A. M. TAYLOR.

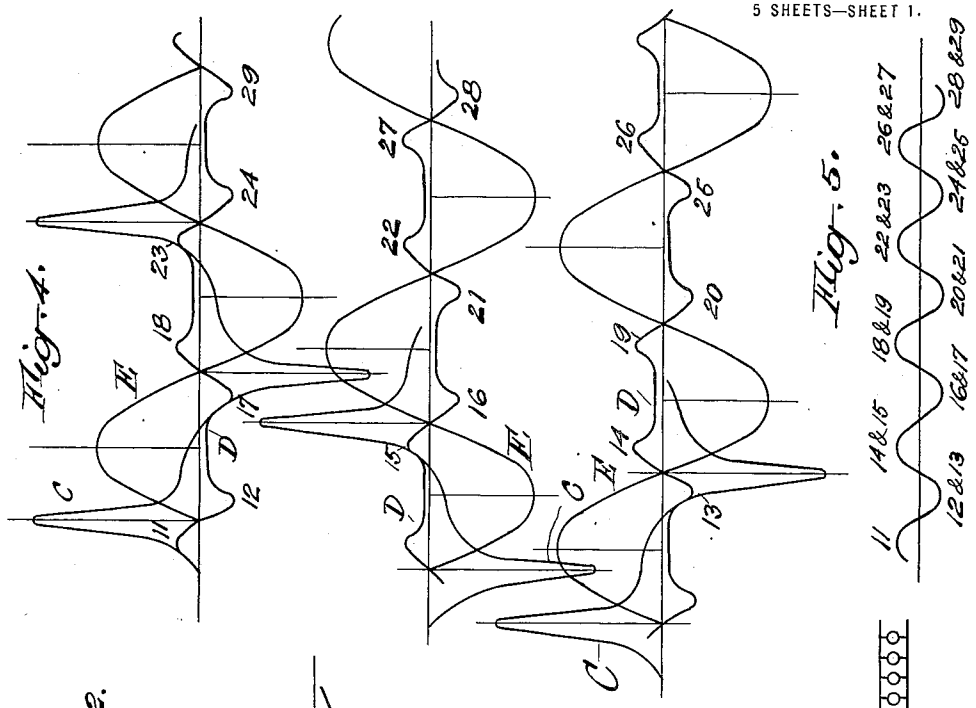
MEANS FOR CHANGING THE FREQUENCY OF ALTERNATING CURRENTS.

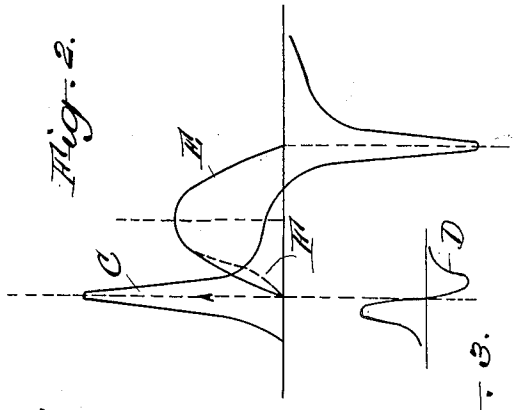
APPLICATION FILED MAR. 30, 1912.

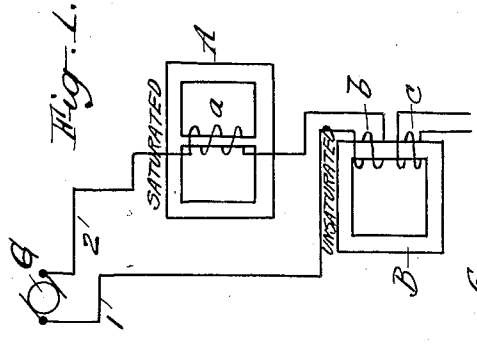
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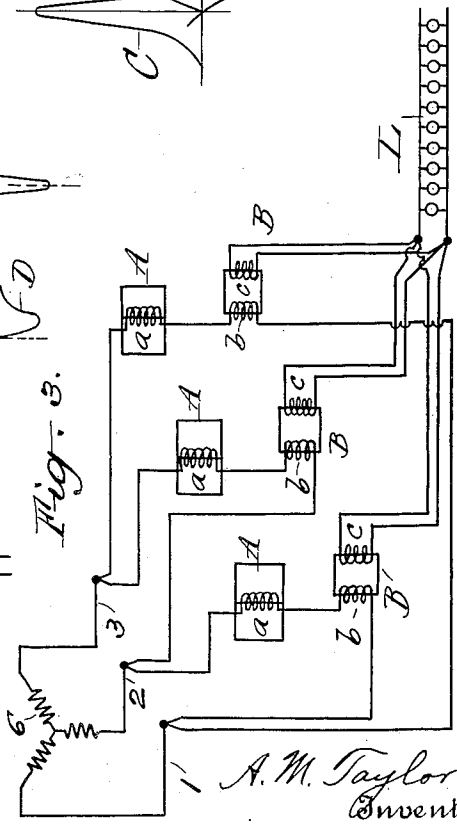
Patented Apr. 25, 1916.

5 SHEETS—SHEET 1.









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5 SHEETS—SHEET 2.

Fig. 7.

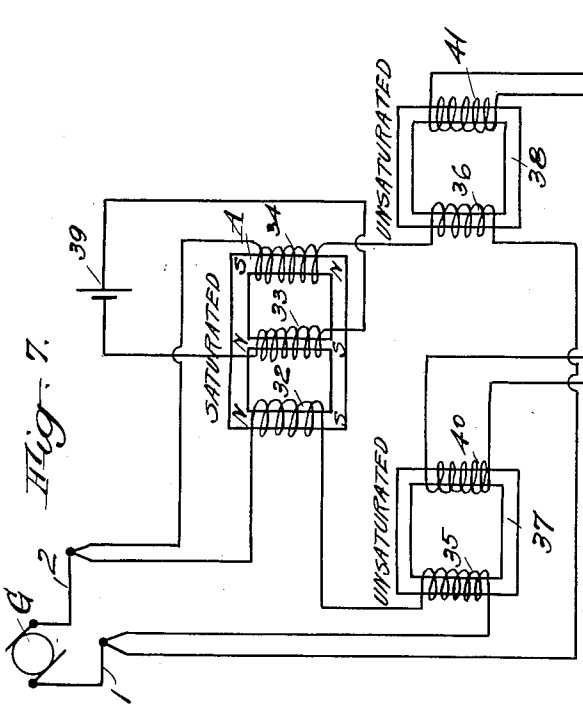


Fig. 8.

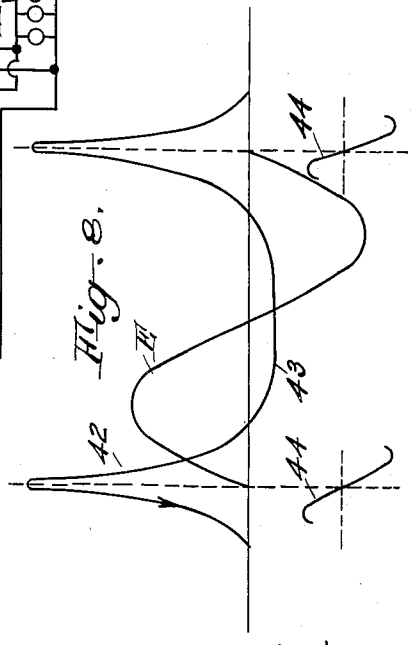
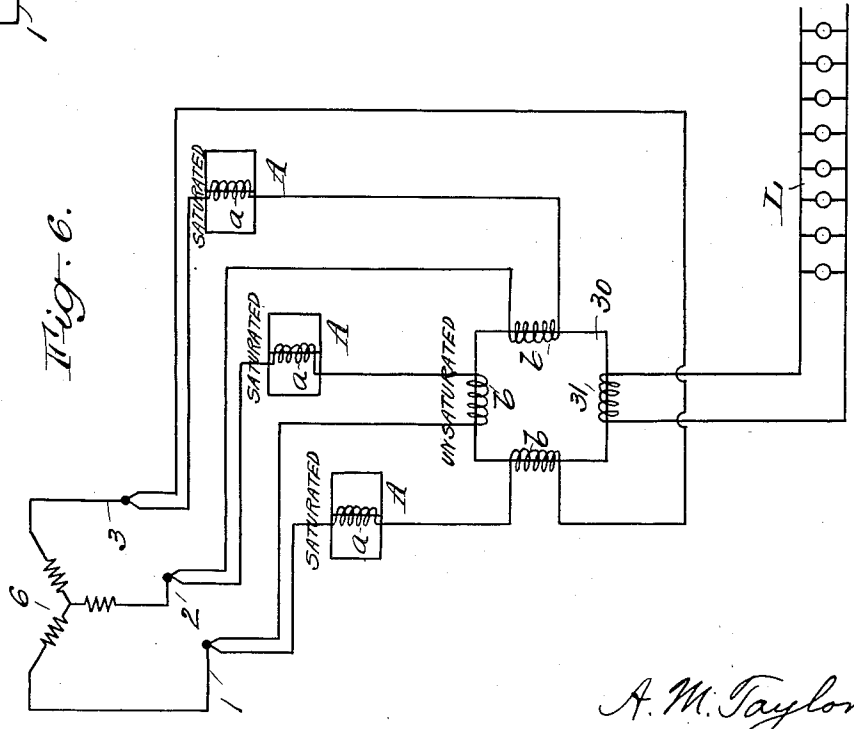


Fig. 6.



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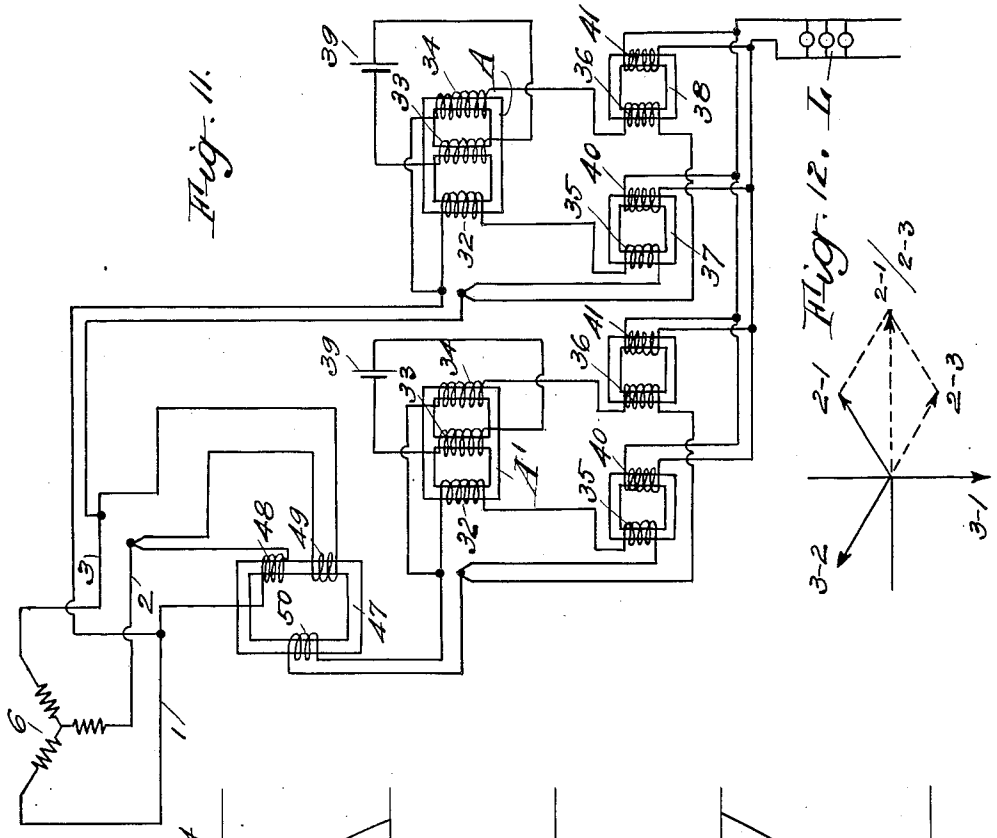


Fig. 11.

Fig. 12.

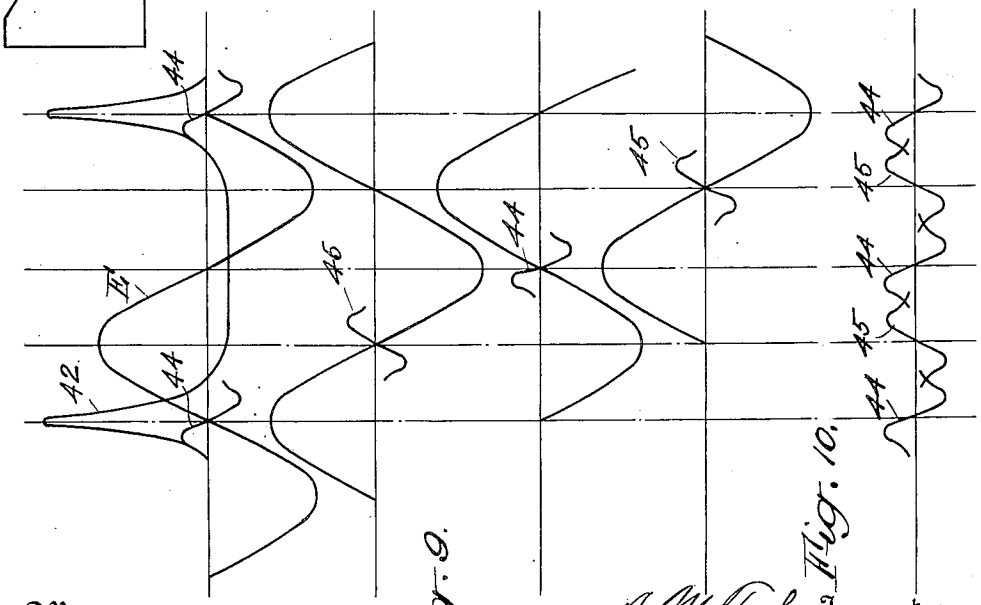


Fig. 9.

Fig. 10.

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5 SHEETS—SHEET 4.

Fig. 15.

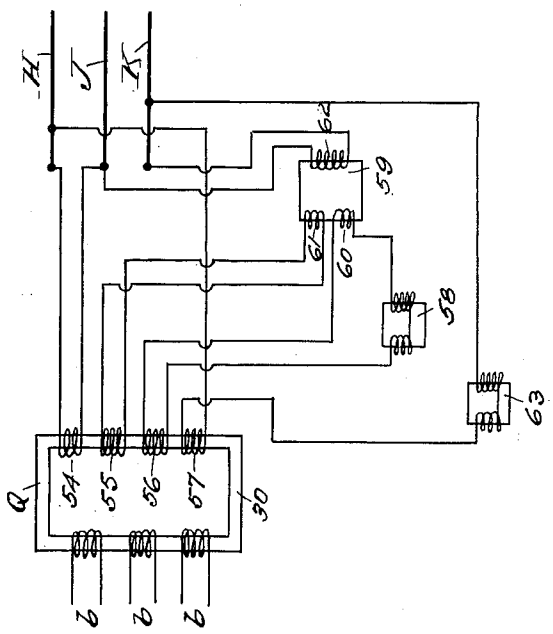


Fig. 16.

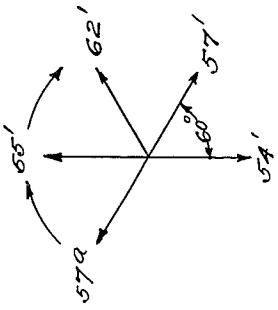


Fig. 13.

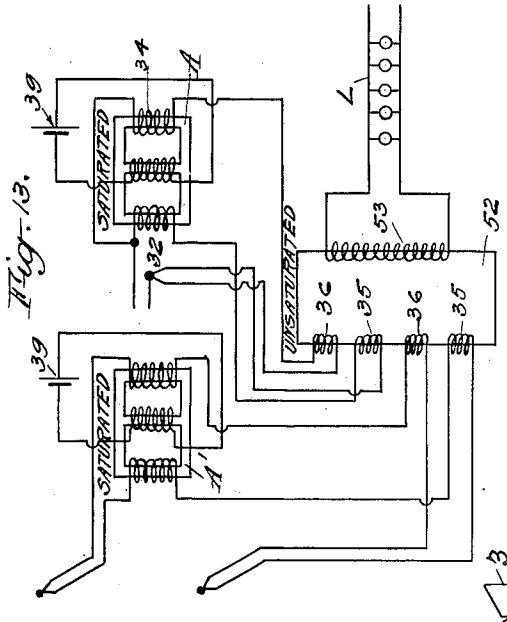
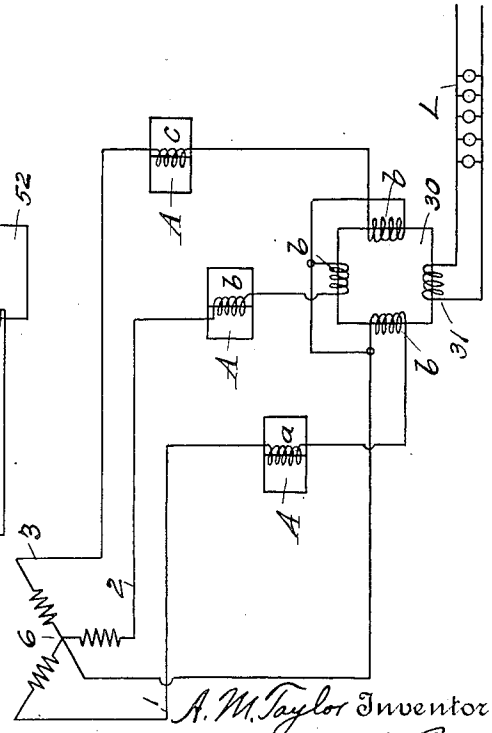


Fig. 14.



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5 SHEETS—SHEET 5.

Fig. 18.

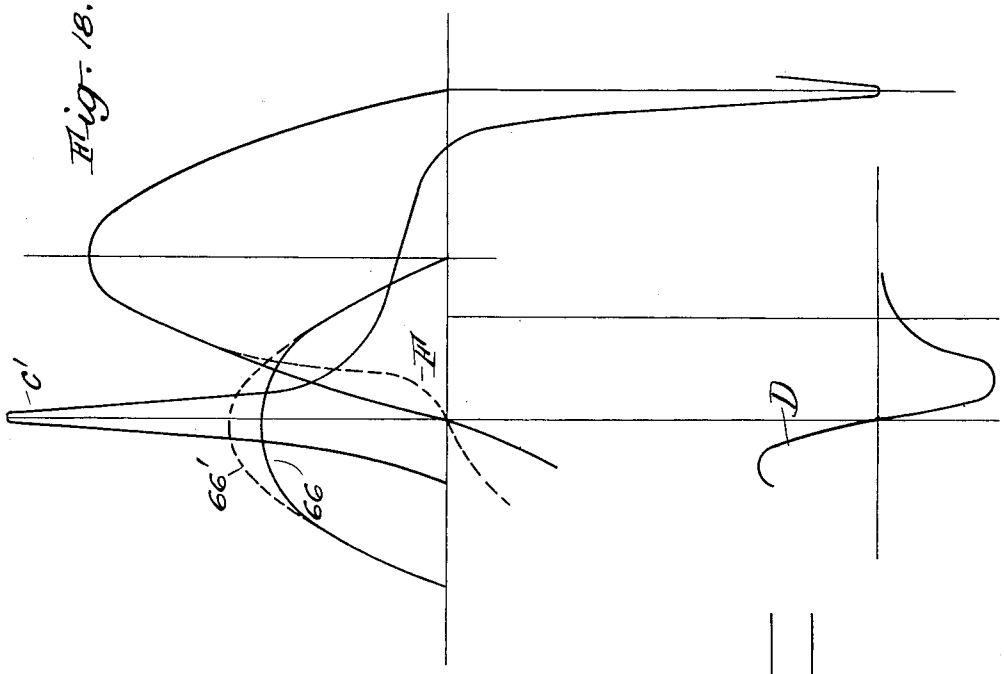
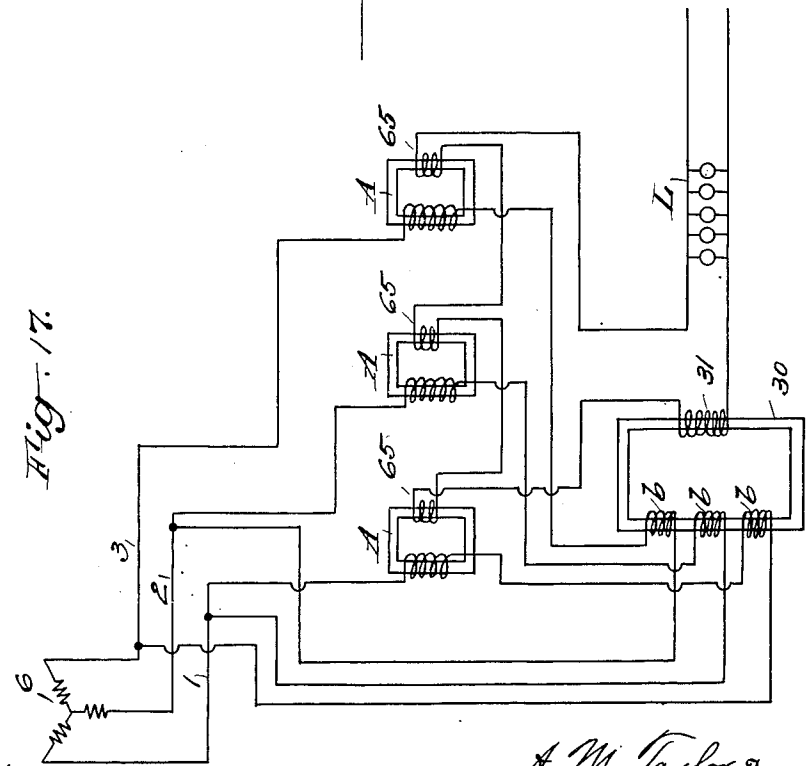


Fig. 17.



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UNITED STATES PATENT OFFICE.

ALFRED MILLS TAYLOR, OF KING'S HEATH, ENGLAND.

MEANS FOR CHANGING THE FREQUENCY OF ALTERNATING CURRENTS.

1,180,800. Specification of Letters Patent. Patented Apr. 25, 1916.

Application filed March 30, 1912. Serial No. 687,313.

To all whom it may concern:

Be it known that I, ALFRED MILLS TAYLOR, a subject of the King of Great Britain, residing at "Avondale," Ashfield Road, King's Heath, Worcestershire, England, have invented new and useful Means for Changing the Frequency of Alternating Currents, of which the following is a specification.

My invention relates to means for obtaining currents of a higher frequency from an ordinary alternating current supply in an economical manner without the employment of rotating machinery, and an object of the present invention is the provision of means whereby the frequency of alternating currents can be increased or diminished while at the same time the pressure may be varied if desired, by means of static transformers arranged in a special manner. Thus, for instance, in many installations a periodicity of 25 periods per second has been chosen with a view to being most suitable for the employment of rotary converters, but with the extension of supply it would be in many cases highly convenient to be able to employ currents of say double the frequency for purposes of distribution, for lighting directly, without the introduction of direct current apparatus. Also, with the advent of low frequency single-phase electric railways, it would be convenient if the periodicity could be increased so as to enable electric lighting to be supplied from the same station. In other cases, as for example, that of wireless telegraphy, it would be convenient to be able to increase the frequency of a supply derived from ordinary lighting systems up to that required for operating the inductive coils.

Other objects of the invention and the exact nature thereof will appear hereinafter.

Referring to the drawings, which illustrate diagrammatically the principles of my invention, Figure 1 represents the elementary connections for a single phase arrangement for obtaining an alternating impulse of short duration; Fig. 2 explains the way in which the operation takes place; Fig. 3 shows the application of the method to a three phase circuit for the purpose of obtaining a triple frequency; Fig. 4 explains the operation which takes place under these conditions; Fig. 5 indicates a triple frequency current obtained as the result of the combination indicated in Fig. 3; Fig. 6 indicates an arrangement whereby a single transformer may be used to generate a triple frequency current; Fig. 7 indicates the elementary connections required for obtaining a double frequency current; Fig. 8 explains the operation of the arrangement shown in Fig. 7; Fig. 9 represents the way in which the fundamental E. M. F.s and phases are arranged in four separate circuits in order to construct a symmetrical double frequency wave of E. M. F. from a combination of the secondary E. M. F.s. Fig. 10 represents the compound double frequency wave so obtained; Fig. 11 gives the connections required for obtaining a double frequency current having the characteristics of Fig. 10; Fig. 12 explains the method of producing the displacement in phase contemplated in Fig. 11; Fig. 13 shows an arrangement for winding the four primary coils of the four unsaturated transformers on a single core in order to obtain currents of double frequency from a single secondary coil wound on that core; Fig. 14 shows the connections required in order to obtain a current of triple frequency when the primaries and the choking coils are connected in star connection; Fig. 15 shows the connections required to produce a three phase current from a single phase high frequency current with a view to a second time triplicating the frequency; Fig. 16 explains the results obtained, by means of a vector diagram; Fig. 17 gives a diagram showing the connections required to effect "compounding", to compensate for any drop in voltage that might occur when the high frequency circuit is loaded up; Fig. 18 explains the actions which take place in effecting this result.

Referring now in detail to Fig. 1, a saturated transformer core A, preferably of the shell type, has a choking coil *a* on its central limb which is electrically in series with the primary coil *b* of a transformer B having an unsaturated core. The coils *a* and *b* are connected to mains 1 and 2 which receive current from a generator G or any other suitable source of single phase alternating currrent. On the transformer B is also wound a secondary coil *c*. Assuming an alternating E. M. F. of a sinusoidal nature at the mains 1 and 2 there occurs, at a certain instant of the cycle, a rush of current through the coils *a* and *b* which is the more pronounced the greater the proportion of the whole E. M. F. of the circuit that is absorbed by the choking coil.

Referring to Fig. 2, the sine curve E represents the E. M. F. supplied from the mains. The curve C represents the current in the coils *a* and *b*. The resultant E. M. F. in the coil *b* is represented by a curve D. The potential difference at the ends of the coil *a* is represented by the broken line curve F, and is the result of subtracting from the ordinates of the curve E the ordinates of the curve D. The effect of the E. M. F. D is to reduce the effective potential difference received from the mains by the coil *a* of the saturated choking coil, and to deform the wave of E. M. F. applied to the coil *a* so that it is no longer of sinusoidal nature. The secondary coil *c* has an E. M. F. induced therein which corresponds to that applied to the coil *b*, and if both coils have the same number of turns, the E. M. F. in the secondary will be substantially that represented by the curve D. This comprises two brief impulses of E. M. F. corresponding with the beginning and end of each half cycle of the E. M. F. at the mains. I utilize this secondary E. M. F. for the purpose of producing an alternating current of any desired frequency, as will presently appear.

If the arrangement of the apparatus shown in Fig. 1 be repeated three times, and if each group of apparatus be connected across one of the phases of a three phase circuit, it is found that the brief pulsations of E. M. F. induced in the secondaries of the unsaturated coils can be grouped in such manner as to produce a single phase current of triple frequency. Fig. 3 shows this arrangement. Three choking coils *a*, on the three cores A are connected, preferably in delta to the three phase mains 1, 2, 3, which receive current from a generator 6, and in series with these coils are arranged the primary coils *b* of the transformers B. The secondary coils *c* on these transformers are connected preferably in parallel circuit with one another and led to the triple frequency load circuit L.

Fig. 4 shows the phase relations of the current passing, and of the E. M. F. set up in the secondary coils of the transformers B (Fig. 3) and Fig. 5 shows how these impulses of E. M. F. may be combined so as to deliver into the load circuit L a current of triple frequency. Each sine curve E, (Fig. 4) representing the E. M. F. of the mains is arranged 120 degrees in advance of the preceding curve, corresponding to the phase relation in the three circuits. The peaks in the three curves D (Fig. 4) are designated by the numerals 11 to 29 and the resultant current delivered into the load circuit, as indicated in Fig. 5 is a current of triple frequency. By connecting the secondary windings in parallel circuit with one another, rather than in series, the current from the transformer which is the active one at any moment is enabled to be discharged directly into the load circuit without having to overcome the impendances of the two other transformers, which are at the moment inert. The magnetizing currents for these two inert transformers are supplied by the active transformers, but as they only amount to some three per cent. of the current supplied from the active transformers this additional load on the latter is not of much consequence.

In Fig. 6 is shown an arrangement for reducing the amount of iron in the transformers which supply the high frequency load circuit by combining all their three primary windings *b* on a single core 30, on which is wound a secondary coil 31 which is connected to the high frequency load circuit L. On referring to Fig. 4 it will be noticed that the wave of current C in the choking coil *a* (Fig. 6) occurs at the moment when the current and the flux in the two other choking coils is nearly zero. That is to say, any E. M. F. which is generated in the secondary coils *b*, in series with these two choking coils, by the impulse of the current in the first-mentioned secondary coil *b* (Fig. 6), is unable to produce an idle or demagnetizing current around the said two coils *b*, and thus waste of energy is prevented. The two primary coils of the idle circuits in fact remain as if they were open circuited. It follows that the active coil *b* in Fig. 6 is able to induce in the secondary coil 31 an E. M. F. which is not materially reduced by any demagnetizing current in the two transformer coils *b* on the other two windings, the choking coils in circuit with these two windings (the cores of which are at the moment unsaturated) opposing any attempt on the part of the coils *b* to produce a discharge through these choking coils. It will be obvious that the transformer 30 is now working at a triple frequency and therefore for a given amount of iron in the core, the output is increased nearly three-fold. It will further be evident that, though the currents in the windings *a*, *a*, *a*, and *b*, *b*, *b*, run up instantaneously to very high values, yet the mean current during a complete cycle is quite small, and the copper has opportunities of cooling down between the peaks of the current, and, therefore, the cross section of copper windings can be materially reduced.

Referring now to Fig. 7, A is a transformer of the shell type, wound with three coils 32, 33, 34, the first and last of which are connected in series with primary coils 35 and 36 wound on the cores 37 and 38. The two circuits formed by these two pairs of coils are connected as shown between the terminals 1 and 2 of a single phase circuit, or between one pole and the neutral point, or between the terminals of one phase of a

three phase circuit such as shown, for example in Fig. 6. The central limb of the transformer A is arranged to be highly saturated magnetically by a direct current which traverses the coil 33 wound on the said limb and supplied from the source of current 39. The two transformer cores 37 and 38 are both arranged to be worked unsaturated, and the secondary coils 40 and 41 of these two transformer cores are connected to the load circuit L. The coils 32 and 34 are so arranged and connected that the current at any instant flowing in one coil, say for example the coil 32, opposes the flux due to the direct current coil 33, and at the same time the current in the other coil 34 assists the flux due to the direct current coil 33, the polarities of the several coils being indicated by the letters NS NS in the diagram. The result of this is that each of the outer limbs of the transformer A is saturated periodically at a certain portion of the period, while at another portion of the period it works entirely unsaturated. This is indicated by the curve 42 shown in Fig. 8, which represents the current in the coil 32 for example. Referring to this Fig. 8, it will be seen that when the magnetomotive force due to the alternating current in the coil 32 assists the magnetomotive force due to the direct current in the coil 33 a sharp rush of current takes place as indicated by the curve 42, which runs up to a sharp peak as shown. When, however, the magnetomotive force of the coil 32 is opposed to the magnetomotive force of the coil 33, only a comparatively small current but of considerable duration, as indicated by the part 43 of the curve, flows through the coil 32.

The E. M. F. induced in the coil 35 is represented by the curve 44 (Fig. 8), and is of the same nature and duration as indicated by the curve D in Fig. 2 in connection with the coil *b* shown in Fig. 1, but it will be noticed that in the present case the inverted peak of current C (shown in Fig. 2) disappears, being replaced by the easy graduation of current from a rising negative value to a falling negative value. The result of this is to eliminate the half-wave of E. M. F. which occurred in Fig. 1 at a point corresponding with the apex of the inverted peak of current of Fig. 2, with the result that there is generated a series of pairs of half waves 44, as shown in Fig. 8, separated by a complete cycle.

Considering now the coil 34 on the right hand limb of the transformer A of Fig. 7 it will be apparent that the current in this coil goes through its cyclical changes at a point exactly 180 degrees of phase difference in time from that in the coil 32, and the sharp peaks of current corresponding to the saturated condition of the right hand limb of the transformer A will now come in point of time opposite the horizontal part 43 of the curve of current in the coil 32. The effect of this will be as indicated in Fig. 9 where the half waves of E. M. F. 44 along the uppermost horizontal lines, are separated by 180 degrees of phase from those on the third horizontal line, corresponding with the E. M. F. generated in the coil 34. This arrangement would of itself tend to give a current of double the periodicity in the load circuit (see Fig. 7) but the E. M. F. wave would be somewhat poorly defined and would be very brief in duration and there would be a long period of idleness between one E. M. F. wave and the next. If, however by repeating the arrangement shown in Fig. 7 but in this case arranging that the additional impulses received from the mains shall differ by only 90 degrees of phase from those in Fig. 7, we could obtain two additional series of curves 45 (see Fig. 9) with E. M. F. impulses separated from one another by 180 degrees of phase, as in the case of the curves 44, we would obtain in a common secondary circuit a double frequency series of waves of E. M. F. as represented in Fig. 10. Such an arrangement is shown in Fig. 11 in which a system like that shown in Fig. 7 is connected directly to the mains 1 and 3, and a duplicate system is introduced and is fed from phases 1 to 2 and 2 to 3 by means of an intermediate transformer 47 wound with two coils 48 and 49 on its primary side, so arranged that they combine their magnetic effect, giving the resultant effect in the secondary coil 50 which is connected to said duplicate system of transformers.

In Fig. 12 is shown by means of a vector diagram how it is practicable to obtain a relation of the current in the transformer A′ to that in the transformer A having 90 degrees of phase difference. The phase difference in the three circuits between the mains 2—1, 3—1, and 3—2, (Fig. 11) is represented by the correspondingly designated lines (Fig. 12) which are 120 degrees apart. By reversing the direction of winding or circuit connections of the coil 49 (connected across the mains 3—2) relative to the coil 48, the phase is reversed and represented by the broken line 2—3, (Fig. 12). The resultant of the two lines 2—1, and 2—3 is a line 2—$1\frac{2}{3}$ perpendicular to the line 3—1. That is, the phase in the secondary coil 50 supplying the transformer A′ is displaced 90 degrees from that supplying the transformer A.

In Fig. 13 is shown an arrangement whereby the four independent transformers of Fig. 11, which supply the load circuit, are combined into one single transformer 52, and in which a single secondary coil 53 leads to the load circuit L. The operation of this arrangement is similar to that described for

the triple frequency arrangement with a single core, as shown in Fig. 6, except that of course in the present case the frequency is only double as indicated by the curve in Fig. 10.

In Fig. 14 is shown an alternative connection to Fig. 6, the three choking coils, A, A, A, being connected to the mains 1, 2, 3 in star instead of in delta.

The arrangement shown in Fig. 6 may be made, with small modifications, to transform the high frequency current a second time to a frequency triple of that obtained by the arrangement of Fig. 6; that is to say, a frequency of nine times the original can be obtained or if necessary, twenty-seven times. In order to do this I proceed as follows:—The three primary coils *b* (Fig. 15) are the same as the coils so designated in Fig. 6, and receive current from the same source. I substitute for the single secondary coil 31 of Fig. 6 a group of four coils 54, 55, 56, 57, as shown in Fig. 15. I lead connections from coil 54 direct to the two conductors H J of the three phase system H J K. I also lead connections from coil 56 through a choking coil 58 to a transformer 59 and wind this conductor to form one primary coil 60 of the transformer 59 as shown. I similarly run two leads from coil 55 without the interposition of any choking coil to a second primary coil 61 wound on the transformer 59, and I reverse these leads as compared with the leads from coil 56. The currents from the secondary coils 55 and 56 then combine to form a resultant flux in the transformer 59, and from the secondary coil 62 of this transformer I take leads direct to conductors J and K as shown. Lastly I take leads from secondary coils 57 through a choking coil 63 to the conductors H and K of the three phase system.

The operation of the four coils 54, 55, 56, 57, considered as secondaries to either of the primary coils *b* will produce a three phase current in the system H J K, and this will be understood from the vector diagram in Fig. 16. Referring to this figure and assuming the phases to rotate in a clockwise direction it will be seen that if the choking coil 63 imparts a lag of 60 degrees to the current from coil 57 which is co-phasal with the coil 54, we obtain a current whose time relation is indicated by the vector 57′ lagging 60 degrees behind the radius vector 54′ corresponding to the current from coil 54. If we now reverse the connections from this coil 57 (as shown in Fig. 15) we obtain a current whose phase relation is indicated by radius vector 57^a the time position of which is 120 degrees in advance of 54′. Thirdly if we take coil 55 and reverse its connections we obtain a current whose time position is represented by the vector 55′ and if we take the coil 56 and pass the current through a choking coil 58, so as to impart to it a lag of 60 degrees, its time position being then indicated by radius vector 57′, the joint windings from the two coils 55 and 56, will give a resultant flux in the core of transformer 59, which lags 120 degrees behind the phase of the current in coil 54 as is indicated in Fig. 16 by the vector 62′.

In Fig. 17 is shown a modification of Fig. 6, involving an arrangement for compensating for the drop in voltage which may occur on the secondary coil 31 as the load on the outside circuit L increases. In circuit with the coil 31 are coils 65 wound on the cores A. Each coil 65 is so wound that it tends to demagnetize its core A when the impulse of current comes from the secondary coil 31, due to the rush of current through the primary coil *b* in series with the choking coil *a* of said core A. The three compensating coils 65 together operate, at a particular period in each phase of the low frequency circuit, to give an E. M. F. which opposes the E. M. F. of the coil 31, and so tends to compensate for the rise in voltage on the load circuit L which might otherwise occur when the load is reduced. In addition, however, to these six impulses of E. M. F. delivered by the coils 65 there is also the E. M. F. generated in these three coils due to the cyclic changes of the cores A upon which they are wound. These low frequency E. M. F.s however, do not make themselves manifest in the load circuit L, since, by a well known property, the sum of their E. M. F.s is at any moment equal to zero.

Fig. 18 is given with a view to indicating how the out of balance triple frequency E. M. F. is arranged to be generated in the coils 65 in a manner increasing with the reduction of load on the secondary circuit. This figure may be more readily understood by a comparison with and review of Fig. 2. If C′ represents the peak of the current C, (Fig. 18) taken by any one of the three choking coils *a*, (Fig. 17), in the vicinity of the zero value of the curve E then, as already shown, in connection with Fig. 2, and assuming that the coil 31 is open-circuited, an E. M. F. D is induced in the corresponding primary coil *b* of the unsaturated transformer 30 which opposes the E. M. F. E of the mains and causes the E. M. F. applied to the choking coil *a* to follow approximately the curve F. This means that the flux in the core A of the choking coil *a* instead of following the true sine law as indicated by the broken line 66′, follows the curve 66, which it will be noticed is flattened on its top. Now if the coil 31 is short circuited (which corresponds to the extreme condition of load) then there will be no appreciable flux in the core 30, nor any appreciable back E. M. F. in the primary coil *b*,

with the result that the flux in the core A will be increased to the value 66′ so that it now follows a sine law and consequently generates in the choking coil *a*, a sine E. M. F. which is approximately equal and opposite to the E. M. F. E of the mains. This increment of the flux in the core A caused by short-circuiting the coil 31, tends to cause the out of balance E. M. F. of the coils 65 (which had previously existed owing to the deformation of the flux wave) to disappear; that is to say, an opposing E. M. F. is now removed from the circuit of the secondary coil 31, which is the same thing in effect as adding an E. M. F. to the circuit of coil 31. The action may be described in another way by saying that the maximum out of balance E. M. F. of the three coils 65, occurs when the load on the secondary circuit 31 is a minimum (the deformation of the flux wave in the core A being at this moment a maximum) and therefore at this time the maximum counter E. M. F. is inserted in the secondary circuit of the coil 31, thus preventing an undue rise of voltage on the load circuit L. Again the impedance introduced into the secondary circuit by the remaining two coils 65 (which are at this moment inert, so far as the triple frequency current is concerned though generating equal and opposite E. M. F.s of low frequency) is negligible and current passing through the load circuit L is unable to produce any material effect in the flux on either of the corresponding cores A on account of the ampere turns in the coils 65 being insignificant in comparison with those in coils *a*.

I am aware that it has been proposed to obtain from a transformer, or pair of transformers, supplied from a single phase circuit, a triple-frequency current in which the energy of the fundamental wave of E. M. F. is transformed into three waves of equal amplitude with one another, or a double frequency current in which the energy of the fundamental wave of E. M. F. is transformed into two waves of equal amplitude with one another, by employing transformers having somewhat different degrees of saturation, and I do not claim this feature broadly.

What I claim is:—

1. The combination with a three phase alternating current circuit, of a choking coil in one phase of the circuit, a highly saturated magnetic core on which said coil is wound, a transformer having an unsaturated magnetic core and a primary coil in series with said choking coil, said arrangement of transformer and coils being repeated in each phase of the said circuit, the transformer secondary coils being connected in parallel in a secondary circuit.

2. The combination of a three phase alternating current circuit, a choking coil in each phase of the circuit, magnetic cores on which said coils are wound and saturated by the current in said coils, primary transformer coils in series with the choking coils, and a secondary transformer circuit comprising windings in the magnetic field of the primary transformer coils to cause said secondary circuit to receive an induced current from the primary coils.

3. The combination of a three phase alternating current circuit, a choking coil in each phase of the circuit, magnetic cores on which said coils are wound and saturated by the current in said coils, primary transformer coils in series with the choking coils, whereby in each transformer coil impulses of current of less duration than the fundamental wave are produced, and a secondary circuit comprising windings in the magnetic field of the primary transformer coils to cause said secondary circuit to receive current impulses derived from said primary impulses and combined to produce a periodic secondary current of higher frequency than that of the fundamental current.

4. The combination of a three phase alternating current circuit, a choking coil in each phase of the circuit, magnetic cores on which said coils are wound and saturated by the current in said coils, primary transformer coils in series with the choking coils, whereby in each transformer coil, impulses of current of less duration than the fundamental wave are produced, a transformer core common to the said primary coils, a secondary coil wound on the common core and deriving impulses of the electro-motive-force from the said primary coils which impulses combine to produce in the outside secondary circuit a current of higher frequency than the fundamental current.

5. Means for changing the frequency of alternating currents, which comprises circuits for the several phases of a multiphase current, coils in said circuits, magnetically saturated material on which the coils are placed, additional coils in said circuits, unsaturated magnetic material on which said additional coils are placed, whereby when current impulses of a multiphase current are passed through said coils, there are derived from each fundamental or primary phase, intermittent current impulses, each of said derived impulses being of shorter duration than the fundamental electro-motive-force from which it is derived, and a secondary circuit having windings within the influence of said additional coils in the first mentioned circuits, whereby is derived from said short impulses a secondary current in which the impulses are combined to produce a current of higher frequency than the original.

6. The combination with a three phase al-

ternating current circuit, of a choking coil in each phase, saturated cores for said coils, primary transformer coils in series with the choking coils, a secondary circuit comprising windings in the magnetic field of the primary transformer coils to cause said secondary circuit to receive a derived current from the transformer coils, and demagnetizing windings on the choking coils, said windings being in the secondary circuit.

7. The combination of a three phase alternating current circuit, a choking coil in each phase of the circuit, magnetic cores on which said coils are wound and saturated by the current in said coils, demagnetizing windings on said coils, primary transformer coils in series with the choking coils, a transformer core common to said primary coils, and a secondary circuit comprising windings in the magnetic field of the primary transformer coils to cause said secondary circuit to receive current derived from the primary coils.

8. In means for changing the frequency of alternating currents, the combination of circuits to receive respectively the different phases of a multiphase alternating current, a winding in each circuit, cores of magnetic material for the respective windings each saturated to such a degree that there is produced in a portion of the circuit, periodic current impulses of shorter duration than the impulses of the fundamental electro-motive-force from which they are derived, the ratio of the period of the impulses of electro-motive-force to the duration of the corresponding current impulses being equal to the number of phases in the primary current, and a secondary circuit having windings within the inductive influence of said current impulses and deriving therefrom a secondary current of higher frequency than that of the said electro-motive-force.

9. Means for changing the frequency of alternating currents, comprising a number of circuits, means for impressing on each of said circuits a periodic electro-motive-force, the electro-motive-forces for the several circuits being out of phase, means coöperating with the electro-motive-forces to cause in a portion of each circuit, current impulses of shorter duration than the impulses of electro-motive-force impressed on said circuits, the ratio of the duration of said short impulses to the periods of the electro-motive-forces from which they are derived, being inversely proportional to the number of said circuits, and a secondary circuit including means for transforming and combining said current impulses for producing in said secondary circuit a current having a frequency equal to the frequency of the electro-motive-force in one of said first named circuits, multiplied by the number of said first named circuits.

Dated the 22d day of March, 1912.

ALFRED MILLS TAYLOR.

Witnesses:
JOHN ALEX. FRASER,
WALTER BERNARD LANCASTER.