Aug. 26, 1969 D. J. FEWINGS 3,463,945

PIEZO-ELECTRIC CRYSTAL CIRCUIT ARRANGEMENTS

Filed Jan. 23, 1967 2 Sheets-Sheet 1

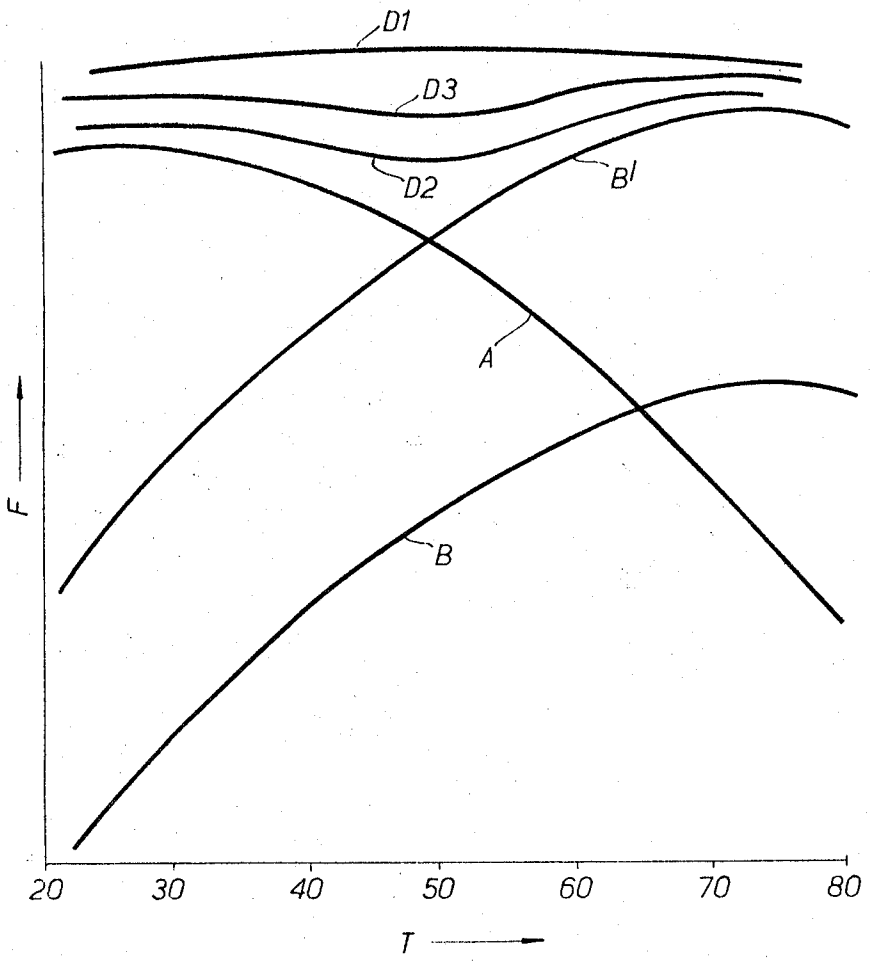


FIG. 1.

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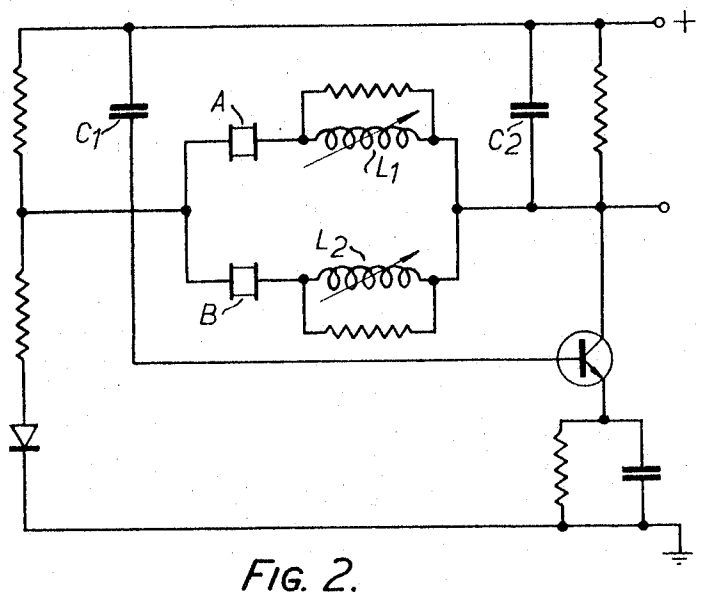


FIG. 2.

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3,463,945

PIEZO-ELECTRIC CRYSTAL CIRCUIT ARRANGEMENTS

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Int. Cl. H03b 5/32
U.S. Cl. 310—8.9 5 Claims

ABSTRACT OF THE DISCLOSURE

Piezo-electric circuit arrangement of good temperature stability consisting of a number of crystals each having a parabolic frequency/temperature characteristic and each connected in one of a like number of paralleled circuits. The crystals are chosen to have their individual "turnover temperatures" at the same frequency but at different temperatures spaced apart over a temperature range to be covered.

This invention relates to piezo-electric crystal circuit arrangements and has for its object to provide improved multiple crystal circuit arrangements in which the variation of frequency with temperature shall be relatively small and very small in relation to the frequency-temperature characteristic which would be exhibited by one of the crystals of the arrangement if employed alone. The invention, though not limited to such use, is partcularly well adapted for use in conjunction with the invention contained in the co-pending application of David John Fewings and Harvey Joyce Pipe, Ser. No. 539,059, filed Mar. 31, 1966.

Certain forms of crystal, notably "AT" cut crystals, exhibit only comparatively small frequency variations over a wide temperature range but such crystals have the serious defects that the law relating frequency with temperature is complex and not predictable in advance of manufacture. This means that, in many cases, when a crystal is required for a particular oscillator it has to be selected from a batch. Moreover, if a compensating circuit (e.g. as in the aforesaid co-pending application No. 539,059) for compensating for temperature variations of frequency is employed for such a crystal it becomes complicated and difficult to design.

There are, however, forms of crystal which exhibit a low or characteristic connecting frequency (ordinates) with temperature (abscissae) which is substantially parabolic in shape and has what is called a "turnover temperature" i.e. a temperature, corresponding to the "crown" of the parabola, where maximum frequency occurs. These substantially parabolic characteristic crystals are considerably better as regards complexity of the law connecting frequency with temperature and, moreover, individual such crystals taken from a batch are much more alike in performance. Such crystals, however, are considerably more frequency-dependent on temperature, especially when the temperature range is wide. Because of the substantially parabolic shape of the characteristic a low rate of change of frequency with temperature is obtained only over a limited temperature range around the "turnover temperature." Outside this limited range frequency changes increasingly rapidly with change of temperature. Moreover if a compensating circuit is required to be used in conjunction with such a crystal it becomes undesirably complex and expensive if the range over which it is required to provide compensation is materially wider than the limited range above mentioned. To quote practical figures a compensating circuit as described in the aforesaid co-pending

application Ser. No. 539,059 if used with a "BT" cut crystal (a well known form of crystal having a substantially parabolic frequency-temperature coefficient) having a turnover temperature of 25° becomes considerably more complex and expensive and requires more transistors if the temperature range materially exceels 0°–50° than if that range is all that has to be handled.

The present invention seeks to provide improved piezo-electric crystal circuit arrangements which shall, despite employing crystals each of which individually has a substantially parabolic frequency-temperature characteristic, exhibit a wide range frequency-temperature characteristic with considerably less variation in frequency than does the characteristic of an individual component crystal.

According to this invention a piezo-electric crystal circuit arrangement comprises a plurality of crystals each in one of a plurality or circuits in parallel and each having an at least approximately parabolic frequency-temperature characteristic said crystals having their individual "turnover temperatures" occurring at substantially the same frequency but at different temperatures spaced apart in a temperature range to be covered.

In the preferred and simplest embodiment of the invention there are two circuits in parallel, one containing one crystal and the other containing a second crystal in series with a reactance dimensioned to cause the second crystal to have its "turnover temperature" at the same frequency as that of the first despite being at a different temperature. The invention is not, however, limited to the use of only two crystals in parallel circuits and larger numbers of crystals in parallel circuits: for example five crystals in parallel circuits have been successfully employed in experimental practice.

One form of crystal which may be employed in carrying out the invention is the "BT" cut crystal.

The invention is illustrated in the accompanying drawings in which FIGURE 1 is an explanatory graphical figure and FIGURE 2 is a circuit diagram of one embodiment of the invention.

Referring to FIGURE 1, curves A and B are the frequency-temperature characteristics of two "BT" cut crystals A and B, of which A, alone and as manufactured, has a "turnover temperature" of 27° C. and B, alone and as manufactured, has a "turnover temperature" of 75° C. In FIGURE 1 F is frequency and T is temperature. These two crystals are connected in two parallel circuits, a preferred oscillator circuit arrangement using a transistor as the active element being shown in FIGURE 2. As will be seen each of these two circuits includes a resistance shunted adjustable inductance L1 or L2 and condensers C1 and C2, which may also be adjustable if desired, are connected as shown. The values of condensers C1 and C2 are chosen to secure maximum flatness of the frequency-temperature characteristic of the combination and the inductances L1 and L2 enable the turn-over frequency of each crystal to be set at the required value despite minor variations due to unavoidably cutting tolerances. The circuit is so dimensioned that the curve B is lifted along the frequency axis to curve B′ the "turnover temperature" of which is substantially at the same frequency as that of curve A. Curves A and B′ are substantially symmetrical about the middle of the temperature range, i.e. about the temperature of 51° C. Curves D1, D2 typify resultant frequency-temperature characteristics obtainable from arrangements of the nature of that shown in FIGURE 2.

The actual curve obtained in any individual case depends on detailed design. The curve D1, which mathematical analysis indicates to be the maximally flat curve, is obtainable by suitable choice of component values, but, depending on the component values actually chosen, any of a family of curves lying approximately between curves D1

and D2 e.g. curve D3, can be obtained. It will be seen that in none of the curves is there any great variation of frequency with temperature and, in curve D1, the frequency varies very little with temperature. The frequencies of these overall resultant curves are higher than those of either curve A or B' because of modification of circuit parameters due to the presence of both crystals. It may be shown mathematically that if an oscillator is offered two alternative frequencies at which it can oscillate it will oscillate at the frequency at which the series resistance is lower. In the embodiment of FIGURE 2 there are in effect two series resonant circuits in parallel and at any given temperature the oscillator frequency tends to be that of the crystal offering the lower series resistance at that temperature, i.e. the crystal which at that temperature resonates at the higher frequency. In the middle temperature range (around 51° C.) both crystals offer substantially equal series resistances and both contribute to the oscillator frequency. In a practical embodiment the "changeover" from one crystal to the other as the temperature moves through the mid-temperature occurs smoothly and no discontinuity is discernable in practice.

The condition to be satisfied to obtain maximum flatness of the frequency-temperature characteristic is

$$X_c = -8\pi L\beta T_x^2 \qquad (1)$$

where X_c=to the reactance of the total circuit capacitance in series with the crystal combination (i.e. the reactance of C_1 and C_2 in series in FIGURE 2 L=the inductance of each crystal (assuming they are equal in inductance) $\beta=\alpha f_c$ where α is the coefficient (see Equation 2 below) of either parabola (assuming they are equal and f_c is the frequency of either crystal at turnover and T_x=half the difference in temperature between the two turnover temperatures. Because the frequency-temperature coefficient is (theoretically) parabolic

$$\frac{f-f_o}{f}=\alpha(T-T_o)^2 \qquad (2)$$

where:

f_o=frequency at the turnover temperature T_o and
f=frequency at any temperature T

Equation 1 above enables crystals to be chosen to provide maximum compensation at any desired frequency. Equation 3 below determines the frequency of the crystal combination and enables crystals to be chosen to give a desired compensated frequency f_k.

$$f_k=f_c+3\beta T_x^2 \qquad (3)$$

As will be seen from Equation 1 the limit of compensation is reached when X_c becomes too large for the oscillator to oscillate. The possible range of compensation at any frequency is determined by the crystal inductance at that frequency. BT cut crystals have relatively low inductance at 8 mc./s. and therefore this is a favourable frequency as regards compensation. It has been found possible, in experimental practice at this frequency and using only two BT cut crystals in parallel circuits, to keep the frequency constant to one part in a million over a temperature range extending from −26° C. to +66° C. Even wider temperature ranges can be handled by increasing the number of crystals. Calculation indicates that at 10.5 mc./s., it is possible to achieve compensation to one part in a million over a range of −40° C. to +80° C. by using three crystals in parallel circuits. Any small remaining variations of frequency with temperature can easily be virtually eliminated, if required, by using a compensating circuit, for example, as described in the aforesaid co-pending application Ser. No. 539,059 despite that a wide range of temperature variation may be involved.

The invention is, of course, not limited to the particular circuit shown in FIGURE 2 and other (and simpler) circuits are possible. Pribabaly the simplest circuit consists merely of two branches in parallel, one containing one crystal alone and the other containing a second crystal in series with a condenser.

I claim:

1. A piezo-electric crystal circuit arrangement comprising a plurality of crystals each in one of a plurality of circuits in parallel, each of said crystals having an at least approximately parabolic frequency-temperature characteristic, said crystals having their individual "turnover temperature" occurring at substantially the same frequency but at different temperatures spaced apart in a given temperature range to be covered and the frequency-temperature characteristic of each of said crystals intersecting the frequency-temperature characteristics of those of said crystals having adjacent "turnover temperatures."

2. An arrangement as claimed in claim 1 wherein there are two circuits in parallel, one containing one crystal and the other containing a second crystal in series with a reactance dimensioned to cause the second crystal to have its "turnover temperature" at the same frequency as that of the first despite being at a different temperature.

3. An arrangement as claimed in claim 1 wherein each crystal has an adjustment inductance in series therewith.

4. An arrangement as claimed in claim 1 wherein the crystals are BT cut crystals.

5. An arrangement as claimed in claim 1 wherein the circuit elements are dimensioned at least aprpoximately to satisfy the equation

$$X_c = -8\pi L\beta T_x^2$$

as herein defined.

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J D MILLER, Primary Examiner

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310—8.1, 8.6; 331—116; 333—72