

Dec. 2, 1941.

L. F. KOERNER

2,264,764

CRYSTAL-CONTROLLED OSCILLATOR

Filed May 3, 1939

FIG. 1

FIG. 1A

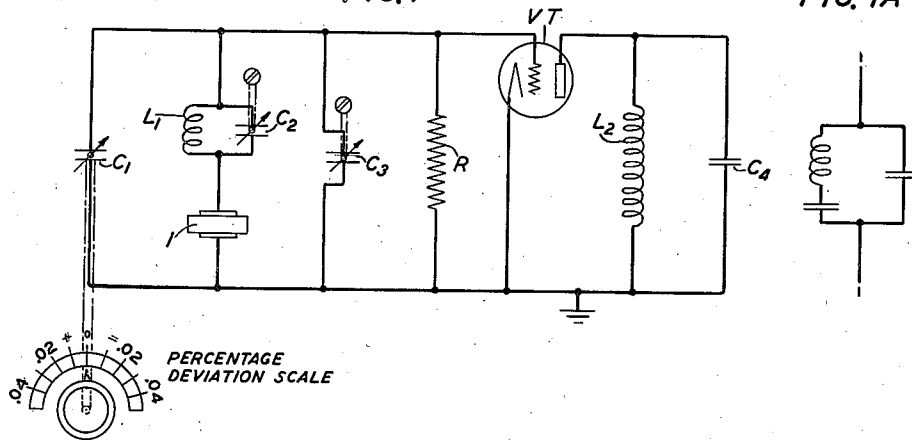
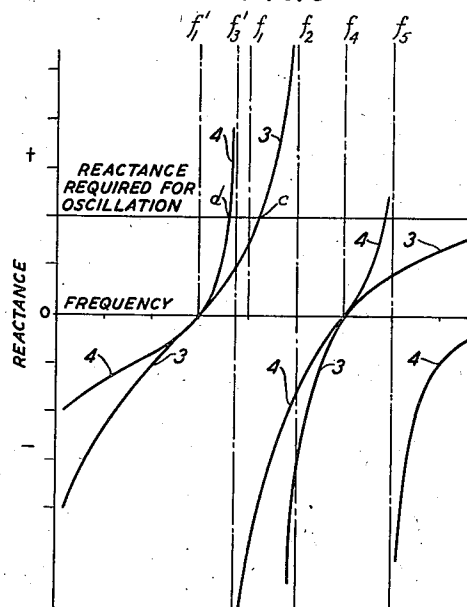
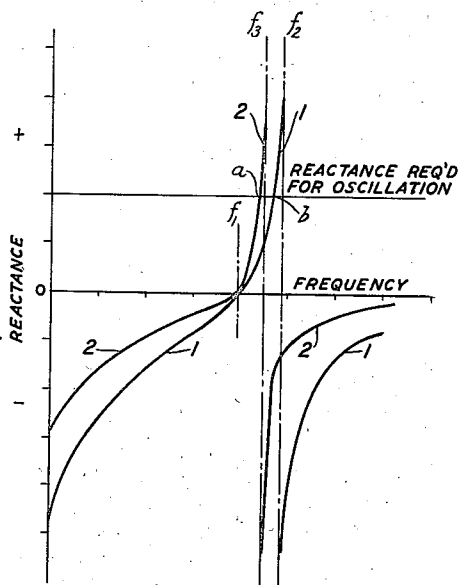


FIG. 2

FIG. 3



INVENTOR
L. F. KOERNER
BY *Guy T. Morris*
ATTORNEY

UNITED STATES PATENT OFFICE

2,264,764

CRYSTAL-CONTROLLED OSCILLATOR

Lawrence F. Koerner, Summit, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application May 3, 1939, Serial No. 271,427

3 Claims. (Cl. 250—36)

This invention relates to a piezoelectric crystal-controlled oscillator in which the immediate electrical environment of the crystal which controls and determines the oscillation frequency is so modified from prior practice, and so correspondingly modifies the operation of the crystal in relation to this environment, as to result in certain specific and desirable variances in the characteristic of the controlled oscillator as compared with prior practice.

A recent ruling of the Federal Communications Commission makes it mandatory for all stations operating in the ultra-high frequency broadcasting band to have frequency monitors. The limit of deviation from the assigned carrier frequency is ± 0.01 per cent. This requirement and limit tend to induce the use of a monitor oscillator which indicates percentage deviation rather than cycle deviation as is required in the instance of the present low frequency broadcast band. For practical convenience an important characteristic of such a monitor would be the use in it of a linear percentage frequency scale. For instance, since this implies a uniform dial calibration, it would tend to avoid an undue crowding at the critical portion of the frequency scale. What is more important, where crystal control is used, as would be desirable and almost necessary for accurate frequency indication, it would tend to make it more nearly possible to use a common percentage frequency dial or scale for a choice of piezoelectric crystal units all nominally having characteristic frequencies satisfying the given frequency requirement. This assumes, of course, that the crystal-controlled monitor oscillator is provided with means for varying the frequency slightly but to well outside of the limit of deviation. This variation of frequency might well be accomplished, and is accomplished in the present invention, by use of a so-called trimming impedance associated with the crystal.

Not only should there be a uniform scale calibration, as above, and therefore a linear relation between frequency and the variation of the trimming impedance by which the frequency is varied, but for corresponding reasons the variation of frequency by means of such trimming impedance should be large enough to so accommodate this choice of crystal unit without danger of stopping the oscillations.

It is an object of the invention to so electrically condition the circuits immediately associated with a control piezoelectric crystal that a linear percentage frequency variation results

from operation of an impedance element corresponding, for example, to the usual trimming inductance or capacitance associated with said crystal.

Another object of the invention is to so electrically condition the impedance network comprising the control crystal of the crystal-controlled oscillator that the characteristic frequency of the oscillator may be varied by said trimming impedance to a greater extent than is represented by prior practice without stoppage of the oscillation. Of course it is contemplated as a very desirable object that the relatively wide range of frequency variation necessary to satisfy the second object should, as well, satisfy the linear percentage frequency variation characteristic of the first object over as large a portion of the frequency band as possible.

Recognizing that while a fixed electrical conditioning of said network for wide range frequency variation represents a very important desideratum, optimum results may be achieved by more or less critical choice of said electrical conditions to suit, for example, a particular choice of crystal. Therefore, it is a subsidiary object of the invention to employ facile means for effectively changing the electrical conditioning of the network within the frame of the above objects.

The above objects are realized in this invention by adding to a standard crystal controlled oscillator circuit comprising a trimming impedance, especially a trimming capacitance, a second impedance, and preferably an inductance, in a complementary relation to the first impedance. For instance, if a shunt trimming condenser is used, an inductance is inserted between one terminus of the crystal and the terminus of the condenser otherwise connected thereto. The size of this inductance must be determined experimentally as it will vary not only with the percentage deviation required but also with the type of crystal, the frequency of the crystal, and the range of the trimming condenser. In order to provide an effective variation of said inductance, the invention contemplates the use of an adjustable condenser in shunt to the inductor, or with like result, the choice of one of a plurality of fixed condensers, the combination of inductance and capacitance at the frequency concerned of course having an inductive characteristic.

The nature of the invention and its various features and objects will appear more fully in the detailed description to follow when taken with

the accompanying drawing forming a part of this specification.

In the drawing:

Fig. 1 represents a preferred form of the crystal-controlled oscillator of the invention;

Fig. 1A represents the equivalent electrical circuit of the crystal of Fig. 1; and

Figs. 2 and 3 taken together comprise a graphical representation of the operation and characteristics of the oscillator of Fig. 1 as effected by the use of the impedance constituting an important element of the invention.

Per se the crystal controlled oscillator of the invention is merely a crystal controlled oscillator made variable by the usual trimming impedance, a shunt trimming condenser in the preferred form of Fig. 1, wherein the percentage frequency change varies linearly with the variation of the trimming impedance as indicated by the uniform percentage scale. The rotor shown diagrammatically in Fig. 1, the displacement of which is a measure of the percentage frequency change, is integral with the rotor of the variable condenser C_1 by means of which, solely, the frequency of the oscillator is varied while under the control of the crystal f . Thought of as a monitor oscillator, the wave from the oscillator is used to combine with an incoming carrier wave to give a zero beat and the setting of the percentage frequency scale at that point may be used to determine the percentage deviation from the standard frequency. For instance, the monitor oscillator itself may constitute a standard frequency source and the standard frequency may, by obvious mechanical adjustment, be made to coincide with the condition shown in Fig. 1 in which said standard frequency occurs for a zero reading of the percentage deviation dial. The subsequent change of frequency to equality with the incoming wave frequency will be indicated in the percentage deviation scale. Otherwise account may be taken of the particular point on the dial corresponding to such standard frequency.

The oscillator, except for the elements shown in immediate association with the crystal f is of a standard type with the grid leak R , vacuum tube VT and tuned plate circuit L_2C_4 . The frequency is set and determined by the natural frequency of the crystal f in the customary manner. That is, the impedance network in the input circuit of the vacuum tube and comprising the crystal as one element is distinguished by a frequency-reactance characteristic, mostly contributed by the crystal itself, which principally determines the frequency when treated as a reactance cooperating with the interelectrode capacitance of the tube and the impedance of the plate circuit which, at the control frequency, has an inductive characteristic. Because of the exceedingly great frequency discrimination displayed by this characteristic curve as effected principally by the crystal, a very close frequency control is impressed on the oscillator as a whole. The condensers C_1 and C_3 , of which condenser C_1 has already been mentioned, shunt the input circuit of the tube and the circuit comprising the crystal f and the effective inductance constituted by the inductor L_1 shunted by condenser C_2 . Condenser (capacitor) C_1 simulates the usual shunt trimming condenser and is a means for varying the frequency over a small range within the control of the crystal. The condenser C_3 functions similarly as the variable condenser C_1 but is invariable during the normal operation of the os-

cillator. It is used to adjust the zero of the dial at the desired nominal frequency, either by adjustment if capable of adjustment or by substitution otherwise. The convention used in Fig. 1 to indicate the character of this condenser is intended to suggest a screw-driver adjustment as distinguished from a variation in the common sense of the word.

The inductor L_1 is the most important element of the invention, in combination, and it serves two purposes, namely, to widen the range of frequency variation by the variable condenser C_1 without stopping the oscillations and to insure, over an adequate portion of this range, that the variation of frequency follows the linear percentage deviation law desired, and as indicated by the dial or scale of Fig. 1.

The range of frequency variation by the variable condenser C_1 , when the coil L_1 is used, is adequate to take account of necessary changes of crystals, that is, is great enough to compensate for deviations from the nominal frequency of each of a plurality of available crystals. However, to insure best operation and to avoid too great reliance on the condenser C_3 to adjust to zero of the dial, it is expedient to effectively vary the inductance of inductor L_1 and this is a function of shunt condenser C_2 since the combination of these two elements is inductive at the frequency concerned. This adjustment may be achieved by adjustment of the condenser C_2 itself or by substitution of one such condenser for another.

Of course, by proper choice of the network reactances the oscillator of the invention may be adapted for any frequency for which crystals may be used as the control means. Further, a particular network by proper choice of the crystal, may be used at any one of a number of different crystal harmonics covering a wide frequency range. Experience has proved that by this use of harmonics a carrier frequency range from 5 to approximately 100 megacycles may be covered by the circuit of the invention.

It has been found in practice that the maximum frequency deviation obtained by a shunt trimming condenser such as condenser C_1 alone, that is, without the use of the inductance of the invention, is not over ± 0.02 per cent and in most cases is less than ± 0.01 per cent. Since high frequency transmitters in general have a frequency accuracy of ± 0.025 per cent, in order to develop a monitor oscillator of these frequencies, in which therefore the variable frequency highly stable oscillator could be made to zero beat for the transmitter frequency, some means had to be developed to increase the frequency deviation range to at least this figure of ± 0.025 per cent. It was found that by the use of the inductance L_1 and by proper adjustment thereof deviations were possible up to ± 1 per cent, that is about fifty times the former deviation obtainable.

A plot of percentage frequency deviation against capacitance for various effective values of the inductance of element L_1 , either by varying the inductance itself or by adjustment or substitution of the shunting capacitance, was made and it was found that the curves were of the form

$$\frac{\Delta f}{f} = KC^n$$

where

$$\frac{\Delta f}{f}$$

equals percentage frequency deviation, K is a constant, C is the capacitance of the condenser C_1 and n is a number varying with the value of the positive reactance of the inductor L_1 , in which n varies from some value less than 1 for zero inductance to a maximum of about 2.1. Accordingly, to make possible a linear percentage deviation of frequency by variation of capacitance C_1 , it is necessary only to effectively adjust the inductance until n has a unity value. A practicable routine for the adjustment, actual or effective, of the inductance and therefore for setting up the circuit initially to satisfy a given condition is as follows. The method, which may well be practised by adjusting C_2 although an adjustment directly of L_1 would also be effective is cut and try, but fairly simple since it involves only three frequency measurements, one at the center of the dial and one at either end of the dial. The percentage frequency deviation corresponding to the two ends of the dial equally spaced from the center should be equal and the required percentage away from the center setting. The trimmer condenser C_3 is then adjusted to give the proper absolute frequency desired with the dial of C_1 set at center.

Figs. 2 and 3 together represent an attempt to explain, in terms of elemental network theory, how a network of the invention may have the characteristics demonstrated experimentally for the circuits of the invention. The Fig. 2 group of curves demonstrate the effect of the trimming condenser C_1 alone, the Fig. 3 group of curves representing the additive effects of a series inductance of the invention, at least to the extent of indicating how the range of frequency variation obtainable by varying the capacitance of condenser C_1 is increased thereby.

Curve 1 of Fig. 2 represents the frequency-reactance characteristic of the crystal alone, that is, without the trimming condenser. The crystal is simulated by the electrical circuit of Fig. 1A. In Fig. 1A the series inductance and capacitance of course represent the dynamic state of the crystal, the condenser in shunt therewith representing the static impedance, that is, capacitance of the crystal. This shunt capacitance would be that measured when the crystal is passive and would be closely simulated by a condenser using electrodes like the electrodes of the crystals and having a dielectric whose characteristics as such simulate those of the crystal. When a crystal is represented in the simple manner of Fig. 1A the shunt capacitance shown takes into account not only the actual static capacitance of the crystal but also the capacitance effectively in series with the crystal because of the spacing between the crystal and its electrodes and which is not shown separately in the simulated circuit. This curve 1 demonstrates by its exceedingly great slope in its inductive region the distinguishing characteristic of a crystal as a means for frequency control, since in most crystal-controlled circuits and in the circuit of Fig. 1, the crystal operates in this region.

Curve 2 represents the conditions as affected by adding a trimming condenser like condenser C_1 in shunt to the crystal. It is evident that this curve exhibits a greater slope than curve 1. This difference gives a measure of the slight coercion of frequency made possible by adjustment of this capacitance. That is, the crystal may be thought of as being conditioned thereby so as to give greater scope to frequency change within the limitation that the frequency must

accord with a value on the inductive portion. It is notable that the zero reactance points are coincident for the two curves. It is assumed that the capacitance contemplated by this curve 2 is not great enough to stop oscillation. While the zero reactance point is not changed, the infinite reactance point or antiresonant frequency is appreciably changed, that is, it is changed from frequency f_2 to f_3 .

For practical reasons it is not possible to operate at all inductance points of either curve 1 or curve 2. It is assumed, which is quite reasonable, that operation may occur with a reactance indicated by the line shown above and parallel with the zero reactance line. This line intersects curves 1 and 2 at points b and a , respectively. Therefore, the frequency difference corresponding to these two points is a measure of the possible variation of frequency by a shunt trimming capacitance. That is, while the control frequency, where the crystal alone is used, occurs somewhere in the range of frequency from zero resonance frequency f_1 to the frequency corresponding to point b , and correspondingly when the trimming condenser is used the control frequency occurs at the same reactance value somewhere between said frequency f_1 and the frequency corresponding to point a , the frequency difference corresponding to points a and b is alone attributable to the variation of the shunt trimming capacitance.

In the group of curves of Fig. 3, the same literal designations as in the group of the curves in Fig. 2 are used so far as possible to indicate analogous conditions. As has been already indicated, these curves represent the case of the use of the series inductance of the invention. Curve 3 assumes a value of shunt trimming capacitance equal to zero, curve 4 a value of shunt trimming capacitance equal to that used before. Accordingly, curves 3 and 4 correspond to curves 1 and 2 of the Fig. 2 group. The effect of the use of the inductance is to shift the zero or series resonance point, as compared with the condition represented by curve 1 of Fig. 2 from frequency f_1 to frequency f_1' , but does not change the conditions as to anti-resonance. When the shunt trimming capacitance is added to make the curve 4, the zero reactance frequency remains the same but the infinite reactance or anti-resonant frequency now shifts from frequency f_2 (as compared with curve 2 of Fig. 2) to f_3 and an additional infinite reactance frequency f_3 is obtained. The oscillator would operate at frequencies corresponding to the inductive portions of the curve near either f_3' or f_3 but the series inductance is kept sufficiently low to make f_3 too far distant to be tuned by the plate circuit of the oscillator. The maximum frequency deviation has been increased, as is further shown by the intersections of the line corresponding to the reactance required for oscillation with the two curves at d and c , the difference in the corresponding frequencies being greater than in the case of the curves in Fig. 2 where no series inductance is assumed to be used. This demonstrates the efficacy of the series inductance in increasing the range of frequency deviation without stoppage of oscillation, as has been pointed out. It has been found possible to multiply this range by a factor of as much as 50 by the use of this expedient when the value of the inductance is adjusted to suit the conditions represented by the different values of shunt trimming capacitance. It is notable that although the principle of

the invention is well exemplified by the particular choice of reactive elements indicated in Fig. 1, and positioned as there indicated, it may be exemplified also by variant types of circuit networks particularly by making use of the complementary character of inductance and capacitance when used in relatively contrasting circuit positionings. That is, a series inductance simulates in character a shunt capacitance, the converse being true. The principle of the invention might well be exemplified also in a circuit in which the trimming impedance of the invention might be constituted as before by a capacitance, but with a series inductance like that of Fig. 1 in series with it. In other words, in shunt to the crystal would be the inductance and capacitance in series, with either the inductance some fixed value determined by the linearity of the frequency characteristic desired plus a variable condenser, or a fixed condenser with a variable inductance, such as variometer, in series.

What is claimed is:

1. In a crystal-controlled frequency monitoring system including an electric discharge device having input and output terminals and a piezoelectric crystal and adapted to generate electrical oscillations of frequencies determined by vibrations of said crystal, a frequency-shifting circuit of two branches connected in parallel between the input terminals of said device, one of said branches solely comprising said crystal and a positive reactance impedance means connected in series, the other of said branches solely comprising a variable negative reactance impedance means, and a scale adapted to indicate the variations of said negative reactance and hence the frequency variations of said generated oscillations, said positive reactance having such an empirically determined value that when said variable negative reactance is varied in equal degree in either direction from the scale point corresponding to a given frequency, as indicated by corresponding equal scale displacements, the corresponding percentage frequency changes from said given frequency are likewise equal for

a frequency range of substantially ± 1 per cent of the operating frequency, that whereby changes of said negative reactance effect linear percentage changes of the oscillation frequency.

2. The combination with an electric discharge device having input and output terminals for generating electrical oscillations and a piezoelectric crystal for confining said oscillations to vibration frequencies of said crystal, of a circuit arrangement for effecting percentage frequency changes of the oscillation frequency which are linear with changes of a circuit element comprising a circuit of at least two parallel branches, connected at its terminals to the input terminals of the discharge device, one branch of said circuit solely consisting of the crystal and an inductive impedance means connected in series, a second branch consisting solely of a variable capacitive reactance means, other branches of said circuit, if any, being capacitively reactive, and a scale adapted to indicate the variations of capacitance in said variable capacitive impedance means and hence the frequency variations of the generated oscillations, the inductance of said inductive impedance means having such a value as empirically determined that when the capacitance of said variable capacitive impedance means is varied in equal degree in either direction from that corresponding to a given frequency, as indicated by corresponding equal scale displacements, the corresponding percentage frequency variations from said given frequency are likewise equal for a frequency range of substantially ± 1 per cent of the operating frequency, whereby changes of said reactance may effect linear percentage changes of the oscillation frequency.

3. The organization specified in claim 2 including a third branch in parallel to said first-mentioned branches, consisting solely of a variable capacitive impedance means and adapted by adjustment of its capacitance to determine, independently of other means, a given frequency corresponding to a given initial scale reading.

LAWRENCE F. KOERNER.