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2,180,816

FREQUENCY CONVERSION CIRCUIT

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2 Sheets-Sheet 2

FIG. 3

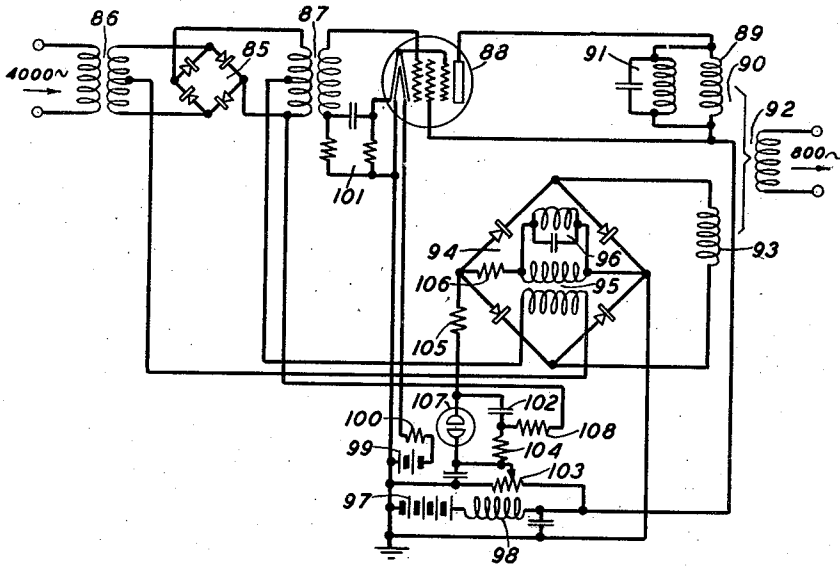
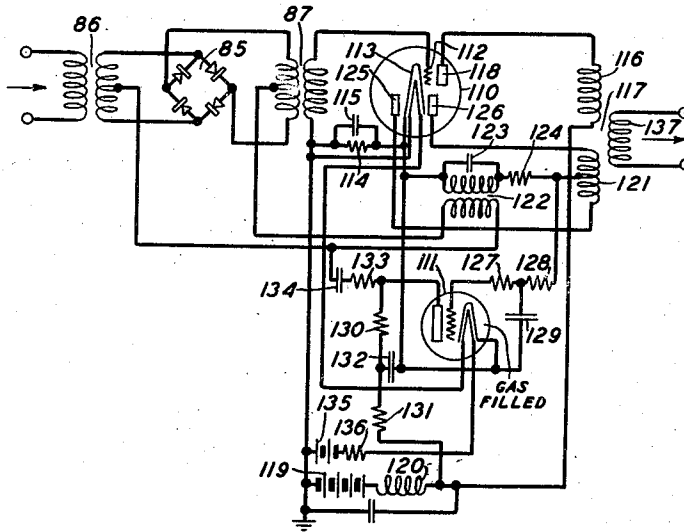


FIG. 4



UNITED STATES PATENT OFFICE

2,180,816

FREQUENCY CONVERSION CIRCUIT

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9 Claims. (Cl. 250—36)

This application is a division of my copending application, Serial No. 156,698, filed July 31, 1937. The invention relates to the production of alternating current waves by frequency conversion methods.

An object of the invention is to convert alternating current waves of one frequency into alternating current waves of a different frequency.

A more specific object is to produce alternating current waves of desired frequencies which are accurate fractions of a given base frequency.

These objects are attained in accordance with the invention by frequency conversion circuits utilizing a process which may be termed regenerative modulation. Regenerative modulation is produced in general by feeding back the output of a balanced type modulator to the balanced or conjugate input thereof through a selective network, such as a filter, and an amplifier of fixed gain μ . Such a circuit is stable and of a non-oscillatory nature as long as the loss due to the balanced condition and the network or filter is greater than the gain μ of the amplifier.

The frequency conversion circuits of the invention employing this process, to be described hereinafter, may be used to produce electrical waves which are exact fractional ratios of a given frequency applied to the input, and which will follow amplitude and frequency variations in the applied waves over quite wide ranges, these circuits having exceptional frequency stability and efficiency in operation.

The various features and advantages of the circuits of the invention will be brought out in the following detailed description thereof when read in connection with the accompanying drawings of which:

Fig. 1 shows schematically a circuit which illustrates the basic principles of the invention;

Fig. 1A shows a modification of this basic circuit; and

Figs. 2 to 4 show schematically in greater detail frequency conversion circuits embodying different modifications of the invention.

The fundamental concept of regenerative modulation as applied to frequency conversion may be described by referring to Fig. 1.

The frequency converter circuit of Fig. 1 includes a balanced modulator 1 of the second order type, such as that disclosed in F. A. Cowan Patent No. 1,959,459, consisting of four copper-oxide rectifier units connected in a Wheatstone bridge formation, an input transformer 2 and an output transformer 3, the secondary winding of the input transformer and the primary winding of the output transformer being connected in shunt with one diagonal 4, 5 of the bridge and a source of modulating current being connected to the other conjugate diagonal 6, 7 of the bridge. The copper-oxide rectifier units 8,

9 are poled so that each is conductive in the direction toward the common terminal 6, and the other rectifier units 10, 11 are poled so that each is conductive away from the common terminal 7. The primary winding of the input transformer 2 is connected to a source (not shown) of the base frequency f_1 to be converted, and a filter 12 is connected between the secondary winding of the output transformer 3 and the output terminal of the circuit. The source of modulating waves applied to the conjugate terminals 6, 7 of the modulator bridge is the regenerative circuit 13 comprising the filter network 12 and the one-way amplifier 14 of gain μ having its input connected across the output of filter 12 and its output connected across the conjugate terminals 6, 7 of the bridge 1 through the transformer 15. The gain μ of the amplifier 14 in the regenerative circuit is selected so as to provide the required stability. As indicated, a frequency multiplier 16, indicated by the box so labeled in Fig. 1A, would be included in the regenerative circuit 13 where it is desired to secure a fractional frequency having a denominator larger than 2.

Now if the input frequency f_1 is applied to the input of the second order modulator in the system of Fig. 1 and any frequency f_2 in the output thereof is selected by the filter 12 and fed back through the amplifier 14 and transformer 15 to the conjugate terminals 6, 7 of the modulator, the two frequencies f_1 and f_2 will combine in the modulator to produce the two side-band frequencies $f_1 \pm f_2$ which are at a certain loss with respect to f_2 . If the amplification μ is greater than the side-band loss plus the loss provided by the filter 12, the side-band frequencies will be fed back and will be applied to the conjugate terminals 8, 9 of the modulator 1 but at a greater amplitude. If the following arbitrary case is set up

$$f_1 \pm f_2 = f_2 \quad (1)$$

which is the case where f_2 will sustain itself, it will be found that

$$f_2 = \frac{f_1}{2}, 0 \quad (2)$$

so that the wave appearing in the output of the frequency conversion circuit is half the frequency of the wave applied to the input thereof from the base frequency source, or

$$\frac{f_1}{2}$$

as indicated. In the general case for this type of circuit depending upon the order of modulation used

$$nf_1 \pm mf_2 = f_2 \quad (3)$$

or

$$f_2 = \frac{n}{1 \pm m} f_1 \quad (4)$$

where n and m are integers depending upon the order of modulation. For the case of third order modulation, where a third order instead of a second order modulator is used,

$$n=1, m=2 \text{ or } n=2, m=1 \quad (5)$$

and

$$f_2 = \frac{1}{3}f_1, f_1. \quad (6)$$

In the case where the frequency multiplier 16 of Fig. 1A is used in the regenerative circuit 13, the following equations may be set up:

$$f_2 = nf_1 \pm mf_3 \quad (7)$$

$$f_3 = rf_2 \quad (8)$$

where f_3 is the frequency in the output of the multiplier and r is the factor by which the feedback frequency f_2 is multiplied.

Solving these two equations simultaneously gives

$$f_2 = \frac{n}{1 \pm mr} f_1 \quad (9)$$

$$f_3 = \frac{rn}{1 \pm mr} f_1 \quad (10)$$

If the input wave is represented by the equation

$$e_{f_1} = A \cos \omega t \quad (11)$$

and the frequency component f_2 at the input of the modulator is represented as

$$e_{f_2} = B \cos \left(\frac{\omega t}{2} + \Phi \right) \quad (12)$$

then the two side-band outputs which are obtained are given by

$$e_{s,b} = KAB \left[\cos \left(\frac{\omega t}{2} - \Phi \right) + \cos \left(\frac{3\omega t}{2} + \Phi \right) \right] \quad (13)$$

In general, the frequency of interest is the frequency

$$\frac{\omega t}{2}$$

the other frequency being eliminated by the filter 12 in the regenerative circuit. Since the input to the modulator from the regenerative circuit is obtained from the side-band output in the case of a self-sustaining wave, then the condition for the phase relation of the regenerative component at the input and output of the modulator is

$$\cos \left(\frac{\omega t}{2} + \Phi \right) = \cos \left(\frac{\omega t}{2} - \Phi + \theta \right) \quad (14)$$

where θ is the phase shift which may be introduced by the filter 12 and the amplifier 14. From this is obtained

$$\Phi = \frac{\theta}{2} \quad (15)$$

and it has been found that the frequency f_2 in the feedback circuit will automatically adjust its phase with respect to f_1 , so that its phase is right to reproduce itself, and its ability to produce a sustained frequency should be independent of any phase shift in the feedback circuit. This action has been verified experimentally.

An important consideration is the relation of the amplitude of a sub-harmonic component to that of the fundamental. Since the sub-harmonic is produced by a process of modulation its amplitude cannot exceed that of the fundamental. Thus, there can be no runaway condition as in an ordinary oscillation which is limited only by the overload capacity of the oscillator. The amplitude of the sub-harmonic will be such that

the modulation loss is equal to the gain μ of the amplifier, less the loss of the filter network. In general, the amplitude of the sub-harmonic will be a function of the fundamental, although it may not be a linear relation.

Fig. 2 shows a frequency converter circuit in accordance with the invention which may be used for producing accurate fractional ratios of a given frequency, for example, a 3/5 ratio (such as 4,000 to 2,400 cycles) or a 1/5 ratio (such as 300 cycles to 60 cycles).

The frequency converter circuit of Fig. 2 comprises a double balanced type of modulator such as is disclosed in Cowan Patent No. 2,025,153, comprising a four-element copper-oxide rectifier bridge 29 with the individual elements poled in the same direction, an input transformer 30 and an output transformer 31, an amplifier comprising the two amplifying vacuum tubes 43, 44 of the pentode type, an output transformer 45 for the tube 43, and a regenerative circuit comprising the duplex diode-triode unit 46 and the tuned feedback transformer 47 for feeding back the output of the amplifying tube 44 to the conjugate balanced input of the modulator.

The amplifying vacuum tube 43 comprises the heater type cathode or filament 43, the control grid 49, the suppressor grid 50 connected directly to the cathode 43, the anode or plate 51 and the screen grid 52 connected to the anode 51 through the primary winding of output transformer 45. The amplifying vacuum tube 44, which is of the variable μ type, comprises the heater type cathode 53, the control grid 54, the suppressor grid 55 connected directly to the cathode 53, the plate or anode 56 and the screen grid 57 connected to the anode 56 through the resistance 58 and the primary winding of the transformer 59.

The control grid-cathode circuits of the amplifying vacuum tubes 43 and 44 are connected in parallel across the secondary winding of the modulator output transformer 31, the former circuit including in series the condenser 60 and resistance 61 and the latter circuit including in series the condenser 62 and the resistance 63. An anti-resonant circuit 64 is connected across the control grid-cathode circuit of the amplifying vacuum tube 43 and an anti-resonant circuit 65 is connected across the control grid-cathode circuit of tube 44.

The double diode or full-wave rectifier portion of the unit 46 is used to obtain a frequency multiplier whose output is nearly linear with input, and the triode part is used as an amplifier at the desired harmonic frequency to be fed back to the conjugate input of the modulator 29, 30, 31.

The full-wave rectifier portion of the tube 46 comprises the cathode 66 of the heater type connected to the mid-point of the secondary winding of transformer 59 through a resistance 67 shunted by a resistance 68 in series with a condenser 69, and two rectifier anodes 70, 71 connected respectively to the two terminals of the secondary winding of transformer 59. The amplifier portion of the tube 46 comprises the cathode 66, the control grid 72 and the anode 73. The control grid 72 is connected to the mid-point of the secondary winding of transformer 59 through the condenser 75. The cathode-anode circuit of the amplifier portion of tube 46 includes the primary winding of the feedback transformer 47, which winding is shunted by the anti-resonant circuit 76.

Space current is supplied from plate battery 77 through choke coil 78 to the plates of the am-

plifier tubes 43 and 44 through the primary windings of transformers 45 and 59, respectively, and to the plate of the amplifier portion of tube 46 through the primary winding of the feedback transformer 47. Appropriate heater potentials are applied from the battery 79 to the cathode heaters of tubes 43, 44 and to the cathode heater of tube 46 through the resistance 80, and suitable fixed biasing potentials are applied to the grids of these tubes from that battery through the resistance network 81, and the resistance 74, as indicated.

The secondary winding of the feedback transformer 47 is connected across the mid-point of the secondary winding of the modulator input transformer 30 and the mid-point of the primary winding of the modulator output transformer 31 so that the feedback circuit is in conjugate relation with the incoming circuit through the input transformer 30 and with the inputs of amplifiers 43 and 44.

The cathode-control grid circuit of the variable mu amplifier tube 44 is connected to a point between the resistance 68 and condenser 69 in the common branch of the full-wave rectifier portion of tube 46, through the retard coil 82 so that the d-c component of the rectifier provides a variable grid bias to automatically control the gain of the variable mu tube. When an input to the variable mu tube 44 is first applied through the modulator output transformer 31, this tube has very small control grid bias and thus a high gain for starting the regenerative action; as the regenerative component builds up to the steady state condition, the voltage drop produced by the d-c component in the resistances 67 and 68 of the common branch of the full-wave rectifier portion of tube 46 coupled to the output circuit of the amplifier tube 44 by transformer 59 will increase the bias applied to the control grid circuit of the latter tube causing its gain to be automatically decreased.

In the circuit of Fig. 2, if the output frequency of the modulator is represented as f_1 , then the frequency out of the multiplier (output of tube 46) is $r \times f_1$ where r is the harmonic used. Denoting f as the input frequency to the modulator, the relation between the two frequencies is:

$$f \pm r f_1 = f_1 \quad (20)$$

$$f_1 = f \left(\frac{1}{1 \pm r} \right) \quad (21)$$

In the operation of the circuit of Fig. 2, the numerator of the fractional frequency obtained in the output transformer 45 will depend upon the tuning of the resonant circuit 64 in the input of amplifier 43, the denominator being determined by the sub-multiple frequency f_1 which is present in the regenerative circuit. If a fractional ratio of $3/5$, for example, a conversion of 4,000 cycles to 2,400 cycles, is desired, the amplifier 43 will be tuned by resonant circuit 64 to $3f/5$ (2,400 cycles), the first stage of amplification in the regenerative circuit (amplifier 44) would be operated at $1/5$ of the input frequency (800 cycles) by tuning the resonant circuit 65 in the control grid circuit of that amplifier to that frequency, and by operating the second amplifier stage in the regenerative circuit (amplifier of tube 46) at $4/5$ of the input frequency (3,200 cycles) by tuning the resonant circuit 76 in shunt with the feedback transformer 47 to that frequency.

There will be a considerable amount of $2f/5$

(1,600 cycles) present in the output of the duplex diode unit 46, as well as $4f/5$ (3,200 cycles) which is necessary for regeneration, and the former will modulate against f (4,000 cycles) in the modulator 29, 30, 31 to produce $3f/5$ (2,400 cycles) at the output of the modulator. This will be filtered out by means of the highly selective resonant circuit 64 tuned to $3f/5$ (2,400 cycles), and will be amplified by amplifier 43 and impressed in amplified form on the outgoing circuit through output transformer 45.

Other fractional ratios, for example, $1/5$, $3/5$, $4/5$, . . . , may be obtained by a suitable tuning of the resonant circuit 64.

If the condenser 60 is connected to the mid-point of transformer 59, instead of to transformer 31, fractional ratios of $2/5$, $4/5$, $3/5$, . . . , can be obtained.

Other sub-multiple ratios may be obtained by suitable tuning of the two amplifiers in the regenerative circuit. That is, if a sub-multiple ratio $f/3$ is desired, the first amplifier in the regenerative circuit will be tuned to $f/3$ and the second amplifier therein to $2f/3$ and the amplifier associated with the output circuit to $f/3$. In similar manner fractions of $1/3$, $2/3$, $4/3$, $5/3$, . . . can be obtained. By removing the connection to either of the diode plates 70 or 71, odd harmonics can be obtained in the multiplier circuit, thus making it possible to secure sub-multiple ratios of $1/4$, $1/6$, . . . If the duplex diode triode unit 46 is omitted, the circuit will give $1/2$ the input frequency, provided the amplifier in the feedback circuit is tuned approximately to $1/2$ of the input frequency.

Any other type of rectifier which is nearly linear over a considerable range may be used in place of the duplex diode triode.

The general conditions for stable operation of the type of circuit shown in Fig. 2 can be stated as follows:

(1) The total gain in the feedback circuit must be less than unity or of a non-oscillatory nature when considered as on a single frequency basis; and (2) the gain of the feedback circuit when considered on a basis of the magnitude of f_1 at the output of the modulator to that of $r f_1$ into the modulator, should be greater than the loss of the modulator.

There are numerous advantages of the type of sub-multiple generator shown in Fig. 2 over sub-multiple generators of the prior art. Probably the most important of these is the fact that the circuit cannot go out of step with the input frequency. Another important advantage is that if the input becomes too low, the circuit will not go out of step, but will simply become inoperative.

Another important advantage of the circuit of Fig. 2 is that the upper limit in frequency is determined only by the ability of the circuit to modulate and amplify the frequencies in question. This limit may extend into the ultra-high frequency range.

It may be demonstrated that regenerative modulators which employ frequency multipliers in their feedback circuits, such as illustrated in Fig. 2, usually require a finite value of the sub-multiple frequency present in the feedback circuit before they will build up to a steady-state condition. The magnitude of the sub-multiple frequency and the length of time which it must be present for purposes of starting will depend upon the amount of amplification of the amplifier and the characteristics of the frequency multiplier. Without an auxiliary starting circuit, it

is necessary to make the gain of the regenerative modulator circuit so high that it might be self-starting due to amplifier noise and circuit unbalances, and to make use of a rectifier unit which will maintain its sensitivity down to very low levels.

These requirements are dispensed with in the circuits of Figs. 3 and 4 by providing auxiliary means for supplying the small amount of sub-multiple frequency necessary for starting purposes, so that equivalent results are obtained with much simpler circuit arrangements. The general method employed in these circuits is to supply a sharp pulse of low amplitude to one of the resonant circuits, which pulse creates a damped oscillation which will at some time during its decay satisfy the conditions for starting.

The circuit of Fig. 3 employs a modulator of the double balanced type similar to that used in the circuit of Fig. 2, consisting of a copper-oxide rectifier bridge 85, an input transformer 86 having its primary winding connected to the alternating current source of the frequency (e. g., 4,000 cycles) to be converted and its secondary winding connected across one diagonal of the bridge, and an output transformer 87 having its primary winding connected across the other diagonal of the rectifier bridge. The control grid-cathode circuit of a pentode type amplifying vacuum tube 88, similar to those illustrated in the system of Fig. 2, is connected across the secondary winding of transformer 87. The anode-cathode circuit of tube 88 includes the primary winding 89 of the transformer 90, this winding being shunted by the resonant circuit 91 tuned to the desired sub-multiple (say, 800 cycles) of the input frequency (4,000 cycles). A second winding 92 of transformer 90 coupled to the winding 89 is provided for taking off the former frequency. A third winding 93 of the transformer 90, coupled to the winding 89, is connected across one diagonal of the balanced four-element copper-oxide rectifier bridge 94 acting as a frequency multiplier, the other diagonal of the bridge being coupled by the feedback transformer 95 tuned by the resonant circuit 96 connected across its primary winding to the necessary multiple (3,200 cycles) of the applied frequency (800 cycles), which when modulated in the modulator with the original input frequency (4,000 cycles) will produce as one component the desired sub-multiple frequency. The secondary winding of the feedback transformer 95 is connected across the mid-point of the secondary winding of the modulator input transformer 86 and the mid-point of the primary winding of the modulator output transformer 87, as shown.

Plate current is supplied to the plate of the amplifying vacuum tube 88 from the plate battery 97 through the retardation coil 98 and the winding 89 of transformer 90 in series. The battery 97 through the retardation coil 98 supplies a suitable bias to the screen grid of tube 88. Heating current is supplied to the heater for the cathode of tube 88 from battery 99 through the series resistance 100, and a fixed bias is supplied to the control grid of the tube 88 from that battery through the resistance-condenser network 101 and the secondary winding of the modulator output transformer 87, as shown.

The arrangement now to be described is used for producing a sharp pulse of low amplitude and applying it to the regenerative circuit to start regeneration if, for any reason, it is stopped.

The condenser 102 is arranged to be charged to the potential of the plate battery 97 through the potentiometer 103 shunting that battery and choke coil 98, the resistance 104 connected thereto, the resistances 105 and 106 associated with the frequency multiplier unit 94, and the primary winding of feedback transformer 95. If the regenerative modulator is not operating, the condenser 102 will charge up to the breakdown potential of the neon lamp 107 connected across it in series with resistance 104. The breakdown of the neon lamp 107 discharges the condenser 102 through the resistance 104, a small part of this discharge being applied to the modulator regenerative circuit through the resistance 108 connected between a point intermediate condenser 102 and resistance 104, and one terminal of the primary winding of transformer 87 in the input of that circuit. When the charge on the condenser 102 falls below the ionizing potential of the neon tube 107, it will be again charged up from battery 97 over the path previously traced.

This cycle of operations will be repeated at regular intervals to apply a series of pulses to the regenerative circuit until the regenerative modulator starts. As the regenerative modulator builds up, the amplified modulator output voltage applied from the output of amplifier 88 through transformer 90 to the rectifier bridge 94 produces a D. C. voltage drop in the resistance 106 in series with the primary winding of the feedback transformer 95 in the output of the bridge, which voltage opposes the battery voltage applied from the plate battery 97 and, by suitable choice of the circuit constants, is made sufficient to prevent the breakdown of the neon lamp 107. Thus, when the regenerative modulator circuit is working normally, the neon lamp 107 remains inactive, but as soon as the regenerative modulator stops operating the neon lamp will attempt to start it as described.

When the circuit is operating normally, the multiple frequency (3,200 cycles) appearing in the output of the frequency multiplier unit 94 is fed by the tuned feedback transformer 95 to the conjugate terminals of the balanced modulator and modulates therein with the base frequency (4,000 cycles) impressed thereon through the primary winding of the modulator input transformer 86, to produce combination frequencies in the output of the modulator which are amplified by the amplifier 88. The desired fraction of the input frequency (800 cycles) is selected by the resonant circuit 91 in the output of amplifier 88 and is impressed by transformer 90 on the utilization circuit connected to the winding 92 of that transformer, and also on the multiplier 94 through winding 93.

The circuit of Fig. 4 shows a similar starting circuit applied to a frequency converter of the regenerative modulator type in which a duplex diode-triode unit 110, such as was described in connection with the system of Fig. 2, is used for the amplifier and multiplier in the regenerative circuit in place of the amplifier 88 and copper-oxide rectifier bridge 94 employed as the frequency multiplier in the system of Fig. 3.

The starting circuit in the system of Fig. 4 also differs from that shown in Fig. 3 in the use of a three-element, hot-cathode, gas-filled discharge tube 111 in place of the cold cathode neon tube 107 used in the system of the previous figure, because in the case of a duplex diode only a negative voltage can be obtained with respect to the cathode which is usually at or near ground

potential. By using a three-electrode, gas-filled vacuum tube instead of the cold cathode discharge tube, the same action may be obtained except that the voltage which is developed by the multiplier is used to control the grid of the three-electrode, gas-filled tube.

In the system of Fig. 4, the control grid 112 and the cathode 113 of the amplifier portion of the duplex 110 are connected across the secondary winding of the modulator output transformer 87, the control grid-cathode circuit including the usual grid bias combination resistance 114 shunted by condenser 115, and the winding 116 of a transformer 117 is connected between the amplifier anode 118 and the cathode 113 of tube 110, in series with the plate battery 119 and the choke coil 120.

The full-wave rectifier portion of the tube 110 operating as a frequency multiplier, comprises the cathode 113 connected to the mid-point of the winding 121 of the transformer 117, through the primary winding of the feedback transformer 122, which is shunted by the tuning condenser 123, and the resistance 124 in series, and the two rectifier anodes 125, 126 connected respectively to the two terminals of the winding 121 of the transformer 117. The secondary winding of the feedback transformer 122 is connected across the mid-point of the secondary winding of the modulator input transformer 86 and the mid-point of the primary winding of the modulator output transformer 87.

The control grid of the gas-filled discharge tube 111 is connected to the mid-point of winding 121 of transformer 117 through series resistances 127 and 128 so as to receive a variable direct current bias due to the voltage drop in the resistance 124 in the rectifier output of the tube 110, and a condenser 129 is connected between the cathode 111 and a point between the resistances 127 and 128. The resistances 130 and 131 are connected in the anode-cathode circuit of tube 111 in series with the plate battery 119 and choke coil 120, and the condenser 132 is connected from a point between resistances 130 and 131 to the cathode of tube 111. The plate of tube 111 is connected through resistance 133 and condenser 134 in series to a point in the regenerative circuit connecting the secondary winding of feedback transformer 122 across the mid-point of the secondary winding of the modulator input transformer 86 and the mid-point of the primary winding of the modulator output transformer 87.

The heaters for the cathodes of the tubes 110 and 111 are supplied in series with heating current from the battery 135 through series resistance 136.

The starting circuit in the system of Fig. 4 operates as follows: The condenser 132 is charged to the potential of the plate battery 119 through the choke coil 120 and the resistance 131. If the regenerative modulator is not operating, the condenser 132 will charge to the breakdown potential of the gas-filled tube 111, the plate-cathode circuit of which is connected across condenser 132 in series with resistance 130. The breakdown of the gas-filled tube discharges the condenser 132 through the resistance 130, a small part of the discharge being applied to the modulator regenerative circuit through resistance 133 and condenser 134 in series. When the charge on condenser 132 falls below the ionization potential of the tube 111, that condenser will again be charged from plate battery 119 over the path previously traced.

This cycle of operations will be repeated at regular intervals to apply a series of sharp pulses to the regenerative circuit of the modulator until the regenerative modulator starts. As the regenerative modulator builds up, the amplified voltage in the output of the amplifier portion of tube 110 is applied through transformer 117 to the output circuit of the converter, and to the double diode portion (rectifier) of tube 110 and produces a D. C. voltage drop in the resistance 124 which will cause the grid voltage of the gas tube 111 to become sufficiently negative to prevent the gas-filled tube 111 from breaking down. It will be seen, therefore, that the gas-filled tube will remain unoperated unless and until this negative voltage is built up to the point to make that tube inoperative as will occur only when the regenerative modulator circuit is operating properly, and when this voltage is not built up the gas-filled tube is operated in the manner described to attempt to start regenerative modulation.

When the regenerative modulator is working properly, a wave of a frequency which is the desired multiple of the frequency applied to the input of the double diode rectifier unit 110 (multiplier) is selected by the tuned feedback transformer 122 and is applied to the conjugate terminals of the modulator to modulate therein with the base frequency wave applied to the primary winding of the input transformer 86, to produce the desired fraction of the base frequency in the output of the modulator. This frequency is amplified by the triode portion of the tube 110 and is impressed by transformer 117 on the utilization circuit connected to the winding 137 thereof.

Only one starting unit of the type described in connection with Fig. 3 or 4 should be necessary for any cascaded series of regenerative modulators. That is, where several regenerative modulators are used in series, the starting unit would be controlled by the last one and the starting pulses would be applied to each regenerative modulator stage in the manner previously described for the single regenerative modulator in the previous figures. As each individual stage builds up, it will continue to operate regardless of the small impulses received from the starting circuit. As soon as the last unit builds up, the starting circuit will cease operating.

Although the starting circuit will supply a short pulse to the output of the frequency conversion circuit, this will not be objectionable since it has been found that this pulse will be approximately 20 decibels below the normal output level, and by proper adjustment of the circuit may be made to occur not oftener than once a second. If no input is applied to the frequency conversion circuit, the amplitude of the impulse in the output will be even lower because of the greater loss of the modulator. This pulse may be even made use of, if desired, to give an indication at a distant point of trouble in some preceding part of the system. For example, the operator at the distant point could by a simple test on the line determine whether the trouble was in the transmission line or in the regenerative modulator, according to whether the pulse was or was not heard. The lighting of the neon lamp in the case of the starting circuit of Fig. 3 would also give an indication of trouble at the point where it is located.

Other modifications of the circuits illustrated and described above within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. A frequency converter comprising a balanced modulator having one input supplied with a wave of a base frequency to be converted to a wave of another frequency, and a second input in conjugate relation with said one input, a regenerative circuit for feeding back waves derived from the output of said modulator to said second input thereof to modulate in said modulator with said wave of base frequency, said regenerative circuit including an amplifier supplying the necessary gain, a frequency multiplier and selective networks, for determining the frequency and amplitude of the fed-back waves so that when they are combined in said modulator with said wave of base frequency the combination waves will include a sustained component of the desired converted frequency, means for selecting a sustained wave of said converted frequency from the output of said modulator and means to start and maintain said converter in operation comprising auxiliary means operative to so increase the energy supply to said second input during an initial time interval after the wave of said base frequency is supplied to said one input as to establish the regenerative action in said frequency converter and to prevent the energy supply to said second input from exceeding the proper operating value thereafter.

2. The frequency converter of claim 1, in which said frequency multiplier comprises a double diode rectifier and said auxiliary means comprises a variable mu amplifying vacuum tube in said regenerative circuit having a control grid the bias on which is controlled by the direct current component produced by said diode rectifier so as to produce a high gain in said regenerative circuit for starting which automatically decreases as regeneration builds up to the steady-state condition.

3. A frequency converter comprising a balanced modulator having two conjugately connected inputs, a source of waves of the given frequency to be converted connected to one input of said modulator, a regenerative circuit for feeding back a wave derived from the output of said modulator to the other input thereof, the feedback circuit including an amplifier supplying the necessary gain but limited so as to make the circuit stable, a frequency multiplier and selective circuits, for determining the frequency of said derived wave, means for selecting a combination product of the wave of given frequency and the derived wave from the output of said modulator, and means for automatically starting and maintaining the regenerative action in said feedback circuit while said waves of given frequency are supplied to said modulator comprising means operating to periodically supply sharp pulses of low amplitude to said modulator until the regenerative action is started.

4. The frequency converter of claim 3 in which the last-mentioned means comprises a condenser, means for charging up said condenser and discharging it through said feedback circuit at intervals, and means responsive to the building up of said regenerative action for preventing said condenser from discharging through said feedback circuit.

5. The frequency converter of claim 3 in which the last-mentioned means comprises a condenser, a direct current source normally charging said

condenser, a discharge circuit for said condenser including said feedback circuit, means responsive to the charge on said condenser when it reaches a predetermined value to cause its discharge through said discharge circuit, and means responsive to the restarting of said regenerative action to prevent the charge on said condenser from reaching said predetermined value.

6. A frequency converter for producing accurate fractions of a given base frequency comprising a balanced modulator having one input supplied with a wave of said base frequency and a second input in conjugate relation with said one input, a regenerative circuit for feeding back waves derived from the output of said modulator to said second input to modulate in said modulator with the supplied wave of base frequency, said regenerative circuit including an amplifier, means for selecting a sub-multiple of said base frequency from the output of said modulator, and means including a frequency multiplier for producing and supplying to said second input of said modulator a wave of a frequency which is a harmonic of the selected sub-multiple frequency, said sub-multiple selecting means and said frequency multiplier being tuned to such frequencies and the gain of said amplifier being so chosen that the wave supplied to said second input is of the proper frequency and amplitude to cause the combination waves in the output of the modulator to include a sustained component of a frequency which is a desired fraction of the base frequency, means for selecting a sustained wave of said desired fraction frequency from the output of said modulator, and means to start and maintain said converter in operation comprising auxiliary means operative to so increase the energy supply to said second input during an initial time interval after the wave of said base frequency is supplied to said one input as to establish the regenerative action in said converter and to prevent the energy from exceeding the proper operating value thereafter.

7. The frequency converter of claim 1, in which said frequency multiplier comprises a full-wave rectifier and said auxiliary means comprises means to utilize a direct current component produced by said rectifier to bias said amplifier so that it provides a high gain during said initial time interval and a lower gain when regeneration is established.

8. The frequency converter of claim 1, in which said auxiliary means comprises means to supply pulses of direct current to said second input of said modulator during said initial time interval, and means responsive to the building up of said regenerative action to stop the operation of the pulse supply means.

9. The frequency converter in claim 1, in which said auxiliary means comprises a capacitor, a charging circuit for said source including a direct current source, a gas-filled discharge device connected across said capacitor and operative to discharge said capacitor through said regenerative circuit when the charge on said capacitor reaches a predetermined value, and means responsive to the building up of regeneration in said regenerative circuit to prevent the charge on said capacitor from reaching said predetermined value.

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