

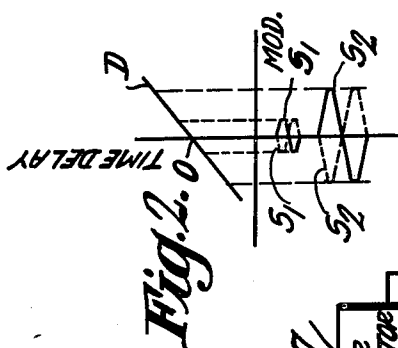
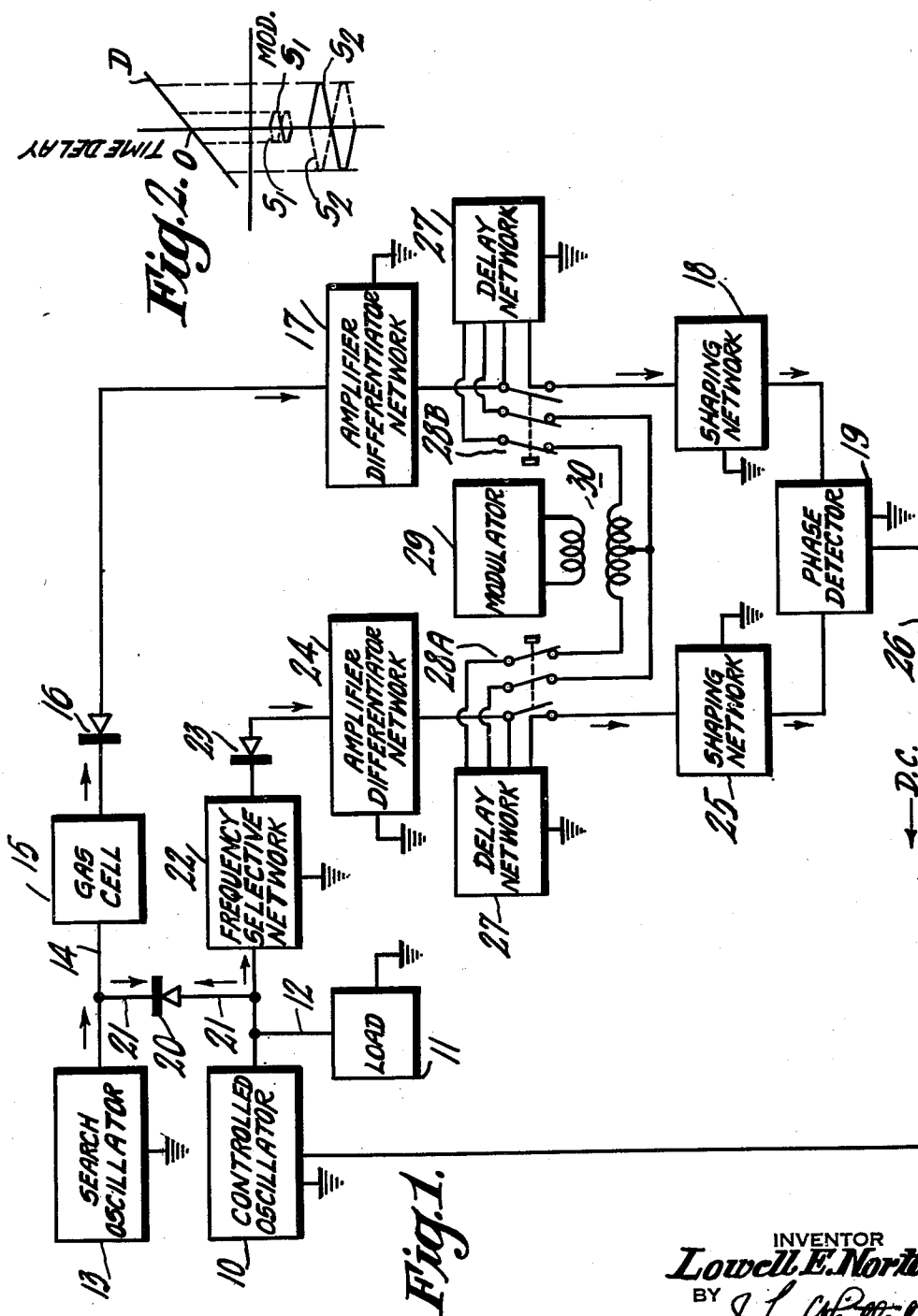
March 10, 1953

L. E. NORTON
METHOD AND SYSTEM FOR FREQUENCY-MODULATING
STABILIZED OSCILLATORS

2,631,269

Filed Sept. 14, 1949

4 Sheets-Sheet 1



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Fig. 2.

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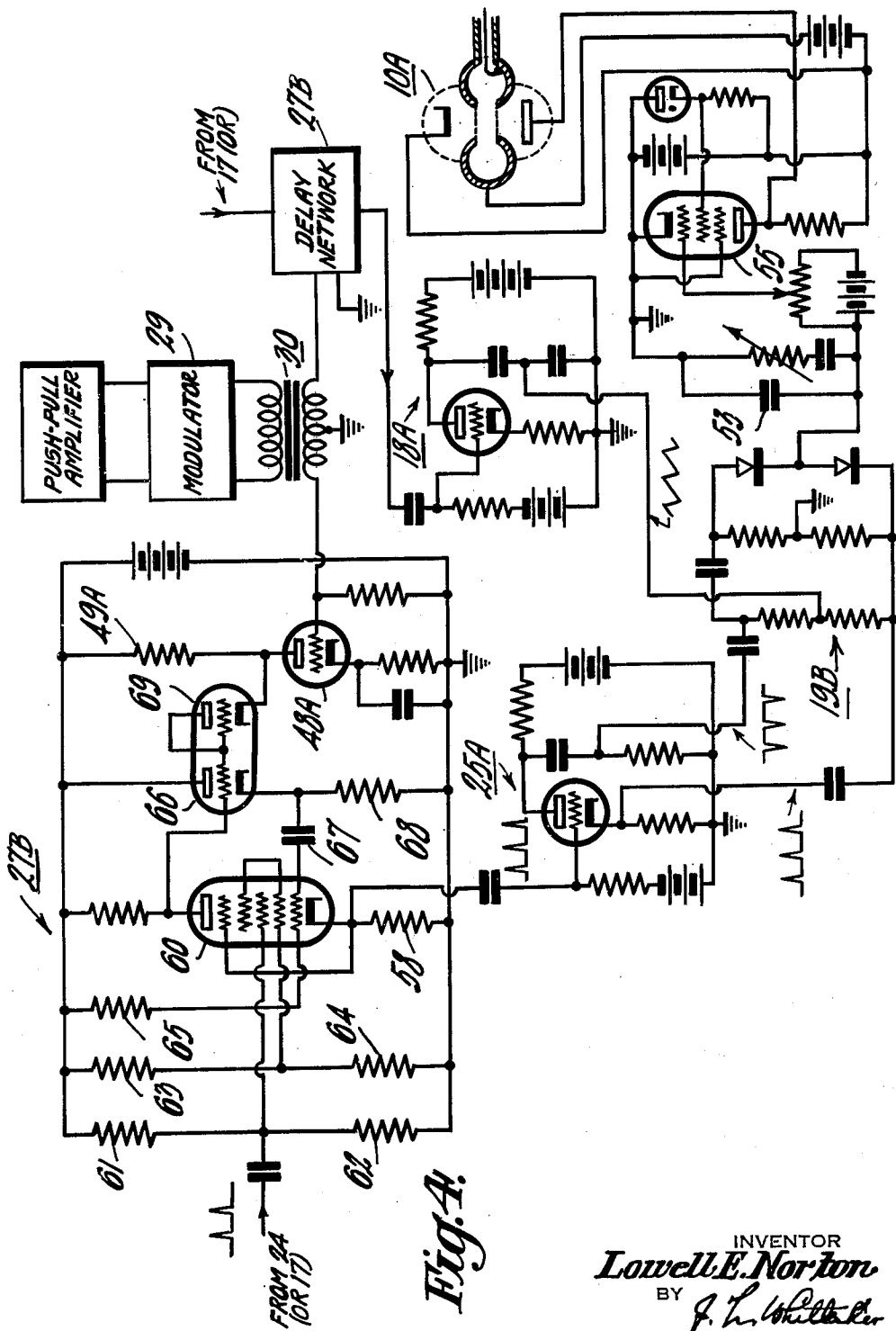
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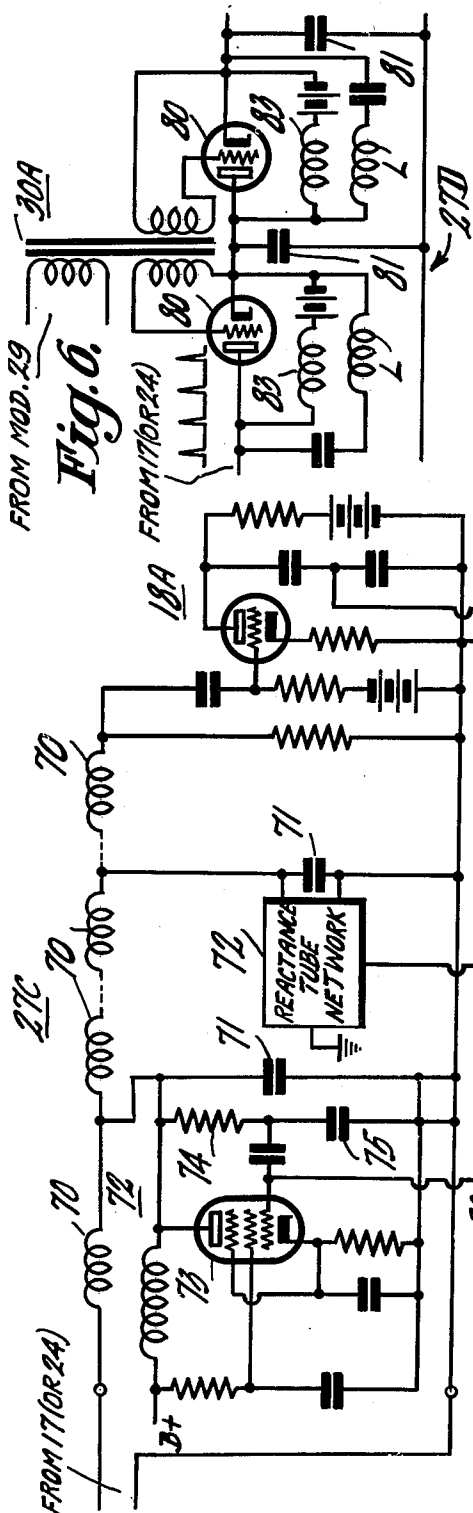
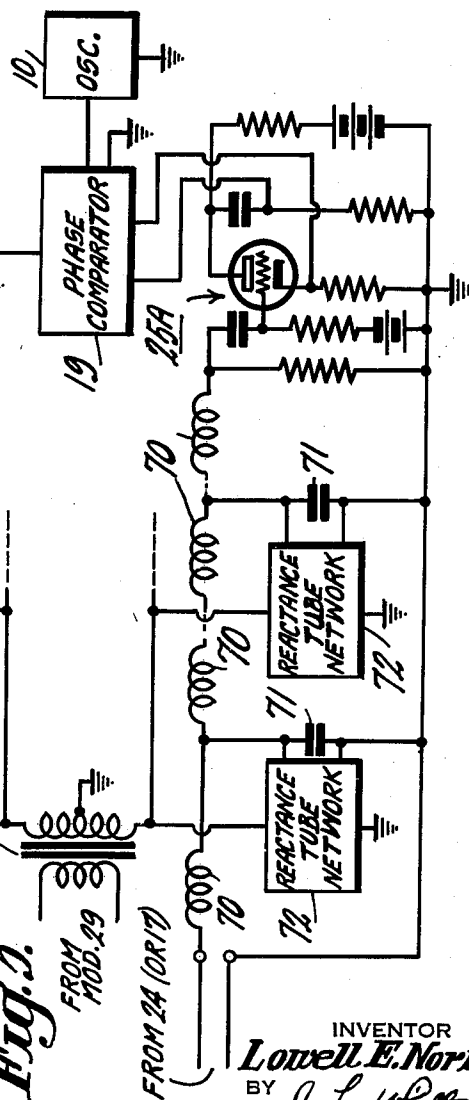


Fig. 5



UNITED STATES PATENT OFFICE

2,631,269

METHOD AND SYSTEM FOR FREQUENCY-MODULATING STABILIZED OSCILLATORS

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Application September 14, 1949, Serial No. 115,698

19 Claims. (Cl. 332-19)

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This invention relates to methods and systems for frequency-modulating an oscillator, particularly a microwave oscillator whose mean carrier frequency is stabilized.

In frequency-stabilizing systems and methods such as disclosed in copending applications Serial No. 4,497, filed January 27, 1948; Serial No. 35,185, filed June 25, 1948, Patent No. 2,584,608, granted February 5, 1952; Serial No. 49,934, filed June 30, 1947, Patent No. 2,602,897, granted July 8, 1952; Serial No. 5,563, filed January 31, 1948; Serial No. 29,836, filed May 28, 1948 (abandoned, Serial No. 236,945, filed July 16, 1951, is a continuation thereof); Serial No. 51,253, filed September 25, 1948, Patent No. 2,559,719, granted July 10, 1951; Serial No. 58,295, filed November 4, 1948; Serial No. 58,296, filed November 4, 1948, Patent No. 2,555,131, granted May 29, 1951; Serial No. 68,643, filed December 31, 1948; and Serial No. 73,626, filed January 29, 1949, there are produced two series of pulses, one series containing frequency-error information, and the other series containing standard-frequency information, whose time or phase relation is compared, as by a phase or coincidence detector for determination of the frequency of an oscillator from its desired value. The frequency of the oscillator is automatically controlled, as by the output of the phase detector, to minimize deviation from a predetermined time or phase relation of the pulses of the respective series which corresponds with the desired oscillator frequency.

In accordance with the present invention, the stabilized oscillator is frequency modulated, as at audio or video frequencies, by delaying the pulses of at least one of the aforesaid series in accordance with the modulation; preferably, the pulses of the respective series are differentially delayed both substantially to increase the modulation factor and to reduce hum or noise.

More specifically, in some forms of the invention, the pulse-delay network comprises a pulse generator, such as a multi-vibrator, "phantastron" or the like, which is triggered by the frequency-error or standard-frequency pulses of constant repetition rate and the modulation is utilized to determine, directly or indirectly, the timing or the corresponding output pulses, the interval between successive output pulses varying with the modulation. In other modifications of the invention, the frequency-error or standard-frequency pulses are applied to a delay line having a suitable number of reactance-resistance sections whose delay characteristics is varied in accordance with the modulation by applying the

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modulating potential to one or more electronic tubes utilized as reactors or resistors of the delay line. In all forms of the invention, the phase or time relation between the two series of pulses is determined jointly by the modulation and by drift of the oscillator frequency from its desired value. The pulse repetition rate is high compared to the highest modulating-frequency so that the control of the mean carrier frequency is rigid despite the modulation and so that the stabilizing pulses may be filtered out and not appear as a modulation component.

The invention further resides in methods and systems having novel and useful features herein-after described and claimed.

For further understanding of the invention and for illustration of embodiments thereof, reference is made to the accompanying drawings in which:

Fig. 1 is a block diagram of a frequency-modulated, frequency-stabilized oscillator system;

Fig. 2 is an explanatory figure referred to in discussion of the operation of Fig. 1;

Figs. 3, 4, 5, and 6 schematically illustrate various pulse-delay networks and associated components utilizable in the system of Fig. 1.

Referring to Fig. 1, the block 10 is generically illustrative of a frequency-controlled oscillator, particularly a magnetron, klystron or other microwave generator, for supplying high-frequency energy to a load 11 through a suitable transmission line 12. The load 11 may be an antenna system, a power amplifier or the attenuator network of a signal generator. The block 13 is generically illustrative of a search oscillator whose frequency is repeatedly swept over a range of frequencies, as by a mechanical or electronic modulating means, not shown. The range of frequencies swept by oscillator 13 includes the resonant frequency of a high Q standard 15, which for microwave frequencies is preferably a section of waveguide or resonant cavity containing gas exhibiting molecular resonance. The transmission line 14 which transmits energy from the oscillator 13 to the gas cell 15, or equivalent, may, like transmission line 12, be a waveguide, a concentric line, or other transmission line suitable for transmission at the frequencies involved.

High-frequency energy transmitted by or through the gas cell 15, or equivalent, is impressed upon a demodulator 16, such as a diode or crystal rectifier, to produce a series of pulses each occurring as the frequency of oscillator 13 sweeps through the resonant frequency of the standard 15. These pulses, after being amplified

and shaped by the networks 17 and 18, are applied to one input circuit of a phase detector 19 to serve as a frequency/time standard.

The outputs of the oscillators 10 and 13 are in part impressed through directional couplers 21, 21 or the like upon a mixer 20, which may be a crystal rectifier, so to produce a varying beat-frequency corresponding, for example, with the difference-frequency of the two oscillators. This varying beat-frequency is converted, as by a frequency-selective network 22 and demodulator 23, into a second series of pulses each occurring as the beat-frequency passes through a predetermined fixed value. As discussed in the aforesaid applications, this fixed frequency may be the pass frequency of a beat-frequency amplifier, the cutoff frequency of a filter, or the null-output frequency of a discriminator. In all cases, this second series of pulses contains frequency error/time information corresponding with the deviation of the carrier frequency of oscillator 10 from its desired value. This second series of pulses, after amplification and shaping by the networks 24 and 25, is applied to a second input circuit of the phase detector 19. The unidirectional output voltage of the phase detector 19, which may be of any suitable form including those disclosed in the aforesaid applications and some of which appear in later described figures hereof, is applied through line 26 automatically to stabilize the frequency of oscillator 10.

When the oscillator tube is a reflex klystron, the output voltage may be applied by line 26 to vary the potential of the reflector anode; when the oscillator tube is a magnetron, the control voltage may be applied to a frequency-control electrode within the tube, as disclosed in certain of the aforesaid applications, or to a frequency-controlled tube associated therewith; for lower-frequency oscillators, the control-voltage output of phase detector 19 may be applied in known manner to a reactance tube controlling the oscillator frequency.

As thus far described, the system of Fig. 1 is for rigidly stabilizing the frequency of oscillator 10 in manner generic to the various methods and systems of the aforesaid copending applications. In all of them, any departure from a predetermined time or phase relation of the two series of pulses applied to phase detector 19 produces changes in the output voltage of the detector which is representative of deviation of oscillator 10 from its desired value and which is applied in correction for such deviation.

In accordance with the present invention, the phase relation between the two series of pulses is also varied in accordance with the desired modulation, at audio or video frequencies, so to effect frequency-modulation of the output of oscillator 10. To that end, the pulses of one or both series are delayed in accordance with the modulation; when both series of pulses are variably delayed, they are delayed differentially, as later more fully described.

As shown in Fig. 1, a delay network 27 may be included in circuit between the demodulator 23 and the phase detector 19, as by a switch 28a which also couples the delay network to a modulator 29. Thus in their passage from the demodulator 23 to the phase detector 19, the frequency-error pulses are subject to a variable delay corresponding with the applied modulation, and the time or phase relation between the two series of pulses, as compared by phase

detector 19, will therefore vary with the modulation and correspondingly vary the unidirectional output voltage of the phase detector. This causes the instantaneous frequency of the oscillator 10 to vary with the modulation. The delay network 27 preferably has a linear characteristic D, Fig. 2, so that the delay introduced is proportional to the amplitude of the modulating signal. The delay corresponding with zero modulation is at an operating point O intermediate or substantially midway the limits of the characteristic D so that the delay time increases and decreases in accordance with the modulating signal S, the magnitude of the increase and decrease depending, as aforesaid, upon the amplitude of the modulating signal. As evident from Fig. 2, for signals S₁ of low amplitude, the range of the time delay is substantially smaller than for signals S₂ of larger amplitude because the condenser 33 charges up to a higher value for the larger signals. As the repetition rate of the pulses is high compared to the frequency of the modulation, each wave of the modulation corresponds with many pulses, and these are each advanced or retarded in time in accordance with the amplitude and polarity of the instantaneous values of the signal during its cycle.

Alternatively, or in addition, a similar delay network 27 may be interposed, as by switch 28b, in circuit between the demodulator 16 and the phase detector 19 to shift the standard-frequency pulses in accordance with the modulation. When, and as preferably, both delay networks 27 are included, the modulation is applied to them differentially, as by transformer 30 so that the modulating voltages are applied to the delay networks 180° out-of-phase, as indicated by the dotted and full line waves S₁ and S₂ of Fig. 2. Accordingly, as the modulation is applied to one delay network to decrease the time delay of pulses passing through it, the modulation potential concurrently applied to the other delay network increases the delay suffered by the other series of pulses. Thus, the shift in phase relation between the two series of pulses which is due to modulation, is effectively doubled as detected by the phase comparator 19. By differentially delaying the pulses in accordance with modulation, the modulation factor in the system is substantially increased and any hum or noise is substantially balanced out when, as preferable, the two delay networks are of substantially similar composition. As the repetition rate of the pulses is substantially higher than the highest modulating frequency, the pulse frequency may be readily highly attenuated to eliminate it as a modulation component of the output voltage of 19.

In the particular form of delay network shown in Fig. 3, the standard-frequency pulses or the frequency-error pulses are applied to one grid of tube 31 and the modulation signal is applied to another grid of that tube. Accordingly, the output of tube 31 is a series of pulses having the same repetition rate as the sweep frequency of oscillator 13 and whose peak values vary in accordance with the modulating signal. These amplitude-modulated pulses are applied as triggering pulses for a multi-vibrator network 27a including the tubes 32 and 33 whose grids and anodes are cross-connected by coupling condensers 34, 34. In the interval between successive pulses, the tube 32 is conducting whereas tube 33 is non-conducting because biased to or beyond cutoff

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by the resistance-capacitance network 35—36. When a negative pulse is applied to the grid of tube 32, its anode current is cut off and the pulse as applied to tube 33 causes it to conduct. The condenser 38 in the grid circuit of tube 32 is charged to a potential closely approximating the peak value of the negative pulse. The voltage across condenser 38 then gradually decreases by discharge through resistor 37 until a critical value is reached, at which time tube 32 again conducts and tube 33 is again cut off. This sequence of operations is repeated for each successive pulse from tube 31. The periods during which tube 32 conducts can be made to vary substantially linearly with the peak values of the pulses from tube 31 by providing that the time constant of the network 37—38 shall be large compared to the repetition period of the pulses. The output of the multi-vibrator therefore consists of a series of square-wave pulses having the same repetition rate as the search oscillator 13, the duration of the pulses varying with the signal from modulator 29. These square-wave pulses are differentiated by a condenser-resistance network 41—42 to provide positive and negative pulses corresponding with initiation and termination of the square-wave output pulses of the multi-vibrator. In the particular arrangement disclosed, the diode 43 effectively removes the positive pulses leaving a series of negative pulses of the same repetition frequency as search oscillator 13 but with the interval between successive pulses varying as a linear function of the modulating signal.

In other words, the pulses across the resistor 42 correspond with the pulses from demodulator 16 or 23, each delayed, however, in accordance with the instantaneous amplitude of the modulating signal. These pulses are converted by a shaping network 18a to sawtooth waves of the same repetition frequency as the search oscillator, but of slope which varies with the modulation. More specifically, the delayed pulses of negative polarity from the delay network 27a are converted to positive pulses by the amplifier 44 and impressed upon a sawtooth generator including tube 35. The output pulses of the sawtooth generator are impressed, as by transformer 46, upon the phase comparator 19a which, in the specific form shown in Fig. 3, is a bridge network including two pairs of rectifiers 47 of diode or crystal type.

When, as shown in Fig. 3, the modulation is applied variably to delay both the frequency-error pulses and the standard-frequency pulses, the modulating signal may be applied to a tube 48 having load resistances 49 and 50 respectively in the anode and cathode circuits to afford push-pull output. The modulating-voltage appearing across the load resistor 49 is impressed, as above described, upon the tube 31 of one of the delay networks 27A, and the modulating signal across cathode resistor 50 is applied to the corresponding tube of a second similar delay network 27A upon which is impressed the pulses from the demodulator 16. Thus, the standard-frequency pulses are also delayed in accordance with the modulation, and after shaping by the network 25 including tube 54, condenser 51 and resistor 52 are impressed upon the second input circuit of the phase comparator 19a.

There is thus produced across the output terminals of the phase-detector 19A a unidirectional voltage which varies not only with the deviations from normal of the frequency of oscillator

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10, but also in accordance with the modulating signal. In the particular circuit shown in Fig. 3, the frequency-control voltage produced by comparator 19a is applied to the grid of a frequency-control tube 55 for a reflex klystron 10A. The anode-cathode resistance of tube 55, as affected by the potential of its control grid, determines the potential of the reflex-anode of the klystron 10A and therefore determines the output frequency of the klystron. The klystron may be set approximately to its desired operating frequency by adjustment of the dimensions of its cavity, as understood by those skilled in the art, and may be more closely adjusted to proper frequency by adjustment of the fixed component of the potential of the control grid of tube 55; specifically, the grid circuit of tube 55 may include a potentiometer 56 and battery 57 for the latter purpose. The grid potential of tube 55 is determined both by the setting of potentiometer 56 and by the output voltage of the phase detector 19a, which as appearing across condenser 53, includes both frequency-corrective and frequency-modulating components.

In the modification shown in Fig. 4, the delay network 27B for use in the system of Fig. 1 comprises one form of the so-called "phantastron" circuit. For other forms thereof and for description of their operation, reference is made to the "Design of phantastron time delay circuits" appearing in the April 1948, issue of "Electronics." In the form shown, frequency-error pulses, or the standard frequency pulses, are applied to the #3 grid of tube 60, which may be of the 6SA7 type. This grid is at positive potential with respect to ground, this operating potential being determined by the relative magnitudes of the voltage-dividing resistors 61 and 62; the #2 and #4 grids of this tube are also of positive potential with respect to ground, the magnitude of this operating potential being determined by the relative magnitudes of resistors 63 and 64. When a pulse is applied, the time at which the corresponding pulses appear across the cathode resistor 58 depends upon the instantaneous potential of the #1 grid as determined by resistor 65, condenser 67 and cathode resistor 68 of an associated triode 66. Variably to delay the output pulses in accordance with the modulation, the modulating signal is applied to the grid of tube 48A whose anode is coupled to the grid of tube 66 and to the anode of tube 60 by a diode 69. Actually, the triode 66 and diode 69 may be the two halves of a 6SN7 tube, the plate and grid of one section being connected together to serve as a diode. The operation of the "phantastron" circuit per se is quite complicated, and being fully discussed in the aforesaid issue of "Electronics," is not in detail described here. It suffices here to say that the output pulses of the delay network 27B correspond in number with the input pulses from demodulator 16 or 23, Fig. 1, with the time interval between successive output pulses varying in accordance with the modulating voltage. The output pulses of network 27B are shaped by networks 25a or 18a and impressed upon a phase discriminator which may be of any suitable type; in the form shown, phase discriminator 19b is of the type more fully disclosed in aforesaid copending applications Serial Nos. 4,497 and 29,836. The instantaneous magnitude of the output voltage of the phase comparator follows the modulating signal and accordingly varies the frequency of oscillator 10A. The average magnitude of the output voltage of the phase comparator in this, as in all other modifications, varies with deviation

of the mean-carrier frequency of the oscillator from its desired value and is accordingly effective to correct such deviation.

In the modification shown in Fig. 5, the delay network 27C interposed in either or both of the input circuits of the phase comparator 19 comprises a delay line having a suitable number of sections each including a series inductance 70 and a shunt capacitance 71. To vary the delay of the standard-frequency or frequency-error pulses, the effective shunt capacitance of a suitable number of sections of the delay line is varied in accordance with the modulation. Specifically, each of one or more of the condensers 72 is shunted by a reactance tube network 72 which exhibits capacitive reactance of magnitude determined by the potential of the grid of tube 73 of the network. Specifically, the tube 73 is a pentode, such as a 6SJ7 or 6AC7 type of tube having its grid coupled to a point between resistance 74 and condenser 75 in parallel to condenser 71 and to the anode-cathode circuit of the tube. As the operating principles of a reactance tube are well understood by those skilled in the art, further description of network 72 is unnecessary here. It suffices to say that the frequency-error or standard-frequency pulses applied to the input terminals of the line 27C appear across the output terminals thereof with delay varying linearly as a function of the modulating signal applied to tube or tubes 73. These delayed pulses are impressed upon the phase comparator 19 and accordingly the unidirectional output voltage of the phase comparator, applied to the oscillator 10 for control of its frequency, varies in accordance with the modulation.

In the modification shown in Fig. 6, the delay network 27D for variably delaying the standard frequency pulses and/or the frequency error pulses of Fig. 1 comprises a delay line of suitable number of sections including series inductance L modified by variable resistance 80, and shunt capacitance 81. Each of one or more series resistances of the line is the cathode-anode resistance of a tube 80 whose grid potential is varied in accordance with the modulation. The choke 83 in the anode current supply circuit of the tube is of high impedance to the pulses. Accordingly, the frequency-stabilizing pulses applied to the input terminals of the line 27D appear at the output terminals thereof with time-spacing which follows the modulation and therefore the instantaneous frequency of the oscillator is varied in accordance with the modulation, the mean carrier frequency of the oscillator, however, being rigidly stabilized as in the aforesaid compounding applications.

From the foregoing explanation, it shall be understood the invention is not limited to the specific arrangements described but that changes and modifications may be made within the scope of the appended claims.

What is claimed is:

1. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises generating search oscillations, repeatedly sweeping the frequency of said search oscillations over a range including a standard frequency to produce a series of pulses, producing a second series of pulses each occurring as the beat frequency of the oscillator frequency and said search oscillations passes through a predetermined value, delaying the pulses of at least one of said series in accordance with the desired modulation, and varying the frequency

of the oscillator in accordance with sense and magnitude of the variations in the time relation between the pulses of the two series as affected both by the modulation and by drift of the mean carrier frequency.

2. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises generating search oscillations, repeatedly sweeping the frequency of said search oscillations over a range including a standard frequency to produce a series of pulses, producing a second series of pulses each occurring as the beat frequency of the oscillator frequency and said search oscillations passes through a predetermined value, differentially delaying the corresponding pulses of the respective series in accordance with the desired modulation, and varying the frequency of the oscillator in accordance with sense and magnitude of the variations in the time relation between the pulses of the two series as affected both by the modulation and by drift of the mean carrier frequency.

3. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises generating search oscillations, repeatedly sweeping the frequency of said search oscillations over a range including a standard frequency to produce a series of pulses, producing a second series of pulses each occurring as the beat frequency of the oscillator frequency and said search oscillations passes through a predetermined value, delaying the pulses of one of said series in accordance with the desired modulation, and varying the frequency of the oscillator in accordance with sense and magnitude of the variations in the time relation between the pulses of the two series as affected both by the modulation and by drift of the mean carrier frequency.

4. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises producing a series of pulses containing frequency error information, producing a second series of pulses containing frequency error information, producing a second series of pulses containing standard frequency information, delaying the pulses of at least one of said series in accordance with the desired modulation, and varying the frequency of the oscillator in accordance with variations of the time relation between the pulses of the two series as affected both by the desired modulation and by any drift of the mean carrier frequency.

5. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises producing a series of pulses containing frequency error information, producing a second series of pulses containing standard frequency information, differentially delaying the pulses of the respective series in accordance with the desired modulation, and varying the frequency of the oscillator in accordance with variations of the time relation between the pulses of the two series as affected both by the desired modulation and by any drift of the mean carrier frequency.

6. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises producing a series of pulses containing frequency error information, producing a second series of pulses containing standard frequency information, converting the pulses of at least one of said series of pulses to pulses of duration varying in accordance with a modulating signal, differentiating the converted pulses to produce pulses of corresponding number but with time-spacing varying with the mod-

ulation whereby the phase relation between the two series of pulses is dependent both upon the modulation and upon the frequency error of the oscillator, and applying to the oscillator a frequency-control signal of magnitude varying with variations of said phase relation.

7. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises producing a series of pulses containing frequency error information, producing a second series of pulses containing standard-frequency information, delaying the pulses of at least one of said series, varying said delay characteristics in accordance with a modulating signal, comparing the phase relation of the pulses of the respective series as affected both by frequency error of the oscillator and by the modulating signal, and applying to the oscillator a frequency-control signal of magnitude varying with variations of the compared phase relation of the pulses.

8. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises producing a series of pulses containing frequency error information, producing a second series of pulses containing standard frequency information, delaying the pulses of at least one of said series, varying said delay characteristic in accordance with a modulating signal, comparing the phase relation of the respective series as affected both by frequency error of the oscillator and by the modulating signal, and applying to the oscillator a frequency-control signal of magnitude varying with variations of the compared phase-relation of the pulses.

9. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises producing two series of pulses respectively containing frequency error versus time information and standard frequency versus time information, converting the pulses of each of said series to pulses of duration varying in accordance with a modulating signal, the variation being differential for pulses of the different series, differentiating the variable duration pulses to produce two series of pulses corresponding with the original series but with a differential time shift dependent upon the modulation, and applying to the oscillator a frequency-control signal of magnitude varying with variations of the phase relation of the differentiated pulses.

10. The method of frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises producing two series of pulses respectively containing frequency error versus time information and standard frequency versus time information, separately delaying the two series of pulses, differentially varying said delayed series of pulses in accordance with a modulating signal, comparing the phase relation of the differentially delayed pulses, and applying to the oscillator a frequency-control signal varying in accordance with the compared phase relation of the pulses and so containing both frequency error corrective and modulation components.

11. The method of utilizing resonant microwave absorption in a gas for frequency-modulating and stabilizing the mean carrier frequency of an oscillator which comprises generating variable frequency microwave oscillations, repeatedly sweeping the frequency of said microwave oscillations over a range including the molecular resonant frequency of a gas, applying said oscillations

to said gas, deriving a series of pulses containing standard frequency versus time information in response to said gas resonant absorption, producing a second series of pulses each occurring as the beat frequency of the oscillator and said swept oscillations passes through a predetermined frequency so to contain frequency error versus time information, shifting the phase relation between the two series of pulses in accordance with the desired modulation, comparing the phase relation of the pulses of the respective series as affected both by the modulation and by deviation of the mean carrier frequency of said oscillator, and applying to said oscillator a frequency-control signal varying with variations of the compared phase relation of said pulses.

12. A frequency-modulated, frequency-stabilized oscillator system comprising an oscillator, a high precision frequency standard, a search oscillator for repeatedly sweeping a range including the resonant frequency of said standard, a demodulator for producing a series of pulses each occurring as the search oscillator frequency sweeps the resonant frequency of said standard, means including a mixer and a frequency-selective network for producing a series of pulses each occurring as the beat frequency of said oscillators sweeps a predetermined frequency, a phase detector having input circuits upon which said two series of pulses are respectively impressed for producing a unidirectional output voltage varying in accordance with variations in the phase relation of the pulses of the respective series, delay means in at least one of said input circuits, modulating means for varying the delay characteristic of said delay means so to vary the phase relation between pulses of the respective series in accordance with the modulation, and means for applying said output voltage to stabilize the mean frequency of the first-named oscillator and to vary the instantaneous frequency thereof in accordance with the modulation.

13. A frequency-modulated, frequency-stabilized oscillator system comprising an oscillator, a high precision frequency standard, a search oscillator for repeatedly sweeping a range including the resonant frequency of said standard, a demodulator for producing a series of pulses each occurring as the search oscillator frequency sweeps the resonant frequency of said standard, means including a mixer and a frequency-selective network for producing a series of pulses each occurring as the beat frequency of said oscillators sweeps a predetermined frequency, a phase detector having input circuits upon which said two series of pulses are respectively impressed for producing a unidirectional output voltage varying in accordance with variations in the phase relation of the pulses of the respective series, delay means in each of said input circuits, modulating means for differentially varying the delay characteristics of said delay means so to vary the phase relation between pulses of the respective series in accordance with the modulation, and means for applying said output voltage to stabilize the mean frequency of the first-named oscillator and to vary the instantaneous frequency thereof in accordance with the modulation.

14. A frequency-modulated, frequency-stabilized oscillator system comprising an oscillator, means for producing a series of pulses containing frequency error information, means for producing a second series of pulses containing standard frequency information, a phase detector having input circuits upon which said pulses are respec-

tively impressed for production of a unidirectional output voltage varying in accordance with variations in the phase relation of the pulses of the respective series, delay means in at least one of said input circuits, modulating means for varying the delay characteristics of said delay means so to vary the phase relation between pulses of the respective series in accordance with the modulation, and means for applying said unidirectional output voltage to stabilize the mean carrier frequency of the oscillator and to vary its instantaneous frequency in accordance with the modulation.

15. A frequency-modulated, frequency-stabilized oscillator system comprising an oscillator, means for producing a series of pulses containing frequency-error information, means for producing a second series of pulses containing standard-frequency information, a phase detector having input circuits upon which said pulses are respectively impressed for production of a unidirectional output voltage varying in accordance with variations in the phase relation of the pulses of the respective series, a time-delay network in each of said input circuits, modulating means for differentially varying the delay characteristics of said delay networks, and means for applying said output voltage to stabilize the mean frequency of the oscillator and to vary its instantaneous frequency in accordance with the modulation.

16. A frequency-modulated, frequency-stabilized oscillator system comprising an oscillator, means for stabilizing the mean carrier frequency of said oscillator comprising means for producing two series of pulses respectively containing standard-frequency versus time information and frequency-error versus time information, and a phase comparator having input circuits upon which said series of pulses are respectively impressed and producing a frequency control for said oscillator of magnitude varying with variation of the time relation of the pulses of the respective series, and means for frequency-modulating said oscillator comprising a pulse generator interposed in at least one of said input circuits for triggering by the corresponding series of aforesaid pulses to produce a corresponding number of output pulses for application to said phase comparator, and means for applying a modulating signal to said pulse generator variably to delay said output pulses in accordance with the modulation.

17. A frequency-modulated, frequency-stabilized oscillator system comprising an oscillator, means for stabilizing the carrier frequency of said oscillator comprising means for producing two series of pulses respectively containing standard-frequency versus time information and frequency-error versus time information, and a phase comparator having input circuits upon which said series of pulses are respectively impressed and producing a frequency control for said oscillator of magnitude varying with variation of the time relation of the pulses of the respective series, and means for frequency-modulating said oscillator comprising pulse generators

interposed in said respective input circuits respectively for triggering by said two series of pulses, each to produce output pulses of the same repetition rate, and means for applying a modulating signal to said pulse generators differentially and variably to delay said output pulses in accordance with the modulation.

18. A frequency-modulated, frequency-stabilized oscillator system comprising an oscillator, means for stabilizing the mean carrier frequency of said oscillator comprising means for producing two series of pulses respectively containing standard-frequency versus time information and frequency-error versus time information, and a phase comparator having input circuits upon which said series of pulses are respectively impressed and producing a frequency control for said oscillator of magnitude varying with variation of the time relation of the pulses of the respective series, and means for frequency-modulating said oscillator comprising a delay line interposed in one of said input circuits and having series and parallel impedances, at least one of which is an electronic tube, and means for applying a modulating signal to said tube variably to delay the transmission of pulses by said line to said comparator in accordance with the modulation.

19. A frequency-modulated, frequency-stabilized oscillator system comprising an oscillator, means for stabilizing the mean carrier frequency of said oscillator comprising means for producing two series of pulses respectively containing standard-frequency versus time information and frequency-error versus time information, and a phase comparator having input circuits upon which said series of pulses are respectively impressed and producing a frequency control for said oscillator of magnitude varying with variation of the time relation of the pulses of the respective series, and means for frequency-modulating said oscillator comprising delay lines respectively interposed in said input circuits and each having series and parallel impedances, at least one of which is an electronic tube, and means for applying a modulating signal to said tubes differentially and variably to delay the transmission of pulses by said lines to said comparator in accordance with the modulation.

LOWELL E. NORTON.

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FOREIGN PATENTS

Number	Country	Date
590,886	Great Britain	July 31, 1947