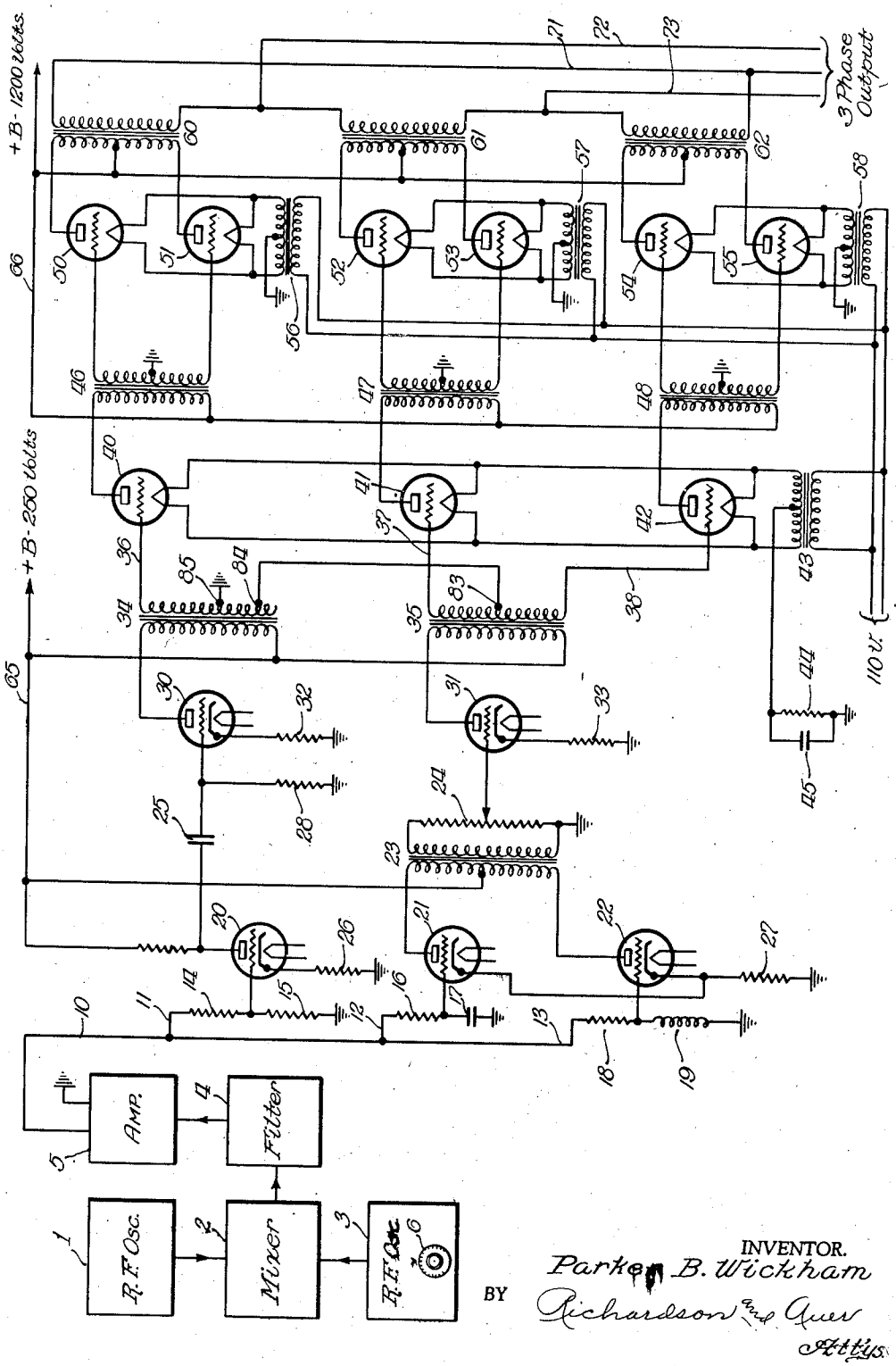
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SINGLE PHASE TO POLYPHASE CONVERTERS

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SINGLE PHASE TO POLYPHASE CONVERTER

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The present invention relates in general to single phase to polyphase converters, and the object of the invention is the production of a new and improved apparatus of this character. More in particular, the invention deals with the utilization of a variable frequency source of single phase alternating current having a negligible power output to obtain, by suitable conversion and amplification, a variable frequency quarter phase or three phase output of several kilowatts or more with good voltage regulation and suitable for use in running a polyphase motor at a variable speed. It may be stated, moreover, that the invention not only provides a power output of variable frequency, but affords means for adjusting the frequency to any desired value within the limits of the equipment.

The invention has application to numerous industrial problems where an alternating current motor with accurately adjustable speed is required, and solves these problems in an economical and satisfactory manner.

The invention and various features thereof will be described more fully hereinafter, reference being made to the accompanying drawing, which shows by means of a conventional type of circuit diagram sufficient of the apparatus and circuit connections to enable the invention to be explained and understood.

Referring to the drawing, the rectangles 1 to 5, inclusive, represent the component parts of a beat frequency oscillator, which comprises the radio frequency oscillators 1 and 3, a mixer stage 2, and filter and amplifier stages 4 and 5. The construction and operation of a beat frequency oscillator are well known and hence the circuits are not shown in detail. It will suffice to say that the outputs of the two radio frequency oscillators 1 and 3 are combined at the mixer stage 2, to produce a beat frequency which is equal to the difference between the oscillator frequencies. The output from the mixer stage also includes components having the oscillator frequencies and a component having a frequency equal to the sum of the oscillator frequencies, but these undesired components are eliminated at the filter stage 4, which is arranged to pass only the beat frequency component. The filter output is delivered to the amplifier stage 5, having a grounded output circuit 10.

The output circuit 10 may be regarded as having three parallel branches 11, 12, and 13. These branch circuits include resistances 14, 16, and 18, respectively, which may have a value of about 100,000 ohms each. The branch circuit 11 also includes a resistance 15, but in circuits 12 and 13 the corresponding elements are a condenser 17 (circuit 12) and an inductance 19 (circuit 13). The capacity and inductance values depend on the frequency range but in any event are calculated to have substantially equal reactances at the average frequency.

The branch circuits 11, 12, and 13 are employed to control the grids of the three tubes 20, 21, and 22, which may be Type 6C5G tubes, for example. These three tubes with their associated input circuits constitute a phase shifting arrangement, whereby a quarter phase output is secured, as will be explained more fully hereinafter.

At the next circuit stage two tubes 30 and 31 are employed, one for each phase of the output from the preceding stage. These tubes may be of the Type 6F6G. The plate circuit of tube 20 is coupled to the grid of tube 30 by means of a condenser 25, the grid being provided with a grid leak 28. The plate circuits of the tubes 21 and 22 are coupled to the grid of tube 31 by means of a transformer 23 and potentiometer 24.

The plate circuit of the tube 30 includes the primary winding of the transformer 34, while the plate circuit of the tube 31 includes the primary winding of the transformer 35. The secondary windings of these two transformers are wired in accordance with the familiar "Scott connection" to provide a three phase output circuit comprising the conductors 36, 37, and 38. This arrangement will be readily understood, although it may be stated that the tap 83 is at the midpoint of the secondary winding, while the tap 84 is an 86.6 per cent tap, it being assumed that the two secondary windings have the same number of turns.

The remainder of the circuit drawing shows a two stage three phase amplifier. The first stage comprises the three tubes 40, 41, and 42, which are preferably Type 845 tubes. These are filament type tubes, having their filaments connected in parallel and supplied with heating current by the transformer 43. The grids of the tubes 40, 41, and 42 are controlled over the three conductors 36, 37, and 38, respectively, to which they are directly connected. A common grid return is provided by the grounded tap 85, which should be located one-third of the distance from tap 84 to the upper end of the secondary winding.

The last or power stage comprises six Type 805 power tubes connected in pairs to provide

three push-pull power amplifiers, one for each of the three phases. These are also filament type tubes. A transformer 56 supplies heating current to tubes 50 and 51, another transformer 57 supplies heating current to tubes 52 and 53, while transformer 58 supplies heating current to tubes 54 and 55. The plate circuit of tube 40 is coupled to the grids of tubes 50 and 51 by means of a transformer 46. Similarly, the plate circuit of tube 41 is coupled to the grids of tubes 52 and 53 by the transformer 47, while the plate circuit of tube 42 is coupled to the grids of tubes 54 and 55 by means of transformer 48. The center points of the secondary windings of these three transformers are grounded to complete the grid circuits of the tubes.

The plate circuits of the tubes of the three power amplifiers include the primary windings of the transformers 60, 61, and 62, respectively. The secondary windings of these transformers are delta connected, and are provided with the three phase output leads 71, 72, and 73.

Suitable sources of direct current are provided for the various plate circuits of the tubes. The plate supply for tubes 20, 21, 22, 30, and 31 may have a potential of 250 volts. The plate voltage at the tubes of the three phase amplifier is higher, preferably in the neighborhood of 1200 volts. These direct current sources are not shown in the drawing, which merely shows the two conductors 65 and 66, with appropriate labels, as is customary in such circuit drawings. It will be understood, however, that conductors 65 and 66 are connected to the positive poles of the 250-volt and 1200-volt direct current sources, respectively, and that the negative poles of these sources are grounded.

The cathodes of the various tubes are of course grounded also, in order to complete the cathode plate circuits through the tubes. Thus in the case of the power tubes 50 to 55, inclusive, the cathodes or filaments are connected to ground by grounding the center taps of the secondary windings of the heating current transformers 56, 57, and 58. Where a grid bias is necessary or desirable, cathode resistors are provided. Thus the filaments of tubes 40, 41, and 42 are grounded through the resistor 44, which is preferably shunted by a by-pass condenser 45. Tubes 20, 30, and 31 are provided with individual cathode resistors 26, 32, and 33, respectively, while tubes 21 and 22 have a common cathode resistor 27.

The tubes 20, 21, 22, 30, and 31 require suitable arrangements for supplying current for heating their cathodes. These circuits are well known, however, and are not shown in the drawing.

The apparatus and connections thereof having been briefly described, the operation of the complete circuit will now be explained.

The output frequency of the beat frequency oscillator may vary over a considerable range, from 60 cycles per second to 400 cycles per second, for example. Within this range the frequency is adjusted to any desired value by adjusting the frequency of one of the radio frequency oscillators. For this purpose the oscillator 3 may be provided with adjustable tuning means controlled by a dial 6, which is calibrated in cycles per second, the calibrations referring to the beat frequency output. It may be assumed that the oscillator is adjusted to some frequency near the middle of the frequency range, say 230 cycles per second.

The beat frequency oscillator accordingly maintains a flow of single phase alternating current at 230 cycles per second in the output circuit 10. It will be understood that no appreciable amount of power is furnished by the oscillator, its function being to supply control voltages of the desired frequency.

As previously explained, the output circuit 10 has three branch circuits 11, 12, and 13. The three branch circuits are used for controlling the grids of tubes 20, 21, and 22, respectively. The manner in which this takes place will be briefly explained.

Considering first the branch circuit 11 and tube 20, the resistance 15 in circuit 11 is also included in the grid circuit of the tube and accordingly alternating voltages are impressed on the grid, these voltages having a value which is determined by the voltage drop across the resistance 15. In other words, the potential across the resistance 15 is available and effective to control the grid. The circuit 11 has no inductive or capacitative reactance, and accordingly the voltages impressed on the grid are in phase with the applied voltage derived from the oscillator.

In the branch circuit 12 there is a condenser 17 instead of a resistance such as 15. There is a voltage drop across the condenser which is impressed on the grid of tube 21, the value of the impressed voltage depending on the impedance of the condenser. The grid of tube 21 is therefore controlled similar to the way the grid of tube 20 is controlled. The voltages applied to the grid of tube 21 are, however, displaced in phase from the voltages applied to the grid of tube 20 by approximately ninety degrees. Explaining this briefly, it may be stated that the current in the branch circuit 12 is nearly in phase with the applied voltage, due to the fact that the capacitative reactance of the condenser is relatively small as compared to the value of the resistance 16. The voltage across the condenser, which is the voltage effective to control the grid of tube 21, lags behind the current by ninety degrees, and accordingly is approximately ninety degrees out of phase with the voltage applied to the grid of tube 20.

In the branch circuit 13 there is an inductance 19 and the voltage drop across this inductance is impressed on the grid of tube 22. In circuit 13 also the current is nearly in phase with the applied voltage, due to the large value of the resistance 18 as compared to the inductive reactance of coil 19. The voltage across the inductance 19, however, leads the current by ninety degrees, and accordingly the voltage impressed on the grid of tube 22 is approximately ninety degrees out of phase with the voltage impressed on the grid of tube 20. The grid voltage at tube 22 is leading, whereas the grid voltage at tube 21 is lagging, from which it will be seen that the grid voltages at tubes 21 and 22 are displaced in phase from each other by one hundred eighty degrees, approximately.

The control voltages impressed on the grid of tube 20 cause variations of plate current in tube 20 and the resulting variations in plate voltage at the tube are impressed on the grid of tube 30 through the condenser 25.

Similarly, the control voltages impressed on the grid of tube 21 bring about fluctuations of plate current in the tube, and since the plate circuit includes a part of the primary winding of the transformer 23, alternating currents are caused to flow in the secondary winding of the transformer and in the potentiometer resistance 24. There is a fall of potential across the re-

sistance 24, and a portion of this voltage is impressed on the grid of tube 31, the value of the impressed grid voltage depending on the adjustment of the potentiometer.

The grid voltages at tubes 30 and 31 are ninety degrees out of phase with each other due to the described phase shift in the grid voltage at tube 21, which lags behind the voltage at the grid of tube 20 by ninety degrees. This phase displacement is carried over to the grids of tubes 30 and 31, as will be obvious from the fact that phase shifts of one hundred eighty degrees such as are produced by tubes and couplings cannot change a ninety degree phase difference.

Now it will be recalled that the grid voltage at tube 22 leads the applied voltage by the same angle that the grid voltage at tube 21 lags behind it; that is, the grid voltages at tubes 21 and 22 are out of phase with each other by one hundred eighty degrees; and it will be appreciated that these conditions are correct for push-pull operation of the tubes 21 and 22 in supplying fluctuating current to the primary winding of the transformer 23. These two tubes cooperate therefore in the well known manner in supplying power to the transformer. Operating at a frequency of 230 cycles per second, the impedances of the condenser 17 and the inductance 19 are approximately equal, and accordingly there will be approximately equal control voltages applied to the grids of the tubes. This means that the two tubes have substantially equal ranges of plate voltage and that they supply substantially equal amounts of power to the transformer.

It would be rather difficult to design the transformer 23 for an output voltage exactly the same as the output voltage derived from the plate circuit of tube 20, in view of the different types of couplings employed, and it is preferable not to attempt to do so. A standard transformer is used here, therefore, having windings such that the secondary voltage is largely in excess of that required. By means of the potentiometer the voltage is reduced to the required value, the potentiometer being adjusted so that the voltage impressed on the grid of tube 31 is the same as that impressed on the grid of tube 30.

As explained, the voltages at the grids of tubes 30 and 31 are out of phase with each other by ninety degrees. The tubes 30 and 31 may therefore be regarded as a two phase or quarter phase amplifier, which operates in a manner which will be readily understood and which requires no detailed explanation.

The two phase output from tubes 30 and 31 is converted into a three phase output by means of the transformers 34 and 35, the secondary windings of which are connected in accordance with the known "Scott connection," as previously mentioned. The operation of this circuit arrangement is also well understood.

In this manner there is produced a three phase output in the three phase circuit comprising conductors 36, 37, and 38, which is used to control the grids of tubes 40, 41, and 42, these tubes constituting a three phase amplifier. Each tube operates to amplify one phase, and to deliver controlling voltages to the associated tubes in the power amplifier. Thus the tube 40 is controlled over conductor 36 and by means of transformer 46 supplies control voltages to the push-pull connected power amplifier comprising tubes 50 and 51. In a similar manner the tube 41 controls the power amplifier comprising tubes 52 and 53, while the tube 42 controls the power amplifier comprising the tubes 54 and 55.

In connection with the foregoing it may be remarked that the power amplifiers are class B amplifiers, and hence the grids of the tubes draw grid current, which means that the tubes at the preceding stage must supply a certain amount of power in order to properly control the grids at the power tubes. This is the reason for using the Type 845 tubes at the preceding stage. A Type 845 tube has a power output of about thirty watts, which is ample for the purpose.

The outputs of the three power amplifiers are coupled by means of transformers 60, 61, and 62 to the three phase output circuit comprising conductors 71, 72, and 73, as previously stated. These conductors may extend directly to a motor and supply three phase power for operating it. The transformer windings are, of course, designed to give the desired output voltage. The output frequency is the same as the output frequency of the beat frequency oscillator, or 230 cycles per second.

It may be assumed now that it is desired to increase the speed of the motor. This is accomplished by raising the frequency to a value which will give the desired motor speed. The change in frequency is made by adjusting the dial 6 at the radio frequency oscillator 3, which may be reset for an output frequency of 300 cycles per second, for example.

The change in oscillator frequency does not affect the proper operation of the apparatus; that is, it produces only the intended result, which is to raise the output frequency of the power amplifier to 300 cycles per second. It is noted in particular that the output voltages of tubes 30 and 31 remain equal, which insures equal voltages in the three phases of the power output circuit. This is due to a compensating action which takes place at tubes 21 and 22, as will now be explained.

When the frequency of the output circuit 10 is raised, the impedance of the condenser 17 is correspondingly decreased and the drop across this circuit element is decreased, which lowers the voltages impressed on the grid of tube 21. In other words, the voltage drop across the condenser and the voltages impressed on the grid of tube 21 are inversely proportional to the frequency. At tube 21, therefore, the result of the increase in frequency is to decrease the range of plate current fluctuations, which would, unless compensated for in some way, reduce the voltages induced in the secondary winding of the transformer 23 and the voltages impressed on the grid of tube 31.

The necessary compensation is provided by tube 22. When the frequency is raised, the effective impedance of the inductance 19 is increased proportionately, and the voltages impressed on the grid of tube 22 are increased. That is, the drop across the inductance 19 and the voltages impressed on the grid of tube 22 are directly proportional to the frequency. The effect of the increased frequency at tube 22, therefore, is to increase the range of plate current fluctuations, which tends to increase the voltages induced in the secondary winding of transformer 23 and the voltages impressed on the grid of tube 31.

The net result of the foregoing is that the changes in output at the tubes 21 and 22 approximately cancel each other and the impressed voltages on the grid of tube 31 are maintained substantially unchanged in spite of the change

in frequency. The greater part of the grid voltage at tube 31, however, is due to the operation of tube 22; that is, the push-pull hookup of tubes 21 and 22 is now in unbalanced condition, with tube 22 supplying the greater part of the effective energy delivered to the transformer 23.

The change in frequency has no effect on the operation of tube 20, since the branch circuit 11 is made up substantially of pure resistance. The voltages delivered to the grid of tube 30, therefore, have a constant amplitude and since the voltages delivered to the grid of tube 31 are also maintained substantially constant in the manner explained, the voltage balance between the different phases, both in the quarter phase section and in the three phase section, is not disturbed, and satisfactory operation of the equipment as a whole is maintained.

In case the frequency is lowered instead of raised, the necessary compensation is effected in a manner similar to that described, as will be readily understood. If the frequency is lowered to 100 cycles per second, for example, the impedance of the condenser 17 is increased, while that of the inductance 19 is decreased, with the result that the roles enacted by the tubes 21 and 22 are reversed, the former instead of the latter now supplying the greater part of the effective energy delivered to the transformer 23 and there utilized in generating grid control voltages for the tube 31.

In view of all the foregoing, it will be seen that the frequency can be varied over a considerable range, affording a wide range of motor speed, the equipment operating satisfactorily without adjustment other than the adjustment of the dial 6 to change the frequency. The balanced condition of the equipment is maintained automatically by the compensating arrangement.

It will be understood that a two phase power amplifier can be substituted for the three phase amplifier shown herein if a two phase power output is desired. A two phase or three phase inverter could also be used in place of an amplifier.

It will be understood also that the invention permits of other modifications within the principles set forth, and that the embodiment specifically described herein is intended merely as an illustration of one way in which the invention may be carried out in practice. I do not therefore wish to be limited to the exact form of the invention as shown and described herein, but desire to include and have protected by letters patent all forms and modifications of my invention that come within the scope of the appended claims.

I claim:

1. In combination, a single phase circuit supplied with a variable frequency alternating current, a two phase circuit, means including said single phase circuit and a phase shifting device for supplying alternating current to said two phase circuit, and means for preventing the voltages in the two phases of the two phase circuit from changing relative to each other in response to a change in the frequency of the current in said single phase circuit.

2. In combination, a single phase circuit supplied with a variable frequency alternating current, a two phase circuit, means including said single phase circuit and a phase shifting device for supplying alternating current to said two phase circuit, and compensating means for automatically maintaining equal voltages in the two phases of the two phase circuit while the frequency of the single phase circuit is changed.

3. In combination, a single phase circuit supplied with a variable frequency alternating current, a two phase circuit, means including said single phase circuit and a phase shifting device for supplying alternating current to said two phase circuit, said means including condenser and transformer couplings for the two phases, respectively, means for adjusting the voltage in the transformer coupled phase, and means for automatically preventing changes in the adjusted voltage in response to changes in the frequency of said single phase circuit.

4. In combination, a single phase circuit supplied with a variable frequency alternating current, a three phase circuit, means including said single phase circuit, phase splitting devices, and a plurality of amplifiers for supplying power to said three phase circuit, adjusting means for equalizing the voltages in the three phases of the three phase circuit, and automatic compensating means for preventing a change in the frequency of the single phase circuit from changing said voltages.

5. In combination, a single phase circuit supplied with a variable frequency alternating current, a two phase circuit, means including said single phase circuit for supplying power to one phase of said two phase circuit, means including said single phase circuit and two phase shifting devices for supplying power to the second phase of said two phase circuit, and means whereby the said phase shifting devices cooperate to prevent frequency changes in the single phase circuit from changing the voltage in said second phase.

6. For use in a single phase to polyphase converter, a phase shifting arrangement comprising two space discharge devices, means including capacitative and inductive reactances for impressing lagging and leading control voltages on the grids of said devices, respectively, said means including a source of alternating current, and means for combining the outputs of said devices to energize a common output circuit, said last means including means for utilizing the opposite changes in said control voltages in response to changes in the frequency of said source for preventing voltage changes in said output circuit.

7. For use in a single phase to polyphase converter, a phase shifting arrangement comprising two space discharge devices, two input circuits for said two devices, respectively, to which alternating voltages may be applied, means in one circuit for producing control voltages on the grid of the associated device which are inversely proportional in amplitude to the frequency of the applied voltages and which lag the same by ninety degrees, means in the other circuit for producing control voltages on the grid of the associated device which are directly proportional in amplitude to the frequency of the applied voltages and which lead the same by ninety degrees, an output circuit, and means including said discharge devices for applying control voltages to said output circuit which are ninety degrees out of phase with the said applied voltages and which have a constant amplitude independent of the frequency of said applied voltages.

8. In combination, a single phase circuit supplied with a variable frequency alternating current, said circuit having three branches, a resistance in the first branch, a condenser in the second branch, an inductance in the third branch, three space discharge devices, circuit connections

for impressing the voltages developed across said resistance, condenser, and inductance on the grids of said tubes, respectively, a two phase circuit, means for supplying power to one phase from the discharge device controlled over said first branch, and means including a push-pull connected transformer whereby power is supplied to the second phase by the discharge devices which are controlled over the said second and third branches.

9. In combination, a single phase circuit supplied with a variable frequency alternating current, said circuit having three branches, a resistance in the first branch, a condenser in the second branch, an inductance in the third branch, three space discharge devices, circuit connections for impressing the voltages developed across said resistance, condenser, and inductance on the grids of said tubes, respectively, two additional space discharge devices, means for controlling the grid of the fourth discharge device by voltages supplied from the discharge device controlled over the first branch, means for controlling the grid of the fifth discharge device by voltages derived from push-pull operation of the two discharge devices controlled over the second and third branches, and a two phase circuit supplied with power from the fourth and fifth discharge devices.

10. In combination, a three phase power supply circuit, three power amplifiers for supplying power to the three phases of said circuit, respectively, a three phase amplifier for supplying grid voltages for said power amplifiers, means including a two phase amplifier and suitable transformer connections for supplying grid voltages to said three phase amplifier, a beat frequency oscillator, and means including said oscillator and phase shifting means for supplying grid voltages to said two phase amplifier.

11. In combination, a single phase circuit, means for supplying alternating current to said circuit, a two-phase circuit, means for supplying power to said two phase circuit from said single phase circuit, including reactance means for securing a phase displacement of approximately 90 degrees between the voltages in the two phases of said two phase circuit, means for varying the frequency of said alternating current, and means for preventing such frequency variation from creating a difference in the amplitudes of the voltages in the two phases of said two phase circuit.

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