Nov. 12, 1946. W. F. SANDS 2,411,003

LOCKED-IN OSCILLATOR CIRCUIT

Filed Jan. 14, 1944

Fig. 1.

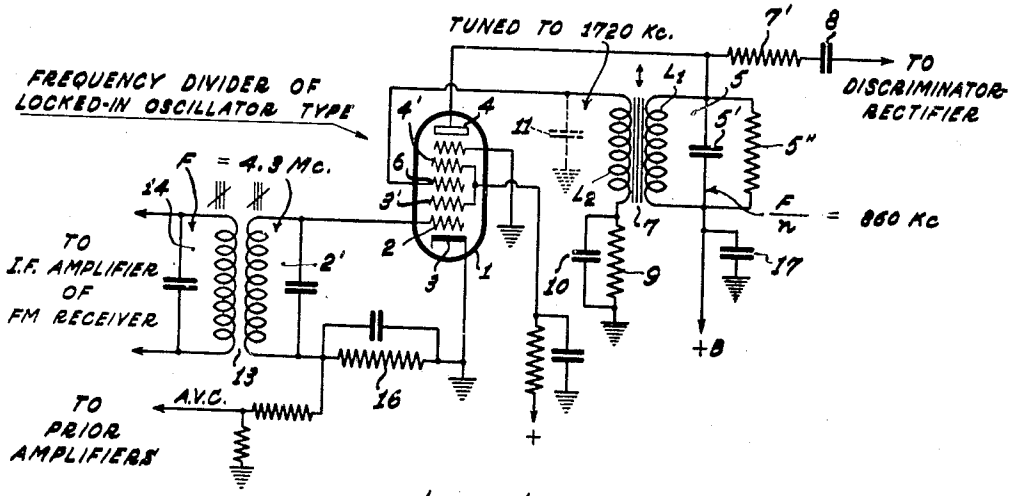


Fig. 2.

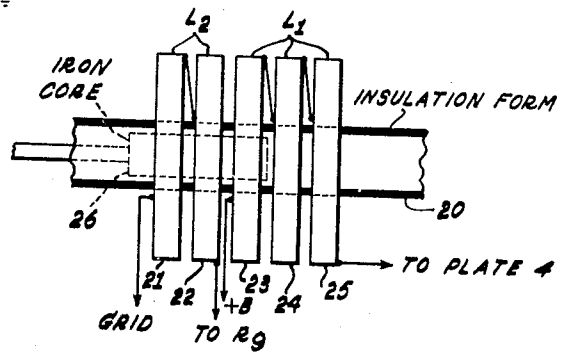
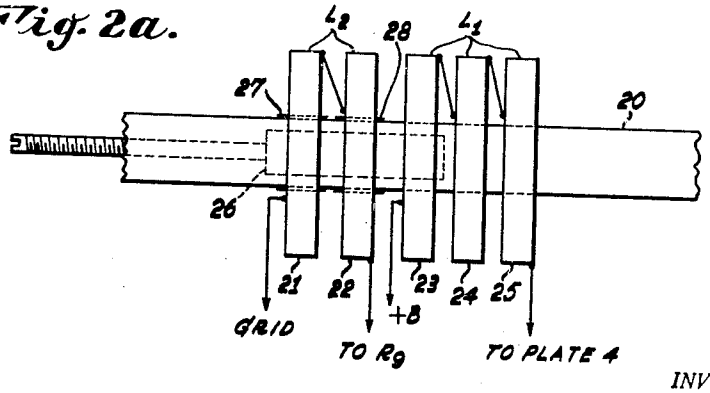


Fig. 2a.



INVENTOR.
WILLIAM F. SANDS
BY
H. S. Grover
ATTORNEY.

Patented Nov. 12, 1946

2,411,003

UNITED STATES PATENT OFFICE

2,411,003

LOCKED-IN OSCILLATOR CIRCUIT

William F. Sands, Haddonfield, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application January 14, 1944, Serial No. 518,252

3 Claims. (Cl. 250—36)

1

My invention relates generally to improved locked-in oscillator circuits, and more particularly to a novel and simplified means for extending the lock-in range of frequency dividers of the locked-in oscillator type.

In his application Serial No. 430,588, filed February 12, 1942, U. S. Patent No. 2,356,201, granted August 22, 1944, George L. Beers has disclosed and claimed novel circuits for receiving angle modulated carrier waves employing a locked-in oscillator acting as a frequency divider. In the illustrative embodiment described in the Beers patent, voltage of a desired subharmonic frequency (the fifth) is developed in the plate circuit of a pentagrid-type tube, and angle modulated wave energy of a predetermined frequency F is applied to the input control element of the tube. The third grid of the pentagrid tube is regeneratively coupled to the plate circuit continuously to provide oscillations of mean frequency F/n in the plate circuit, where n is a small integer. The subharmonic wave energy in the plate circuit is angle modulated, and is locked in with the input signal energy over a predetermined lock-in range.

The manner of operation of such locked-in oscillator circuits has been further explained by Murlan S. Corrington in his application Serial No. 513,371, filed December 8, 1943. In his application Corrington has disclosed and claimed a general method of extending the lock-in range of a locked-in oscillator thereby to overcome undesirable effects due to a "break-out" phenomenon of the oscillator. More generally, his application discloses a method of adjusting the range of a locked-in oscillator by controlling the harmonic content of the voltage on the oscillator grid, or input grid, of the locked-in oscillator tube.

One of the main objects of my present invention is to provide a simplified and efficient arrangement for increasing the lock-in range of a locked-in oscillator. In my present circuit no additional components are added to the aforesaid Beers' oscillator circuit, and at least one circuit component may be dispensed with.

Another important object of my invention is to provide a frequency-dividing locked-in oscillator having its tank circuit tuned to the desired subharmonic frequency of the input mean frequency, the oscillator grid coil being resonated to the second harmonic of the subharmonic frequency for extending the lock-in range of the oscillator at the extreme frequency values of the input signal energy. Preferably, also, the oscillator grid is tuned solely by means of the self-capacitance of the coil and the capacity of the third grid to all other electrodes.

Another object of my invention is to improve the operation of a receiver of angle modulated

2

carrier wave energy of the type shown in the aforesaid Beers patent, particularly when a tube is employed for the frequency-dividing locked-in oscillator such that the saturation plate current is low in value; such tubes, for example, as the conventional 6SA7, or, miniature versions (i. e., developmental type A5639 tube) of the high transconductance pentagrid tubes normally used in the Beers' oscillator circuit. When used in the circuit arrangement of the said Beers patent, such tubes having low saturation plate current will produce only a moderate lock-in range. However, in the present invention with such tubes, a coupling transformer is utilized between the oscillator anode and grid such that a very substantial improvement is secured in lock-in range over the circuit arrangement shown in the said Beers patent.

A more specific object of my invention is to simplify the construction of the locked-in oscillator disclosed in the aforesaid Corrington application; my present invention employing solely a coupling transformer, which may be of the adjustable core type, between the anode and grid of the oscillator to secure the increase in the lock-in range.

Still other objects of my invention are to improve generally the efficiency, reliability and range of locked-in oscillators, and more especially to provide locked-in oscillators of extended range which are economical in construction and assembly.

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 is a circuit diagram of a portion of a frequency modulation receiver embodying my invention,

Fig. 2 shows the construction of the oscillator coupling transformer,

Fig. 2a shows a modification of Fig. 2.

Referring now to the accompanying drawing, wherein like reference numerals in the different figures designate similar circuit elements, reference is made to the locked-in oscillator circuit shown in Fig. 1. The circuit is of the general type disclosed in the aforementioned Beers patent. The circuit comprises a tube 1 which may be of the pentagrid type. Between the input grid 2 and cathode 3 there is impressed high frequency signal energy of carrier frequency F. The resonant input circuit 2' provides the signal energy. The plate 4 has connected in circuit therewith a resonant output circuit 5 which is tuned to a subharmonic F/n of F, the symbol n denoting a small integer. By way of illustration, the fifth subharmonic may be employed. The plate 4 is estab-

lished at a positive potential with respect to the grounded cathode. The second and fourth grids 3' and 4' of the tube are connected in common to a point of positive potential of a direct current source through a voltage reducing resistor whose upper end is bypassed to ground by a suitable condenser. These positive grids function as a positive screen grid for the intermediate grid 6.

The grid 6 is regeneratively coupled, as at 7, to the plate circuit 5. The fifth grid of tube 1 is connected back to the grounded cathode, and the grid functions as a suppressor electrode. The cathode 3, grid 6 and plate or anode 4 provide the oscillator section of the circuit. This oscillator section produces oscillations at the subharmonic frequency F/n even in the absence of signal energy at grid 2. The oscillations developed across circuit 5 are transferred through resistor 7' and coupling condenser 8 to any utilization network. As indicated in Fig. 1, the utilization network is the discriminator-rectifier of an FM (frequency modulation) receiver.

The oscillator coupling transformer 7 consists of a primary winding L_1 and a secondary winding L_2. The winding L_2 has its upper end connected to grid 6, while the lower end thereof is connected to ground through the resistor 9. The latter is bypassed for high frequency currents by condenser 10. The resistor 9 functions to provide self-bias for grid 6. During positive swings of the oscillatory voltage on the grid 6 current flows through resistor 9. According to my invention the winding L_2 is resonated to the second harmonic of the frequency F/n. The inherent circuit capacities across coil L_2 may be employed to tune it to the desired second harmonic frequency value. The capacity 11 shown in broken lines across coil L_2 represents the capacity from grid 6 to ground, the distributed capacity across coil L_2 and other inherent electrode capacities. If desired, however, there may be employed a physical condenser across coil L_2.

The resonating of the oscillator grid coil to the second harmonic of the desired subharmonic frequency F/n secures a substantial increase in the lock-in range of the locked-in oscillator circuit. Before explaining the electrical actions which occur in the tube circuit, it will be assumed that the latter acts as a frequency-dividing network in a receiver of the type disclosed in the aforementioned Beers patent. As more fully explained in the said patent, the oscillator functions concurrently to reduce or divide the mean frequency of applied frequency modulated (FM) signal waves, and proportionately to reduce the extent of frequency deviation of the waves. The present invention is not limited to reception of FM waves, but may be used for PM (phase modulated) carrier waves. Generically, the expression "angle modulated" includes FM, PM or hybrids thereof.

Assuming that the FM receiver is of the superheterodyne type, and that the networks prior to the locked-in oscillator tube are conventional in nature, the transformer 13 will have its primary circuit 15 and its secondary circuit 2' tuned to the operating intermediate frequency (I. F.) of the system. As explained in the aforesaid Beers patent, the received FM waves are those which are transmitted in the assigned FM band of 42 to 50 megacycles (mc.). Of course, the invention is not limited to any particular frequency band. Those skilled in the art of radio communication are fully aware of the fact that the FM waves transmitted in the assigned FM band are presently allotted a maximum over-all frequency swing of 150 kc. with respect to the mean or center frequency F. The extent of frequency deviation is dependent upon the amplitude of the modulation signals at the transmitter, while the rate of frequency deviation is dependent upon the modulation frequency per se.

The collected FM waves are selected in one or more separate stages of tunable radio frequency amplification, after which they are combined with locally-produced oscillations at the first detector network. The output of the first detector or converter is the intermediate frequency (I. F.) energy. In other words, the I. F. energy is the original selected FM wave whose mean frequency has been reduced to a much lower frequency, but whose frequency deviation is unchanged. After amplification in one or more separate stages of I. F. amplifiers, the I. F. energy is applied to the locked-in oscillator for concurrent frequency division and frequency deviation reduction.

The I. F. transformer 13, which may be of the iron core type, preferably has a response curve whose mean frequency is located at 4.3 mc., whereas the passband is substantially 150 kc. wide. This signifies that the I. F. network up to grid 2 is capable of efficiently transmitting the entire frequency swings of the FM wave whose mean frequency has been reduced to the operating I. F. value. While the value of 4.3 mc. has been assigned as the operating I. F. value, it is to be clearly understood that any other satisfactory frequency value may be employed depending upon the various factors encountered in the design of the receiver.

The FM signal energy is applied to the input grid 2. The input grid 2 is connected to the high alternating potential side of the secondary circuit 2'. The low potential side of circuit 2' is returned to the grounded cathode 3 through a resistor and shunt condenser network designated by the numeral 16. The function of the network 16 is to provide voltage across its resistor element in response to grid current flow through the input grid circuit. Such grid voltage developed across the network 16 may be used for automatic volume control (AVC). The AVC voltage is employed automatically to bias gain control grids of preceding controlled amplifier tubes in a manner well-known to those skilled in the art.

The plate circuit 5, which consists of the primary winding L_1 and the shunt condenser 5', is in the present application of the invention resonated to a frequency of 860 kc. The resistor 5'' is connected in shunt with the resonant circuit 5 to provide an appropriate and suitable degree of damping for the circuit. The numeral 17 designates a bypass condenser connected to ground from the low potential side of resonant circuit 5. Assuming a frequency division by a factor of 5, there will be developed across the plate circuit 5 FM energy whose mean frequency is divided by a factor of 5 with respect to the mean frequency of 4.3 mc. In other words the response curve at the output circuit 5 will ideally have a passband width of 30 kc. with a mean frequency of 860 kc. This follows by virtue of the action of the locked-in oscillator network, which is to divide the mean frequency of the FM wave energy and the overall frequency deviation range by the same factor. The locked-in oscillator produces an output of substantially uniform amplitude, thus tending to eliminate any amplitude modulation effects which may have been created on the FM wave energy in the transmission through space or during the

passage of the signal energy through the receiver networks.

The advantages of frequency division at this point of the receiving system have been fully explained in the aforesaid Beers patent. The extension of the lock-in range of the oscillator accomplished by this invention, as compared with the arrangements shown in the Beers patent, will enable reception of waves which are frequency modulated over a wider range, and will guard against the distortion which might otherwise occur by reason of the "break-out" effect which has been described in the aforementioned Corrington application. The extension of the lock-in range is simply secured herein by resonating the secondary winding L_2 to the second harmonic (1720 kc.) of the plate circuit frequency.

A practical embodiment of the transformer **7** is shown in Fig. 2. In the latter figure there is shown an insulation form **20** upon which are mounted the various coil sections or "pies" which are employed to provide the primary winding and secondary winding of transformer **7**. Thus, pies **21** and **22** are electrically series-connected to provide winding L_2, while pies **23**, **24** and **25** are electrically series-connected to provide winding L_1. The appropriate electrical connections to the various circuit elements of the locked-in oscillator circuit are indicated at suitable points of the coil sections. The iron core **26** is shown co-axially arranged for adjustment within the insulation form **20**.

It will be understood that the coil sections of winding L_2 may be adjusted with respect to each other, and also as a group with respect to the coil sections of the other group, i. e., L_1.

This is shown by the modification of Fig. 2*a* in which sections **21** and **22** are each mounted on separate collars **27** and **28** which may be slid along the main coil form **20**. After the final adjustment is made, the collars may be sealed in place by a drop of wax, liquid cement, or by other suitable means. In this way the degree of coupling between windings L_1 and L_2 may be varied (for maximum lock-in range) by adjusting the distance between coil section **23** and the coil sections **21** and **22**. The inductance value of winding L_2 can be varied by adjusting the spacing between coil sections **21** and **22**. Of course, the core **26** may be adjusted to provide the proper inductance value for the winding L_1. With the arrangement shown it has been found possible to secure a lock-in range of $\pm$190–195 kc., when using a high-transconductance pentagrid type tube (such as the developmental A–5581) as the frequency-dividing locked-in oscillator. Furthermore, a lock-in range of at least $\pm$150 kc. can be readily secured for tubes such as the well known 6SA7, or for miniature versions (A5639) of the high-transconductance pentagrid tube.

The frequency divided signal energy transmitted through condenser **8** may be applied to any desired form of discriminator-rectifier network for the purpose of providing the modulation voltage which will be amplified and ultimately reproduced. Those skilled in the art of radio communication are well acquainted with discriminator-rectifier circuits. For example, there may be used the circuit shown by Conrad in his U. S. Patent No. 2,057,640, or the circuit disclosed by S. W. Seeley in his U. S. Patent No. 2,121,103. The discriminator-rectifier circuit shown in the aforesaid Beers patent may be employed, if desired. That type of discriminator-rectifier is disclosed and claimed by J. D. Reid

in his application Serial No. 353,028, filed August 17, 1940, U. S. Patent No. 2,341,240, granted February 8, 1944.

As explained in the aforementioned Corrington application, harmonics of F/n are impressed on the oscillator grid **6** due to the considerable non-linearity of the characteristic relating grid voltage of grid **6** and current through the plate circuit of tube **1**. These harmonics include the second and third harmonics of the 1720 kc. frequency of resonant circuit L_2—**11**. These harmonics are respectively the fourth and sixth harmonics of the 860 kc. frequency of circuit **5** (F/n being assumed to be 860 kc. in this case). The presence of the fourth and sixth harmonics of the 860 kc. frequency serves greatly to extend the oscillator lock-in range. Since Corrington has explained in detail the theoretical aspects of the lock-in range extension, I will generally make reference thereto herein.

The applied FM signals, assumed to be of a frequency of 4300 kc. in the present case, will beat with the aforementioned fourth and sixth harmonics to provide a difference frequency whose value is the same as the desired fundamental frequency of 860 kc. (the fifth subharmonic of 4300 kc.). This new component (termed "harmonic difference component" to differentiate it from the normal oscillator current of 860 kc.) will not, in general, have the same phase as the normal oscillator current. It is, thus, equivalent to injecting into the plate circuit an out-of-phase current. The oscillator tube acts in the manner of the well-known reactance tube by virtue of this phenomenon. If the oscillator frequency is not exactly one-fifth of the applied signal, the natural frequency of circuit **5** is "pulled over" until the frequency of oscillations is exactly one-fifth. In this condition the oscillator section is said to be "locked in" with the applied FM signals.

The maximum amount the natural frequency of the oscillator can be pulled over or adjusted, and still be locked in, occurs when the harmonic difference current injected into the oscillator plate circuit is in quadrature (90 degrees out of phase) with respect to the normal oscillator current. This is true, because in this quadrature state there exists maximum out-of-phase current. When the injected current (the harmonic difference current) is leading the normal oscillator current in phase, the frequency of oscillations will be pulled to one side of its natural frequency (860 kc.). When the injected current lags, the oscillatory frequency will be pulled to the other side of its natural frequency. It is evident, therefore, that there is developed in the plate circuit a frequency modulated current which is "locked-in" with the applied FM signals. This follows from the fact that the applied FM energy has a frequency which changes from instant to instant with respect to the mean or center frequency F thereof.

There is a limitation on the lock-in range. This arises from the fact that the amount of fourth and/or sixth harmonic on the oscillator grid is limited. This limits the magnitude of the injected current, and thus it follows that the lock-in range of the oscillator is limited. The result is that when the deviation of the oscillator frequency exceeds a certain frequency spacing from the mean frequency (860 kc.), the oscillator frequency suddenly returns to its mean value. This is termed "break-out", and gives rise to distortion at the output of the FM

detector. There are several operating causes for appearance of the "break-out" effect.

Corrington has shown in his aforesaid application various arrangements for increasing the harmonic magnitude at the oscillator grid. My present invention provides increased value of fourth and sixth harmonics at grid 6 by simply tuning the grid circuit to the second harmonic of 860 kc. Instead of utilizing distributed capacity 11, there could be used a smaller feedback coil at L_2 in conjunction with suitable shunt capacity to tune to 1720 kc. However, by using the larger inductance value and capacity 11 there are secured two advantages. First, the cost of an additional capacitor is saved. Second, the highest possible L/C ratio is secured, and, therefore, the largest voltage at 1720 kc. is obtained. The oscillator grid voltage-plate current characteristic should be as non-linear as possible to provide strong harmonic components of 1720 kc. By tuning the grid circuit to the second harmonic of 860 kc. there is secured the advantage of having the fourth and the sixth harmonics thereof appear at the oscillator grid.

The advantage of the present arrangement is well illustrated in the case of a locked-in oscillator circuit using a miniature type tube at 1, and having the grid circuit of the oscillator tuned to an intermediate frequency between 860 and 1720 kc. In such case a lock-in range of ±39 to 53 kc. was secured with FM signals of 4.3 mc. mean frequency. An oscillator transformer as shown in Fig. 2 was then substituted in the circuit, and a lock-in range of ±150 kc. could be readily secured for any of the miniature tubes (A–5639 for example). The miniature tubes are characterized by only moderate saturation plate current.

It is desirable when using an extended lock-in range that the band width of the I. F. amplifier (in fact the overall receiver selectivity) be sufficiently broad so that at the maximum deviation of the desired signal, the signal will not be attenuated below the value to keep the oscillator locked in. The following specific constants are provided by way of illustration:

L_2=490 microhenrys
C_{11}=17.5 micro-microfarads (mmf.)
L_1=500–650 microhenrys
C_5'=38 mmf.
R_5''=47,000 ohms
R_9=15,000 ohms
C_{10}=390 mmf.

The value of L_1 will depend upon the setting of core 26, self-capacitance of winding L_1, output capacitance of the frequency dividing locked-in oscillator tube and the wiring capacitance.

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 frequency modulated high frequency oscillations, an electron discharge device having input and output electrodes coupled together to provide oscillations whose frequency is substantially the fifth subharmonic of the mean frequency of oscillations from said source, means for controlling the electron stream of said device in response to said source oscillations, a resonant circuit connected to said output electrode, said resonant circuit being tuned to said fifth subharmonic, a second resonant circuit, coupled to said first resonant circuit, connected to said input electrode, said second resonant circuit being tuned substantially to the second harmonic of the frequency of said first resonant circuit, a transformer providing said coupling between the two resonant circuits, said transformer having its windings providing the inductances for said resonant circuits, the secondary winding of said transformer consisting of a plurality of relatively adjustable sections to provide adjustment of its inductance to a relatively large value, said secondary winding being shunted by solely inherent circuit capacitance to provide said second resonant circuit with highest possible inductance to capacitance ratio, and the characteristic relating input electrode voltage and output electrode current of said device being sufficiently non-linear to cause substantial production at said input electrode of the second and third harmonics of said second harmonic whereby the lock-in range of the oscillations is greatly extended.

2. In an oscillator circuit employing an electron discharge tube having a cathode, a grid and an anode, a resonant circuit connected to said anode, said resonant circuit being tuned to the frequency of desired oscillations, an oscillation transformer including the coil of said resonant circuit as one of the windings thereof, a second winding of the transformer being connected to the grid of said tube, the second winding being naturally resonated to a predetermined harmonic of the frequency of said resonant circuit by the inherent capacity to ground of the grid, the oscillator grid voltage-anode current characteristic being non-linear, said transformer comprising an insulation form, each of said windings being mounted on said form as a plurality of series-connected sections, an adjustable core within said form common to said sections, and means for controlling the electron stream of said tube at a frequency which is harmonically related to the frequency of the oscillator resonant circuit.

3. In a frequency dividing locked-in oscillator circuit, an electron discharge tube having at least a cathode, a grid and an anode, a resonant circuit connected to said anode, means for controlling the electron stream of said tube at a frequency which is to be divided, said resonant circuit being tuned to the fifth subharmonic frequency of the controlling frequency, an oscillation transformer including the coil of said resonant circuit as one of the windings thereof, a second winding of the transformer being connected to the grid of said tube, the second winding being tuned to the second harmonic of the frequency of said resonant circuit, the oscillator grid voltage-anode current characteristic being non-linear, said transformer comprising an insulation form provided with an adjustable iron core, said windings each consisting of a plurality of series-connected sections, and the sections of said second winding being adjustable relative to the sections of the first winding.

WILLIAM F. SANDS.