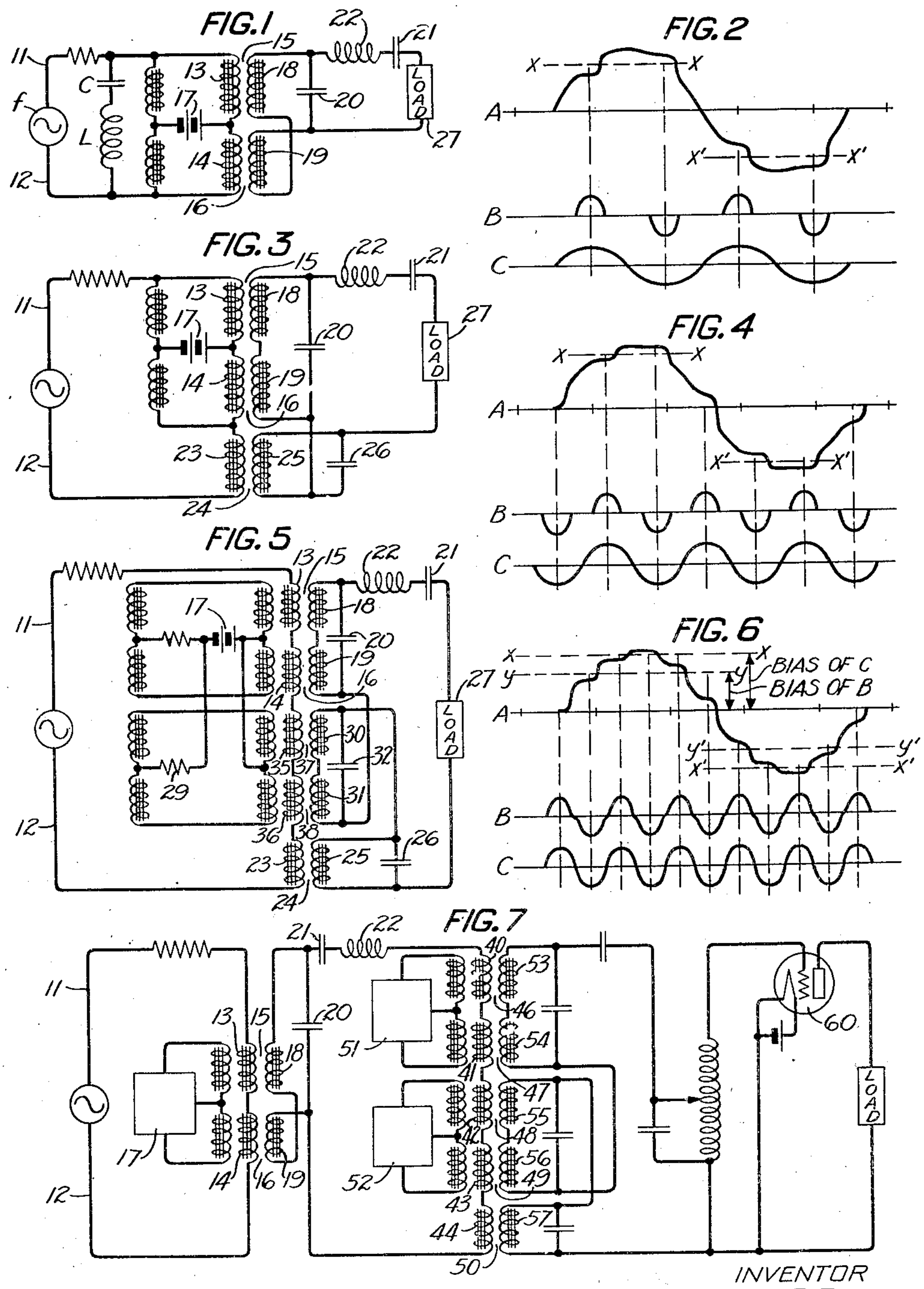
July 11, 1933. E. T. BURTON 1,917,921

FREQUENCY CHANGER SYSTEM

Filed Oct. 4, 1928



INVENTOR
EVERETT T. BURTON
BY J. W. Schmied
ATTORNEY

Patented July 11, 1933 1,917,921

UNITED STATES PATENT OFFICE

EVERETT T. BURTON, OF MILLBURN, NEW JERSEY, ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

FREQUENCY CHANGER SYSTEM

Application filed October 4, 1928. Serial No. 310,233.

This invention relates to frequency changer systems where static frequency-transformers are employed for increasing the frequency of an alternating current.

An object of this invention is to increase the frequency of an alternating current without introducing certain types of distortion in the current wave of increased frequency. A feature of the invention resulting from the accomplishment of this object resides in the fact that the new frequency has substantially no current components of even orders of harmonics present therein.

Various types of frequency multipliers are known in the art, the most generally known types being rotary generators and the static or stationary frequency-transformers. Rotary generators, particularly those which are designed to yield appreciable amounts of energy, entail considerable expense especially in systems employing high frequencies. The static frequency-transformers, to which the present invention relates, are particularly adaptable to use in signaling systems employing relatively high frequencies and in this field have been used to a large extent because of the economy effected and the efficiency with which the increase in frequency is obtained. Heretofore, in systems employing transformers for increasing the frequency, the chief concern was the production of harmonics which, when superimposed on the fundamental frequency, would result in the desired frequency. The current wave thus produced might be constituted of both the odd and even multiples of the new frequency and in order to eliminate the distortion introduced by the even multiples it was necessary to employ numerous complex networks which required frequent adjustments. Furthermore, in these systems the increase in frequency effected in a single step was relatively small, such as the doubling or tripling of the fundamental, and if it were desired to obtain a much higher frequency the operation involved in the single step had to be repeated several times.

Static frequency-transformers employed in accordance with the present invention are capable of producing relatively high frequencies in a single step and when very high frequencies are desired they may be readily had by repeating the first step a less number of times than heretofore were needed with transformers.

A feature of the invention is the production of secondary impulses which may be so spaced that the new frequency may be an even or odd multiple of the fundamental as desired.

Another feature is the substantial elimination of all even multiples of the new frequency, thereby avoiding the distortion due to such multiples.

Another feature resides in the fact that the lowest frequency voltage appearing in the secondary circuit is that of the desired multiple frequency.

The invention will be better understood by reference to the following detailed description taken in connection with the accompanying drawing in which:

Fig. 1 shows in schematic form the arrangement of a pair of static frequency-transformers for increasing the fundamental frequency twofold;

Fig. 2 graphically represents the input current of the fundamental frequency, the secondary voltage, and the output current of the double frequency in the arrangement shown in Fig. 1;

Fig. 3 shows a modification of Fig. 1 wherein the fundamental frequency is increased threefold;

Fig. 4 illustrates current and voltage waves of the arrangement shown in Fig. 3;

Fig. 5 shows a modification of Fig. 3 whereby the fundamental frequency is increased fivefold;

Fig. 6 represents the wave forms and the changes effected in increasing the frequency by the arrangement of Fig. 5; and,

Fig. 7 shows a combination of the arrangements shown in Figs. 1 and 5 whereby the fundamental frequency is increased ten times and then impressed on the grid circuit of a vacuum tube amplifier.

In the following detailed description like numbers represent like parts and theoretically ideal cases are discussed with the understanding that departures from ideal conditions always result from the limitations of apparatus, non-linearity of magnetization curves, etc.

Referring to Fig. 1 an alternating current of a certain frequency is received over conductors 11 and 12 from a source *f* of frequency and passed through the primary windings 13 and 14 of a pair of high permeability transformers 15 and 16 which are of the type disclosed in applicant's copending application corresponding to British Patent 312,338, accepted June 10, 1930. The cores of these transformers are oppositely biased by direct current of a value less than the maximum value of the alternating current, from source 17 through windings 13 and 14. Thus, while in one transformer the alternating and direct current components may be aiding, in the other they will be opposed and will neutralize each other twice during a half cycle when the alternating current passes through values equal to that of the direct current.

The transformer cores are of a magnetic material, such as permalloy, which has a very high permeability at low magnetizing forces, and which consequently very soon becomes saturated when those forces are increased, with the result that the permeability is again reduced to a very low value. Since the mutual inductance between the primary and secondary windings of a transformer is directly proportional to the permeability of the core it is evident that by using a biasing arrangement such as shown in Fig. 1 the mutual inductance of each transformer may be controlled to have two maxima during a half cycle of the alternating current, namely, at those values of this current at which the magnetizing force is zero.

Considering now the E. M. F. induced in the secondary windings, it is a well known fact that this E. M. F. is directly proportional to the rate of change of the primary current and to the mutual inductance. Therefore, when, as in the present arrangement, very great variations of the permeability take place with correspondingly great variations in mutual inductance, the effect of the rate of change in current may be insignificant except at such times when the mutual inductance takes on values appreciably higher than those prevailing during saturation conditions. Even at such times an increase in mutual inductance may more than offset a decrease in the rate of change of primary current.

Thus at those instants when the alternating and direct currents in the transformer windings nearly neutralize each other the mutual inductance will be so high that an appreciable E. M. F. will be induced in one of the secondary windings. At any other times, whether when one current predominates over the other or when they aid each other, the core material will be saturated and the permeability and mutual inductance will be so low that no appreciable E. M. F. will be induced in the secondary winding, no matter what the rate of change of energizing current may be under the assumed conditions.

Therefore, when the alternating current rises from zero in the opposite direction to the biasing current in one of the transformers 15 and 16, no secondary E. M. F. will be induced until its value approaches that of the biasing current. The mutual inductance then increases many fold and a voltage impulse is induced which lasts until the alternating current exceeds the biasing current by a small value. At this time the mutual inductance is again reduced and no secondary E. M. F. occurs until the decreasing alternating current again approaches the biasing current in value when another voltage impulse will occur. However, since the current now is decreasing this impulse will be of the opposite polarity of the first impulse. As the alternating current now continues to drop to its zero value and then rises through values of the opposite polarity, two impulses of voltage of opposite polarities are generated in the other of the secondary windings. Due to the reversed connections of windings 18 and 19, as shown in the drawing, the impulses produced in winding 19 are reversed so as to form with the impulses produced in winding 18 a series of impulses of alternate polarity, two impulses of opposite polarities being produced by each half cycle of alternating current in windings 13 and 14. By the insertion of suitable networks such as constituted of condensers 20 and 21 and inductance coil 22 in the output circuit 27 of the transformer, a series of secondary current impulses may be produced in circuit 27 which are smoothed out to form a sinusoidal wave of a frequency double that of the alternating current in the input circuit comprising conductors 11 and 12.

In Fig. 2 curve A represents the input current wave of a particular frequency flowing through primary windings 13 and 14; curve B, the voltage variations produced in the secondary windings 18 and 19 by the primary current at intensities of primary current indicated in curve A by broken lines x—x and x'—x' which are equal to the biasing currents in the primary windings 13 and 14; and curve C, the current wave in the output circuit 27 after it has passed through a suitable network and having a frequency twice that of the input circuit. It should be understood that the illustrated relation between curves B and C is not intended to show the phase relation between the impulses represented by these curves.

In Fig. 3 is shown a circuit arrangement wherein a current of a particular frequency is changed into a current of three times that frequency. This arrangement is similar to that shown in Fig. 1 except that an additional high permeability transformer, having no biasing current in its winding, is connected in series with the primary windings of the other transformers and the secondary windings of the polarized transformers are so connected to each other that the two secondary voltage impulses generated in one winding will follow those generated in the other winding in opposite order as to polarity. In Fig. 3 an alternating voltage of a particular frequency is received over conductors 11 and 12 and impressed upon the primary windings 13, 14 and 23. Transformers 15 and 16 are oppositely polarized by current from a source 17 as described above for Fig. 1, so that the mutual inductance between their primary and secondary windings is maintained at a negligible value except when the alternating current in the primary windings approximately neutralizes the polarizing current in either of the windings. The additional high permeability transformer is unbiased. The mutual inductance between its primary winding 23 and secondary winding 25 therefore rises to a high value for an instant at times different from those of the windings 13 and 14, or every time the alternating current in primary winding 23 passes through amplitudes of about zero value. At such times a voltage impulse will be generated in the secondary winding, in the manner described above. The secondary winding 25 is connected in series with the secondary windings 18 and 19 in such manner that the induced voltage impulses in winding 25 together with those in windings 18 and 19 will form a uniform series of impulses of regularly alternating polarity. The voltage impulses produced in the secondary windings are short and are separated by somewhat long intervals of substantially zero voltages, but by inserting suitable network such as shown in Fig. 3 comprising condensers 20, 21 and 26 and inductance coil 22 in the output circuit 27, the series of short secondary voltage impulses may produce a substantially true sinusoidal current wave, and inasmuch as each half cycle of alternating current in the primary windings 13, 14 and 23 produces three voltage impulses of alternate polarities, the resultant current in the output circuit 27 will be of a frequency three times that of the primary current.

Fig. 4 represents graphically the voltages and currents occurring in the circuit arrangement of Fig. 3. Curve A represents the input current wave of a certain frequency supplied from a suitable source and impressed upon the primary windings 13, 14 and 23; curve B, the short voltage impulses produced in secondary windings 25, 18 and 19, the impulse produced in winding 25 being inverted with respect to the direction of variation of the primary current which produces it; and curve C represents the current produced by the voltage pulses shown by curve B after it has passed through the smoothing networks in the output circuit 27, the frequency of this secondary current being three times that of the primary current shown in curve A.

In Fig. 5 is shown an arrangement wherein five high permeability transformers are employed for producing an alternating current of five times the frequency of the input current. Two of these transformers are polarized to a certain extent in opposite directions, two others are similarly polarized but to a different extent, and the remaining transformer is unpolarized. In this figure the polarized transformers have been shown with separate windings for effecting the polarization of each of the polarized transformers but it should be understood that the polarizing current, if desired, may be applied to the primary windings as shown in Fig. 3. Assuming as hereinbefore that an alternating current of a certain frequency is received over conductors 11 and 12, the current in this arrangement is passed through the primary windings 13, 14, 35, 36 and 23 of transformers 15, 16, 37, 38 and 24 respectively. Transformers 15, 16, 37 and 38 are polarized by separate windings connected as shown to a common source 17 of direct current, polarizing current for transformers 37 and 38 being made of a lower value than that for transformers 15 and 16 by resistance 29 in the polarizing circuit of the transformers 37 and 38. The secondary windings 18, 19, 30, 31 and 25 of transformers 15, 16, 37, 38 and 24 respectively are connected in series and form a part of the output circuit 27. The windings 30 and 31 are connected to the other secondary windings 18, 19 and 25 in such manner that the induced voltages are inverted. By the insertion of suitable networks, such as comprise condensers 20, 21, 32 and 26 and inductance coil 22, the series of voltage impulses induced in the secondary windings will produce in the output circuit a current of a substantially pure sinusoidal wave of a frequency five times that of the primary current.

In Fig. 6 curve A represents the input current wave supplied from a suitable means and impressed upon the primary windings 13, 14, 35, 36 and 23, shown in Fig. 5, x—x and x'—x' indicating the intensities at which the primary current overcomes the polarizing flux in transformers 15 and 16, and y—y and y'—y' indicating the intensities at which the primary current overcomes the polarizing flux in transformers 37 and 38. Curve B represents the induced voltage impulses in the secondary windings, the first impulse shown being that produced in winding 25 when the rising primary current passes through its zero value; the second impulse being that produced in and inverted by winding 30 when the primary current reaches amplitude y—y; the third impulse being that produced in winding 18 when the primary current reaches intensity x—x; the fourth impulse is that produced in winding 19 when the decreasing primary current reaches intensity x—x after attaining the peak value; the fifth impulse is that produced in and inverted by winding 31 when the primary current passes intensity y—y, and so on similarly for the impulses produced by the other half cycle of the primary current, the impulses forming a uniform series of alternating potentials. Curve C represents the sinusoidal current wave effected by the suitable network inserted in the output circuit 27, having a frequency which is a fifth multiple of the frequency of the primary current.

In Fig. 7 is shown an arrangement wherein the frequency of an alternating current is increased ten times by combining the arrangements of Figs. 1 and 5. The alternating current of a particular frequency is received over conductors 11 and 12 and passed through primary windings 13 and 14 of transformers 15 and 16 in a wave form such as shown in curve A of Fig. 1. When transformers 15 and 16 are polarized in opposite directions by passing a direct current from source 17 through windings 13 and 14 or through separate windings as shown, the primary current produces in the secondary windings 18 and 19 a series of voltage impulses as shown in curve B of Fig. 2. These impulses after proper correction by suitable networks produce a sinusoidal current wave of a frequency double that of the input current in conductors 11 and 12.

The sinusoidal wave so produced is passed through primary windings 40 to 44 of transformers 46 to 50 respectively. Transformer pairs 46 and 47, and 48 and 49 are polarized to a different extent by direct current sources 51 and 52 respectively. By arranging the primary windings 40 to 44 and the secondary windings 53 to 57 in a manner similar to that shown for the windings in Fig. 5 the voltage impulses induced in the secondary windings by the current in the primary windings 40 to 44, form a wave having five impulses of alternate polarities to each half cycle or impulse of current in the primary windings 40 to 44. By means of suitable networks a sinusoidal current wave is produced in the output circuit of a frequency five times that of the current in primary windings 40 to 44 and ten times that of the current in the primary windings 13 and 14.

It will be noted in curves A of Figs. 2, 4 and 6 that the input voltage shows a lag in the wave formed at points corresponding to the intensities at which the permeability of the transformer cores reaches its effective values. This is due to the self-induction of the primary windings which rises to a high value at intervals in which the permeability is effected and therefore this self-induction momentarily serves as a high impedance during such intervals. The effects of this self-induction is explained in more detail in applicant's copending application corresponding to the British Patent 312,338 supra.

Likewise in the same figures of the drawing, the voltage impulses shown in curves B are of the same shape for both polarities, which impulses when smoothed out by suitable networks produce a symmetrical wave as shown in curves C. The fact that the new waves are symmetrical for both polarities indicates the absence of the even multiples of the new frequency.

Various combinations of the arrangements shown may be made in order to increase the frequency any desired amount, it being understood that in cases where a very high frequency is desired amplifying means such as a vacuum tube 60 shown in the output circuit of Fig. 7 may be employed for strengthening the impulses supplied either to the load or to devices for further increases in frequency. In such cases it may also be found desirable to insert the amplifying means between the secondary windings and the shaping network.

What is claimed is:

1. In a frequency multiplying device which comprises a winding upon a body of magnetic material, a direct current source connected to cause current to flow in at least a part of the winding, an alternating current source connected to cause alternating current to flow in at least a part of the winding, and a load circuit, the method of operation which comprises saturating in one direction the body by the direct current flow in said winding, causing a half cycle of said alternating current to unsaturate said body and further causing the same half cycle to saturate said body in the opposite direction, and causing the same half cycle to successively unstaturate and saturate said body in the same direction as in the first operation, whereby a series of impulses equal in number to the number of said unsaturations appear in said output circuit.

2. The method of increasing a wave frequency which comprises maintaining a mass of highly permeable material normally magnetically saturated and superposing thereon a periodically reversing magnetizing force of continuous wave form having higher amplitudes than the force producing the normally saturated condition to momentarily unsaturate said material, utilizing successive momentary unsaturated conditions of said material to form a wave of a higher frequency consisting of electrical impulses of equal du-

ration and equal maximum amplitudes and of alternately opposite polarities, and impressing said wave of the higher frequency on a load circuit wherein said last mentioned wave is smoothed-out to form, by utilizing the whole energy produced by the superposed force, a continuous wave of said new frequency wherein only the odd multiples of the new frequency are present.

3. A method of increasing a wave frequency which comprises impressing a steady current of a predetermined value in opposite directions on a plurality of serially connected coils respectively mounted on cores whereby the magnetic circuits of said cores are normally maintained in a saturated condition, superimposing alternating current of a higher value and of a definite frequency on said steady current to alternately oppose the normally saturated magnetic fields of said cores whereby each magnetic field normally saturated in one direction, is first neutralized and then resaturated, but in the opposite direction, to produce during each positive and each negative sweep of the alternating current a plurality of voltage impulses of alternate opposite polarities in other serially connected coils respectively arranged in proximity to the first mentioned coils, said second mentioned coils being connected in a load circuit in opposite relation to each other to invert alternate pairs of adjacent impulses, and impressing said impulses on said load circuit with successive impulses oppositely directed.

4. A method of increasing a wave frequency which comprises impressing an alternating current wave of a definite frequency on serially connected primary windings of a plurality of transformers having core material of a high permeability at low magnetizing forces, the magnetic circuits of said transformers being adapted to become saturated at intensities of alternating current slightly above zero value, superimposing on the alternating current in said respective windings steady currents of different values to normally maintain said magnetic circuits in saturated condition, the maximum magnetizing force due to the alternating current minus the magnetizing force due to the direct current being sufficient to produce saturation of the cores, whereby in response to each positive and each negative sweep of said alternating current above the values of said steady currents a plurality of short, sharp voltage impulses of equal duration and equal maximum amplitudes are produced in serially connected secondary windings arranged on said transformers, inverting certain of said voltage impulses whereby the produced voltage wave is constituted of impulses of alternately opposite polarities, and impressing said voltage impulses through a smoothing-out network to produce in a load circuit a uniform sinusoidal current wave which is a multiple of the wave in the primary winding.

5. In a frequency changer device, a circuit, a plurality of coils connected in series in said circuit and comprising cores designed to become saturated at intensities of current slightly above zero value, a plurality of other coils connected in series with each other and connected inductively with the first mentioned coils, means for transmitting through the first mentioned coils a periodically alternating current of a particular frequency which is effective to produce a short, sharp voltage impulse in either of the second mentioned coils every time said current passes through intensities near the points of saturation and unsaturation of said cores, said voltage impulses being of equal duration and equal maximum amplitudes, a source of current for normally biasing said first mentioned coils in opposite directions whereby the range of amplitudes in which the voltage impulses are produced is shifted to include any group of intensities of alternating current between zero and maximum values, and a load circuit comprising a smoothing-out network which utilizes the entire energy of the impulses produced in said shifted range as a continuous current wave of successive impulses oppositely poled and of equal duration and equal maximum amplitudes.

6. In a frequency changer system, a circuit comprising a plurality of serially connected inductance coils mounted on cores designed to become saturated at an intensity of current slightly above and below zero value, a source of current for normally maintaining the magnetic circuits of said cores saturated in opposite relation, a plurality of other serially connected inductance coils arranged in opposite relation to each other and respectively disposed in proximity to the first mentioned coils, means for transmitting in the first mentioned coils a periodically alternating current of a particular frequency whereby each magnetic circuit normally saturated in one direction is first neutralized and then saturated in the opposite direction to produce short, sharp voltage impulses of equal duration and equal maximum amplitudes in either of the second mentioned coils every time said alternating current passes through the intensities near the points of saturation and unsaturation and means for shaping the reproduced waves to form a sinusoidal wave of increased frequency.

7. In a frequency changer system as set forth in claim 6, other coils respectively connected in series with said first and second mentioned coils, a magnetic circuit for the third mentioned coils arranged to be normally unsaturated, whereby the periodically alternating current is effective to produce a short, sharp voltage impulse in the coil connected to the second mentioned coils every

time the alternating current passes through the intensities slightly above or below zero value to thereby increase the number of impulses produced by each half cycle of alternating current, and a load circuit including said second mentioned coils and one of said third mentioned coils wherein certain of said impulses are inverted to form in conjunction with the other of said impulses a continuous uniform sine wave of increased frequency.

8. In a frequency changer device, a circuit, a plurality of transformers connected in series with said circuit, and comprising cores designed to become saturated at an intensity of current slightly above zero value, means for transmitting through the transformer primary windings a periodically alternating current of a particular frequency which is effective to produce a short, sharp, voltage impulse in the transformer secondary windings every time said current passes through the intensities near the points of saturation and unsaturation, a source of current for biasing the transformers in opposite directions whereby the range of intensities in which the voltage impulses are produced is shifted to include any group of intensities between zero and maximum values, means for inverting certain of said impulses whereby the produced voltage wave is constituted of impulses of alternately opposite polarity, and means for shaping the reproduced waves to form a sinusoidal wave of increased frequency.

9. In a frequency changer system as set forth in claim 8, another transformer having its primary and secondary windings respectively connected in series with the primary and secondary windings of said plurality of transformers, the secondary winding of the last mentioned transformer being connected in opposite relation to the secondary windings of the other transformers, a magnetic circuit for the last mentioned transformer arranged to be normally unsaturated whereby the periodically alternating current is effective to produce short, sharp voltage impulses of equal duration and equal maximum amplitudes in the secondary winding of the last mentioned transformer every time said alternating current passes through intensities slightly above or below zero value to thereby increase the number of impulses of equal duration and equal maximum amplitude produced by each half cycle of alternating current, and other means for shaping the impulses produced in the secondary winding of said last mentioned transformer to form in conjunction with the voltage impulses produced in the secondary windings of said plurality of transformers a continuous uniform sinusoidal wave of further increased frequency.

10. A frequency multiplying device comprising a source of alternating input current, a coil having a winding traversed by said input current, a core for said coil, a polarizing source magnetizing said core, the magnetizing forces of said source of alternating current and said polarizing current being such that for each half cycle of said alternating current a plurality of separate and discrete impulses appear in a connected output circuit.

11. A frequency multiplying device comprising a source of alternating input current, a plurality of coils each having cores magnetically related to windings supplied by said alternating current, and sources connected to windings for magnetically polarizing certain of said coils to a different degree but in the same direction with respect to an output circuit which is also magnetically related to said cores.

In witness whereof, I hereunto subscribe my name this 28th day of September, 1928.

EVERETT T. BURTON.