

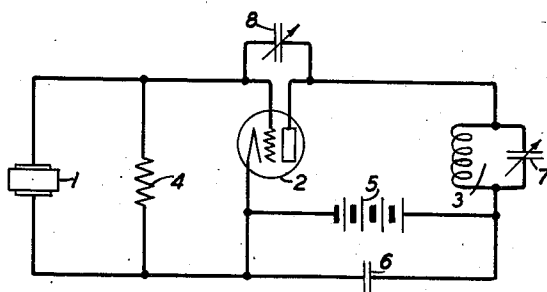
April 5, 1938.

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2,113,210

FREQUENCY STABLE ELECTRIC DISCHARGE OSCILLATOR

Filed Sept. 12, 1936



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2,113,210

FREQUENCY STABLE ELECTRIC DISCHARGE
OSCILLATOR

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Application September 12, 1936, Serial No. 100,429

4 Claims. (Cl. 250—36)

This invention relates to frequency stable electric discharge oscillators and especially to piezoelectric crystal controlled electric discharge oscillators embodying means operative with respect to the electric discharge device and circuit, that is, to elements external to the crystal itself, to make said electric discharge device and associated circuit elements comparatively immune to effects of temperature and voltage changes which would otherwise tend to change the oscillation frequency. The oscillator circuit of the invention is also frequency stable with relation to other changes in conditions of the various elements which, likewise as above, tend unless annulled or compensated for to change the oscillation frequency.

It has long been known that piezoelectric crystal controlled oscillators, although much more stable as to frequency than their prototypes which utilize electrical networks as the primary frequency determining means, have not been frequency stable enough for many purposes without resort to special accessory devices and expedients. They have not been stable enough for certain types of communication systems such as those adapted for single side-band telephony at high frequencies; and they have not been stable enough for frequency measurements or standardization of broadcast station transmitters; or for a variety of other purposes for which they are otherwise naturally adapted. This deficiency in frequency stability results from the significant fact that although in a crystal controlled oscillator, the crystal is the primary frequency determining means and preponderates over other frequency significant elements in the circuit organization as a whole because of its superb elastic characteristics in comparison with its electrical analogue coexisting in the circuit as a whole, nevertheless in the final analysis the circuit must be treated as a whole in this consideration of what determines the frequency. That is, all impedance elements in the circuit as a whole which have energetic relations with each other and with the crystal necessarily constitute therewith a network, and exert their composite characteristics therein in the determination of frequency. Because the circuit elements so associated with the crystal in the network as a whole are more gross, so far at least as concerns frequency significant characteristics, than the crystal, the oscillator organization as a whole nominally controlled as to frequency by the crystal has not measured up to the crystal itself as to frequency stability.

In the prior practice of the art, recognizing these deficiencies, special devices have been employed to keep voltages constant, to eliminate vibration difficulties, to keep the temperature of the crystal and circuit elements constant, etc., and often these devices must be calibrated or adjusted with particular tubes or electric discharge devices and are useless if a new tube has to be inserted upon the termination of the life of the original tube.

The present invention embodies a circuit which is devoid of most of these types of troubles, is simple enough to be manufactured and sold commercially, and which has a frequency stability which can otherwise be achieved if it can be achieved at all only by much more elaborate equipment. Frequency stabilized circuits in the past have commonly been considered as "stabilized" when they were so constructed or adjusted as to maintain their frequency substantially constant with reasonable variations in supply voltages. Variations in frequency induced by temperature changes, vibration, aging, etc., have been generally ignored as of little importance. In trying to meet new requirements in the radio art, such items have become important. This invention overcomes the difficulty.

The principal object of the invention is to generate oscillations by a crystal controlled oscillator with greater frequency stability than may be achieved by the average commercial crystal controlled oscillator, or than may be achieved by any crystal controlled oscillator with equal simplicity of circuit and operational procedure.

More specific objects of the invention are to generate oscillations by a crystal controlled oscillator with assurance that the frequency of oscillations will not change with variations in the potential applied either to the anode or cathode or with changes in ambient temperature.

Still further objects of the invention are to generate oscillations by a crystal controlled oscillator under conditions where the frequency does not substantially change with reasonable variations in the electrical parameters of the circuit such as would result from aging, moisture, vibration, or change in tube.

The above objects are achieved by a circuit organization which differs from a circuit which is well known in the prior art, comprising a piezoelectric crystal connected in the input circuit of an electric discharge device with a complementary variable reactance in the output circuit, by a critically dimensioned capacitance provided

ing a coupling between the input and output circuits supplementary to that provided by the interelectrode capacitance. The quality of frequency stability inheres in a critical relative adjustment of the value of this coupling capacitance and the reactance in the output circuit. This adjustment may be achieved empirically by sequentially adjusting the condenser which provides this coupling capacitance and the reactor in the output circuit, until a maximum frequency has been secured. This adjustment is to be sharply distinguished from adjustment of somewhat similar continuities of circuits in the prior art where the object to be achieved is a maximum output or maximum stimulation of the crystal with insurance against overstimulation.

For a more complete understanding of the objects and nature of the invention, reference is made to the following specification which is accompanied by a drawing, the single figure of which illustrates a preferred embodiment of the invention.

The drawing adequately discloses the continuity of the circuit of the invention but obviously can not by itself disclose the critical electrical dimensions by which novelty is imputed. The circuit accords with conventional standards so far as embodying a piezoelectric crystal 1 in the input circuit of an electric discharge device 2 the output circuit of which includes a tuned circuit 3. The control electrode biasing resistance 4, anode source 5, and by-pass condenser 6 are disclosed here in a conventional manner and have their usual attributes in the circuit organization. In the operation of this described prototype oscillator, the oscillations are started by an adjustment of the tuning of the circuit 3 relatively to the feedback capacitance constituted by the interelectrode capacity of the electric discharge device and relatively to the simulated impedance of the crystal. Quite obviously the crystal constitutes, effectively, an inductance in the operative adjustment of the circuit as a whole, the output circuit likewise effectively constituting an inductance at the operating frequency. Because the tuned circuit 3 is effectively an inductance it could be constituted solely by a variable inductor or the requisite ultimate variable inductance of the output circuit could otherwise be achieved. In the specific circuit illustrated, it is assumed, as would be expedient in practice, that this effective inductance is varied by variation of the condenser 7 constituting an element of the tuned circuit.

In the circuit of the invention as adapted from said prototype circuit, an auxiliary feedback is provided by the condenser 8 connected between the input and output circuits. This auxiliary feedback means may easily be tolerated with the use of the relatively low frequency crystal elements now available. When these low natural frequencies of crystal vibration are secured by use of cuts other than the conventional X and Y cuts, it is possible to achieve these low frequencies with the incidental very great advantage of a very low or substantially zero temperature coefficient of frequency, or even with the possibility of varying the temperature coefficient of frequency at will without serious effect on the frequency. Examples of low frequency crystal elements of this type are disclosed in copending application of G. W. Willard Serial No. 77,325, filed May 1, 1936. Therein these crystals are designated as the CT and DT types of crystal. It is believed that these designations will come

to be standardized in practice, if they have not been already. The letters C and D refer more generally to the types of cuts, the letter T indicating that the precise cutting and dimensioning is such as to result in a substantially zero temperature coefficient of frequency. The CT type of crystal has been used, with great success, in the circuit of the invention.

While other types of crystals than those above specified could be used in the circuit of this invention where frequency and reactance characteristics are such as to tolerate the use of the auxiliary feedback capacity, the use of crystals having substantially zero temperature coefficient, as illustrated by those designated in the above paragraph, is conducive to the most effective use of the circuit as a whole as contributing, with the specific frequency stabilizing attributes of the circuit as contributed by this invention, to the perfection of a crystal controlled oscillator as a whole which is immune to the effects of variables which would otherwise tend to change the frequency.

The procedure to adjust the circuit to a condition of maximum frequency stability is as follows: The condenser 8 is varied up or down so as to attain a value at which the frequency is a maximum. The reactance of the output circuit is then similarly changed as by means of the condenser 7 to attain a maximum frequency. These conditions of maxima may be very easily ascertained by use of a beat frequency oscillator and rectifier as in accordance with conventional practice. Then the condenser 8 should again be adjusted since it usually happens that the adjustment of one variable means slightly effects the condition of the circuit with respect to the other variable means. The two means are thereafter sequentially adjusted as many times as is necessary until a maximum frequency as determined jointly by these means is achieved. The particular ordering or initiation of these variations may be different from that described and it is immaterial to the result finally achieved.

In the experimental procedure which demonstrated the efficacy of this circuit, and which suggests the operational procedure in adjusting the circuit in practice, curves were plotted between output reactance and frequency for several values of feedback capacitance. It was noted that these curves each had a definite maximum with a broadening or flattening at the maximum point which was definitely a function of the feedback capacitance chosen. Then a similar curve was plotted between feedback capacitance and frequency for a given value of output reactance. As before, the curve was found to go through a maximum. Operating at this maximum, as by operating similarly at the maximum for anode reactance, small changes of the independent variable were found to cause no change in frequency and larger changes could only cause the frequency to decrease. Since varying the potentials applied to an electric discharge device causes changes in the impedances of the device, particularly those from anode to control electrode and from anode to cathode, if the oscillator is so adjusted that variations in these impedances do not affect the frequency, then the frequency should also be independent of voltage. This was demonstrated to be true by plotting curves between anode potential and frequency change for various values of output reactance and feedback capacitance, the trend in the changes of these curves thoroughly checking with deductions from

the curves first described. Finally, a curve was plotted between ratio of increment of frequency change and voltage change against feedback capacitance. It was found that it passed through zero at a value of feedback capacitance which checked closely with the maximum point of the experimental curve between variable capacitance and frequency. The composite adjustment for maximum frequency was found to give the maximum frequency stability.

This circuit has therefore a unique characteristic, not found in other electrical oscillator circuits. When adjusted the frequency does not change when the reactive elements such as control electrode-anode and anode-cathode circuit reactances are varied even though these elements are normally parts of the frequency determining circuit. This circuit is therefore stable with variations in reactance change when such changes are produced by vibration, temperature change, aging, etc.

In order that the frequency of the oscillator may not change when these reactances are changed there must naturally be some peculiar compensating effect occurring when the reactances change. When we look for a possible location for a variation which will compensate for these changes, it would appear that the control electrode-cathode resistance is the only dependent variable. The other variables, that is, the control electrode-anode reactance, anode-cathode reactance, and the anode-cathode resistance of the tube with anode voltage variations are all independent variables which are subject to variation by the previously mentioned causes. It has been found that when this circuit is properly adjusted, these three independent variables can be changed by reasonable amounts without changing the frequency. By reasonable amounts are meant amounts comparable with or larger than those which usually result from vibration, temperature change, aging, moisture, or exchanging the tube for a new one of the same type. There remains one variable in the oscillator which is a dependent variable, the control electrode-cathode resistance. It has been found that when the circuit is properly adjusted, variation in any one of the independent variables acts upon the dependent variable in such a manner as to produce a balancing effect. Varying any independent variable changes the amplitude of oscillations and such change causes the control electrode-cathode resistance to vary, and a compensatory action comes into being. The control electrode-cathode resistance is in parallel with the effective inductance of the crystal between control electrode and cathode and produces a change in

effective inductance which compensates for the independent variation. The circuit is stable for variations in these elements which are large compared to the amount of variations that normally occur in practice.

What is claimed is:

1. A crystal controlled oscillator adapted for maximum frequency stability corresponding to a given mode of crystal vibration comprising an electric discharge device having cathode, anode and control electrodes, an input circuit comprising a piezo-electric crystal element interconnecting said control electrode and cathode, an output circuit comprising a variable reactance means interconnecting said anode and cathode, and a variable capacitance means coupling said input and output circuits, said variable reactance and capacitance having mutually such electrical values as to achieve the maximum frequency of oscillation for a given mode of vibration of the crystal.

2. An oscillator as specified in claim 1 in which the variable reactance means is a tunable circuit comprising a variable condenser and said capacitance means is a variable condenser connected between the control electrode and anode, said condensers being mutually adjusted for a maximum frequency of oscillation.

3. The method of frequency stabilizing a crystal controlled oscillator comprising an electric discharge device having a cathode, anode and a control electrode with a crystal element connected to the control electrode and cathode of the device, and means connected to the anode and cathode of the device for varying the output reactance as in accordance with the crystal element impedance and the interelectrode feedback impedance, which comprises applying additional feedback coupling between the anode and control electrode, external to the device and similar to the inherent coupling within the device, and critically and mutually varying the degree of said external coupling and the output reactance until the oscillator delivers a wave of its maximum frequency for a given mode of crystal vibration.

4. The method of operating a crystal controlled vacuum tube oscillator having a crystal element connected to the input circuit electrodes of the tube, a tunable circuit connected to the output electrodes and a variable condenser between the output and input electrodes of the tube to provide an auxiliary feedback, which comprises critically and mutually varying said variable condenser and the tuning of said output circuit until the oscillator delivers a wave of the maximum frequency for a given mode of crystal vibration.

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