductance 31 in Figure 2 may be increased to a value as large as desired because the stabilizing effect can be produced by designing transformer 32 with the correct exciting current necessary for stabilization. To accomplish this, I prefer to construct the core of transformer 32 with a suitable air gap so that it effectively becomes a linear inductance in parallel with capacitor 14.

The primary winding 33 of transformer 32 can properly be called a stabilizing inductance when the word "inductance" is suitably defined. The term "inductance" as used herein, does not exclude the possible use of the inductance windings as a transformer, but indicates that the action of the element depends on its exciting current. This contrasts with the term "transformer" which ordinarily implies that the exciting current is merely incidental to the function of the element.

In the subharmonic circuit, considering saturable inductance 28 as the subharmonic generator, inductance 31, capacitor 14 and primary winding 33 of transformer 32 are all effectively in parallel with each other. This statement is, of course, based on the assumption of negligible impedance in source 10. This assumption is usually justified, particularly when source 10 is the commercial power supply. Under this condition it is easily seen that increasing the exciting current of transformer 32 has the same effect on the subharmonic current as increasing the exciting current of inductance 31. The effect on the current of the frequency of source 10 is not exactly same, however, and the interchangeability of the two methods of stabilization is somewhat limited by this fact. While I have shown the stabilizing inductance as incorporated in transformer 32, it should be pointed out that a stabilizing inductance not shown may be shunted across condenser 14 without making use of any transformer action if the proper value of capacitor 14 is selected.

An advantage of the arrangement of Figure 2 lies in the possibility of increasing inductance 31 to the point where it allows very little alternating current to pass through direct current source 11. Such an adjustment is advantageous for example, when source 11 is a telephone talking battery.

In Figure 2 output winding 34 is insulated from both the alternating current source 10 and the direct current source 11 and can be constructed to supply any desired output voltage to the load.

Figure 2 also shows primary winding 33 tapped as an autotransformer to step up the voltage on capacitor 14. This sometimes effects an economy in permitting the use of a smaller high voltage capacitor instead of the large low voltage capacitor otherwise required.

The chief structural difference between the circuit of Figure 3 and that of Figure 1 is the substitution of half-wave rectifier 15 in Figure 3 for the direct current source 11 in Figure 1.

In operation, the frequency changer of Figure 3 performs somewhat differently from those of Figures 1 and 2. The direct current bias of saturable inductance 13 is produced by the alternating current flow through inductance 12 and the half-wave rectifier 15, and the oscillations start as a result of the superposition of the direct and alternating currents producing an asymmetrical flux condition in saturable inductance 13 as explained in connection with Figure 1. When the oscillations are started, however, the subharmonic current through inductance 12 and rectifier 15 predominates and the biasing current is chiefly rectified subharmonic current. As a result of this fact, an additional regulating effect besides that explained in connection with Figure 1 can be obtained. When the subharmonic voltage tends to rise, the increase in biasing current increases the saturation of inductance 13 and as a result, tends to hold the voltage down to its normal level. When the voltage falls, the reverse effect is observed. However, when the load is heavy enough a point is sometimes reached where increasing the direct current bias increases the voltage and decreasing the bias decreases the voltage. Under this condition overloads are likely to greatly decrease the output voltage or even cause the oscillations to cease and reducing the load to normal values will not necessarily restore the output voltage to its normal value. This tendency is disadvantageous under some circumstances and is overcome in the circuit of Figure 4.

In Figure 3, the output winding 25 added to inductance 13 provides a simple means for insulating the load from the alternating current supply and for keeping direct current away from the load.

The voltage supplied to the load across winding 25 has a higher harmonic content than when the load is supplied by the voltage across capacitor 14, but in many cases this may not be objectionable.

The circuit of Figure 4 represents the preferred embodiment of my invention, and shows a frequency changer in which the bias for the saturable transformer 22 is provided by a full-wave rectifier bridge 20 supplied with alternating current for winding 18 of transformer 19.

Fundamentally, the operation of the frequency changer of Figure 4 is the same as that of the frequency changers of Figures 1, 2, and 3. Alternating current is supplied from source 10 to primary winding 16 of transformer 19, and from secondary winding 18 to the rectifier bridge 20. Direct current from the bridge 20 is fed through inductance 12 and is superimposed on alternating current from source 10 in primary winding 23 of saturable transformer 22. As a result of this double magnetization, transformer 22 in cooperation with capacitor 14 produces a negative resistance to the subharmonic current and oscillations start. The oscillations build up to a value determined chiefly by the size of capacitor 14, the exciting current of inductance 12 and the saturation of transformer 22, by both direct and alternating current.

In operation, the subharmonic current flowing through inductance 12 divides, part of it flowing through capacitor 21 and part being rectified by the bridge 20. Thus the biasing current includes a component derived from the rectification of the subharmonic current, and the regulating action described in connection with Figure 3 can be used to advantage, particularly when the voltage of source 10 falls to an abnormally low value and the current supplied from winding 18 is insufficient to maintain normal bias. In this case the self-adjusting biasing action obtained by the rectification of subharmonic current is particularly advantageous. By properly proportioning saturable transformer 23, capacitor 14 and inductance 12, I am actually able to cause the subharmonic voltage generated across capacitor 14 to increase with decreases in the voltage of source 10. This action is not fully understood but it may be that reducing the voltage of source 10 increases the impedance of winding 23 of transformer 22, both as a result of reduced voltage on winding 18 and reduced voltage of the source frequency across winding 23, and that the higher impedance of winding 23 causes a higher subharmonic voltage to be developed across it.

Capacitor 21 is not essential to the operation of the frequency changer, but several advantages are gained through its use. It decidedly reduces the peak inverse voltage which must be sustained by the rectifier bridge 20; at the same time its size may be adjusted as a control on the proportion of the subharmonic current flowing through inductance 12 which is to be rectified. Increasing capacitor 21 by-passes more of the subharmonic current around the rectifiers. Thus, the size of capacitor 21 has an effect on the output voltage regulation characteristic of the frequency changer.

The load in Figure 4 is supplied with voltage from winding 24 of saturable transformer 22. As explained in connection with Figure 3, the voltage across the saturable transformer includes a component of the frequency of source 10 and in order to balance the larger part of this component out of the output voltage, winding 24 is connected in series with winding 17 of transformer 19. The turns on winding 17 are preferably proportioned to minimize the component of the frequency of source 10 in the output voltage.

As in the circuit of Figure 1, inductance 12 passes subharmonic current and acts as a stabilizing unit. At the same time, the combination of inductance 12, capacitor 14 and saturable transformer 22 cooperate to produce the correct phase relationship between the subharmonic voltage and the voltage of the frequency of source 10 under varying conditions of load and input voltage to maintain the negative resistance produced in saturable transformer 22 equal to the positive circuit resistance without causing large changes in the subharmonic voltage supplied to the load.

When an extraordinarily heavy overload is applied, the oscillations can be stopped, but in the preferred embodiment of my invention, the oscillations restart when the load impedance is increased only slightly above the value at which the oscillations ceased.

Saturable inductance 26 and capacitor 27 are not essential to the operation of my frequency changer where a substantially sinusoidal load voltage is required. Where the voltage is used as a telephone ringing voltage, however, it is usually desirable to provide a small percentage of high harmonics in the output voltage to serve as audible ringing tone. For this purpose, the relatively small saturable inductance 26 in parallel with the capacitor 27 generates an oscillation of a medium audio frequency which appears in the output as an audible tone. By keeping saturable inductance 26 relatively small and saturating it highly, I am able to minimize its influence at the subharmonic frequency and yet to provide adequate audible tone in the output

voltage. Capacitor 27 accentuates the desired audio frequency component generated by saturable inductance 26.

In order to make the most efficient use of the units, I prefer to superimpose the direct current on the same winding as that carrying the alternating current, as shown in Figure 4. This necessitates using capacitor 14 as a blocking condenser for the direct current, so no step-up transformer is used in connection with capacitor 14 as was done in Figure 2.

It will be apparent to those skilled in the art that many modifications in the arrangement of the parts can be made without departing from the true scope of my invention as hereinafter claimed.

I claim as my invention:

1. A self-starting frequency divider comprising in combination a source of alternating current, a source of direct current, a saturable inductance, a substantially linear inductance, a capacitor, first circuit means connecting said saturable inductance in series with the capacitor and the source of alternating current, and second circuit means connecting said saturable inductance in series with the substantially linear inductance and the source of direct current, the direct current from said source producing an asymmetrical flux condition in the saturable inductance which causes the saturable inductance in cooperation with the capacitor to self-start oscillations of the divided frequency.

2. A self-starting subharmonic generator adapted to be energized from a source of alternating current, comprising in combination, a capacitor and a saturable inductance connected in series circuit relationship with each other and with said source of alternating current, biasing means producing an asymmetrical flux condition in said saturable inductance which causes the saturable inductance in cooperation with the capacitor to self-start sub-harmonic oscillations, and output means supplying a load with subharmonic voltage.

3. A self-starting subharmonic generator adapted to be energized from a source of alternating current, comprising in combination, a capacitor and a saturable inductance connected in series circuit relationship with each other and with said source of alternating current, biasing means producing an asymmetrical flux condition in said saturable inductance, and output means for supplying a load with subharmonic voltage, and circuit means causing said biasing means to respond to changes in the subharmonic voltage to control the voltage delivered by said output means.

4. A self-starting frequency divider comprising in combination a source of alternating current, a source of direct current, a saturable inductance, a substantially linear inductance, a capacitor, first circuit means connecting said saturable inductance in series with the capacitor and the source of alternating current, and second circuit means connecting said saturable inductance in series with the substantially linear inductance and the source of direct current, and third circuit means connecting a load substantially in parallel with said capacitor.

5. A self-starting frequency divider comprising in combination a source of alternating current, a source of direct current, a saturable inductance, a substantially linear inductance, a capacitor, first circuit means connecting said saturable inductance in series with the capacitor and the source of alternating current, and second circuit means connecting said saturable inductance in series with the substantially linear inductance and the source of direct current, and third circuit means connecting a load substantially in parallel with said saturable inductance.

6. A self-starting magnetic frequency changer adapted to be energized from a source of alternating current and to supply a load with voltage of a frequency one-half the frequency of said source, comprising in combination, a saturable inductance, a capacitor, a substantially linear inductance, and a rectifier, first circuit means connecting said saturable inductance in series with said capacitor and said source of alternating current, and second circuit means carrying direct current from said rectifier through said linear inductance and said saturable inductance in series.

7. A frequency changer adapted to be energized from a source of alternating current, and to supply a load with voltage of a frequency which is an even subharmonic of the frequency of said source comprising in combination a saturable inductance, a capacitor, biasing means producing a unidirectional flux in said saturable inductance, first circuit means connecting said saturable inductance in series with said capacitor and the source of alternating current, said saturable inductance, capacitor, and biasing means cooperating to produce in response to a change in the resistance of the load, a shift in phase between the voltage of the frequency of said source and the voltage of the subharmonic frequency across said saturable inductance to maintain operation under variable loads with only slight changes in output voltage.

8. A frequency changer adapted to be energized from a source of alternating current and to supply a load with alternating current having a component of a frequency which is an even subharmonic of the frequency of said source comprising in combination, saturable magnetic core means, capacitive means, biasing means producing a unidirectional flux in said saturable magnetic core means, winding means on said saturable magnetic core means, and circuit means connecting said winding means in series with the capacitive means and said source of alternating current, output circuit means for connecting a load substantially in parallel with said capacitive means.

9. A self-starting magnetic frequency divider comprising in combination a saturable inductance, a substantially linear inductance, a capacitor, and biasing means producing an unsymmetrical flux condition in said saturable inductance, said saturable inductance and capacitor being arranged in a series circuit, said linear inductance being arranged in parallel circuit relationship with said saturable inductance, output circuit means supplying voltage of the divided frequency to a load.

10. A self-starting subharmonic generator adapted to be energized by a source of alternating current, comprising in combination a saturable inductance having a laminated ferromagnetic core, a capacitor, biasing means producing unidirectional flux in said ferromagnetic core, circuit means connecting said saturable inductance in series with said capacitor and the source of alternating current, producing a series circuit for subharmonic oscillations, means for stabilizing the subharmonic oscillations consisting of an air

gap in at least a portion of the laminations in said laminated ferromagnetic core.

11. A self-starting subharmonic generator adapted to be energized from a source of alternating current, comprising in combination, a non-linear inductance, a substantially linear inductance, a first capacitor, a second capacitor, a full-wave rectifier, first circuit means connecting said non-linear inductance in series with said first capacitor and the source of alternating current, second circuit means connecting said rectifier in parallel with said second capacitor and in series with the substantially linear inductance and the non-linear inductance, third circuit means adapted to supply voltage from said source to said full-wave rectifier, and fourth circuit means adapted to supply a load with a voltage which is the sum of voltage from said saturable inductance and voltage from said source of alternating current.

12. A self-starting frequency divider adapted to be energized by a source of alternating current, comprising in combination, a non-linear inductance, a substantially linear inductance, a capacitor, a full-wave rectifier, first circuit means connecting said non-linear inductance in series with said capacitor and the source of alternating current, second circuit means connecting said rectifier in series with the substantially linear inductance and the non-linear inductance, third circuit means adapted to supply voltage from said source to said full-wave rectifier, and fourth circuit means adapted to supply a load with a voltage which is the sum of voltage from said non-linear inductance and voltage from said source of alternating current.

13. A magnetic frequency changer adapted to be energized by a source of alternating current, comprising in combination, a first, a second, and a third inductance, a capacitor, a source of direct current, said first inductance having a saturable magnetic core, first circuit means connecting said first inductance in series with said capacitor and said source of alternating current, second circuit means connecting said source of direct current in series with said first inductance and said second inductance and third circuit means connecting said third inductance substantially in parallel with said capacitor.

14. A frequency changer adapted to be energized by a source of alternating current and to supply a load with power at a frequency lower than the frequency of said source, comprising in combination, a saturable inductance, a substantially linear inductance, a capacitor, a rectifier, first circuit means connecting said saturable inductance in series with the capacitor and the source of alternating current, second circuit means connecting said linear inductance in series with the saturable inductance and the rectifier, said rectifier being energized with subharmonic voltage and with voltage of the frequency of said source and providing direct current bias for said saturable inductance.

15. A self-starting frequency divider adapted to be energized by a source of alternating current, comprising in combination, a first non-linear inductance, a substantially linear inductance, a first capacitor, a full-wave rectifier, first circuit means connecting said non-linear inductance in series with said capacitor and the source of alternating current, second circuit means connecting said rectifier in series with the substantially linear inductance and the first non-linear inductance, third circuit means adapted to supply voltage from said source to said full-wave rectifier, fourth circuit means adapted to supply a load with a voltage which is the sum of voltage from said first non-linear inductance and voltage from said source of alternating current and means for introducing harmonics into said load voltage, comprising a second non-linear inductance in series with said first capacitor and a second capacitor in parallel with said second non-linear inductance.

16. A self-starting subharmonic generator adapted to be energized from a source of alternating current, comprising in combination, a non-linear inductance, a substantially linear inductance, a first capacitor, a second capacitor, a full-wave rectifier, first circuit means connecting said non-linear inductance in series with said first capacitor and the source of alternating current, second circuit means connecting said rectifier in parallel with said second capacitor and in series with the substantially linear inductance and the non-linear inductance, third circuit means adapted to supply voltage from said source to said full-wave rectifier, and output circuit means adapted to supply current of a reduced frequency to a load.

17. A self-starting subharmonic generator adapted to be energized from a source of alternating current, comprising in combination, a capacitor and a saturable inductance connected in series circuit relationship with each other and with said source of alternating current, biasing means including a rectifier for producing an asymmetrical flux condition in said saturable inductance, and output means for supplying a load with subharmonic voltage, and circuit means causing said biasing means to respond to changes in the subharmonic voltage to stabilize the voltage delivered by said output means.

18. A frequency charger adapted to be energized by a source of alternating current and to supply a load with power at a frequency lower than the frequency of said source, comprising in combination, a saturable inductance, a substantially linear inductance, a capacitor, a rectifier, first circuit means connecting said saturable inductance in series with the capacitor and the source of alternating current, second circuit means connecting said linear inductance in series with the saturable inductance and the rectifier, said rectifier being energized with voltage of the frequency of said source and providing direct current bias for said saturable inductance.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,068,620	Stocker	Aug. 3, 1937