April 21, 1942. C. N. KIMBALL 2,280,527

OSCILLATOR DRIFT COMPENSATION DEVICE

Filed Sept. 7, 1940

Fig. 1

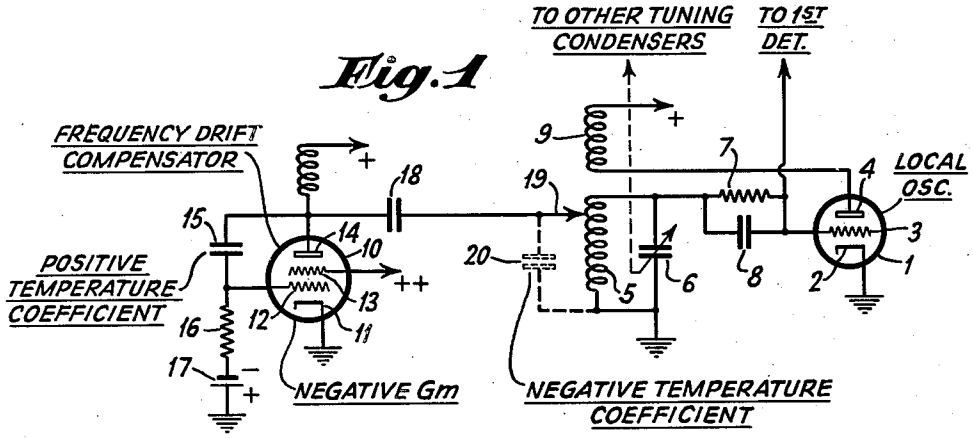


Fig. 2

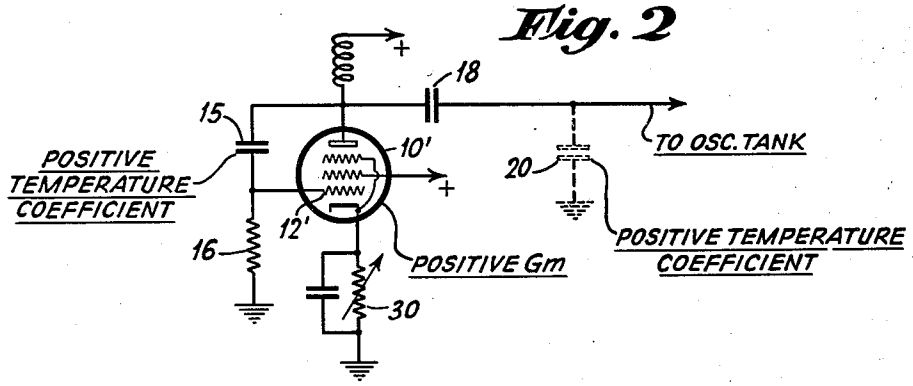
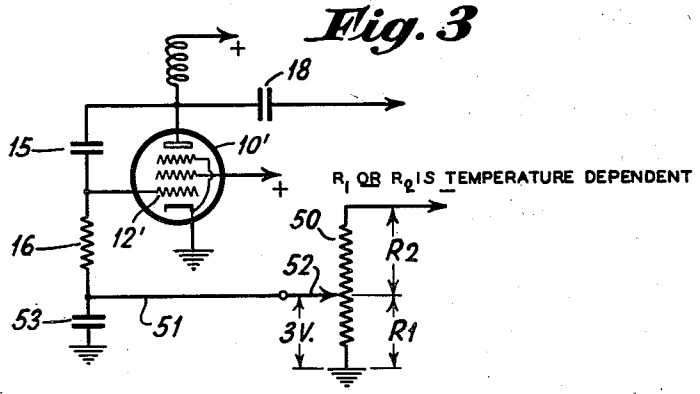


Fig. 3



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Patented Apr. 21, 1942 2,280,527

UNITED STATES PATENT OFFICE

2,280,527

OSCILLATOR DRIFT COMPENSATION DEVICE

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Application September 7, 1940, Serial No. 355,714

9 Claims. (Cl. 250—36)

My present invention relates to devices for reducing oscillator frequency drift due to thermal effects, and more particularly to electronic devices adapted to minimize oscillator drift at ultra-high radio frequencies.

One of the main objects of my present invention is to provide a frequency drift compensation device for the tank circuit of an oscillator, especially one operating at ultra-high frequencies, wherein the compensation device comprises an electronic device constructed and arranged to simulate across the tank circuit a reactive effect capable of compensating for the reactive effect causing the frequency drift.

Another important object of this invention is to improve frequency drift compensation devices, and the latter essentially comprising a tube having a mutual conductance of a predetermined polarity sign, a phase shift network being associated with the input and output electrodes of the tube to produce between the output electrodes a capacity effect whose sign of temperature coefficient is the same as, or reverse of, the sign of temperature coefficient of a capacity included in said phase shift network, but whose magnitude of temperature coefficient is altered by the capacitive multiplying action of the control tube.

Another object of the invention is to provide a capacity having a negative temperature coefficient of arbitrary value by utilizing a tube having a negative mutual conductance to provide between its output electrodes the said negative coefficient, a phase shift network employing a capacity of positive temperature coefficient being arranged in the tube circuits to provide a phase quadrature relation between the input and output electrode potentials of the tube.

Still another object of my invention is to provide a positive mutual conductance tube with a phase shift network embodying a positive temperature coefficient condenser, and there being produced between the tube output electrodes a reactive effect having a positive temperature coefficient.

Yet other objects of my invention are to improve generally the efficiency and reliability of frequency drift compensation devices, and more especially to provide frequency drift reducing networks, adapted for ultra-high frequency oscillation circuits, which are economically manufactured and assembled.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 shows an oscillator circuit embodying the invention,

Fig. 2 illustrates a modification,

Fig. 3 shows another modification.

Referring now to the accompanying drawing, wherein like reference characters in the different figures designate similar circuit elements, there is shown a tube 1 which may be of any well-known type. The tube is included in the tunable local oscillator network of a radio receiver of the superheterodyne type adapted to receive ultra-high carrier frequencies. For example, such carrier frequencies may be included in the frequency modulation (FM) band of approximately 40 to 50 megacycles (mc.). Of course, the present invention is not restricted to use in a radio receiver. Generally speaking it is directed to compensation of frequency drift in any oscillation circuit. Hence, by way of illustration, let tube 1 be provided with a cathode 2, a control grid 3 and a plate 4, and assume that coil 5 and variable condenser 6 provide the usual tunable tank circuit connected between the grid and cathode. The usual grid leak resistor 7, shunted by the capacity 8, is inserted in the grid side of the tank circuit. The plate is connected to the customary positive voltage source through a feedback coil 9 coupled reactively to tank coil 5. Where the circuit is used as the local oscillator of a superheterodyne receiver, the locally-produced oscillations may be taken off from the grid and applied to the first detector, or mixer, tube.

Now it is found that during the first 30 to 60 minutes of warm-up time frequency drift occurs in the tank circuit 5—6 due to changes in the values of the frequency-determining reactive elements produced by the thermal effects. In most practical cases the total change in the reactive elements with temperature may be denoted by changes in the capacity of variable condenser 6. Usually such drift has been corrected by paralleling the tuning capacitance with a small condenser known to have an appropriate value of negative temperature coefficient, it being assumed, of course, that the capacitance of the circuit has a positive temperature coefficient.

According to the present invention a highly flexible and efficient electronic device is used in

place of a physical shunt condenser. A tube is utilized in such a manner that its plate to cathode impedance is essentially a capacitative load across the tank circuit, or a portion thereof. In Fig. 1 the reactance tube is designated by the numeral 10, and it may be provided with a cathode 11, an input grid 12, an auxiliary grid 13 and a plate 14. The plate is fed with a proper positive voltage through a radio frequency choke, while a phase shift network comprising condenser 15 and a series resistor 16 are connected between the plate 14 and the grounded cathode. The negative biasing source 17 is connected between the lower end of resistor 16 and ground.

The grid 12 is connected to the junction of condenser 15 and resistor 16. Hence, the grid 12 has a fixed negative bias relative to its cathode. The plate 14 may be coupled to any desired point along coil 5 by the condenser 18, and an adjustable tap 19 may be used to provide the simulated capacitance 20 across any desired portion of the tank coil 5. The condenser 15 may have any arbitrary temperature coefficient in this form of the invention. The temperature coefficient (K) may be positive or negative, but not zero. By way of illustration, let it be assumed that the tuning capacitance of the tank circuit has a positive temperature coefficient. It is desirable, then, that the simulated capacitance 20 have a negative temperature coefficient so as to compensate for the capacity change with temperature in the tank circuit. This is readily accomplished by choosing a condenser 15 whose K is positive, and utilizing for tube 10 one having a negative mutual conductance ($-g_m$). The latter is simply secured by applying a substantially higher positive voltage to screen 13 than to plate 14. Those skilled in the art are fully aware of the many ways of producing a $-g_m$ tube.

It can be shown that the net change in total capacitance across the tank circuit 5—6 due to temperature is:

$$C_1K_1\Delta t - C_2K_2\Delta t g_m R \quad \text{---------- (1)}$$

where C_1 is the capacity of condenser 6 plus that of 20; K_1 is the effective temperature coefficient of condenser 6; Δt is the temperature change; C_2 is the capacity of condenser 15; K_2 is the temperature coefficient of 15 and is positive, but not necessarily equal to K_1; R is the resistance of resistor 16. The expression (1) can be made zero by making:

$$g_m R = \frac{C_1K_1}{C_2K_2} \quad \text{---------- (2)}$$

Hence, if K_2 is positive (value of C_2 increasing with temperature) g_m must be negative, and vice versa.

The advantage of the present arrangement resides in the control which is afforded over the effective value of K_2. This can be changed merely by adjustment of the g_m of tube 10. Thus, effectively,

$$K_2 = \frac{C_1K_1}{C_2g_mR} \quad \text{---------- (3)}$$

If no control tube 10 were used the value of K in the shunt correction condenser would have to be equal in magnitude, and opposite in sign, to the value of K in the drifting tuning capacitance. This is of importance to the set designer since it is often difficult to secure physical condensers of just the desired magnitude and sign of temperature coefficient. The present invention enables the designer to choose at random a condenser 15 of any small value, and of any sign for K, and by proper adjustment of tube 10 is able to magnify or diminish the value of 15 to the desired value, and even properly adjust the sign of K.

The invention is not limited to use of a negative g_m tube at 10, since the control tube may be a positive g_m tube. In general, the sign of the resultant capacity temperature K as seen at the control tube plate is determined by the quotient of g_m and the phase shifter condenser K. Hence, if either g_m or K_{15} is negative, then K_{20} is negative. If both K_{15} and g_m are positive or negative at the same time, K_{20} is positive. Thus, Fig. 2 shows tube 10' of the high plate impedance type, as a pentode, while the phase shifting network consists of condenser 15 whose K is positive and series resistor 16. The input grid 12' is connected to the junction of 15 and 16. The reactive effect 20 in this case is a capacitance having a positive K. The cathode lead may include an adjustable resistor 30, properly by-passed, to permit initial adjustment of the negative bias of grid 12' thereby to control the gain of tube 10'. As in the case of Fig. 1, the resistor 16 should have a sufficiently small magnitude to cause substantially a 90 degrees phase shift between the plate potential and input grid potential. Under these conditions the plate to cathode impedance of tube 10 (or 10') presents a capacitance effect across the tank circuit. Those skilled in the art are fully aware of this phenomenon. It can readily be shown that the plate to cathode impedance has a reactance equal to that which would be caused by a condenser whose magnitude and sign depends upon the magnitude and sign of the tube mutual conductance and on the value of the shifting network resistor. As the ambient temperature increases the magnitude of the tuning capacitance varies. Automatically the magnitude of capacity 15 varies and by virtue of the multiplying effect of tube 10 is able to produce a change in simulated capacitance 20 to an extent, and in such a direction, that the tuning capacitance change is accurately compensated for. This invention can readily be utilized for the ultra-high radio freqeuncies of the FM band. With the small variations in tuning capacitance encountered in tuning from one end to the FM band to the other the arrangement is as inherently capable of reducing oscillator drift as would be the more conventional direct application of a shunt condenser of negative or positive K to the oscillator tank.

In Fig. 3 there is shown another use of the invention. In this embodiment the phase shifter condenser 15 has a substantially zero K. The cathode of tube 10', which may be a pentode, is grounded. The grid 12' is connected to a negative potential point on voltage divider resistance 50 through a path comprising resistor 16, lead 51 and tap 52. The condenser 53 bypasses the resistor 16 to ground. Resistor 50 may include a bi-metallic or other temperature-dependent element so that the control tube grid bias is caused to change in a manner such that the frequency drift is maintained at a low value. The resistor 50 is connected across a direct current voltage supply source of negative polarity say about 20 volts. Tap 52 may be applied to a point which is about —3 volts relative to ground.

In the arrangement of Fig. 3 the g_m of tube 10' varies with temperature, while maintaining C_{15} constant. Thus, K_{15} is zero, and the control action would be effected by changes in g_m. The latter effect is produced by causing the tube bias

to vary with temperature. This may be done by employing a special construction for divider **50**. The divider resistor **50** is divided into two sections R_1 and R_2. One section has constant resistance not varying with temperature. The other section has a resistance varying with temperature. Since in most pentodes g_m varies approximately linearly with bias it follows that the effective K of the tube is the K of the resistor which varies with temperature in the divider. Thus, if it is desired to have g_m decrease as the temperature rises, which would cause the net output capacitance of the control tube to fall as the temperature rises, that is, the effect of a negative K, one can employ elements in the reactance tube grid circuit which have substantially zero change with temperature. There are several possibilities, all of which depend upon the fact that R_2 is substantially greater than R_1. This permits the assumption that $I=E/R_2$. The bias circuit may then be considered as a "constant current" circuit. Either R_1 or R_2 may be variable with temperature, although both may be variable if their temperature coefficients differ sufficiently to provide a reasonable relative resistance variation with temperature.

R_1 and/or R_2 may be obtained in either positive or negative K commercially. For example, wire wound resistors (copper, nickel etc.) have positive K. Carbon has a negative K. Based on an assumption of R_2 being greater than 10 R_1 the following combinations are possible:

R_1	R_2	g_m of tube 10'	Apparent capacitance of reactance tube
Constant with temp.	Rises with temp. (+K).	Rises as temp. rises (+K).	Rises as temp. rises (+K).
Rises with temp. (+K).	Constant with temp.	Falls with temp. (−K).	Falls with temp. (−K).
Falls as temp. rises (−K).	Constant with temp.	Rises as temp. rises (+K).	Rises as temp. rises (+K).
Constant with temp.	Falls as temp. rises (−K).	Falls with temp. (−K).	Falls with temp. (−K).

While I have indicated and described several systems 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 organizations shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. In combination with a resonant circuit adapted to vary in frequency by virtue of temperature effect on the circuit reactance, an electron discharge tube having at least a cathode and two cold electrodes, means applying alternating voltage across said circuit between said cathode and one of said cold electrodes, a phase shifter connected with said one cold electrode for developing from said voltage a second voltage in phase quadrature therewith, means applying the second voltage between the second cold electrode and cathode, and said phase shifter including a reactive element having a temperature coefficient of predetermined sign so related to the mutual conductance of said tube that a reactive effect is produced between said one electrode and cathode which has a temperature coefficient that effectively compensates for said frequency variation.

2. In combination with a resonant circuit adapted to vary in frequency by virtue of temperature effect on the circuit reactance, an electron discharge tube having at least a cathode and two cold electrodes, means applying alternating voltage across said circuit between said cathode and one of said cold electrodes, a phase shifter comprising a condenser in series with a resistor connected with said one cold electrode for developing from said voltage a second voltage in phase quadrature therewith, means applying the second voltage between the second cold electrode and cathode, and said phase shifter condenser having a temperature coefficient so related to the mutual conductance of said tube that a reactive effect is produced between said one electrode and cathode which effectively compensates for said frequency variation.

3. In combination with a resonant circuit adapted to vary in frequency by virtue of temperature effect on the circuit reactance, an electron discharge tube having at least a cathode and two cold electrodes, means applying alternating voltage across said circuit between said cathode and one of said cold electrodes, a phase shifter connected with said one cold electrode for developing from said voltage a second voltage in phase quadrature therewith, means applying the second voltage between the second cold electrode and cathode, and said phase shifter being so constructed and related to the mutual conductance of said tube that a reactive effect is produced between said one electrode and cathode which effectively compensates for said frequency variation, said phase shifter comprising a condenser and resistor in series, said condenser having a temperature coefficient of a positive sign, said mutual conductance being negative, and said reactive effect being of a negative temperature coefficient.

4. In an oscillator network having a tube provided with a tunable oscillation tank circuit whose tuning capacitance has a temperature coefficient of a predetermined sign, a device for producing a capacitance having a temperature coefficient of the opposite sign, said device comprising a tube having input and output electrodes, said output electrodes being coupled to said tank circuit, a phase shifter network connected to the output electrodes for developing an alternating voltage in substantially phase quadrature with the alternating voltage applied to the output electrodes from the tank circuit, means for applying said developed voltage to the input electrodes, said shifter including a capacitance having a temperature coefficient of the same sign as said tuning capacitance coefficient, and said last tube having a mutual conductance whose sign is such that there is developed between said output electrodes a capacitance whose temperature coefficient is opposite in sign to said tuning capacitance coefficient.

5. In an oscillator network having a tube provided with a tunable oscillation tank circuit whose tuning capacitance has a temperature coefficient of a predetermined sign, a device for producing a capacitance having a temperature coefficient of the opposite sign, said device comprising a tube having input and output electrodes, said output electrodes being coupled to said tank circuit, a phase shifter network connected to the output electrodes for developing an alternating voltage in substantially phase quadrature with the alternating voltage applied to the output electrodes from the tank circuit, means for applying said developed voltage to the input electrodes, said shifter including a capacitance hav-

ing a temperature coefficient of the same sign as said tuning capacitance coefficient, and said last tube having a mutual conductance whose sign is such that there is developed between said output electrodes a capacitance whose temperature coefficient is opposite in sign to said tuning capacitance coefficient said latter coefficient being positive in sign.

6. In an oscillator network having a tube provided with a tunable oscillation tank circuit whose tuning capacitance has a temperature coefficient of a predetermined sign, a device for producing a capacitance having a temperature coefficient of the opposite sign, said device comprising a tube having input and output electrodes, said output electrodes being coupled to said tank circuit, a phase shifter network connected to the output electrodes for developing an alternating voltage in substantially phase quadrature with the alternating voltage applied to the output electrodes from the tank circuit, means for applying said developed voltage to the input electrodes, said shifter including a capacitance having a temperature coefficient of the same sign as said tuning capacitance coefficient, and said last tube having a mutual conductance whose sign is such that there is developed between said output electrodes a capacitance whose temperature coefficient is opposite in sign to said tuning capacitance coefficient said latter coefficient being negative in sign.

7. In an oscillator network having a tube provided with a tunable oscillation tank circuit whose tuning capacitance has a temperature coefficient of a predetermined sign, a device for producing a capacitance having a temperature coefficient of the opposite sign, said device comprising a tube having input and output electrodes said output electrodes being coupled to said tank circuit, a phase shifter network connected to the output electrodes for developing an alternating voltage in substantially phase quadrature with the alternating voltage applied to the output electrodes from the tank circuit, means for applying said developed voltage to the input electrodes, said shifter including a capacitance having a temperature coefficient of the same sign as said tuning capacitance coefficient, and said last tube having a mutual conductance whose sign is such that there is developed between said output electrodes a capacitance whose temperature coefficient is opposite in sign to said tuning capacitance coefficient, said mutual conductance being so chosen that said output electrode capacitance has a coefficient magnitude variation substantially equal to that of said tuning capacitance coefficient change.

8. In an oscillator network having a tube provided with a tunable oscillation tank circuit whose tuning capacitance has a temperature coefficient of a predetermined sign, a device for producing a capacitance having a temperature coefficient of the opposite sign, said device comprising a tube having input and output electrodes, said output electrodes being coupled to said tank circuit, a phase shifter network connected to the output electrodes for developing an alternating voltage in substantially phase quadrature with the alternating voltage applied to the output electrodes from the tank circuit, means for applying said developed voltage to the input electrodes, said shifter including a capacitance having a temperature coefficient of the same sign as said tuning capacitance coefficient, and said last tube having a mutual conductance whose sign is such that there is developed between said output electrodes a capacitance whose temperature coefficient is opposite in sign to said tuning capacitance coefficient, said shifter network comprising a condenser in series with a resistor, and said input electrodes being coupled across said resistor.

9. In combination with a resonant circuit adapted to vary in frequency by virtue of temperature effect on the circuit reactance, an electron discharge tube having at least a cathode and two cold electrodes, means applying alternating voltage across said circuit between said cathode and one of said cold electrodes, a phase shifter connected with said one cold electrode for developing from said voltage a second voltage in phase quadrature therewith, means applying the second voltage between the second cold electrode and cathode, and said phase shifter being so constructed and related to the mutual conductance of said tube that a reactive effect is produced between said one electrode and cathode which effectively compensates for said frequency variation, said phase shifter including a condenser, said reactive effect having a temperature coefficient which is determined by the quotient of the tube mutual conductance and the condenser temperature coefficient.

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