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COMBINED FREQUENCY DIVIDER AND DETECTOR

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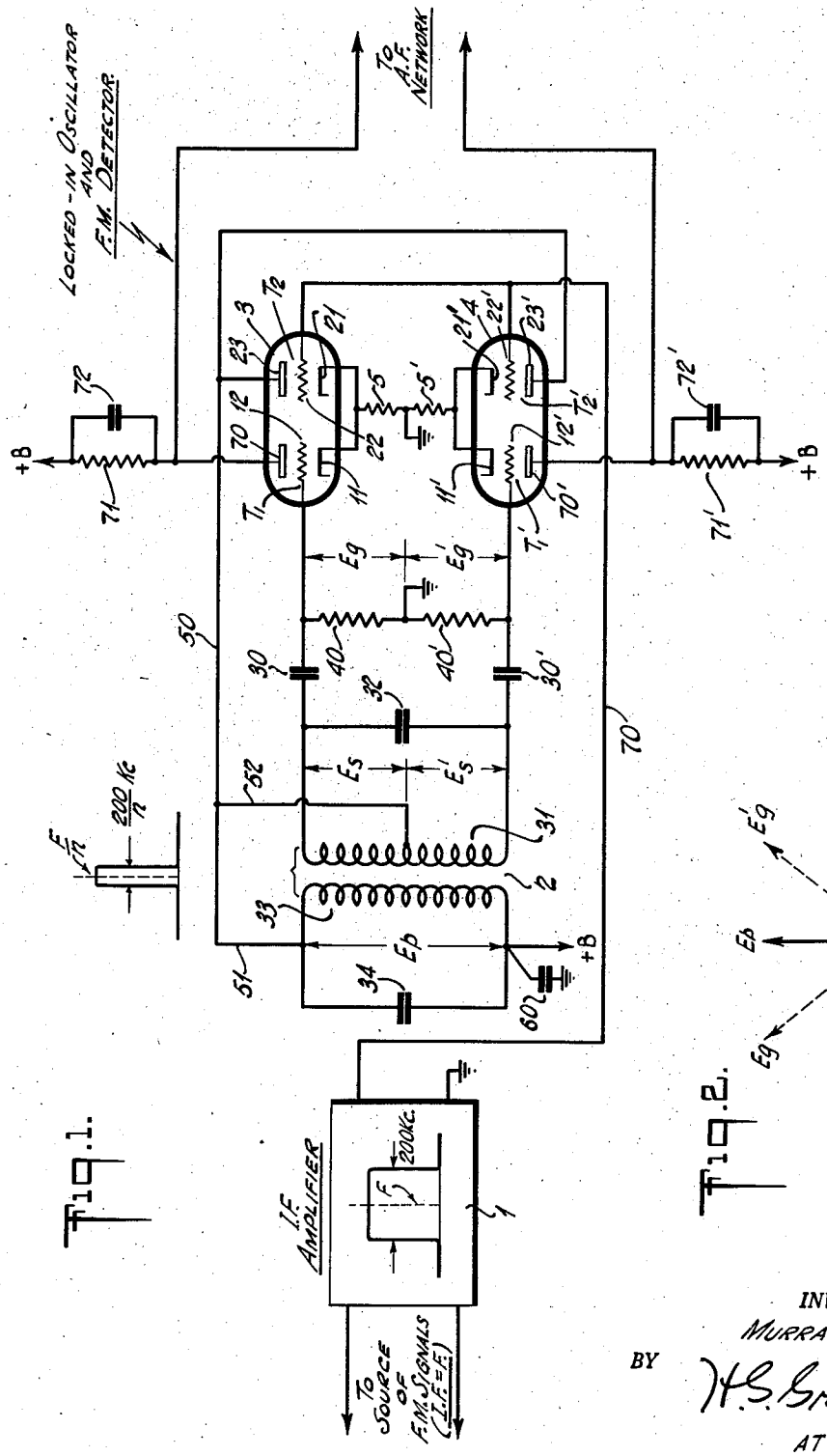


Fig. 1.

Fig. 2.

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COMBINED FREQUENCY DIVIDER AND DETECTOR

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My present invention relates generally to detectors of angle modulated high frequency waves, and more particularly to a novel method of, and means for, concurrently frequency dividing, discriminating and rectifying frequency modulated (FM) carrier waves.

In the past there have been proposed various systems for frequency dividing FM waves for the purpose of concurrently reducing the carrier or center frequency of the waves and the deviation range proportionally. Frequency division networks have been disclosed in my U. S. Patent No. 2,064,106 granted December 15, 1936, and U. S. Patent No. 2,230,231 granted February 4, 1941. In the latter patent it is shown that the frequency divider may employ a locked-in oscillator. In the circuits of these patents, prior to demodulation of the modulated carrier waves the latter are subjected to frequency division so as to reduce the effective pass band of the modulated carrier wave in the same proportion as the carrier or center frequency is reduced. Such division is particularly advantageous in the reception of frequency, or phase, modulated carrier waves, since it has been found to improve the signal to noise ratio at the output of the receiver and also to increase the selectivity with respect to adjacent channel interference (see Proc. I. R. E. for December 1944, "A frequency-dividing locked-in oscillator frequency modulation receiver," by G. L. Beers).

It is an important object of my present invention to provide a frequency divider which concurrently functions as a demodulator for angle modulated waves thereby eliminating the need for a special demodulator network.

Another important object of my present invention is to provide a locked-in oscillator system which functions concurrently as a discriminator detector thereby to provide economy of construction.

In my U. S. Patent No. 2,269,417 granted January 6, 1942, I have disclosed and claimed an oscillator circuit generally comprising a pair of electron discharge devices connected so that the cathode circuit of one device drives the cathode circuit of the other device. A tuned circuit is utilized in the plate circuit of one device and is coupled to the grid circuit of the other device, the conjoint operation of the two devices having a negative trans-conductance characteristic.

It is another object of my present invention to employ an oscillator circuit of the last-mentioned type as a locked-in oscillator with or without frequency division.

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It is a more specific object of this invention to assign an additional function to a frequency discriminator which may be the type disclosed and claimed by S. W. Seeley in his U. S. Patent No. 2,121,103 granted June 21, 1938, the additional function being that of a tank circuit for a locked-in oscillator feeding into the discriminator.

More specific objects of my invention are to employ a pair of oscillator circuits of the type shown in my aforesaid U. S. Patent No. 2,269,417 in push-pull relation; to utilize the resultant push-pull circuit as a balanced FM detector; and to cause said push-pull system to function as a frequency divider of the locked-in oscillator type.

Still other features will best be understood by reference to the following description, taken in connection with the drawing, in which I have indicated diagrammatically a circuit organization whereby my invention may be carried into effect.

In the drawing:

Fig. 1 shows an embodiment of the invention; and

Fig. 2 shows vector relations ideally existing at the discriminator at "in-tune" condition.

Referring now to Fig. 1 of the drawing, the circuit details of one embodiment of my invention are shown; it is to be understood that the locked-in oscillator system shown is adapted for use in any desired and suitable type of receiver of angle modulated high frequency waves. The generic term "angle modulated" includes phase modulation (PM), frequency modulation (FM), or hybrid modulation possessing characteristics common to PM and FM. The receiving system is assumed to be a superheterodyne form of receiver, and the received waves are assumed to come from a transmitter radiating FM waves whose center frequency is in the 40 to 50 megacycle (mc.) band. Of course, a different type of receiver and any other frequency band suitable for FM or PM carrier wave transmission may be employed.

The numeral 1 designates a suitable intermediate frequency (I. F.) amplifier network which is to be employed between a suitable converter, mixer or first detector and the discriminator circuit. The operating I. F. value is preferably chosen from a range of 2 to 20 mc., and it may be assumed that an I. F. value of 5 mc. is employed. The network 1 may include one or more selective amplifier stages each tuned to 5 mc. However, for operation under present FM broadcasting standards which provide for a frequency deviation up to ±75 kilocycles, each selector circuit, and this is true of all the signal

selector circuits between the antenna and the output terminals of network 1, is constructed to pass a band as wide as 200 kilocycles. Of course, such a pass band is substantially in excess of the maximum freqency swing of 150 kilocycles (kc.) permitted at the transmitter. At the FM transmitter the carrier wave is deviated in accordance with the modulating signal amplitude, the rate of deviation being a function of modulation frequency per se.

The FM carrier waves usually are selectively amplified at carrier frequency and converted to I. F. without change in frequency deviation, and the I. F. energy is likewise selectively amplified at the I. F. value without change in frequency deviation range. However, for reasons stated above, it is desirable to present to the demodulator, or FM detector, signals whose mean or center frequency and frequency swing or deviation have been reduced by a common factor. If the curve within rectangle 1 is ideally representative of the I. F. pass band, then the curve above transformer 2 is ideally representative of the desired pass band at the discriminator transformer 2. Comparing these curves it will be seen that whereas the pass band of network 1 is 200 kc. wide with a center frequency of F, the pass band of the discriminator transformer 2 is $200/n$ kc. while the center frequency is F/n kc. The factor n is an integer. If, for example, n is equal to 5, then the pass band width at the discriminator is 40 kc. and the center frequency is 1 mc. The factor n may be unity or any larger number. In the former case there would be no frequency division.

According to my invention, the step of frequency division is secured by employing an oscillatory system which utilizes the teaching of my aforesaid U. S. Patent No. 2,269,417. However, in my present system the oscillatory system is caused to lock in with the FM signals at the output of network 1 whereby the frequency divided output at discriminator transformer 2 is faithfully controlled by the frequency deviation of the transmitted FM wave. The oscillatory system comprises a pair of twin triode tubes 3 and 4. Since the circuits and functions associated with the electrodes of tube 4 are the same as in the case of tube 3, there will be provided an explanation of the construction and operation of tube 3 and it will be understood that tube 4 duplicates the operation. Hence, similar numerals, but with prime designations, are used for tube 4 and its electrode circuits.

Tube 3 shows a pair of triodes, or electron discharge structures, T_1 and T_2 enclosed in the same envelope. While I have shown the use of a twin triode it is to be distinctly understood that my invention is not limited thereto, but that a pair of entirely separate and distinct tubes may be used. It should, further, be understood that I intend by the use of the term "tubes" to mean structures comprising a cathode electrode, an anode electrode within an evacuated space, and means for influencing, or otherwise controlling, an electron stream between said electrodes regardless of whether the evacuated space is common to more than one electrode assembly or how it is maintained in an evacuated condition. Furthermore, the invention is not limited to the use of triode tubes, since pentode or beam tubes may be used. Different types of tubes such as the triode and a beam tube may be combined.

The cathodes 11 and 21 of tube 3 are connected in common through the unbypassed resistor 5

to ground; in the same way cathodes 11' and 21' of tube 4 are connected by unbypassed resistor 5' to ground. The grid or control electrode 12 of triode T_1 is connected through the direct current blocking condenser 30 to one side of the resonant secondary circuit of transformer 2. The resonant secondary circuit consists of secondary coil 31 shunted by condenser 32. The primary circuit of the transformer consists of the primary coil 33 shunted by condenser 34. Each of the primary and secondary circuits of transformer 2 is tuned to the frequency F/n. In other words, if n equals 5, the primary and secondary circuits of transformer 2 are each tuned to the fifth subharmonic of the frequency F. The control electrode 12' of triode T'_1 is connected through direct current blocking condenser 30' to the opposite side of the secondary circuit 31, 32.

Each of control electrodes 12 and 12' is connected to ground through a respective one of the direct current return resistors 40 and 40'. The respective anodes or plates 23 and 23' of triodes T_2 and T'_2 are connected in parallel to a lead 50. Lead 50 divides into a direct current connection 51 to the upper end of primary coil 33 and a second direct connection 52 to the midpoint of the secondary coil 31. The lower end of coil 33 is connected to a +B terminal of a suitable source of direct current thereby to apply a desired positive potential to the parallel-connected plates 23 and 23'. The lower end of coil 33 is connected to ground for high frequency currents by condenser 60.

The signal input waves for the tubes 3 and 4 are derived from the output terminals of the I. F. amplifier network 1. One of these output terminals is the ground terminal, whereas the other terminal is connected by lead 70 to the control grids 22 and 22' of triodes T_2 and T'_2. In other words, the respective input electrodes are connected in parallel to the high alternating potential output terminal of the I. F. amplifier network 1. Accordingly, it will be appreciated that the potential of the control grids 22 and 22' is varied in accordance with the frequency variations or swing of the FM signal output energy of the I. F. network 1. The oscillations generated in the oscillatory system are locked in to follow the frequency variations at grids 22 and 22', but the oscillations generated and developed in the secondary circuit 31, 32 are of a mean or center frequency and frequency deviation reduced respectively by a factor of n relative to the input signals.

Considering, first, the manner in which tube 3 and its associated circuit connections function to provide oscillations, the common cathode resistance 5 is utilized for cathodes 11 and 21 so that the output voltage which results from the impression of voltage on grid 12 is fed to the cathode circuit of triode T_2, as well as to that of triode T_1. Utilizing the cathode circuit of T_1 as an output circuit results in 100% inverse feedback on grid 12, and the voltage applied to grid 12 appears unamplified on its associated cathode 11. Due to this high degree of inverse feedback the grid 12 may be swung over a wide range of voltage without drawing grid current so that the impedance presented to the tuned circuit 31, 32 by the grid is that of a negatively biased or class A grid, which is very high.

Triodes T_1 and T_2 constitute a negative transconductance device, since the resulting transconductance between the input grid 12 and the output plate 23 is negative with respect to the usual single-triode transconductance. It is made nega-

tive in the present case by the phase reversal produced by the common cathode resistor drive. In order to produce sustained oscillations the feedback voltage from plate 23 (also 23') is applied to secondary circuit 31, 32 by means of lead 50 and the primary circuit 34, 33, the latter being magnetically coupled to tuned circuit 31, 32. This feedback voltage must be fed back to the grid 22 of triode T_2 with a 180° phase reversal in order to produce oscillations. This is readily accomplished due to the fact that the common cathode resistor 5 effects such reversal. A positive voltage on the grid 12 tends to cause more current to flow through the resistor 5 and thereby makes both cathode 11 and cathode 21 more positive. The cathode 21 becoming more positive is equivalent to grid 22 becoming more negative. Thus, a positive voltage change on the grid 12 is equivalent to a negative voltage change on grid 22, and the required 180° phase reversal is thus obtained.

The tube 4 and its associated circuits function in the same way to sustain oscillations at the desired divided frequency F/n. However, it will be noted that the voltage E_p across the primary circuit 34, 33 is applied to the grids 12 and 12' of the discharge devices T_1 and T'_1 in push-pull relation by virtue of the magnetic coupling between coils 33 and 31. These induced voltages across secondary winding 31 are represented in Fig. 2 by the vectors E_s and E'_s. These voltages are equal and of opposite polarity.

At the same time, and because of the direct connection of the upper end of coil 33 to the midpoint of coil 31 through leads 51 and 52, the entire primary voltage E_p is applied in parallel, i. e. in like phase, to the grids 12 and 12'. Hence, the vector representation E_p in Fig. 2 is shown in phase quadrature to voltages E_s and E'_s. It will be understood that when the I. F. energy has an instantaneous frequency F the frequency divided FM energy at transformer 2 has a frequency F/n, and, therefore, a 90° phase shift occurs in the transfer of energy from the primary circuit 34, 33 to the secondary circuit 31, 32 by means of the inductive coupling. For instantaneous frequencies deviating from the center frequency the phase shift departs from phase quadrature.

The resultant voltages at grids 12 and 12' at frequency F/n are indicated in Fig. 2 by vectors as E_g and E'_g. Obviously at the center frequency of the frequency divided signal energy the voltages E_g and E'_g will be equal. However, should the instantaneous frequency of the locked-in oscillations depart from the center frequency F/n, then the vectors E_g and E'_g will become unequal in accordance with the usual and well known manner of operation of the Seeley type discriminator. Since the phase relations between the voltage E_p and each of voltages E_g and E'_g is less than 90°, the discriminator phase relations will in no way prevent the conditions suitable for sustaining oscillations.

The action referred to in the preceding paragraph may be further explained as follows. Potentials conveyed by lead 52 to the midtap of secondary 31 of transformer 2 are impressed in like phase on grids 12 and 12' of triodes T_1 and T'_1 respectively. Such potentials result in like phase currents in parallel through the respective anode-cathode space discharge paths 23, 21 and 23', 21' of triodes T_2 and T'_2. Potentials transferred across transformer 2 to secondary 31 are impressed in opposite phase on grids 12 and 12'. However, as concerns the production of oscillations, it may be considered that the in-phase

potentials on grids 12 and 12' are the controlling ones. If we assume an instantaneous potential, positive or negative, on grids 12 and 12' by transfer of energy to the midtap on secondary 31, the action of transformer 2, if the generated frequency is at one side of the mean oscillator frequency, may be to add to the instantaneous potential on grid 12 and to subtract from that on grid 12'. When the generated frequency changes to the other side of the mean frequency, the action of transformer 2 will then be to add to the instantaneous potential on grid 12' and to subtract from that on grid 12. The resulting effect is to cause an increase in the intensity of oscillation in the tube receiving the adding effect from transformer 2 and to decrease the intensity in the tube receiving the subtracting effect.

The respective voltages E_g and E'_g are rectified by devices T_1 and T'_1. The rectification occurs by virtue of the respective grid leak circuits 30, 40 and 30', 40'. It will be noted that plate 70 is connected to a source of positive potential through a load resistor 71 which is bypassed for high frequency currents by condenser 72. In the same way plate 70' is provided with a load resistor 71' also bypassed for high frequency currents by condenser 72'. These load resistors 71 and 71' respectively develop thereacross rectified voltages.

It will be obvious that these rectified voltages represent the frequency variations of the locked-in oscillations. They may be differentially combined to feed a single ended modulation amplifier, or they may be separately applied to the input terminals of a push-pull modulation amplifier. At the instantaneous center frequency of the locked-in oscillations the respective rectified voltages across resistors 71 and 71' are equal, and the differential combining thereof will provide zero output since the rectified voltages are of like polarity. Zero output will, also, be secured by feeding the voltages to a push-pull combining system. However, for departures from center or carrier frequency the voltages of the rectifiers will be unequal, and, therefore, the differential output voltage will have a magnitude and polarity dependent on the amount and direction of deviation from center or carrier frequency. This is similar to the action in the known balanced diode detector system.

By properly choosing circuit constants and electrode voltages for the oscillator tubes the locked-in oscillator system is provided with a substantially constant current output regardless of signal amplitude variations at the input of network 1. The locked-in oscillator may be adjusted to have a wide lock-in range by adjusting the band width of the band pass transformer 2 to have a wide band width. Hence, the lock-in range may be controlled by adjustment of the effective band width of transformer 2.

While I have indicated and described a system for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organization shown and described, but that many modifications may be made without departing from the scope of my invention.

What I claim is:

1. In combination with a source of angle modulated carrier waves of a predetermined center frequency and deviation range, a frequency divider locked-in oscillator comprising a pair of oscillator systems having separate input elec-

trodes connected in parallel to said source, a common tank circuit for said oscillator systems electronically coupled to said input electrodes thereby to provide lock-in over said deviation range, said tank circuit being tuned to a predetermined subharmonic frequency of said center frequency, each of said oscillator systems including a respective output circuit and a respective control electrode therefor, said tank circuit being constructed as a phase shifter and providing from frequency divided, locked-in oscillations a pair of voltages whose relative magnitude and phase are dependent on the amount and direction of deviation of the locked-in oscillations from said subharmonic frequency, and means for applying each of the pair of voltages to a respective one of said control electrodes thereby to provide a rectified voltage in each output circuit.

2. In combination with a source of angle modulated carrier waves of a predetermined center frequency and deviation range, a locked-in oscillator comprising a pair of oscillator systems having separate input electrodes connected in parallel to said source, a common tank circuit for said oscillator systems electronically coupled to said input electrodes thereby to provide lock-in over said deviation range, said tank circuit being tuned to a frequency having a predetermined relation to said center frequency, each of said oscillator systems including a respective output circuit and a respective control electrode therefor, said tank circuit being constructed as a phase shifter and providing from locked-in oscillations a pair of voltages whose relative magnitude and phase are dependent on the amount and direction of deviation of the locked-in oscillations from said tank circuit frequency, means for applying each of the pair of voltages to a respective one of said control electrodes thereby to provide a rectified voltage in each output circuit, and means for differentially combining the said rectified voltages for utilization.

3. In combination with a source of angle modulated carrier waves of a predetermined center frequency, a locked-in oscillator comprising a pair of oscillator systems having separate input electrodes connected in parallel to said source, a common tank circuit for said oscillator systems electronically coupled to said input electrodes thereby to provide lock-in with said waves, each of said oscillator systems including a respective output circuit and a respective control electrode therefor, said tank circuit being constructed as a phase shifter and providing from locked-in oscillations a pair of voltages whose relative magnitude and phase are dependent on the amount and direction of deviation of the locked-in oscillations, and means for applying each of the pair of voltages to a respective one of said control electrodes thereby to provide a rectified voltage in each output circuit.

4. In a system as defined in claim 3, said tank circuit comprising a primary circuit connected in parallel to respective anodes associated with said input electrode, a secondary circuit inductively coupled to said primary circuit, a direct current connection from one side of the primary circuit to the midpoint of the secondary circuit, and said control electrodes being connected to opposite sides of said midpoint.

5. In a frequency dividing, locked-in oscillator system, a pair of oscillator circuits, each circuit comprising a pair of electron discharge devices each having an anode, cathode and a grid, a first resonant circuit coupled in parallel to like anodes of one of the devices of each of said pairs of devices, a second resonant circuit coupled to said first resonant circuit, means for coupling to points of opposite polarity of said second resonant circuit respective grids of the second of said devices of each of said pairs, means for maintaining the respective anodes of said second devices at relatively fixed positive potentials, means connected between the cathodes of each pairs of devices and a point of zero reference potential for coupling the cathodes of each pair of devices together, means for varying the respective grids of said one devices with a frequency-variable voltage, and said first and second resonant circuits each being tuned to a desired subharmonic frequency of said frequency-variable voltage.

6. In a locked-in oscillator system, a pair of oscillator circuits, each circuit comprising a pair of electron discharge devices each having an anode, cathode and a grid, a first resonant circuit coupled in parallel to like anodes of one of the devices of each of said pairs of devices, a second resonant circuit coupled to said first resonant circuit, means for coupling to points of opposite polarity of said second resonant circuit respective grids of the second of said devices of each of said pairs, means for maintaining the respective anodes of said second devices at relatively fixed positive potentials, means connected between the cathodes of each pairs of devices and a point of zero reference potential for coupling the cathodes of each pair of devices together, means for varying the respective grids of said one devices with a frequency-variable voltage, separate means in circuit with each of said respective grids of the second of said devices for providing rectification, and an output load resistor in circuit with each of the anodes of said second devices for developing rectified voltage thereacross.

7. In combination with a source of frequency modulated carrier waves of a predetermined carrier frequency and maximum deviation range, a frequency divider locked-in oscillator comprising a pair of oscillator systems having separate input electrodes connected in parallel to said source, a common tank circuit for said oscillator systems electronically coupled to said input electrodes thereby to provide lock-in with said deviation, said tank circuit being tuned to a predetermined subharmonic frequency of said carrier frequency, each of said oscillator systems including a respective output circuit and a respective control electrode therefor, said tank circuit being constructed as a phase shifter and providing from frequency divided, locked-in oscillations a pair of voltages whose relative magnitude and phase are dependent on the amount and direction of deviation of the locked-in oscillations from said subharmonic frequency.

8. In combination with a source of angle modulated carrier waves of a predetermined center frequency and maximum deviation range, a frequency divider locked-in oscillator comprising a pair of oscillator systems having separate input electrodes connected in parallel to said source, a common tank circuit for said oscillator systems electronically coupled to said input electrodes thereby to provide lock-in with said deviation, said tank circuit being tuned to a predetermined subharmonic frequency of said center frequency, each of said oscillator systems including a respective output circuit and a respective control electrode therefor, said tank circuit being constructed as a phase shifter and providing from frequency

divided, locked-in oscillations a pair of voltages whose relative magnitude and phase are dependent on the amount and direction of deviation of the locked-in oscillations from said subharmonic frequency, and means for applying each of the pair of voltages to a respective one of said control electrodes thereby to provide a rectified voltage in each output circuit, and means for differentially combining the said rectified voltages.

9. In combination with a source of angle modulated carrier waves of a predetermined center frequency and maximum deviation range, a frequency divider locked-in oscillator comprising a pair of oscillator systems having separate input electrodes connected in parallel to said source, a common tank circuit for said oscillator systems electronically coupled to said input electrodes thereby to provide lock-in with said deviation said tank circuit being tuned to a predetermined subharmonic frequency of said center frequency, each of said oscillator systems including a respective output circuit and a respective control electrode therefor, said tank circuit being constructed as a phase shifter and providing from frequency divided, locked-in oscillations a pair of voltages whose relative magnitude and phase are dependent on the amount and direction of deviation of the locked-in oscillations from said subharmonic frequency, means for applying each of the pair of voltages to a respective one of said control electrodes thereby to provide rectified voltage in each output circuit each of said control electrodes including in circuit therewith a respective condenser-resistor network to provide grid rectification, said tank circuit comprising a primary circuit connected in parallel to respective anodes associated with said input electrode, a secondary circuit inductively coupled to said primary circuit, a direct current connection from one side of the primary circuit to the midpoint of the secondary circuit, and said control electrodes being connected to opposite sides of said midpoint.

10. In a frequency dividing, locked-in oscillator system, a pair of oscillator circuits, each circuit comprising a pair of electron discharge devices each having an anode, cathode and a grid, a first resonant circuit coupled in parallel to like anodes of one of the devices of each of said pairs of devices, a second resonant circuit coupled to said first resonant circuit, means for coupling to points of opposite polarity of said second resonant circuit respective grids of the second of said devices of each of said pairs, means for maintaining the respective anodes of said second devices at relatively fixed positive potentials, means connected between the cathodes of each pairs of devices and a point of zero reference potential for coupling the cathodes of each pair of devices together, means for varying the respective grids of said one devices with a frequency-variable voltage, and said first and second resonant circuits each being tuned to a desired subharmonic frequency of said frequency-variable voltage.

11. In a frequency dividing, locked-in oscillator system, a pair of oscillator circuits, each circuit comprising a pair of triode devices each having an anode, cathode and a grid, a first resonant circuit coupled in parallel to like anodes of one of the triodes of each of said pairs of triodes, a second resonant circuit coupled to said first resonant circuit, means for coupling to points of opposite polarity of said second resonant circuit respective grids of the second of said triodes of each of said pairs, means for maintaining the respective anodes of said second triodes at relatively fixed positive potentials, means connected between the cathodes of each pairs of triodes and a point of zero reference potential for coupling the cathodes of each pair of devices together, means for varying the respective grids of said one triodes with a frequency-variable voltage, and said first and second resonant circuits each being tuned to a desired subharmonic frequency of said frequency-variable voltage, separate means in circuit with each of said respective grids of the second of said triodes for providing grid rectification, and an output load resistor in circuit with each of the anodes of said second triodes for developing rectified voltage thereacross.

12. In combination with a source of angle modulated carrier waves of a predetermined center frequency and deviation range, a locked-in oscillator comprising a pair of oscillator systems having separate input electrodes connected in parallel to said source, a common tank circuit for said oscillator systems electronically coupled to said input electrodes thereby to provide lock-in over said deviation range, each of said oscillator systems including a respective output circuit and a respective control electrode therefor, said tank circuit being constructed as a phase shifter and providing from locked-in oscillations a pair of voltages whose relative magnitude and phase are dependent on the amount and direction of deviation of the locked-in oscillations, and the lock-in range of said oscillator being dependent upon the band width of said tank circuit.

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