April 24, 1956 H. E. RENFRO 2,743,390

FREQUENCY CONTROL APPARATUS

Filed June 4, 1951

Fig.1.

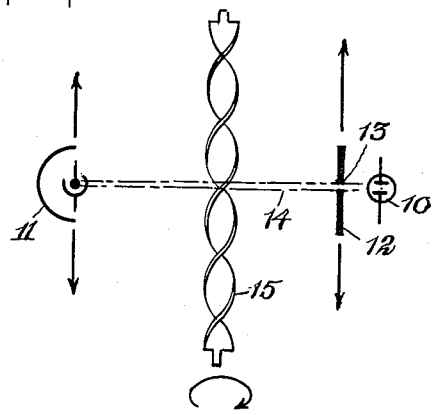


Fig.3.

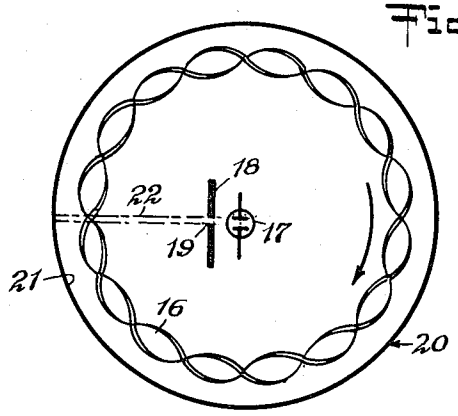


Fig.2.

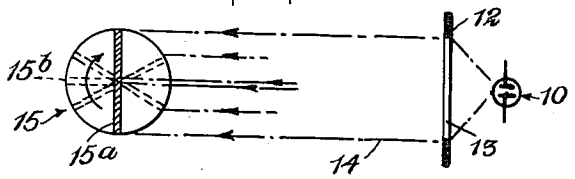


Fig.4.

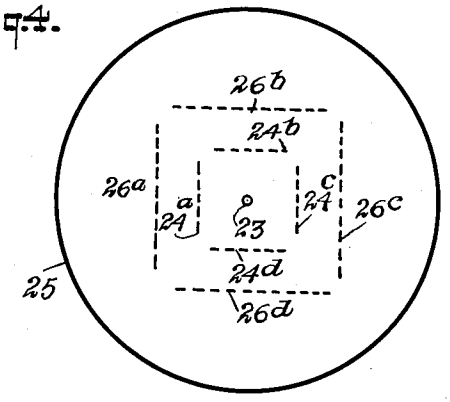


Fig.5.

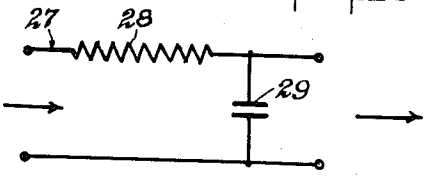


Fig.7.

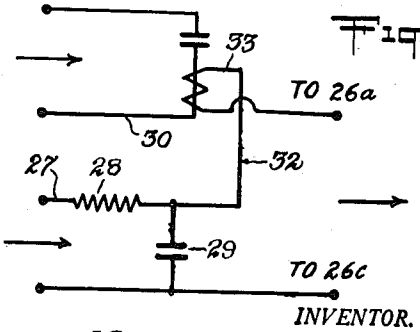
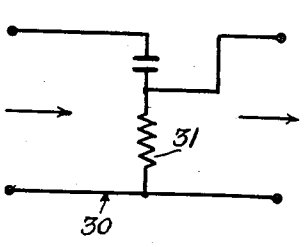


Fig.6.



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FREQUENCY CONTROL APPARATUS

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Application June 4, 1951, Serial No. 229,855

14 Claims. (Cl. 315—14)

This invention relates broadly to apparatus for controlling output frequency and more particularly to a new method of producing an electrical output at a frequency equal to the sum or difference of two or more other frequencies, each possessing a velocity and a direction. The method is applicable to either electrical or mechanical input frequencies as will become apparent in the following description of the invention.

An object of my invention is to intercept a moving energy beam with a moving electrical or mechanical frequency so that the energy impinged upon a receiving plate will cause a plate output of selected frequency.

A further object of the invention is the provision of an electron tube wherein two sets of concentric grids, each having a polyphase alternating voltage applied thereto, are located between the cathode and anode, whereby the inner set of grids convert the emitted electrons into a rotating beam which may make one or less revolutions for each cycle of the applied grid voltage. The voltage applied to the outer set of grids is in a predetermined direction so that the output of the anode is equal to the sum of the grid frequencies if the direction of the said voltages and rotation of the beam are opposite, or equal to the difference of the grid frequencies if these two movements are in the same direction.

Another object of the disclosed invention is the incorporation into the system of a control for the above-mentioned electron tube consisting of a new method of obtaining a distortionless four phase alternating voltage from single phase voltage such as produced by a microphone.

One important advantage of the invention lies in the fact that with an electronic application of the device it is possible to furnish single sideband suppressed carrier amplitude modulated signals for radio and carrier communication.

Still other objects and advantages will become apparent from the following description of the present invention illustrated in the accompanying drawing, in which:

Figure 1 is a schematic view showing a mechanical application of the invention.

Figure 2 is a schematic view of a portion of the mechanical application shown in Figure 1 taken at right angles to Figure 1.

Figure 3 is a schematic view of a modification of the mechanical application shown in Figure 1.

Figure 4 is a schematic view of an electronic application of the invention.

Figure 5 is a diagrammatic view of a circuit with an input resistance high in comparison to the reactance. The output voltage is drawn from across the reactance.

Figure 6 is a diagrammatic view of a circuit with an input reactance high in comparison to the resistance. The output voltage is drawn from across the resistance.

Figure 7 is a diagrammatic view combining the circuit of Figures 5 and 6 with a current transformer replacing the resistor in Figure 6.

As previously mentioned, my system is applicable to either mechanical or electrical input frequencies. Although the entire principle is relatively simple, it is believed that an explanation of the mechanical adaptation first would be more in keeping with a logical and clear disclosure of the invention.

The basic conception of the idea is shown schematically in Figure 1 of the drawing. A conventional light source **10** and a photocell **11** are spaced from one another, as shown. A plate **12** is positioned between light source **10** and photocell **11** and is provided with an elongated slit **13** in order to concentrate the light passing from the source to the photocell into a defined beam designated generally as **14**. The light source, plate and photocell are mounted rigidly together so to be movable as a unit, the purpose of which will become apparent as the description progresses.

A long strip of copper which may be approximately ¾ of an inch wide and 1/16 of an inch thick is twisted to form a screw-like element with a pitch of about two inches. This screw is placed between plate **13** and the photocell in the path of light beam **14** and forms an opaque shutter **15** adapted to rotate about its longitudinal axis as shown by the arcuate arrow in Figure 1. This rotation may be in either a clockwise or counterclockwise direction. It will be seen from Figures 1 and 2 that the beam of light has its narrow dimension parallel to the axis of shutter **15** and its width is substantially equal to the maximum width of the shutter, i. e. ¾ of an inch. The amount of the light beam which impinges on the photocell **11** will thus vary in accordance with its interruption by the projection of revolving shutter **15**. The light assembly comprising the source, plate, and photocell can move parallel to the axis of the shutter in either direction as shown by the vertical arrow in Figure 1.

In the operation of this setup, conventional electrical circuits are completed to show any variation of light intensity on photocell **11**. Thus, when the screw member **15** is continuously rotated at a constant speed, the portion of member **15** that is in the light beam will act as a shutter, diminishing the light received by the photocell when the flat side, or greatest width, of the shutter is presented to the beam and increasing the light received when the narrow edge is presented to the beam. This progressive increase and decrease of light passed by the rotating shutter is clearly illustrated in Figure 2 of the drawing. The minimum intensity is apparent when the greatest width of the shutter is perpendicular to the path of the light beam as shown at **15***a* in Figure 2, and the intensity increases as the involved portion of the shutter approaches alignment with the light ray until the position shown as **15***b* is reached, at which time a maximum portion of the light ray is allowed to pass to the photocell. Thus, one cycle of output energy will be delivered by the photocell for each half revolution of shutter **15**. It is pointed out that proper shaping of the screw-like shutter will produce a sine wave output if desired.

The frequency of the described energy output has up to this point been dependent only on the speed of rotation or frequency of shutter **15**. When the shutter **15** is considered as a screw, an imaginary nut placed thereon would move along the axis of the shutter in one direction at a linear speed of two inches per revolution when using the previously mentioned arbitrary screw pitch as an example. If the light assembly is moved in this direction at the same linear speed as the nut, there will be no variation of intensity brought about by the shutter and the output frequency of the photocell **11** becomes zero. By the same reasoning it is apparent that if the light assembly is moved in the same direction at half the imaginary nut velocity, the output frequency is half the original frequency as obtained with a stationary assembly.

It can be concluded from the above explanation that

when the light assembly is moved in the same direction as the imaginary nut, the output frequency is proportional to the difference between the linear velocity of the light assembly and the angular velocity of the shutter.

On the other hand, if the light aessembly is moved at the imaginary nut velocity, but in the opposite direction, the output frequency of the photocell becomes twice that at light assembly standstill. Likewise, at half nut velocity the out-put frequency is one and one-half times the original frequency. Thus when the light assembly is moved in a direction opposite to that of the imaginary nut, the output frequency is proportional to the sum of the linear velocity of the light assembly and the angular velocity of the shutter. It is to be noted that this sum frequency is caused by reversal of one directional movement only.

The modification shown in Figures 1 and 2 are ideal for illustration of the principle involved but its actual use is impractical due to the fact that the device is limited by the length of shutter **15**. In order to overcome this difficulty a modified form of the device can be constructed with practicability and is schematically shown in Figure 3 of the drawing.

If the ends of the shutter were to be joined, it would make a closed ring **16** that could be rotated either about a central axis as shown in Figure 3 or about its own axis which now becomes a circle. Only rotation about the center of the circle will be discussed here although either method is useable. With this construction, the effective length of the shutter is infinite since it rotates in a circular path. In this modification the light source **17** and apertured plate **18** rotate about the same axis as the shutter ring, the elongated slit **19** bearing the same directional relationship with the dimensions of the screw shutter as in the first modification in Figures 1 and 2.

The above elements are surrounded by a cylinder designated generally as **20** and which has a light sensitive inner surface **21** which acts as a photocell. With shutter **16** removed, the light beam **22** can rotate at any speed without producing any variation in output of the photocell surface **21**. Beam intensity and photocell sensitivity are both uniform. Insertion of the shutter, held stationary, causes the beam intensity and photocell output to vary, producing one cycle of photocell output energy for each 180 degree twist of the shutter.

Rotation of the shutter about the central axis in a direction opposite to light beam rotation produces an increase in the frequency of the photocell output that is exactly proportional to the sum of the two speeds.

Rotation of the shutter about the central axis in the same direction as light beam rotation but at a lower speed produces an output frequency exactly equal to the difference in speeds. When these two relative speeds are equal the output frequency becomes zero. Shutter speeds greater than beam speeds in the same direction have definite uses such as in demodulation but will not be discussed here in the interest of simplicity of description.

A still further use of the principle involved in this invention is its application to an electronic device. The previously mentioned light source and phototube (Figure 3) are replaced by a source of electrons and a concentric collecting plate as shown in Figure 4. The source of electrons is in the form of a small diameter filament **23** heated electrically providing a cathode for the electron tube. This may be considered a line source of electrons without serious error. Surrounding the electron emitting filament are four separate plane grids **24***a*, **24***b*, **24***c* and **24***d*. The segments are about equal in length to the length of the filament and when combined form a square enclosure with the filament in the center as shown in Figure 4.

If a set of four-phase sinusoidal voltages, 90 degrees apart in time phase, is applied between the cathode and the four grids in such a manner that the time-phase rotation of the voltages is in the same order as the space-phase relationship of the four grids taken either clockwise or counter-clockwise, a rotating electric field is produced which has a speed of rotation equal to the frequency of the applied voltages. The field can readily be made uniform if the four grids are biased negatively with respect to the cathode so that no grid current flows and if their configuration is modified from that of a perfect square in such a manner as to form a uniform field. The effect of the rotating electric field upon the electrons emitted by the cathode will be to form a rotating beam of electrons which makes one revolution for each cycle of the four-phase grid voltages and which is the electronic equivalent of the rotating light beam produced by the light source and associated slit in the mechanical application of the invention. The four-phase voltages required may be easily derived from a set of two-phase voltages 90 degrees apart in time phase by proper electrical connections.

The cylindrical plate **25** forms the anode for the electron tube and is concentric with the filament and grids. The plate being made positive with respect to the filament, collects the electrons passed by the grid segments **24***a*, **24***b*, **24***c*, and **24***d*. Obviously, with the input remaining constant, there is no variation in intensity of the electron beam and the plate current remains constant as the electron beam rotates. The operation up to this point is the equivalent of the mechanical adaptation of the invention with the screw-like shutter removed.

A second set of four plane grid segments **26***a*, **26***b*, **26***c* and **26***d*, are located between the previously mentioned grid segments and the plate **25**. One set of grids may be oriented on the central axis in any manner that will give the proper field—not necessarily as drawn. These may be supplied with four-phase sinusoidal voltage with respect to the cathode at a frequency lower than that applied to the inner grid segments (**24***a*, **24***b*, **24***c* and **24***d*). A sine wave output may be obtained by optimum voltage adjustment of the outer grid segments. Thus it will be seen that with a constant amplitude, frequency and voltage applied to the outer grid, the plate output frequency will be equal to the difference in frequency of the inner and outer grids when the rotation of their two fields is in the same direction. Likewise, the plate output frequency is equal to the sum of the frequencies if the two fields rotate in opposite directions.

Considering modulation of the output in either the mechanical or electronic application of the invention, it is pointed out that if the width of the shutter in the first instance could be lessened while in operation, the light impinging on the photocell would not be completely cut off each half revolution. Since the output the photocell varies directly with the change of light intensity, a small variation in intensity will give a small alternating current output, while a large variation will give a large output as long as zero light intensity is never reached. This amplitude modulates the output, which is at the sum or difference frequency.

In regard to the electronic adaptation of the invention, the four-phase potential on the outer grid (segments **26***a*, **26***b*, **26***c* and **26***d*) may be raised or lowered for modulating the electron beam as long as "class A" operation (i. e. not positive with respect to the cathode and never so far negative that plate-current cut-off is reached) is maintained. The sum or difference frequency output of the plate is modulated in a manner similar to the paragraph above. Either intensity variation or area variation of the beam or a combination of the two may be used for modulation. Exponential or other special purpose grids may be used if non-linear output is desired.

Having described my novelly constructed electron tube, I wish to point out that one obvious electronic application of the device is to furnish single sideband suppressed carrier amplitude modulated signals for radio and carrier communication. If the inner grids are driven by the base radio frequency and four-phase modulation (such as voice or music) is applied to the outer grids, the plate

output is only the upper or lower sideband as selected by relative phase rotations previously explained. Since the opposite sideband is not produced, the customary filters to suppress it are unnecessary. The base frequency is not present in the output. Of course, a screen grid may be added between the outer grid and the plate, or other methods may be used to make the plate current independent of plate voltage. Demodulation may also be accomplished with a similar tube structure.

It is well known that electrical currents produced by sound waves impinging on a microphone are normally single phase and of many frequencies. In order to control the electron tube described herein, this single phase input must be changed to polyphase. I have met this problem by incorporating in my system a new method of obtaining distortionless four-phase from single phase, such as produced by a microphone. From this four-phase output, any desired number of phases may be obtained.

Referring first to the circuit **27** in Figure 5 of the drawing, consider a capacitive reactance in series with a resistor **28**. Initially there is no voltage across the condenser **29** and no current flowing in the conductors. When a single phase sine wave voltage is impressed on the terminals, the voltage across the condenser lags 90 degrees behind the applied voltage, if the capacitive reactance is low compared to the resistance.

Consider the equation

$$Q=CE$$

where Q is the condenser charge, C is the capacitance and E is the maximum value of A. C. voltage. If the voltage built up on the condenser is too low to affect the flow of current through the resistor, the voltage on the condenser is maximum at the end of the first alternation, 180 degrees, then decreases to zero at 270 degrees and changes in reverse polarity, thus giving the required 90 degrees lag. Q is proportional to the product of current and time, so that a constant current for a shorter time gives a lower impressed voltage on the condenser. This means that there is a straight line drop in condenser voltage as the frequency is increased. The above may be considered a constant current circuit, i. e., the output no load voltage is proportional to input current and inversely proportional to input frequency.

A constant A. C. voltage input applied to circuit **30** is diagrammatically shown in Figure 6 of the drawing. A high reactance in this case limits the current, which is indicated by the voltage across the very low resistance **(31)** which is too small to affect the voltage distribution. The input current and consequently the output voltage across resistor **31** leads the input voltage by 90 degrees, if the input is supplied from a source of low impedance compared to the capacitive reactance shown.

The frequency response is directly proportional. That is, an increase in frequency produces an increased output voltage. Since

$$Q=CE \text{ and } E=IZ$$

then Z, the A. C. impedance, decreases as the frequency rises; so for a constant E, the current I must increase giving a linear output voltage increase across resistor **31** with increased frequency.

Figure 7 shows a circuit **32** which is a combination of the circuits shown in Figures 5 and 6 with a transformer **33** replacing the resistor **31** of the constant voltage circuit in Figure 6. The replacement of the resistor by a current transformer produces beneficial results, in that phase reversal may be accomplished so that the output voltages of the circuits in Figures 5 and 6 will add in phase. The sum of the outputs can be made independent of the input frequency when both inputs are supplied from the same single phase power source. The output is 90 degrees out of phase with the input, and the output voltage can be made equal to input voltage.

At low frequencies, the lower circuit **(27)** in Figure 7, supplies most of the output voltage. At some medium frequency, each circuit supplies half the voltage. At high frequencies, the upper circuit **(30)** supplies most of the output voltage. This gives a distortionless 90 degrees phase change that, when used with the input voltage, becomes a four-phase supply.

The upper input circuit **(30)** can well be supplied with input voltage from a loaded power output triode which will give good voltage regulation. The other input circuit **(27)** can be supplied by a pentode operated on the constant current portion of its curve and this will take the place of the series resistor shown. Triode and pentode control grids may be driven by the same input voltage.

The circuit shown in Figure 7 will drive the outer grid segments **26***a* and **26***c* while grids **26***b* and **26***d* are driven by the original input frequency to produce a single sideband suppressed carrier modulated output with the electron tube herein described.

From the foregoing description of the present invention it will be seen that I have provided a method of controlling output frequency which can be utilized, among other things, to improve radio and carrier communication by furnishing single sideband signals or to convert a single sideband signal back to audio.

In some cases only the sum or difference frequency is required and modulation is unnecessary.

The functions of grids **24***a*, **24***b*, **24***c* and **24***d* may be combined with those of **26***a*, **26***b*, **26***c* and **24***d* so a single grid structure and appropriate circuits can deliver the sum or difference of the inputs.

While a preferred form of the invention has been shown and described, it will be understood that variation in details of form may be made without departure from the invention as defined in the appended claims. This circuit may be used with other tubes and this tube may be used with other appropriate circuits.

I claim:

1. An apparatus for controlling electrical output frequency comprising a central source of emission of energy, a concentric energy receiving element surrounding and spaced from said source, means connected to said source of energy for converting the emitted energy into one or more rotating beams varying according to a continuous wave shape and having a selected angular velocity and direction, means independent of said converting means, located between said converting means and said element for varying the intensity of said beams with one or more selected frequencies moving in a given direction whereby the frequency of the electrical output of the energy receiving element is controlled by the velocity and direction of the beam relative to that of said moving frequency.

2. An apparatus for controlling electrical output frequency and amplitude comprising a central source of emission of energy, a concentric energy receiving element surrounding and spaced from said source, means connected to said source of energy for converting the emitted energy into one or more rotating beams varying according to a continuous wave shape and having a selected angular velocity, means independent of said converting means, located between said converting means and said element for varying the intensity of said beam with a selected frequency moving in the same direction as the rotating beam whereby the frequency of the electrical output of the energy receiving element is equal to the difference between the velocity of the rotating beam and that of said moving frequency.

3. An apparatus for controlling electrical output frequency comprising a central source of emission of energy, a concentric energy receiving element surrounding and spaced from said source, means connected to said source of energy for converting the emitted energy into one or more rotating beams varying according to a continuous wave shape and having a selected angular veloc-

ity, means independent of said converting means, located between said converting means and said element for varying the intensity of said beams with a selected frequency moving in a direction opposite to that of the rotating beams whereby the frequency of the electrical output of the energy receiving element is equal to the sum of the velocity of the rotating beam and that of said moving frequency.

4. An apparatus for controlling electrical output frequency comprising a cathode and a single anode surrounding it, beam-rotating means comprising a multiple grid structure surrounding said cathode and means connected between the cathode and said grid structure, providing a polyphase alternating voltage applied thereto to produce one or more rotating beams of electrons varying according to a continuous wave shape and directed toward said anode, a second grid structure surrounding the cathode and located between the first mentioned grid structure and the anode; means independent of said beam-rotating means, providing a polyphase alternating voltage to said second grid structure in a given direction whereby the frequency of the output of the anode is controlled by the relative input frequencies and directions of the grids.

5. An apparatus for controlling electrical output frequency comprising a cathode and a single anode surrounding it, beam-rotating means comprising a multiple grid structure concentric with said anode and means connected between the cathode and said grid structure, providing a polyphase alternating current applied thereto to produce one or more rotating beams of electrons varying according to a continuous wave shape and directed toward said anode, a second grid structure surrounding the cathode and located between the first mentioned grid structure and the anode; means independent of said beam-rotating means, providing a polyphase alternating current to said second grid structure in the same direction as the rotating beam whereby the frequency of the output of the anode is equal to the difference between the input frequencies of the grids.

6. An apparatus for controlling electrical output frequency comprising a cathode and a single anode surrounding it, beam-rotating means comprising a multiple grid structure concentric with said cathode and means connected between the cathode and said grid structure, providing a polyphase alternating voltage applied thereto to produce one or more rotating beams of electrons varying according to a continuous wave shape and directed toward said anode, a second grid structure surrounding the cathode and located between the first mentioned grid structure and the anode; means independent of said beam-rotating means, providing a polyphase alternating voltage to said second grid structure in a direction opposite to the directional movement of the rotating beam whereby the output frequency of the anode is equal to the sum of the input frequencies of the grids.

7. An apparatus for controlling electrical output frequency comprising a cathode and a single anode surrounding it, beam-rotating means comprising a multiple grid structure surrounding said cathode and means connected between the cathode and said grid structure, providing a polyphase alternating voltage applied thereto to produce one or more rotating beams of electrons varying according to a continuous wave shape and directed toward said anode, a second grid structure surrounding the cathode and located between the first mentioned grid structure and the anode; means independent of said beam-rotating means, providing a polyphase alternating current to said second grid structure in a given direction whereby the frequency and amplitude of the output of the anode circuit is controlled by the relative input frequencies of the grids, and means connected to the grids for changing single phase voltage to distortionless polyphase voltage for driving said grids.

8. An apparatus for controlling electrical output frequency and amplitude comprising a cathode and a single anode concentric therewith, beam-rotating means comprising a multiple grid structure surrounding said cathode and means connected between the cathode and said grid structure, providing a polyphase alternating voltage applied thereto to produce one or more rotating beams of electrons directed toward said anode, a second grid structure surrounding the cathode and located between the first mentioned grid structure and the anode; means independent of said beam-rotating means, providing a polyphase alternating voltage to said second grid structure in a given direction whereby the frequency and amplitude of the output of the anode circuit is controlled by the relative input frequencies and amplitudes of the grids, means connected to the grids for changing single phase current to distortionless polyphase current for driving said grids, and means comprising a circuit which adds two voltages, one of which is taken across a reactor approaching zero reactance compared to circuit resistance and the other voltage which is produced by the current through a reactor having a reactance approaching infinity as compared to the supply circuit resistance, both of the above voltages originating from the same single phase source.

9. The method of controlling electrical output frequency and amplitude of a circuit having a single anode consisting in converting within said anode a field of electrons into a rotating beam of electrons varying according to a continuous wave shape and, intercepting said beam with a moving electrical field so as to vary the intensity of the electrons impinging the anode.

10. The method of controlling electrical output frequency and amplitude of a circuit having a single anode consisting in imposing within said anode a polyphase alternating current or voltage on a field of electrons to produce one or more rotating beams of electrons varying according to a continuous wave shape and, intercepting said beams with a polyphase alternating current or voltage moving in the same direction as the beam so as to vary the intensity of the electrons impinging the anode whereby the output frequency of the anode circuit will equal the difference of the two input frequencies.

11. The method of controlling electrical output frequency and amplitude of a circuit having a single anode consisting in imposing within said anode a polyphase alternating current or voltage on a field of electrons to produce one or more rotating beams of electrons varying according to a continuous wave shape and, intercepting said beams with a polyphase alternating current or voltage moving in a direction opposite to the movement of the beams so as to vary the intensity of the electrons impinging the anode whereby the output frequency of the anode circuit will equal the sum of the two input frequencies.

12. The method of controlling electrical output frequency and amplitude comprising the steps of producing a beam of energy emanating from a central point to a single anode, within said anode rotating the beam around said central point, and causing said beam to vary according to a continuous wave shape, intercepting said beam with a moving frequency so as to vary the beam intensity, and receiving the beam on said anode concentric with said central point, so that the output frequency is a function of both the frequency of rotation of the beam and the interrupting frequency.

13. Apparatus for providing a modulated output wave, comprising a central source of emission of energy; a single, continuous energy-receiving element surrounding and spaced from said source; a plurality of perforate members interposed between said source of emission and said energy receiving element; means including said perforate members for converting the emitted energy from said source into a rotating pattern varying according to a continuous wave shape and passing simultaneously through said perforate members to the said element; and

means located between the said perforate members and said energy receiving element, for controllably varying the intensity of said pattern, thereby to modulate the output of energy to the said element.

14. Apparatus for controlling electrical output frequency comprising a cathode for emitting electrons and a single anode surrounding the cathode; means for rotating the emission from said cathode, comprising a multiple grid structure surrounding the cathode and circuit means connected between the cathode and said grid structure, applying a polyphase alternating voltage thereto to produce a rotating pattern of electrons varying according to a continuous wave shape and directed toward said anode and passing simultaneously through said multiple grid structure; a second grid structure surrounding the cathode and located between the first-mentioned grid structure and the anode; means independent of said emission rotating means, appying a polyphase alternating voltage to said second grid structure in a given direction

whereby the frequency of the output of the anode is controlled by the relative input frequencies and directions of the grids.

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