

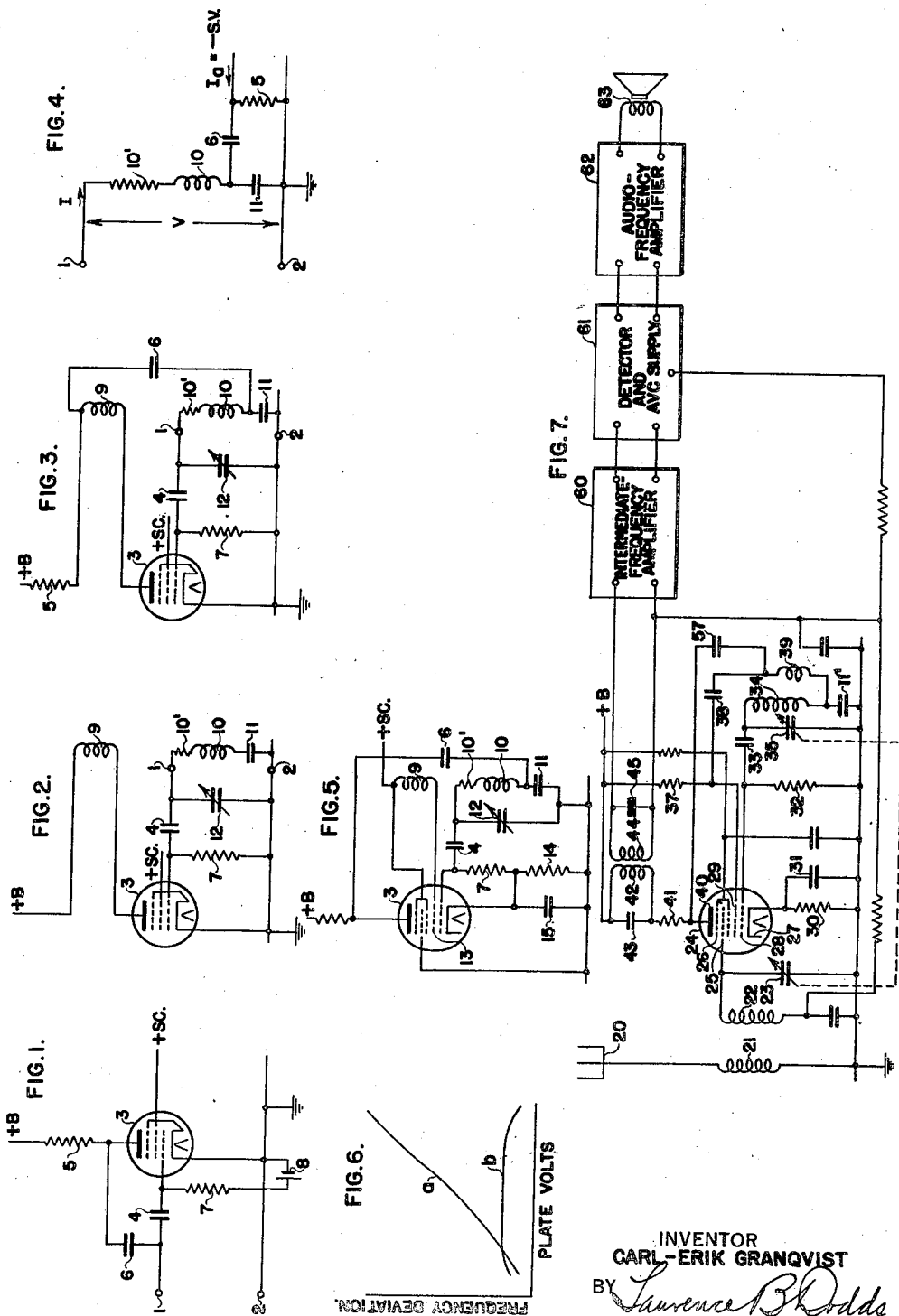
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FREQUENCY STABILIZING ARRANGEMENT

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## FREQUENCY STABILIZING ARRANGEMENT

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This invention relates to a frequency-stabilizing arrangement and, while it is of general application, it is particularly suitable for stabilizing the frequency of an oscillator, for example, the local oscillator of a superheterodyne receiver.

In a superheterodyne receiver comprising a multi-grid vacuum tube which functions as an oscillator-modulator and which is subject to automatic volume control, a change takes place in the slope of the grid-voltage plate current characteristic, or transconductance, of the tube when an automatic amplification control potential is applied to an electrode of the tube. The frequency-determining circuit of such an oscillator-modulator includes the transformed inter-electrode impedances of the tube. Since these impedances are altered by variation of the automatic amplification control potential, it is evident that the resonant frequency of the frequency-determining circuit is correspondingly altered. In superheterodyne receivers, this results in a displacement of the intermediate frequency developed by the oscillator-modulator tube from the mean resonant frequency of the intermediate-frequency selector circuits. The detuning resulting from the variation in automatic amplification control bias to the oscillator-modulator tube effects a distortion similar to that normally due to manual detuning. Such detuning distortion has substantially limited the range of automatic amplification control.

It is an object of the invention to provide a stabilized oscillator, the frequency of which is not substantially altered by variations of the transconductance of the tube.

It is a further object of the invention to provide a stabilized oscillator-modulator for superheterodyne receivers such that the intermediate frequency is not substantially altered by variations of automatic amplification control potential applied to the oscillator-modulator tube.

In accordance with one embodiment of the invention, a high-frequency oscillator comprises a vacuum tube having input and output electrodes, a frequency-determining circuit coupled to the input electrode, and an inductive energy-transfer coupling between the frequency-determining circuit and an output electrode, whereby the oscillator is caused to oscillate at the frequency of the frequency-determining circuit. Means are provided for varying the transconductance of the tube, thereby tending to vary the output frequency of the oscillator, while there are also provided separate means comprising an energy-transfer coupling having a phase opposite to that

of the inductive energy-transfer coupling between the frequency-determining circuit and an output electrode and including reactance and resistance of large impedance relative to the reactance, for coupling into the frequency-determining circuit a reactive component variable with the transconductance of the tube to compensate the above-mentioned tendency.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

Fig. 1 is a circuit diagram of a vacuum-tube repeater having capacitively coupled grid and anode and useful in deriving the fundamental relationships involved in the invention; Fig. 2 is a circuit diagram of an oscillator with inductive feed-back coupling also useful in deriving fundamental circuit relations; Fig. 3 is a circuit diagram of an oscillator combining the features of Fig. 1 and Fig. 2; Fig. 4 is a simplified equivalent circuit diagram of the circuit of Fig. 3; Fig. 5 illustrates an embodiment of the invention in an oscillator comprising a heptode vacuum tube; Fig. 6 is a graph illustrating certain characteristics of the circuit of Fig. 5; and Fig. 7 illustrates an embodiment of the invention in the oscillator-modulator of a superheterodyne receiver.

It is well known that it is possible to cause the input circuit of a vacuum tube to simulate a variable condenser or a variable inductance. This effect of the input circuit of a vacuum tube has been called the Meissner effect or Miller effect. The capacitive or inductive reactance of such a device may be varied by varying the slope of the grid-voltage plate current characteristic, or transconductance, of the vacuum tube as by varying the bias of the control grid of the tube. Fig. 1 shows an example of such arrangement. The input terminals of vacuum tube 3 are represented by numerals 1 and 2. The control grid is coupled through the condenser 4 to the terminal 1 and the cathode is connected to terminal 2. The tube 3 may be, as indicated, of the pentode type. A resistance 5 is connected in the anode circuit and the anode is capacitively coupled to the grid by means of a condenser 6 in series with condenser 4. The control grid is connected to the grounded cathode of the tube through a grid leak 7 and a source of bias potential, such as the battery 8. The impedance Z between termi-

nals 1 and 2 is then given by the following equation:

$$Z = \frac{1}{pC} \frac{1}{1 + g_m R} + \frac{R}{1 + g_m R} \quad (1)$$

5 in which:

Z=impedance between the terminals 1 and 2.  
p=Heaviside operator.

C=capacitance of condenser 6. (The capacitance of condenser 4 is so large that it may be neglected for the purpose of analysis.)

$g_m$ =transconductance of the tube.

R=resistance of resistor 5.

10 It is evident that the effective capacitance included in the impedance Z may be written as:

$$C_{eff} = C \cdot (1 + g_m R) \quad (2)$$

Equation 2 shows that the effective capacity included in the impedance Z may be varied by a variation of the transconductance  $g_m$  of the tube as by a variation of the bias from the source 3. Thus, the effect of the arrangement shown in Fig. 1 is that a reactive component is fed back to the grid circuit through the reactive coupling between the anode circuit and the grid circuit of the tube with the result that the input circuit of the tube simulates a condenser having a capacitance variable with the bias potential supplied to the grid by source 3.

30 By providing a coupling between the anode circuit and the grid circuit having an opposite phase relation to the arrangement of Fig. 1 it is possible to cause the grid circuit of the tube to simulate an inductance variable with bias of the tube. Fig. 2 illustrates such an arrangement in which elements similar to those in Fig. 1 are given the same reference numerals. An inductive coupling between the anode circuit and the grid circuit is effected by connecting in the plate circuit an inductance 9 inductively coupled to a winding 10 in the grid circuit. The mutual inductance between inductances 9 and 10 produces an effect corresponding, but opposite, to the effect of the coupling condenser 6 of Fig. 1.

45 The impedance between points 1 and 2, therefore, has a resistive component as well as an inductive component. With the addition of a variable condenser 12 and a padding condenser 11 in series with inductance 10, forming a frequency-determining circuit, the arrangement of Fig. 2 functions as an oscillator. The series impedance  $Z_1$  of inductance element 10 and condenser 11 is given by the equation:

$$Z_1 = r_1 + pL_1 + \frac{1}{pC_1} \quad (3)$$

55 in which:

$r_1$ =resistance of inductance element 10, represented at 10' in the drawing.

p=Heaviside operator.

60  $L_1$ =inductance of coil 10.

$C_1$ =capacitance of condenser 11.

If the effect of the mutual inductance transformed through tube 3 is taken into consideration, the effective impedance  $Z_2$  of circuit 10, 11 is as follows:

$$\frac{V}{I} = Z_2 = Z_1 \left( \frac{1}{1 + g_m p M} \right) \quad (4)$$

in which:

70 V=voltage between points 1 and 2.

I=current through inductance 10 and condenser 11.

$g_m$ =transconductance of the tube 3.

75 M=mutual inductance between inductance elements 9 and 10.

It should be noted that the mutual inductance M is, in this case, a negative quantity. By varying the transconductance of the tube as by variation of any of the electrode operating potentials, the impedance of circuit 10, 11 is correspondingly changed. From this it follows that the resonant frequency of the frequency-determining circuit of the oscillator is also varied. The present invention is effective substantially to eliminate such frequency variations.

An embodiment of the invention is shown in Fig. 3, which is a combination of the circuit arrangement shown in Figs. 1 and 2. The analysis of the arrangement of Fig. 3 is best carried out by considering separately the effect of the feedback through the mutual inductance between inductances 9 and 10 and that through condenser 6. Accordingly, the circuit will be considered without regard to the mutual inductance between inductances 9 and 10. The equivalent schematic circuit for such an arrangement is shown in Fig. 4. The impedance  $Z_3$  between the terminals 1 and 2 of Fig. 4 is given by the equation:

$$Z_3 = \frac{Z_1 - \left( \frac{1}{pC_1} \right)^2 \left[ \frac{1}{pC} + \frac{1}{pC_1} + R \right]}{1 + \frac{C_1}{C} + 1 + R p C_1} \quad (5)$$

All symbols have the same significance as in the preceding equations. If the capacitance  $C_1$  is made relatively large, as is usually the case, the quadratic factor in the right member in the numerator becomes infinitesimal and, as a first approximation, equation (5) may be written:

$$Z_3 = \frac{Z_1}{1 + \frac{C_1}{C} + 1 + R p C_1} \quad (6)$$

If capacitance C is chosen to be of about the same magnitude as capacitance  $C_1$ , and if resistance R is chosen to be of relatively large value, as is usually the case, the term

$$\frac{C_1}{C}$$

in the second denominator in Equation 6 is small relative to the term  $R p C_1$  and the first two terms in the second denominator in Equation 6 may be disregarded.

Equation 6 then reduces to the following:

$$Z_3 = Z_1 \left( \frac{1}{1 + \frac{g_m}{p C_1}} \right) \quad (7)$$

A comparison of Equations 4 and 7 indicates that the factor

$$\left( \frac{1}{1 + g_m p M} \right) \quad (8)$$

representing the inductive effect given by Equation 4 is the same magnitude as the factor

$$\left( \frac{1}{1 + \frac{g_m}{p C_1}} \right) \quad (9)$$

representing the capacitive effect given by Equation 7 if  $2\pi f M$  is chosen to be equal to

$$\frac{1}{2\pi f C_1} \quad (10)$$

or

$$\omega M = \frac{1}{\omega C_1} \quad (11)$$

It should be noted, however, that Equation 8 is not exact, inasmuch as certain approximations have been made in the transition from Equation 5 to Equation 7, whereas Equation 4 has not been approximated. Thus, a complete compensation of the inductive coupling effect by means of the capacitive coupling effect is not procured. It has been found, however, both by calculation and by experiments, that the inaccuracies due to the approximations are so small as to be of no practical significance. In order to obtain the greatest possible accuracy in compensation through an arrangement according to the invention, the terms appearing in Equation 5 should be given appropriate values to the extent to which one is free to choose their dimensions. If Equation 5 is transformed in a known way from vectorial to algebraic structure, and if  $Z_3$  is differentiated partially with respect to  $C$  and with respect to  $R$ , the condition for the greatest variation of  $Z_3$  with respect to  $C$  and  $R$  is found to be  $R\omega C=1$ ; that is

$$R = \frac{1}{\omega C}$$

or the impedance of  $C$  is equal to the impedance of  $R$  at the frequency of greatest variation of  $Z_3$ . If the oscillator is designed to operate at a constant frequency, this condition can evidently be satisfied. If, on the other hand, the oscillator is tunable over a range of frequencies, the circuit should be designed so that the above-indicated condition is satisfied at the mean frequency of the range.

Another embodiment of the invention is illustrated in Fig. 5. This circuit differs from that of Fig. 3 only in that inductance 9 is not connected in the main plate circuit, but in an auxiliary anode circuit comprising the auxiliary anode 13. A cathode-biasing resistor 14 shunted by a by-pass condenser 15 provides a bias source for tube 3 equivalent to source 8 of Fig. 1. The operation of the arrangement is in all respects similar to that described above with reference to Fig. 3.

The relation between frequency deviation and anode voltage of an oscillator embodying the circuit of Fig. 5 is shown in Fig. 6. Two different scales have been used as ordinates, that is, curve  $a$  having larger frequency units than that for curve  $b$  to enable both curves to be shown on the same diagram and at the same time to be kept within reasonable limits. The abscissae for both curves indicate the plate voltage of the tube. Curve  $a$  shows the frequency deviation of an oscillator not incorporating the feed-back circuit of the invention, while curve  $b$  shows the frequency deviation of such an oscillator embodying the invention and having a smaller frequency scale. It is seen that, in the latter case, the frequency deviation is practically constant with variation of the anode voltage. While Fig. 6 shows the deviation in frequency vs. anode voltage, corresponding characteristics for the circuit of Fig. 3 would preferably be shown as deviation in frequency vs. grid voltage. It is to be understood that the curves of Fig. 6 relate to the mean frequency of the system and a greater deviation of oscillator frequency would be obtained for other frequencies of the band.

Referring now to Fig. 7, there is shown a circuit diagram of a complete modulated-carrier signal receiver of the superheterodyne type embodying the invention, in which certain conven-

tional portions are indicated schematically since, per se, they form no part of the invention. This receiver comprises, in cascade, an antenna circuit 20, 21, a tunable radio-frequency selector 22, 23, a frequency-changer or oscillator-modulator tube 24, an intermediate-frequency selector system comprising the double-tuned transformer 42, 43 and 44, 45, an intermediate-frequency amplifier 60, a detector and automatic amplification control supply 61, an audio-frequency amplifier 62 of one or more stages, and a loud-speaker 63.

The oscillator-modulator 24 comprises an oscillation network 34, 35 and, in order to tune the radio-frequency selector network 22, 23 and oscillation network 34, 35 in unison, the tuning condensers 23 and 35 are ganged for uni-control as shown in the drawing. Neglecting for the moment the parts of the system involving the present invention, the system described above includes the features of a conventional superheterodyne receiver; the operation of such receiver being well understood in the art, detailed explanation is deemed unnecessary. Briefly, however, a desired modulated-carrier signal intercepted by the antenna 20 is selectively amplified in radio-frequency selector 22, 23 and converted in frequency changer 24 to an intermediate-frequency modulated-carrier signal. This signal is selectively amplified by the intermediate-frequency selector comprising double-tuned transformer 42, 43 and 44, 45 and amplifier 60, and translated therefrom to the detector and A. V. C. supply 61, where the audio frequencies of modulation and the automatic amplification control-bias potentials are derived. The audio frequencies of modulation are amplified in the audio-frequency amplifier 62 and reproduced in loud-speaker 63 in a conventional manner. Automatic amplification control potentials are supplied from unit 61 to the control grid 25 of oscillator-modulator 24 and to one or more tubes of intermediate-frequency amplifier 60.

Coming now to the parts of the system involved in the present invention, the cathode 27 of tube 24 is grounded in the usual way through a cathode-bias resistor 30 shunted by a by-pass condenser 31. The oscillator control grid 28 is connected to the cathode through grid leak 32 and coupled to the frequency-determining circuit 34, 35 through condenser 33. The oscillator anode 29 is coupled to a source of positive voltage, indicated as +B, through anode resistance 37 and to the frequency-determining circuit through condenser 38 and inductance 39, inductively coupled to inductance 34. Condenser 11' corresponds to condenser 11 of Figs. 2-5, inclusive. The main anode 40 of the tube 24 is coupled through an anode resistance 41 to the primary winding 42 of the tuned intermediate-frequency transformer 42, 43 and 44, 45. The tuned secondary circuit 44, 45 is connected to the input circuit of intermediate-frequency amplifier 60 in a conventional manner.

When there is being received a station having signals of widely varying amplitude due to fading or other causes, an automatic amplification control bias variable within wide limits is impressed on the outer control grid 25 of tube 24 through the above-described arrangement. This variation in the grid bias of tube 24 varies its transconductance and, as was brought out above, tends to cause the oscillator frequency to be subjected to a corresponding variation. To compensate for this variation the condenser 57 and resist-

ance 41 are provided according to the invention. The condenser 57 couples into the frequency-determining circuit 34, 35 a potential derived from the anode circuit of tube 24 and of proper phase to compensate for the tendency of the frequency of the oscillator to vary with varying transconductance of the tube 24, as described above in connection with Figs. 3-6, inclusive.

It will be understood that the coupling between electrode 29 and the frequency-determining circuit 34, 35 comprising the coupling path 38, 39, as well as the coupling between anode 40 and the frequency-determining circuit 34, 35 comprising the coupling path 57, 39, are each referred to in this specification as a coupling between the frequency-determining circuit and an output electrode of the tube. There is thus provided a separate means comprising an energy-transfer coupling having a phase opposite to that of the inductive energy-transfer coupling between the frequency-determining circuit 34, 35 and an output electrode of vacuum tube 24. This separate coupling means comprises the reactance of condenser 57 and inductance 39, as well as the resistance of resistor 41 of large impedance relative to the reactance of the coupling path, for coupling into the frequency-determining circuit a reactive component which is variable with transconductance of the tube 24 to compensate the tendency of variations in the transconductance of the tube to vary the output frequency of the oscillator.

While there have been described what at present are considered to be the preferred embodiments of the invention, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the spirit and scope of the invention.

What is claimed is:

1. A high-frequency oscillator comprising a vacuum tube having input and output electrodes, a frequency-determining circuit coupled to said input electrode, an inductive energy-transfer coupling between said frequency-determining circuit and an output electrode, whereby said oscillator is caused to oscillate at the frequency of said frequency-determining circuit, means for varying the trans-conductance of said tube thereby tending to vary the output frequency of said oscillator, and separate means comprising an energy-transfer coupling having a phase opposite to that of said inductive energy-transfer coupling between said frequency-determining circuit and an output electrode and including reactance and resistance of large impedance relative to said reactance for coupling into said frequency-determining circuit a reactive component variable with said transconductance to compensate said tendency.

2. A high-frequency oscillator comprising a vacuum tube having input and output electrodes, a frequency-determining circuit coupled to said input electrode, an inductive energy-transfer coupling between said frequency-determining circuit and an output electrode, whereby said oscillator is caused to oscillate at the frequency of said frequency-determining circuit, means for varying the trans-conductance of said tube thereby tending to vary the output frequency of said oscillator, and means comprising a resistor in an output electrode circuit of said tube and a condenser coupled between said last-mentioned

output electrode and said frequency-determining circuit for coupling into said frequency-determining circuit a reactive component variable with said transconductance to compensate said tendency.

3. A high-frequency oscillator comprising a vacuum tube having input and output electrodes, a frequency-determining circuit including a condenser and an inductance in one of its arms and coupled to said input electrode, an inductive energy-transfer coupling between said frequency-determining circuit and an output electrode, whereby said oscillator is caused to oscillate at the frequency of said frequency-determining circuit, means for varying the transconductance of said tube thereby tending to vary the output frequency of said oscillator, and means including a resistor in an output electrode circuit of said tube and a condenser coupled between said last-mentioned output electrode and the junction of said inductance and said first-mentioned condenser for coupling into said frequency-determining circuit a reactive component variable with said transconductance to compensate said tendency.

4. A high-frequency oscillator comprising a vacuum tube having input and output electrodes, a frequency-determining circuit coupled to said input electrode, an energy-transfer circuit between said frequency-determining circuit and an output electrode including an inductance inductively coupled to said frequency-determining circuit, whereby said oscillator is caused to oscillate at the frequency of said frequency-determining circuit, means for varying the transconductance of said tube thereby tending to vary the output frequency of said oscillator, and means including a resistor in an output electrode circuit of said tube and a condenser in series with said inductance and coupled between said last-mentioned output electrode and said frequency-determining circuit for coupling into said frequency-determining circuit a reactive component variable with said transconductance to compensate said tendency.

5. A high-frequency oscillator comprising a vacuum tube having input and output electrodes, a tunable frequency-determining circuit coupled to said input electrode, an inductive energy transfer coupling said frequency-determining circuit and an output electrode, whereby said oscillator is caused to oscillate at the frequency of said frequency-determining circuit, means for varying the transconductance of said tube thereby tending to vary the output frequency of said oscillator, and means including a resistor in an output electrode circuit of said tube, and a condenser coupled between said last-mentioned output electrode and said frequency-determining circuit for coupling into said frequency-determining circuit a reactive component variable with said transconductance to compensate said tendency, said condenser having a reactance equal to the mutual inductive reactance between said frequency-determining circuit and said first-mentioned output electrode at the frequency at which maximum compensation is desired.

6. A high-frequency oscillator comprising a vacuum tube having input and output electrodes, a frequency-determining circuit coupled to said input electrode, an inductive energy-transfer coupling between said frequency-determining circuit and an output electrode, whereby said oscillator is caused to oscillate at the frequency of said frequency-determining circuit, means for varying the transconductance of said tube there-

5 by tending to vary the output frequency of said oscillator, and means including a resistor in an output electrode circuit of said tube and a condenser coupled between said last-mentioned output electrode and said frequency-determining circuit for coupling into said frequency-determin-

ing circuit a reactive component variable with said transconductance to compensate said tendency, said resistor having an impedance equal to that of said condenser at the frequency at which maximum compensation is desired.

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