

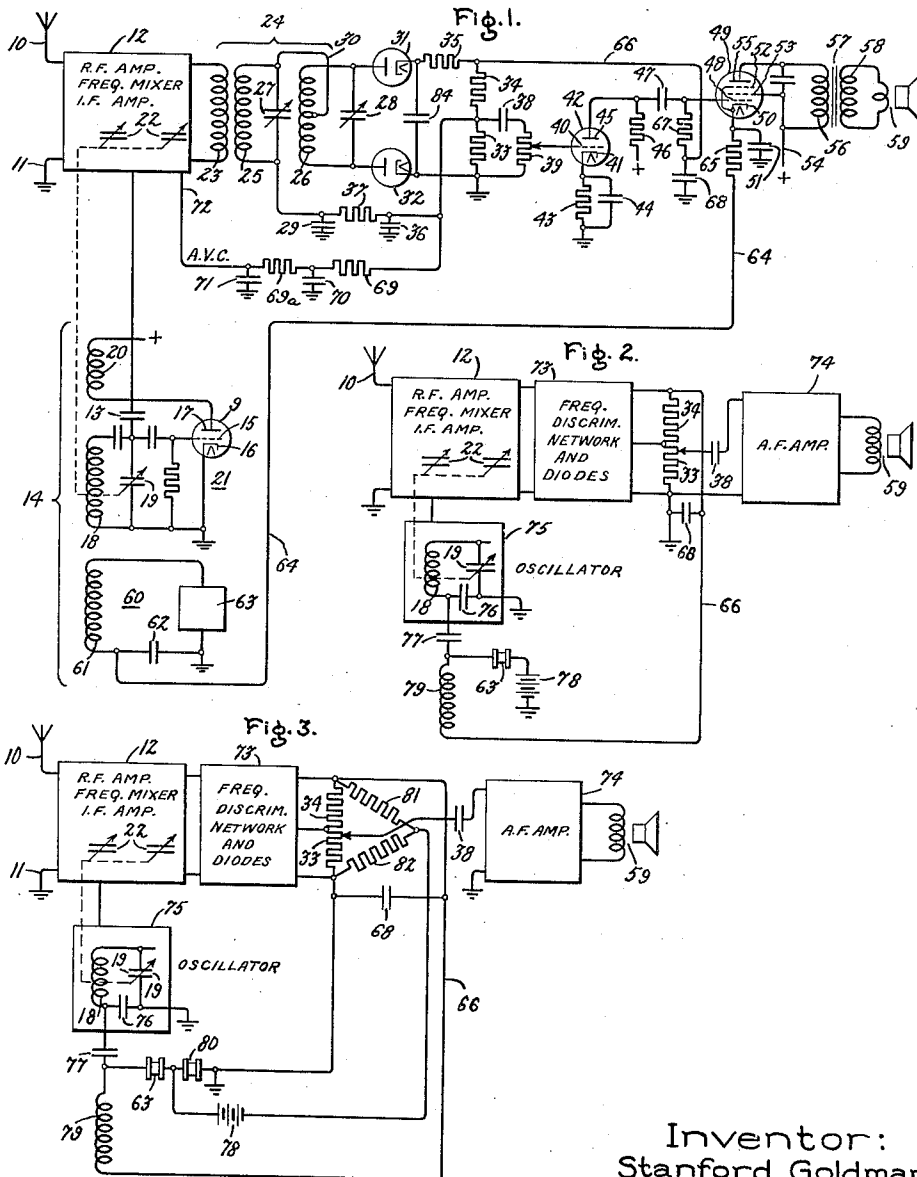
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AUTOMATIC FREQUENCY CONTROL

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AUTOMATIC FREQUENCY CONTROL

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My invention relates to an improved automatic frequency control for a signalling apparatus and more particularly to an improved and simplified arrangement for automatically controlling the frequency of a local generator of oscillations.

There are several instances in the application of high frequencies to communication systems where it is desirable that the frequency of a local generator of oscillations be controlled, preferably in an automatic manner, for the purpose of maintaining either the generated frequency, or one or more frequencies dependent upon the frequency of the generating source, substantially constant in value. Illustrative of this field of application is the superheterodyne type of radio receiver in which the oscillations generated by a local oscillator are mixed with received signal oscillations to produce heterodyne or beat oscillations of intermediate frequency. These intermediate frequency oscillations may then be readily amplified by an intermediate frequency amplifier. The intermediate frequency amplifier generally has a number of sharply tuned circuits resonant at a fixed intermediate frequency and any departure of the intermediate frequency oscillations from their normal value consequently results in a certain amount of highly undesirable distortion of the amplified oscillations.

It is an object of my invention to provide a simplified, reliable and inexpensive arrangement for automatically controlling the frequency of a local generator of oscillations for the purpose of maintaining the frequency of the heterodyne or beat oscillations substantially constant in value at the frequency to which the intermediate frequency amplifier is tuned.

A further object of my invention is to control in an automatic manner the frequency of a generator of local oscillations by an arrangement in which the value of impedance of a circuit is controlled by a device having a variable resistance characteristic whose value of resistance is in turn controlled by the departure of generated oscillations from a normal frequency, and my invention contemplates that the impedance of the circuit shall be suitably coupled into the frequency determining circuit of the oscillator thereby to control its resonant frequency.

Another object of my invention is to provide an automatic frequency control circuit which utilizes the properties of a substance having a variable resistance characteristic and a terminal capacity which varies with the resistance of the substance. The resistance of the substance is controlled by the departure of the generated oscillation fre-

quency from a normal value and, the substance being suitably connected in the frequency determining circuit of the generator of local oscillations, its consequent change of capacity is used to control the frequency of the locally generated oscillations.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 represents an embodiment of my invention which utilizes the resistance value of a resistor having a variable resistance characteristic to control the frequency of a local oscillator; Fig. 2 illustrates a modified embodiment which utilizes the change in terminal capacity of the substance having the variable resistance characteristic; and Fig. 3 shows an additional modification which uses the terminal capacity of a pair of resistors exhibiting the variable resistance characteristic connected in a balanced bridge arrangement.

Referring to Fig. 1 of the drawing, I have illustrated my invention as embodied in a superheterodyne type of radio receiver in which an antenna ground system 10, 11 is connected to supply signal oscillations to a signalling apparatus, represented conventionally by the rectangle 12, which may comprise one or more stages of radio frequency amplification, a mixer or frequency changer for changing the oscillations of signal frequency to oscillations of a lower, or intermediate, frequency, and one or more stages of intermediate frequency amplification for amplifying the oscillations of intermediate frequency. The mixer, or frequency changer, may be of the converter type in which certain of the tube elements are connected in a manner to constitute elements of a local oscillator and the mixing of signal and locally generated oscillations is accomplished electronically; or the mixer stage may be of a more simplified type wherein the signal oscillations and oscillations locally generated by a separate electron discharge device suitably connected to oscillatory circuits, are supplied to the same or different grids of an electron discharge mixer tube. My invention is illustrated with a mixer stage of the latter type in which the mixer tube, not shown, has a control grid connected to receive signal oscillations and a second grid, preferably screened from the signal grid, 55

connected through a condenser 13 to receive oscillations from a local oscillator 21.

The local oscillator 21 is here shown as comprised by an electron discharge device 9 provided with a grid 15, a cathode 16 and an anode 17, the grid 15 and the cathode 16 being connected across a parallel tuned circuit, constituted by the secondary winding 18 of the transformer 14 and the variable condenser 19, while the anode 17 of the device 9 is connected through a primary winding 20 of the transformer 14 to the positive terminal of a source of space current, not shown. It will be understood that the negative terminal of the space current supply is connected through ground to the cathode 16 of the device 9. The oscillator condenser 19 is shown, as indicated by the broken line, mechanically connected for uni-control operation with the input tuning condensers 22 provided for the purpose of tuning the radio frequency stages and the mixer stage to the frequency of the signal oscillations.

Included in the apparatus represented conventionally by the rectangle 12 is one or more stages of intermediate frequency amplification whose output is supplied to the primary 23 of an output intermediate frequency transformer 24. The transformer 24 is provided with a pair of windings 25, 26 which are tuned by the respective condensers 27, 28 to the intermediate frequency. One terminal of the transformer winding 25 is maintained at ground potential for alternating currents of the intermediate frequency by a condenser 29. The other terminal of the winding 25 is connected by a conductor 30 to a center tap on the transformer winding 26. The connection of the transformer windings 25, 26 in this manner provides, with the condensers 27 and 28, a frequency discriminating network which operates in a manner well understood in the art. A detailed explanation of the operation of the frequency discriminating network may be understood from the explained operation of a very similar network in the "Proceedings of the Institute of Radio Engineers," for March 1937, page 289.

Each terminal of the winding 26 of the transformer 24 is connected to an anode provided in the respective electron discharge diode rectifiers 31 and 32. The cathodes of the diode rectifiers 31, 32 are connected together through a pair of resistors 33, 34, across which an automatic frequency control potential may be developed by a departure of the intermediate frequency oscillations from a normal value. An additional resistor 35 is included in the last-named connection for a purpose to be explained hereinafter. The lower end of the winding 25 of the transformer 24 is connected through a filter comprised by the condensers 29 and 36 and a resistor 37 to the junction between the resistors 33 and 34. A capacitor 38 is connected from the cathode of the diode 31 to ground for the purpose of grounding this cathode for audio frequency currents.

The diode rectifier 32 rectifies the modulated intermediate frequency oscillations and produces across the resistor 33 an audio frequency potential corresponding to the modulation component of the modulated signal oscillations. This audio frequency potential is supplied through a condenser 38 to a voltage divider 39 and a portion of the potential drop across the voltage divider is supplied to a control grid 40 and through ground to a cathode 41 provided in an electron discharge device 42. The control grid 40 of the device 42 is biased to a normal operating potential by a

cathode biasing resistor 43 and shunting condenser 44. The device 42 has an anode 45 which is connected through a resistor 46 to the positive terminal of a high voltage space current supply, not shown. The amplified audio frequency oscillations appearing in the anode circuit of the device 42 are coupled through a condenser 47 to a grid 48 provided in the electron discharge device 49. The discharge device 49 has a cathode 50 maintained at ground potential for alternating currents by a condenser 51, a suppressor grid 52 directly connected to the cathode 50, a screen grid 53 connected to the positive terminal 54 of a high voltage space current supply, not shown, and an anode 55 which is connected through the primary 56 of an audio frequency output transformer 57 to the positive terminal 54 of a high voltage space current supply, not shown. The transformer 57 is provided with a secondary 58 which is connected to a loud speaker 59 or other translating device.

For the purpose of automatically controlling the frequency of the local oscillator 21 to maintain the frequency of the intermediate frequency oscillations supplied to the transformer 24 substantially constant in value, an automatic frequency control circuit 60 is provided. This automatic frequency control circuit 60 operates to control the frequency of the local oscillator 21 by virtue of a change in the reactance reflected by the magnetic coupling of a winding 61, provided in the transformer 14, into the frequency determining oscillatory circuit 18, 19 of the local oscillator. The impedance of the circuit 60 is comprised by the reactance of the winding 61, by the reactance of a by-pass condenser 62, and by the resistance at a given moment of a resistor 63, which has a non-linear resistance characteristic. The resistor 63 may, for example, be Thyrite. Thyrite is a substance composed of carborundum (silicon carbide), free carbon, and a suitable binder as clay, all mixed and formed into a compressed mass in a manner disclosed more fully in the United States patent to McEachron 1,822,742, assigned to the same assignee as the present invention. This substance has a terminal resistance and a terminal capacity dependent upon the current flowing through a mass of the substance at a given moment. For example, the resistance of Thyrite decreases rapidly with a negative resistance characteristic and in a non-linear relation as the value of potential impressed across the Thyrite increases. To supply this current, the resistor 63 and the transformer winding 61 are connected in series through a conductor 64 and a resistor 65 between the cathode 50 of the device 49 and ground. Since the negative terminal of the high voltage space current supply, not shown, for the device 49 is also grounded, this connection of the frequency control circuit 60 in the cathode lead of the device 49 places the circuit 60 in the output circuit of the device 49. The resistor 65, in addition to providing a proper operating bias for the grid 48 of the device 49, aids the condensers 51 and 62 in filtering audio frequencies, appearing in the output circuit of the device 49, out of the control conductor 64 so that the current flowing through the resistor 63 is substantially a non-pulsating unidirectional current.

The automatic frequency control circuit is completed by connecting the upper terminal of the resistor 34 through a conductor 66 and a resistor 67 to the grid 48 of the device 49. A by-pass condenser 68 maintains the conductor 66 at

ground potential for oscillations of intermediate and audio frequencies.

An automatic volume control of the receiver here shown is provided by connecting the unidirectional potential appearing across the resistor 33 through a filter comprised by the resistors 69, 69a and condensers 70, 71 to an automatic volume control circuit 72 thereby to control in well known manner the gain of the one or more stages of amplification included in the receiving apparatus 12 to which this control circuit is connected.

In explanation of the operation of the automatic frequency control arrangement, let it be first assumed that the frequency of the local heterodyning oscillations, determined by the oscillatory circuit 18, 19 is such that when mixed with the signal oscillations, an intermediate or beat frequency oscillation results, the frequency of which is exactly the frequency to which the circuits 25, 27 and 26, 28 are tuned. In such case, the average unidirectional potential appearing across the resistor 34 is substantially equal and opposite in polarity to that appearing across the resistor 33 and the bias on the grid 48 of the discharge device 49 is a normal operating bias determined by the potential drop across the resistor 65 added to that across the resistor 63. Under this assumed condition of operation, the frequency control circuit 60 reflects into the oscillatory circuit 18, 19 of the local oscillator 21 a certain reactance, determined by the steady-state space current flowing in the device 49 from the cathode 50 to ground, which is just sufficient to insure that the output frequency of the local oscillator 21 differs from the frequency of the signal oscillations by a frequency equal to that to which the windings of the transformer 24 are tuned.

Assume as a second condition of operation that a drift is experienced in the output frequency of the local oscillator. The intermediate frequency no longer has the optimum or normal frequency, which it previously had but will depart up or down in the frequency spectrum from its former value depending upon the direction of the frequency drift of the local oscillator. As explained in the "Proceedings of the Institute of Radio Engineers" paper previously referred to, the frequency discriminating network 25, 27 and 26, 28 now supplies the diode rectifiers 31, 32 with unequal voltages and the average potential drop across the resistors 33, 34 is consequently no longer equal although the polarity of each potential drop does not change. The magnitude of the difference, and thereby the magnitude of the control potential between the conductor 66 and ground, obviously varies in direct relation to the magnitude of the intermediate frequency departure. The automatic frequency control circuit conductor 66, now either positive or negative with respect to ground depending upon the direction in the frequency spectrum of the local oscillator frequency departure, carries a control potential which adds, with proper polarity, to the biasing potential previously impressed on the grid 48 to bias this grid to a new operating potential. Assuming that the conductor 66 is now positive with respect to ground, the grid 48 is biased more positively than it previously was and the space current flowing from the anode 55 (and from the screen grid 53) to the cathode 50 of the device 49 thereupon increases to a new value. This increased space current flows through the resistor 63 to effect, in

the case of Thyrite, a decrease in its resistance and, the resistor 63 being connected in shunting relation to the transformer winding 61, a consequent change in the reactance of the circuit 60 reflected by the winding 61 into the oscillatory circuit 18, 19 of the local oscillator 21. The local oscillator 21 thereupon changes its output frequency in a direction to offset the frequency drift and thereby to restore the intermediate frequency to its former value.

It should be noted at this point that the control potential appearing between the conductor 66 and ground is very greatly amplified, in its effective control over the resistance of the resistor 63, by the amplifying characteristic of the electron discharge device 49. Thus very small displacements of the intermediate frequency from a normal value result in large changes in the value of resistance of the resistor 63 which, when reflected into the oscillatory circuit of the local oscillator 21, effect substantial changes in the frequency of the local oscillator in a direction tending to restore the intermediate frequency to its former normal value.

The purpose of the resistor 35, in series with diode 31, is to off-balance to a certain extent the equality of the voltages produced across the resistors 33 and 34. This unbalance of voltages is only necessary when a single space current supply source is used for all of the tubes in the receiver and the regulation of the space current supply source is very poor. A poor regulation results in an increase in the space current of the electron discharge device 49 upon the tuning of the input circuits by the condensers 22 to receive a signal oscillation since the automatic volume control operates when a signal is tuned in, to decrease the load on the space current supply source caused by decreasing the space current through the several electron discharge devices in the receiving apparatus 12 to which the automatic volume control circuit 72 is connected. Any increase in the space current of the device 49 in this manner is detrimental to the proper operation of my automatic frequency control and should be avoided. By using the resistor 35, a greater potential drop appears across the resistor 33 than across the resistor 34 when a signal oscillation is received and this excess voltage, since the ungrounded terminal of the resistor 33 is negative with respect to ground, causes the grid 48 of the device 49 thereupon to become biased slightly more negatively than formerly even though the intermediate frequency is at its normal value. Changing the bias of the grid 48 in this manner effectively maintains a constant space current through the device 49 even though the potential of the screen grid 53 and the anode 55 rises by virtue of the poor regulation of the space current supply source. The same result may also be accomplished by eliminating the resistor 35 and by so unbalancing the center tap of the winding 26 of the intermediate frequency transformer 24 that a greater voltage is produced across the resistor 33 than is produced across the resistor 34 at times when the intermediate frequency has a normal value.

Fig. 2 illustrates a modification of my invention in which elements corresponding to like elements of Fig. 1 are designated by like reference characters. The rectangle 73 of this figure represents in conventional manner the frequency discriminating network, the diodes 31, 32, and their interconnected circuit as shown in Fig. 1; the rectangle 74 represents the audio frequency

stages of amplification and includes the electron discharge devices 42 and 49 of Fig. 1; and the rectangle 75 represents the local oscillator 21 of the Fig. 1 arrangement.

- 5 This modification utilizes a characteristic of certain substances, typical of which is Thyrite, which act like capacitors and exhibit an effective terminal capacity which varies with the potential drop across the substance. To utilize the
10 capacitive characteristic exhibited by materials of the class named, a small condenser 76 is connected in the frequency determining network of the oscillator, comprised by the condenser 19 and secondary winding 18 of the oscillator transformer. The Thyrite 63, or other substance exhibiting like characteristics, is then connected
15 through a condenser 77 across the terminals of the condenser 76. It will be evident that changes in the terminal capacity of the Thyrite 63 result in corresponding changes in the resonant frequency of the oscillator frequency determining circuit.

- A change in terminal capacity of the Thyrite 63 in this embodiment is accomplished by including a source of unidirectional potential 78
25 in the circuit between the Thyrite 63 and one terminal of the condenser 76 and by connecting the potential drop produced across the resistors 34, 33 through a suitable filter comprised by the condenser 68 and radio frequency choke 79 across the series connected Thyrite 63 and source of potential 78. Thus the potential drop across the
30 resistors 33 and 34 adds to or opposes the potential of the source 78 thereby to increase or decrease the magnitude of the current flowing through the Thyrite resistor 63. If the potential source 78 has a suitable polarity, the control potential produced across the resistors 33, 34 by the
40 departure of the intermediate frequency oscillations from a normal value operates to change the terminal capacity of the Thyrite resistor 63, by changing the resistance of the Thyrite, in a direction to change the oscillator frequency to restore the intermediate frequency oscillations
45 substantially to their former value.

- The source of potential 78 in this arrangement is necessary in order that an initial biasing current may flow through the Thyrite resistor 63 to
50 cause a restoration in the frequency of the intermediate frequency oscillations whether these oscillations depart upward or downward in the frequency spectrum from their normal value. The initial biasing voltage across the Thyrite resistor 63 should be at least equal to the peak
55 value of the automatic frequency control voltage likely to be developed across the resistors 33, 34.

- The arrangement of Fig. 2 has the objection that the source of potential 78 produces a unidirectional potential drop across the resistors 33,
60 34 which places an initial bias on one of the diode rectifiers included in the apparatus 73.

- The modification illustrated in Fig. 3 overcomes this objectionable feature of the control circuit of Fig. 2 by the use of a resistive bridge
65 circuit. Elements in the Fig. 3 modification corresponding to like elements of Fig. 2 are designated by like reference characters. It will be noted that this modification employs an additional Thyrite resistor 80, the two Thyrite
70 resistors being connected in series relation with each other and, through the condenser 77, in parallel relation with the condenser 76 of the oscillator frequency determining reactive circuit. An additional pair of resistors 81 and 82 are
75 connected across the resistors 33 and 34 and form

with the Thyrite resistors 63 and 80 a normally balanced Wheatstone bridge. The source of potential 78 is now connected across opposite arms of the bridge between the junction of the Thyrite resistors 63 and 80 and the junction of the resistors 81 and 82. This arrangement enables an initial biasing current to flow through the Thyrite resistors 63 and 80 without producing a potential drop across the resistors 33 and 34. The operation of the Fig. 3 arrangement is the same as that
10 of Fig. 2, the terminal capacities of the Thyrite resistors 63 and 80 being employed in series across the condenser 76 to control the frequency of the local oscillator. The Thyrite resistors 63 and 80 preferably have substantially the same
15 resistive characteristics.

It is now evident that my invention provides in a simple, reliable, and relatively inexpensive manner a solution to the problem of controlling the frequency of a local oscillator where, as in a
20 superheterodyne radio receiver, it is desirable that the oscillator under certain conditions shall immediately assume and in any event shall not depart from a predetermined output frequency.

While I have shown particular embodiments of
25 my invention, it will of course be understood that I do not wish to be limited thereto since many modifications may be made in the arrangement and the instrumentalities employed, and I therefore contemplate by the appended claims to cover
30 any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a superheterodyne radio receiver, the
35 combination of means for receiving signal oscillations, means for generating local oscillations, means for producing from said signal oscillations and said locally generated oscillations other oscillations of intermediate frequency, a resistor,
40 means for producing across said resistor a potential drop having a magnitude and polarity dependent upon the direction and extent of the departure in the frequency spectrum of said intermediate frequency oscillations from a normal
45 value, and means responsive to said potential drop for maintaining the frequency of said intermediate frequency oscillations at substantially said normal value, said last named means including a pair of resistors having a terminal capacity
50 which varies according to a variable resistance characteristic of said resistors, means responsive to the terminal capacity of said last named resistors for controlling the frequency of said second named means, and means including a normally balanced Wheatstone bridge arranged to be unbalanced by a potential drop appearing
55 across said first named resistor for controlling the resistance of said last named resistors.

2. The combination of a tunable circuit having a resonant frequency, a resistor, said resistor being formed of a solid substance which exhibits the characteristic that its electrical resistance changes with changes in the value of a potential impressed across said resistor, a source of potential connected across said resistor, means responsive to the resistance of said resistor for controlling the resonant frequency of said tunable circuit, and means for changing the value of the potential of said source to tune said tunable circuit.

3. The combination of a tunable circuit having a resonant frequency, a resistor, said resistor being formed of a solid conductor which exhibits a change of electrical capacity with changes in

unidirectional current through said resistor, means to pass substantial unidirectional current through said resistor, means responsive to the electrical capacity of said resistor for controlling the resonant frequency of said tunable circuit, and means for changing the value of said unidirectional current to tune said tunable circuit.

4. In combination, a tunable circuit having a resonant frequency, a resistor, said resistor being formed of a mass of relatively finely divided carborundum particles and graphite held together with a binder and having a terminal impedance which changes with changes in the value of a potential impressed across said resistor, a source of potential connected across said resistor, means responsive to the resistance of said resistor for varying the frequency at which said tunable circuit is resonant, and means for changing the value of potential of said source to tune said tunable circuit.

5. In a superheterodyne receiver having a tunable input circuit, a local oscillator having a tunable frequency determining circuit, and means to convert the received oscillations and oscillations produced by said local oscillator to intermediate oscillations of substantially constant frequency for all received oscillations, the combination of a solid conductor having the property that its impedance between two points changes in response to the potential between said points, means to supply a potential between said points varying with the frequency of said intermediate frequency oscillations, and means responsive to changes in the impedance of said solid conductor between said points to change the frequency determined by said tunable frequency determining

circuit sufficiently to maintain the frequency of said intermediate oscillations substantially constant during adjustment of the tuning of said tunable input circuit over a substantial range.

6. The combination, of an oscillator having a frequency determining circuit, a solid conductor having different points connected across an element of said frequency determining circuit the capacity of said solid conductor between said points varying dependently upon variations in potential between said points, and means responsive to the frequency of oscillations produced by said oscillator to vary the potential between said points sufficiently to vary the frequency determined by said frequency determining circuit over a substantial range, by reason of variation of said capacity.

7. The combination, in a receiver having a local heterodyne oscillator, and having a circuit across which the unidirectional potential changes dependently upon the relation between the frequency of the received oscillations and the frequency of oscillations produced by said local oscillator, a solid conductor having impedance dependent upon the potential between two points thereon, a source of bias potential for said solid conductor, means to supply unidirectional potential from said source and from said circuit between said two points to vary the impedance therebetween, means responsive to said impedance to control said local oscillator, and means to prevent said source of bias potential from producing unidirectional currents in said circuit.

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