Sept. 18, 1945. D. A. BELL 2,384,789

FREQUENCY MODULATOR

Filed Feb. 11, 1942

Fig. 1

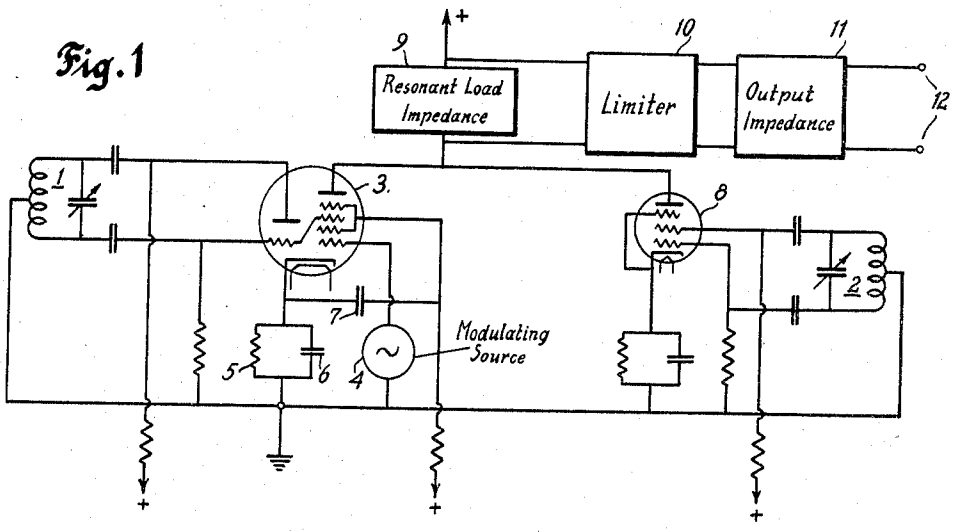
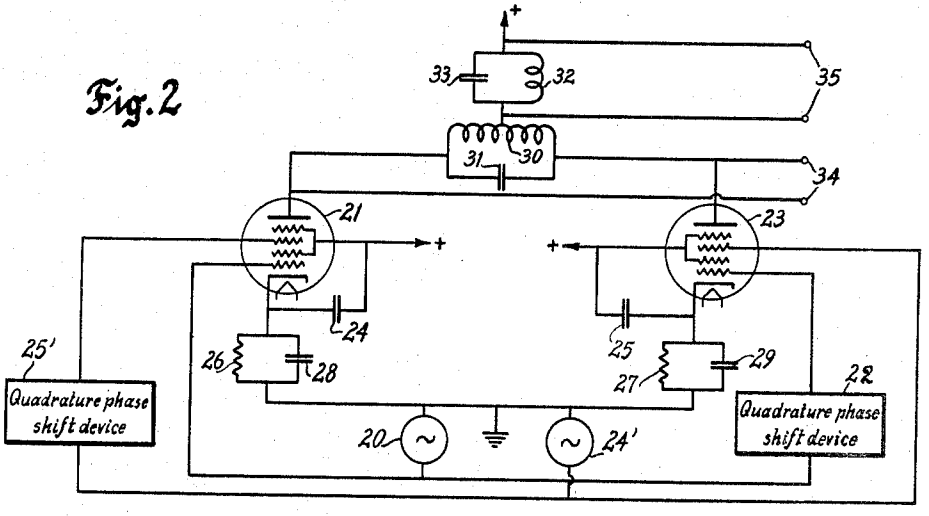


Fig. 2



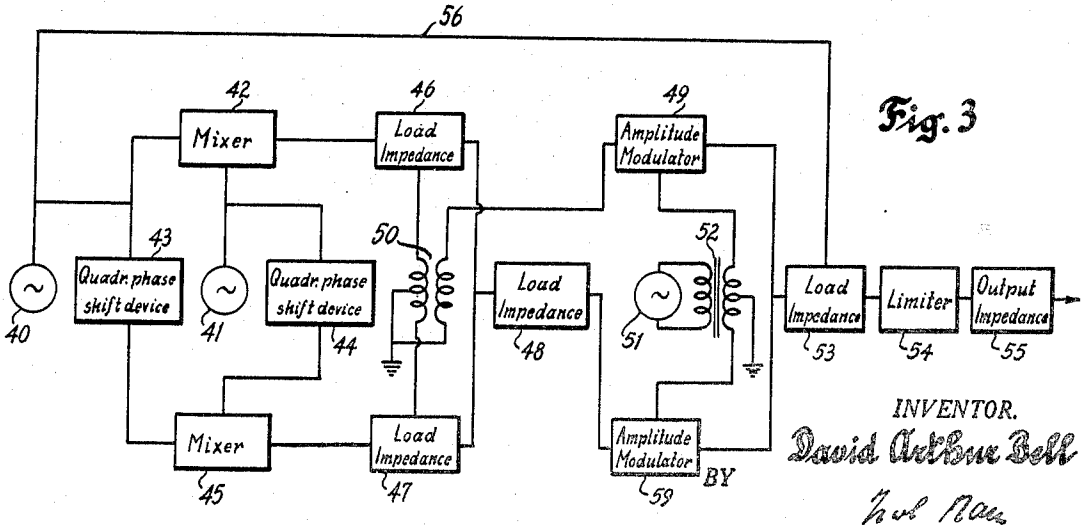


Fig. 3

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FREQUENCY MODULATOR

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8 Claims. (Cl. 179—171.5)

This invention relates to the generation of electrical oscillations.

One feature of the invention is the method of generating a frequency modulated oscillation which comprises modulating the relative amplitudes of two different constant frequency oscillations which are added and applied to a non-linear conductor.

When, for example, two alternating voltages of different frequencies are added and applied to a limiter, one component of the output voltage from the limiter has a frequency between the frequencies of the applied alternating voltages and its frequency will depend on the relative amplitudes of the two alternating voltages. If, therefore, one of the alternating voltages be modulated in amplitude, or if both be modulated in amplitude in opposite phase, the frequency of this output component will be correspondingly modulated.

If the amplitude of one of the alternating voltages is kept constant, while the amplitude of the other is varied within the limits 1.0 to 0.4 times that amplitude, then the frequency varies substantially linearly with the amplitude ratio. The corresponding range of frequency variation is from the mean of the frequencies of the alternating voltages to a departure from that mean of about 36% of the difference between those frequencies.

If the amplitude of one of the alternating voltages is increased while the other is decreased by an equal amount, the variation of frequency with the amplitudes is substantially linear so long as the ratio of either amplitude to the mean amplitude lies between the limits 0.8 and 1.2. The corresponding frequency variation to each side of the mean frequency is about ±19% of the difference between the frequencies of the alternating voltages.

Over the greater part of these ranges the limiter will maintain substantially constant amplitude of the desired component of the output voltage. When, however, the amplitudes of the applied alternating voltages are equal, the amplitude of this component falls to zero. If it is desired to maintain its amplitude at frequencies in the immediate region of the mean frequency, this may be effected by applying to the limiter an additional input alternating voltage having the mean frequency. This will, however, have the effect of reducing the range of frequency modulation obtained for a given variation of amplitude ratio of the input alternating voltages.

If it be desired to obtain frequency modulation over wider ranges than those above mentioned, without loss of linearity, pre-distortion of the modulating voltage may be employed.

A further feature of the invention is directed to the problem of separating components of sum and difference frequencies, which are generated by mixing oscillations of constant amplitude and different frequencies. In the arrangement according to this feature of the invention two mixers are employed and alternating voltages of both input frequencies are applied to each mixer. Those applied to one mixer, however, are in phase quadrature with those applied to the other mixer. By adding in equal amplitude but in opposition the output currents of the two mixers, a current having a component of the sum frequency is obtained substantially free from any component of the difference frequency. By adding them cumulatively, on the other hand, a component of the difference frequency is obtained substantially free from any component of sum frequency.

This feature of the invention is particularly useful when it is desired to separate sum and difference frequencies which are so close together that it is difficult to separate them by means of filters.

Substantial components having the frequencies of each of the input alternating voltages will normally appear, together with some of their harmonics, superimposed on each of the separated sum and difference frequency components. If the sum and difference frequencies are close together, the component having the lower input frequency, and at least the more substantial harmonics, can easily be separated by filters; but this is not true of the component having the higher input frequency. By using for the mixers either balanced modulators or mixers of substantially square law type, however, the components having the input frequencies can be eliminated.

A further feature of the invention is the method of generating a frequency modulated electrical oscillation which comprises mixing oscillations from two sources, one of approximately carrier frequency and the other of a frequency which determines the ratio of frequency modulation band width to amplitude of the modulation source, separating oscillations having the sum and difference frequencies of the sources, modulating the relative amplitudes of the oscillations of sum and difference frequencies and combining them in a non-linear device to extract an electrical oscillation having its frequency modulated in accordance with the amplitude of the modulation source. With this arrangement separate adjust-

ment of the carrier frequency and of the band width can be achieved.

In the accompanying drawing, Figure 1 is a circuit diagram of a frequency modulation generator; Figure 2 is a circuit diagram of a generator of two alternating voltages having frequencies equal to the sum and difference of the frequencies of two alternating sources; and Figure 3 is a schematic circuit diagram of a frequency modulation generator embodying the main principles of operation of the generators shown in both Figures 1 and 2.

In the generator of which Figure 1 is a circuit diagram, the tuned circuits 1 and 2 are resonant at frequencies respectively above and below the range of frequencies of the frequency modulated voltage to be generated.

The triode oscillator section of the triode hexode valve 3 is connected to form with tuned circuit 1 a conventional Hartley oscillator. The output of this oscillator is applied in the usual way to the outer control grid of the hexode modulator section of valve 3, and the modulating voltage is applied from modulation source 4 to the inner control grid. Bias for both control grids is obtained from resistor 5 provided with by-pass condenser 6. The screen grid is connected to the high tension source, and is maintained at cathode potential with respect to alternating currents by condenser 7.

The oscillator associated with tuned circuit 2 is not required to be modulated. A conventional electron coupled oscillator comprising pentode valve 8 is shown.

The anode currents of valve 8 and of the hexode section of valve 3 are passed in parallel through output load impedance 9, which is designed to resonate at the frequencies of the oscillations generated in valves 3 and 8 and over the whole frequency range between them.

The mean amplitude of the oscillation current from valve 3 in impedance 9 is adjusted to, say, about 0.6 times the amplitude of that from valve 8. The modulation range of the oscillation current from valve 3 is from 0.4 to 0.8 times that amplitude. A variation of frequency is then obtained which is substantially linear with oscillation current from valve 3, and which has a range of about 25% of the difference between the frequencies of the oscillations generated in valves 3 and 8.

The alternating voltages developed across load impedance 9 are applied to limiter 10 and the output therefrom is applied to an output impedance 11, which is designed to resonate over the whole frequency range of the frequency modulated voltage to be generated, but not to resonate at the frequencies of the oscillations generated in valves 3 and 8. The output voltage of the generator is developed across impedance 11 and appears at output terminals 12.

The function and operation of the invention will be further understood from the following. Let two sinusoidal oscillations A sin w_1t and B sin w_2t be represented by two vectors of constant angular velocities, w_1 and w_2, respectively. If r is the length at any instant of the resultant vector representing the sum of these vectors and φ is the angle it makes with the reference direction at any time t, then:

$$r=\sqrt{A^2+B^2+2AB\cos(w_1-w_2)t} \qquad (I)$$

and

$$\tan\phi=\frac{A\sin w_1t+B\sin w_2t}{A\cos w_1t+B\cos w_2t} \qquad (II)$$

Substituting $u=A\sin w_1t+B\sin w_2t$ and $v=A\cos w_1t+B\cos w_2t$ in Equation II

$$\tan\phi=\frac{u}{v}$$

From this it follows:

$$\frac{d\phi}{dt}=\frac{d}{dt}\tan^{-1}\frac{u}{v}=\frac{1}{u^2+v^2}\left(v\frac{du}{dt}-u\frac{dv}{dt}\right)$$

or

$$\frac{d\phi}{dt}=\frac{d}{dt}\tan^{-1}\frac{A\sin w_1t+B\sin w_2t}{A\cos w_1t+B\cos w_2t}$$

$$=\frac{A^2w_1+B^2w_2+AB(w_1+w_2)\cos(w_1-w_2)t}{A^2+B^2+2AB\cos(w_1-w_2)t} \qquad (III)$$

The terms involving cos (w_1-w_2) may be neglected because they represent a frequency far beyond the range of modulating frequencies. Accordingly, the instantaneous angular velocity may be represented as follows:

$$\frac{d\phi}{dt}=\frac{A^2w_1+B^2w_2}{A^2+B^2}=w_2+\frac{A^2}{A^2+B^2}(w_1-w_2) \qquad (IV)$$

From (IV) it follows that

$$\frac{d\phi}{dt}$$

or the instantaneous frequency will lie between w_1 and w_2 but will vary according to the relative magnitudes of A and B and for any given values of A and B,

$$\frac{d\phi}{dt}$$

will be fixed. This means that modulation of the relative magnitudes of A and B will yield a frequency modulated oscillation.

So long as the amplitude of the resultant is retained, it is possible to resolve it back into its two components, and therefore, it can be translated only by a circuit capable of responding to the two component frequencies. In order to extract the oscillation of frequency

$$\frac{d\phi}{dt}$$

it is necessary to perform on the actual signal a physical operation corresponding to the mathematical operation of discarding the amplitude and considering only the frequency. This physical operation consists in passing the signal through a limiter.

In the generator illustrated in Figure 2, the alternating voltage of constant amplitude derived from source 20 is applied directly to the inner control grid of hexode mixer valve 21 and through quadrature phase shifting device 22 at the same amplitude, to the inner control grid of hexode valve 23. The alternating voltage of constant amplitude derived from source 24', of different frequency from source 20, is applied directly to the outer control grid of hexode mixer valve 23 and through quadrature phase shifting device 25', at the same amplitude, to the outer control grid of valve 21. The screen grids of both valves are connected to the high tension source and are maintained at the potentials of their respective cathodes for alternating currents by condensers 24, 25. Bias for both control grid circuits of valve 21 is obtained from resistor 26, provided with by-pass condenser 28. Similarly bias for both control grid circuits of valve 23 is obtained from resistor 27, provided with by-pass condenser 29.

The two halves of the resonant circuit formed by centre-tapped inductance 30 and condenser 31

form separate output impedances in the anode circuits of valves 21, 23. The tuned circuit constituted by inductance 32 and condenser 33 is common to the output circuits of valves 21 and 23 and carries the paralleled anode currents.

The output voltage of the generator at the frequency equal to the sum of the frequencies of sources 20 and 24' is developed between terminals 34, this voltage representing the resultant obtained by adding in opposition the voltages developed across the two halves of tuned circuit 30, 31. This voltage is balanced about earth. The output voltage developed between terminals 35 has frequency equal to the difference between the frequencies of sources 20 and 24; this output voltage is asymmetric.

In the generator represented by the schematic circuit diagram Figure 3, source 40 supplies an alternating voltage having the carrier frequency of the frequency modulated voltage oscillation to be generated. Source 41 supplies an alternating voltage having a constant freueqncy a few times greater than the range of frequency modulation required. The oscillations of constant amplitude and of different constant frequencies derived from sources 40 and 41 are applied directly to mixer 42 and through quadrature phase shifting devices 43, 44 to mixer 45. The separate output circuits of mixers 42 and 45 comprise impedances 46, 47 respectively, which offer high impedance at the frequency equal to the sum of the frequencies of sources 40 and 41 and low impedance at harmonics of these frequencies. The common output circuit of mixers 42 and 45 comprises impedance 48 which offers high impedance at the frequency equal to the difference of the frequencies of sources 40 and 41 and low impedance at harmonics of these frequencies.

The output voltage developed across impedance 48 is asymmetric and is applied directly to excite amplitude modulator 59. The output voltage obtained by combining in opposition the output voltages developed across impedances 46 and 47 is symmetric. Transformer 50 indicates diagrammatically means to convert this voltage to asymmetry before application to excite amplitude modulator 49. Modulating voltage derived from modulating source 51, which may be asymmetric, is passed through a device represented by transformer 52 by which it is rendered symmetric before application to modulators 49 and 59. The output currents of modulators 49 and 59, amplitude modulated in opposite phase, are passed through a common output impedance 53 having resonant band width including the sum and difference frequencies of sources 40 and 41 and covering the whole range between them. The voltage developed across the impedance 53 is applied to limiter 54 and the output voltage thereof is applied to final output impedance 55, the resonant band width of which includes all frequencies within the range of frequency modulation required but excludes the sum and difference frequencies of sources 40 and 41. The frequency modulated oscillation output from the generator is developed across the final output impedance 55.

If the modulators are correctly balanced, the mean frequency of the output frequency modulated oscillation will be equal to the frequency of source 40. In order to provide a component of carrier frequency in the output, a further voltage derived direct from source 40 is impressed through lead 56 upon impedance 53. If a component of the frequency of source 40 passes through the modulators 49 and 59, this further voltage which is derived direct is preferably applied in quadrature with said component. This will occur without the provision of a phase-shifter in lead 56.

The carrier frequency is determined by source 40 alone, and its constancy can therefore be maintained by control of a single oscillator. The band-width is controlled by the frequency of source 41.

In some cases the modulators may themselves serve as limiters, in which event output impedance 53 and limiter 54 may be omitted from the circuit. Carrier frequency derived direct from source 40 may be injected, if required, in final output impedance 55. A degree of limitation is obtained in the modulators when hexodes are employed, and their anode potentials are swinging below their screen grid potentials, with consequent appearance of low internal resistance. This limitation affects the total voltage at the anodes, but does not control the proportion of the voltage due to each of the two valves; it is therefore possible for the amplitude-modulation of the two valves separately to vary the composition and hence the effective frequency of the output voltage, in spite of the tendency for the total voltage to be kept constant. The limiting action should therefore be regarded as occurring in the common output circuit.

While the foregoing description applies to a single modulating frequency in which case the circuit which fundamentally produces a phase modulated oscillation likewise generates a frequency modulated wave, a frequency modulated output wave may be obtained in case of a more complex modulating signal comprising more than a single component frequency such as speech or music by the employment of an integrating corrective network in the modulating circuit adapted to render the amplitude of the modulating signal components inversely proportional to their frequency in a manner well known in the art.

I claim:

1. A generator of a frequency modulated voltage oscillation of substantially constant amplitude, comprising a pair of amplitude modulators, means to excite said modulators with oscillations of two different frequencies outside the range of the frequency modulation, means to apply modulating voltages from a common modulating source to both of said modulators to modulate said oscillations in opposite phase, a common output impedance for said modulators, having a resonant band width including both of the frequencies of said oscillations and the whole range between them, a voltage limiter deriving its input voltage across said modulator output impedance, and a final output impedance receiving the output of the limiter and having a resonant band width including all frequencies within the range of frequency modulation but excluding the frequencies of said oscillations.

2. The method of generating a frequency modulated electrical oscillation which comprises mixing oscillations from two sources, one of approximately carrier frequency and the other of a frequency which determines the ratio of frequency modulation band width to amplitude of the modulation source, separating oscillations having the sum and difference frequencies of the sources, modulating the relative amplitudes of the oscillations of sum and difference frequencies and combining them, and limiting the amplitude of the combined waves to extract an electrical oscilla-

tion having its frequency modulated in accordance with the amplitude of the modulation source.

3. A frequency modulated oscillation generator comprising a pair of sources of oscillations one of approximately carrier frequency and the other having a frequency determined by the frequency modulation band to be obtained, means for intermodulating the oscillations of both said sources to produce sum and difference frequency energies, further means for modulating the relative amplitude of the derived sum and difference frequency energies in accordance with a modulating signal, means for combining the modulated sum and difference frequency energies, and limiting means for removing amplitude modulation from the combined energy.

4. A frequency modulated oscillation generator comprising a pair of sources of fixed frequency oscillations, one of approximately carrier frequency and the other having a frequency determined by the frequency modulation band to be obtained, means for intermodulating the oscillations of both said sources to produce sum and difference frequency energies, further means for modulating the produced sum and difference frequency energies in opposite phase in accordance with a modulating signal, means for combining the modulated sum and difference frequency energies, and limiting means for removing amplitude modulation from the combined energy.

5. A frequency modulated oscillation generator comprising a pair of sources of fixed frequency oscillations, one of approximately carrier frequency and the other having a frequency determined by the frequency modulation band to be obtained, a pair of mixers, means to apply input voltages of both source frequencies to each mixer, each of the input voltages to one mixer being in quadrature with the input voltage of the same frequency to the other mixer, separate output circuits for said mixers and a common output circuit of both mixers, means to derive sum and difference frequency energies from said separate and said common output circuits, respectively, means for modulating the relative amplitude of the derived sum and difference frequency energies in accordance with a modulating signal, means for combining the modulated sum and difference frequency energies, and limiting means for removing amplitude modulation from the combined energy.

6. A frequency modulated oscillation generator comprising a pair of sources of fixed frequency oscillations, one of approximately carrier frequency and the other having a frequency determined by the frequency modulation band to be obtained, a pair of mixers, means to apply input voltages of both source frequencies to each mixer, each of the input voltages to one mixer being in quadrature with the input voltage of the same frequency to the other mixer, separate output circuits for said mixers and a common output circuit of both mixers, means to derive sum and difference frequency energy from said separate and said common output circuits, respectively, further means to modulate the derived sum and difference frequency energies in opposite phase in accordance with a modulating signal, means for combining the modulated energies, and limiting means for removing amplitude modulation from the combined energy.

7. A frequency modulated oscillation generator comprising a pair of independent oscillation sources having substantially constant frequencies located outside the range of the desired frequency modulation band, means to modulate the relative amplitude of the source oscillations, means for combining the modulated oscillations, and limiting means for removing amplitude modulation from the combined oscillation energy.

8. A frequency modulated oscillation generator comprising a pair of amplitude modulators, means to excite said modulators with oscillations of two different frequencies outside the desired range of frequency modulation, means to apply modulating voltages from a common modulating source to both said modulators to modulate said oscillations in opposite phase, the ratio of either amplitude of said oscillations to the mean amplitude remaining within the limits .8 to 1.2, a common output impedance for said modulators having a frequency response band including both of the frequencies of said oscillations and the whole range between them, a limiter arranged to derive its input voltage from said output impedance, and a final output impedance receiving the output of said limiter and having a frequency reponse band including all frequencies within the range of frequency modulation but excluding the frequencies of said oscillations.

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