June 27, 1933. F. R. LACK 1,915,368

OSCILLATOR

Filed Aug. 8, 1928

FIG. 1

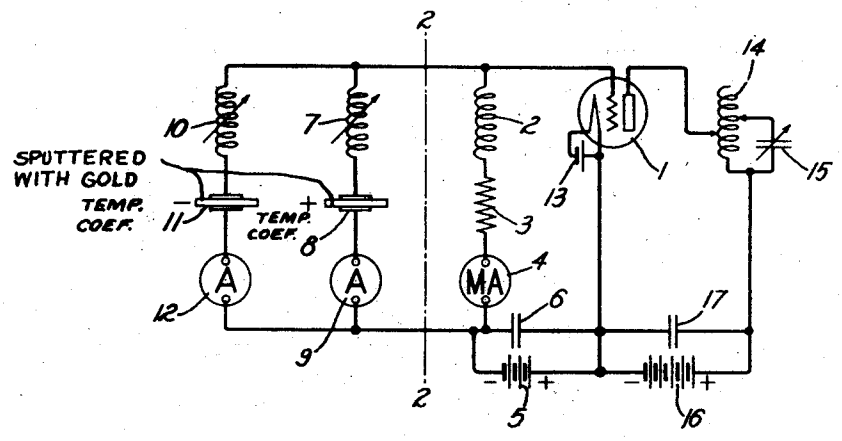
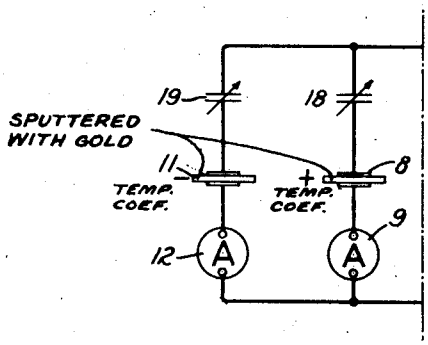


FIG. 2



INVENTOR
FREDERICK R. LACK

BY Gary T. Morris

ATTORNEY

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FREDERICK R. LACK, OF NEW YORK, N. Y., ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

OSCILLATOR

Application filed August 8, 1928. Serial No. 298,166.

This invention relates to control of operation of electric circuits and especially the frequency control of oscillators by piezo electric crystals.

An object of the invention is to reduce undesired variations in the frequency of a crystal controlled electric space discharge oscillator due to temperature variations.

Another object of the invention is to prepare a crystal for use so that it will operate more efficiently in a circuit.

A feature of the invention relates to the use of a plurality of piezo electric crystals, at least one of which has a temperature coefficient of frequency of opposite sign from the rest, for controlling the frequency of the oscillations generated by an oscillator.

Another feature of the invention is a piezo electric crystal which has been sputtered with gold to improve its operating characteristics.

In accordance with this invention, an oscillating system is controlled by a plurality of piezo electric crystals, at least one of which has a temperature coefficient of frequency of opposite sign to that of the others, whereby variations in frequency, due to changes in temperature, are reduced to a minimum.

The principles of this invention will be understood from the following description read in connection with the accompanying drawing; in which

Fig. 1 is a circuit diagram of one form of the invention, and

Fig. 2 shows an arrangement of apparatus alternative to that shown to the left of line 2—2 in Fig. 1.

Referring to Fig. 1 there is shown a space discharge tube 1 having an anode, cathode and control electrode. Connected across the grid and filament of the tube are an inductance coil 2, resistance 3, milliammeter 4 and battery 5. The inductance, resistance and battery are provided for the purpose of applying biasing potential to the grid and may be used jointly or alternatively. The battery 5 is shunted by by-pass condenser 6.

In parallel with the inductance, resistance and milliammeter in the grid circuit, there is connected in series a variable inductance 7, a piezo electric crystal 8 and an ammeter 9, and in parallel with these elements there is connected in series a second variable inductance 10, piezo electric crystal 11, having a temperature coefficient of opposite sign from the first mentioned piezo electric crystal, and an ammeter 12.

The filament of the space discharge tube 1 is heated by a battery 13. The plate of the tube is variably tapped to the inductance of a parallel tuned circuit consisting of inductance 14 and capacity 15, both of which elements are variable. The plate circuit continues from the tuned circuit through a space current supply battery 16 and back to the filament. The battery 16 is shunted by by-pass condenser 17.

Fig. 2 shows an alternative form for the portion of the circuit to the left of line 2—2 of Fig. 1, in which inductive reactances 7 and 10 of Fig. 1 are replaced by capacitive reactances 18 and 19, the remainder of the circuit being the same.

In the operation of the circuit in accordance with the principles of the invention, it is necessary to have two crystals of opposite temperature coefficients of frequency which have been cut to have an approximately equal natural frequency of vibration. The final adjustment of the frequency of the crystals to bring them to resonance at the same frequency may be made by means of the reactances 7, 10 or 18, 19 in series with the crystals. Either of these reactances may be omitted in either case. Thus, in Fig. 1 either inductance 7 or inductance 10 may be omitted and in Fig. 2, either capacity 18 or capactiy 19 may be omitted. However, it is more convenient to employ both. These reactances or other suitable means may be used to vary the natural frequency of the system in conjunction with tuned circuit 14—15.

The two ammeters 9 and 12 are important in this system as they give an indication when the two crystals are vibrating in synchronism. When this condition obtains, a critical amount of current will flow through each circuit branch containing a crystal and the meters will give an indication that the desired value has been reached. The usual

condition will be for equal amounts of current to flow through the two crystals.

At a selected temperature the system will oscillate at the natural frequency of the crystals. When, due to temperature variations or for other reasons the crystals tend to change their rate of vibration, each crystal will tend to pull the other back to the predetermined natural frequency of the system, hence the crystals cooperate to maintain the frequency of the oscillations at a constant, predetermined value, which is independent of temperature variations. This is effected by the reactive coupling between the crystals, through the inductances 7 and 10 or capacities 18 and 19. Since the crystals tend to change their rates of vibration equal amounts, but in opposite directions, these tendencies are counter-balanced by coupling the crystals in the manner shown.

The frequency of vibration of a crystal is affected by the spacing between the crystal and its electrodes. If the crystal shifts its position with respect to its electrodes when vibrating, its frequency is constantly changing.

Very minute changes in spacing materially affect the frequency of vibration. For example, if a crystal is merely turned over between its electrodes, some instances have been observed where a change in frequency of as much as 500 cycles per second occurs, due to the miscroscopic differences in the opposite surfaces of the crystal.

When a crystal is subject to spasmodic variations in its frequency of vibration of such magnitude, it is obvious that a constant frequency could not be obtained by combining the output of two crystals.

In the construction of crystal controlled oscillators, it is therefore necessary, in order to produce a system which will operate satisfactorily, to eliminate all effects due to variable physical relations of the crystals to their immediate environment. The above noted disadvantage may be avoided by coating the surfaces of the crystals with conducting material. The effect of coating a crystal is to combine the crystal and its holder more effectually into an integral unit and thus to eliminate undesired changes in frequency that tend to occur when the crystal shifts its position, as in an ordinary holder.

When the surfaces of the crystal are coated with conducting material, no shift occurs between two electrode surfaces. However, some conducting materials, such as chromium are difficult to apply to a crystal, while other substances, such as silver, which are not so difficult to apply, become corroded with time, making it difficult to make a good connection between the crystal and the circuit.

It has been discovered that the crystal may be coated very easily with gold by sputtering the gold on the crystal, that a crystal thus treated can be satisfactorily connected in a circuit, and that such a coating will not corrode.

What is claimed is:

1. An oscillating system comprising an oscillator, and a plurality of piezo-electric crystals of opposite temperature coefficients of frequency connected in circuit therewith for compensating the effect of temperature variations.

2. An oscillating system comprising an oscillator, having input and output circuits, and a plurality of frequency controlling piezo electric crystals in said input circuit, at least one of which has a temperature coefficient of frequency of opposite sign from the others, the coefficients of the respective crystals and the allocation of the crystals according to sign of coefficient being together such that the system as a whole undergoes substantially no frequency change with change in temperature.

3. A space discharge oscillator comprising a space discharge tube having anode, cathode and control electrodes, a reactance and a piezo electric crystal having a positive temperature coefficient in series between said cathode and control electrode, a second reactance and a second piezo electric crystal having a negative temperature coefficient in series in a path in parallel with said first mentioned reactance and piezo electric crystal.

4. Means for compensating temperature variations in a crystal controlled oscillator comprising two crystals arranged in parallel in the input circuit of said oscillator, one of said crystals having a positive temperature coefficient and the other of said crystals having a negative temperature coefficient.

5. Means for producing a constant frequency comprising a space discharge oscillator having a plurality of crystals of opposite temperature coefficients connected in parallel in its input circuit, and a reactance in series with each crystal, the coefficients of the respective crystals and the allocation of the crystals according to sign of coefficient being together such that the system as a whole undergoes substantially no frequency change with change in temperature.

6. An oscillating system comprising a space discharge oscillator having input and output circuits, and a frequency determining piezo electric crystal having a positive temperature coefficient of frequency and a frequency determining piezo electric crystal having a negative temperature coefficient of frequency connected in said input circuit, the coefficients of the respective crystals having such relative values that the system as a whole undergoes substantially no frequency change with change in temperature.

7. An oscillating system comprising an oscillator having input and output circuits, a frequency determining mechanically vi-

brating element having a positive temperature coefficient of frequency and a frequency determining mechanical vibrating element having a negative temperature coefficient of frequency both said vibrating elements being connected in said input circuit and their coefficients having such relative values that the oscillating system as a whole undergoes substantially no frequency change with change in temperature of said elements.

8. An oscillating system comprising a space discharge tube having input and output electrodes, a plurality of piezo electric crystals in parallel between said input electrodes, said piezo electric crystals having their opposite surfaces coated with gold, and at least one of said crystals having an opposite temperature coefficient of frequency from that of the remainder.

9. An oscillating device comprising a plurality of crystal bodies, means associated jointly with said crystal bodies for causing said bodies to vibrate continuously at their natural frequencies, a part of said bodies being of such type as to be adapted to undergo changes of one sign in response to temperature variations, and the remainder of said bodies being of such type as to be adapted to undergo changes similar in character, but opposite in sign, to the first mentioned changes, in response to the temperature variations.

10. An oscillation generator comprising a plurality of piezo-electric crystal plates, means for electrically interconnecting said plates, each of certain of said plates having a positive temperature coefficient of frequency, and each of certain of said plates having a negative temperature coefficient of frequency.

11. An electric circuit comprising an oscillation generator, a plurality of piezo-electric crystal bodies, means electrically interconnecting said crystal bodies, certain of said bodies having temperature coefficients of frequency of one sign and the remainder of said bodies having temperature coefficients of frequency of opposite sign.

12. A circuit in accordance with claim 11, said crystal bodies having substantially the same natural frequency of vibration.

13. An oscillator comprising an electric space discharge device, means for causing said device to generate self-sustained oscillations of given frequency, and a piezo-electric crystal device included in said means, said crystal device comprising crystal bodies having temperature coefficients of frequency opposite in sign.

In witness whereof, I hereunto subscribe my name this 6th day of August 1928.

FREDERICK R. LACK.