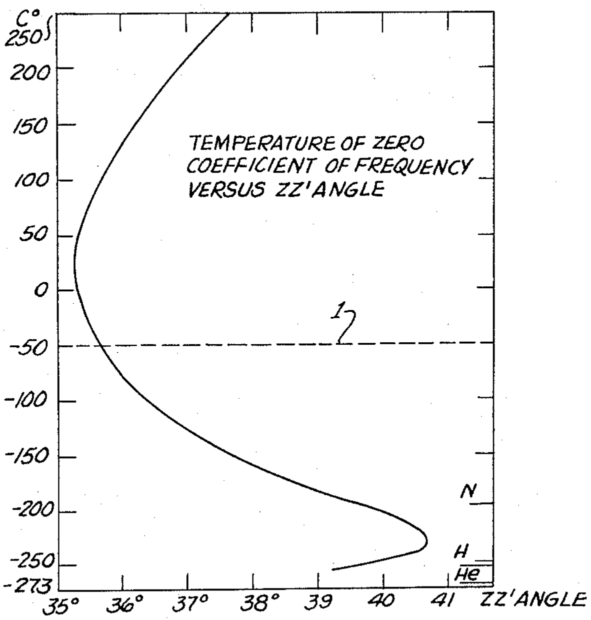
April 5, 1960 P. A. SIMPSON ET AL **2,931,924**

QUARTZ OSCILLATOR UNIT FOR OPERATION AT LOW TEMPERATURES

Filed June 25, 1958 5 Sheets-Sheet 1

Fig. 1



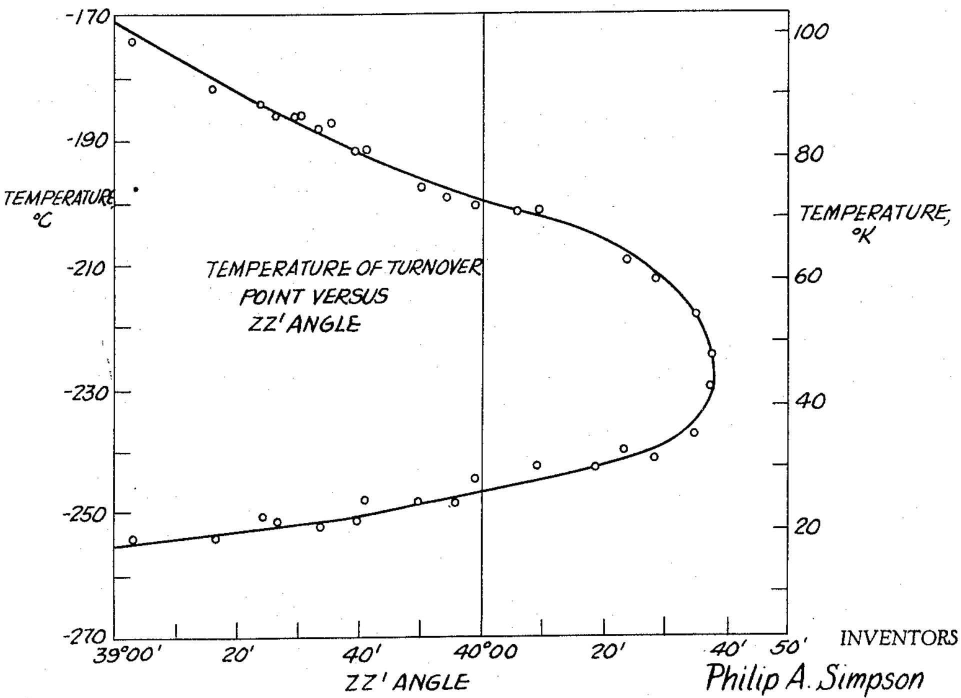


Fig. 2

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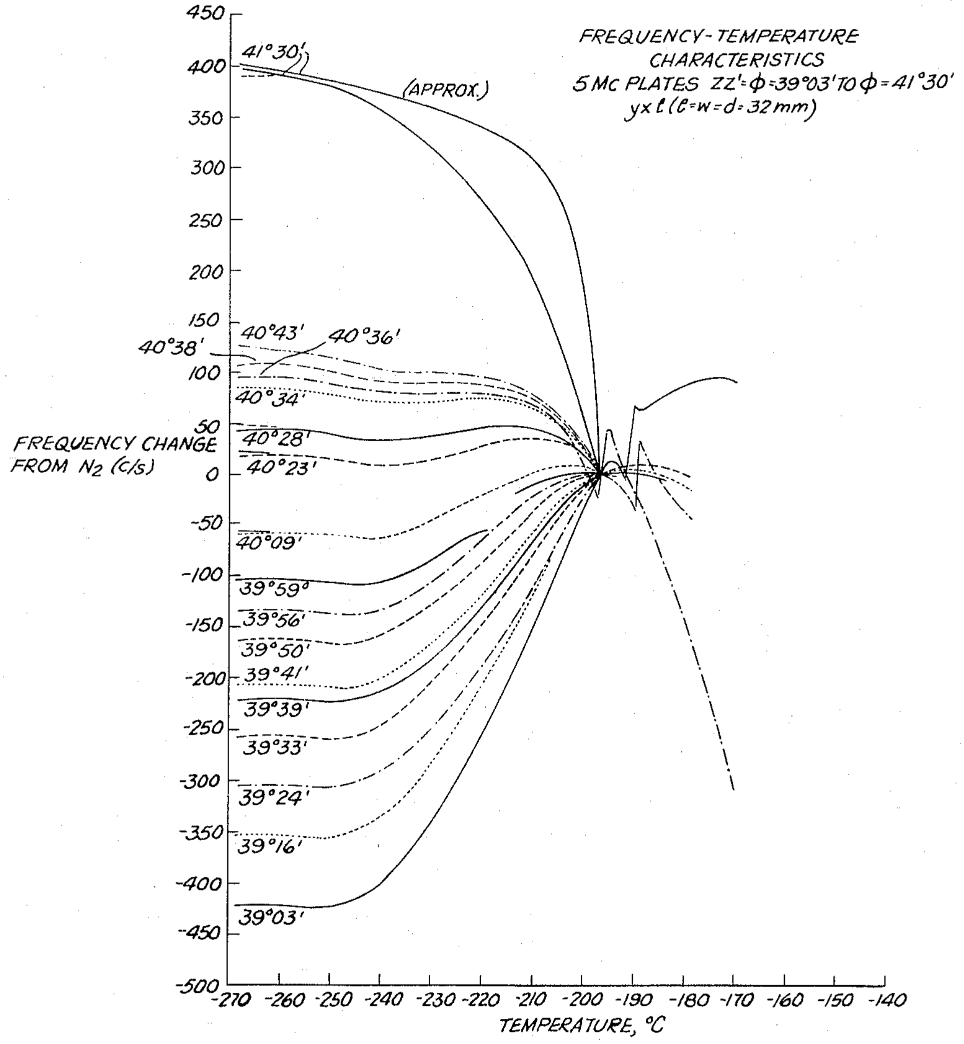

Fig. 3

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QUARTZ OSCILLATOR UNIT FOR OPERATION AT LOW TEMPERATURES

Filed June 25, 1958 5 Sheets-Sheet 3

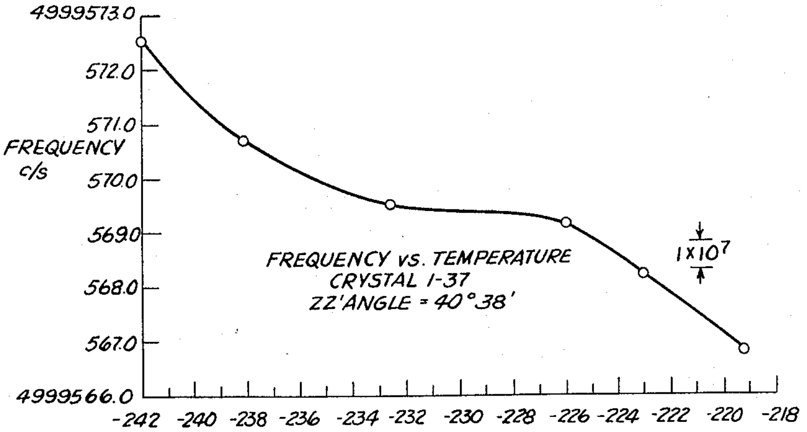

Fig. 4

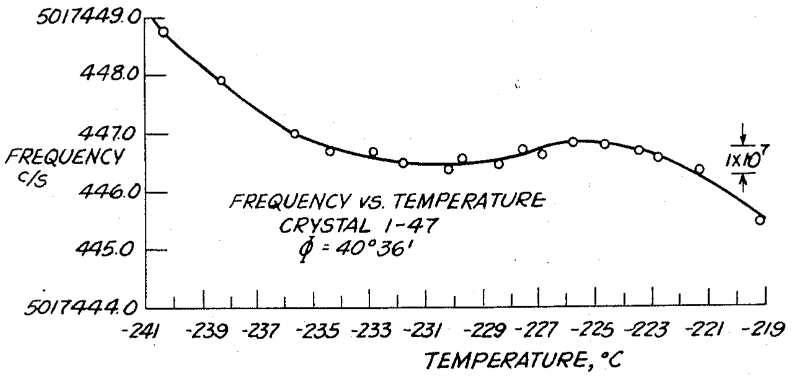

Fig. 5

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QUARTZ OSCILLATOR UNIT FOR OPERATION AT LOW TEMPERATURES

Filed June 25, 1958 5 Sheets-Sheet 4

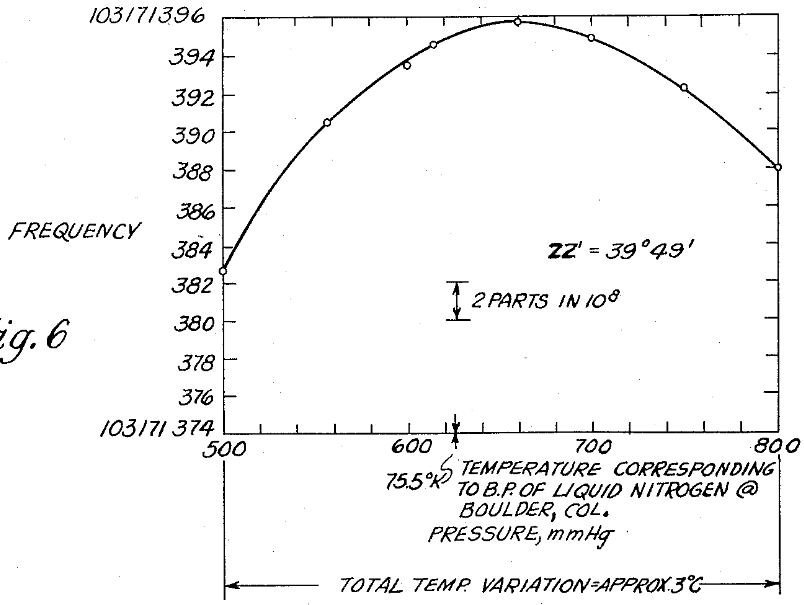

Fig. 6

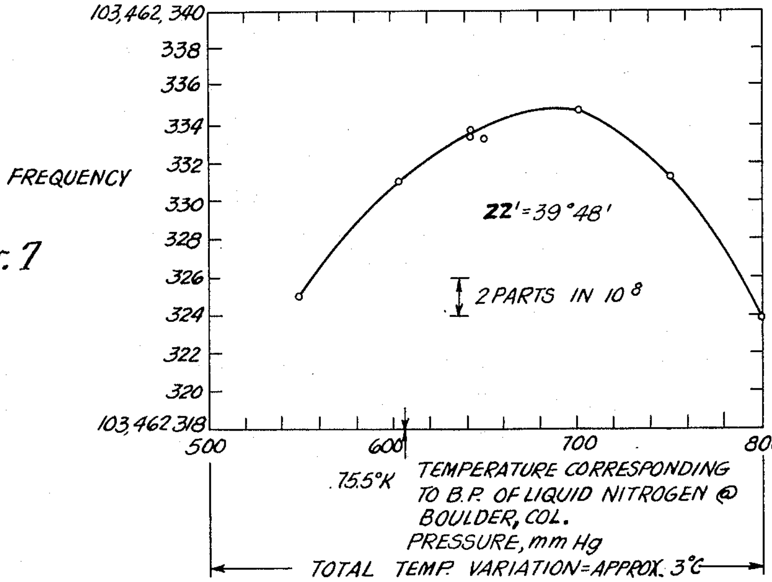

Fig. 7

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Filed June 25, 1958 5 Sheets-Sheet 5

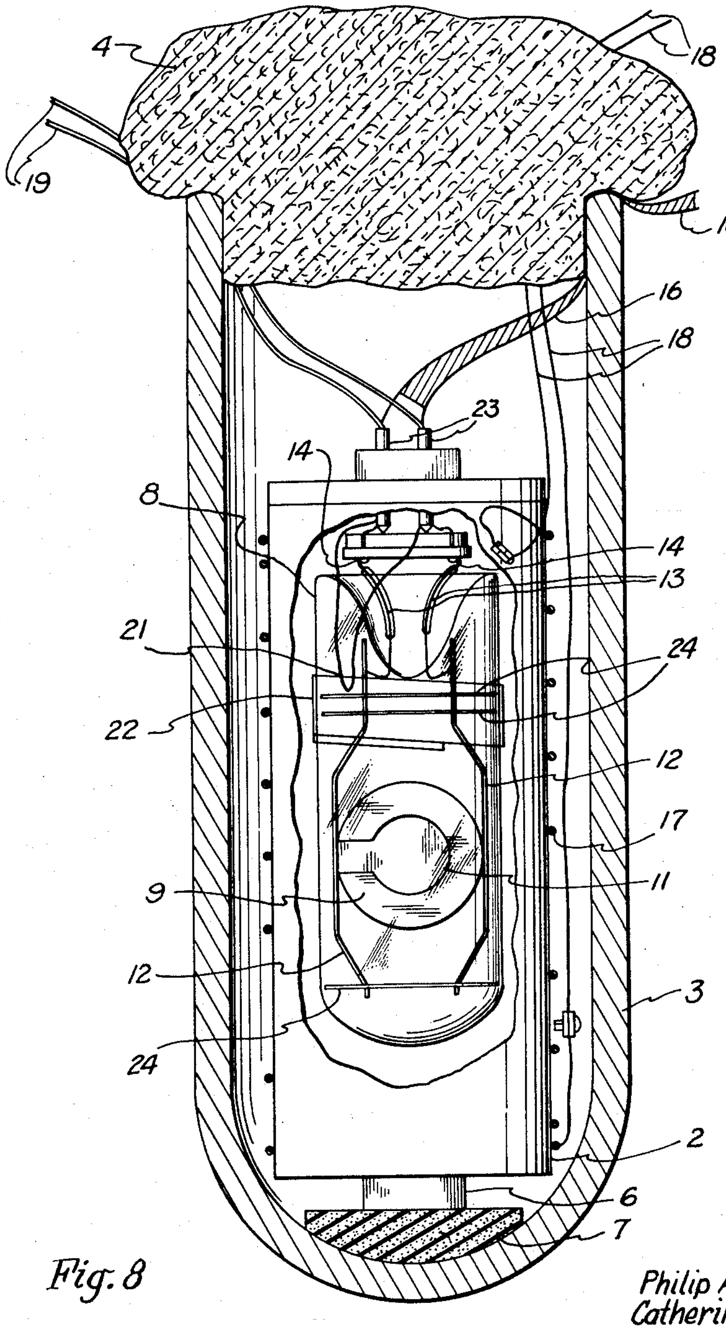

Fig. 8

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United States Patent Office

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QUARTZ OSCILLATOR UNIT FOR OPERATION AT LOW TEMPERATURES

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Application June 25, 1958, Serial No. 744,626

5 Claims. (Cl. 310—9.5)

This invention relates to piezoelectric resonator devices and more particularly is concerned with a novel quartz crystal unit for operation at low temperatures.

As is well known, all crystal oscillator units age; that is, the frequency gradually changes over an extended period of time. This residual shift in frequency may be either positive or negative and cannot be predicted. For crystals fabricated with the utmost care, such as those used to control the output of station WWV of the National Bureau of Standards, the residual drift is usually positive and of the order of one part in 10^9 per day. However, theoretical considerations and recent experiments have shown that the above-mentioned residual drift can be greatly reduced by maintaining and operating the crystal at a very low temperature, such as that of liquid nitrogen or even liquid helium.

As might be expected crystals designed for operation at ordinary temperatures do not give optimum performance at such low temperatures. The present invention provides a novel unit which can be fabricated so as to have a zero or at least a very small temperature coefficient of frequency at any one of a number of very low temperatures. It is therefore one object of the present invention to provide a novel crystal unit for operation at low temperatures.

In accordance with such objective, the present invention provides a crystal having an optimum angle of cut for a particular selected temperature is a cryogenic range generally extending, for example, from the temperature of frozen carbon dioxide down to the boiling point of liquid helium.

Another object of the present invention is to provide a novel modified AT-cut crystal having a rotated ZZ′ angle of approximately 39° 49′ for a unit to operate at temperatures in the neighborhood of −197° C. (liquid nitrogen temperature). If the unit is to operate at some other selected low temperature, the present invention also provides a novel modified AT-cut crystal having a rotated ZZ′ angle which can be optionally selected as being appropriate for the desired temperature.

An additional object of the present invention is to provide a novel quartz crystal unit having substantially improved long-time stability.

Further objects and advantages will become apparent with reference to the drawings, in which—

Fig. 1 is a graph showing the angle of cut (ZZ′ angle) versus the temperature at which the frequency-temperature coefficient is zero. Fig. 1 covers a range of angles from about 35° to 40½° and an operating temperature range from +250° C. to −255° C.,

Fig. 2 shows on an enlarged scale the portion of the curve of Fig. 1 defined by a temperature range of from −170° to −270° C.,

Fig. 3 is a graph of the frequency temperature characteristics of AT-cut crystals having various ZZ′ angles,

Fig. 4 is a graph of frequency versus temperature for an AT-cut crystal having a ZZ′ angle of 40° 38′,

Fig. 5 is a graph of frequency versus temperature for an AT-cut crystal having a ZZ′ angle of 40° 36′,

Fig. 6 is a graph of frequency versus temperature for an AT-cut crystal having a ZZ′ angle of 39° 49′,

Fig. 7 is a graph similar to Fig. 6 for an AT-cut crystal having a ZZ′ angle of 39° 48′, and

Fig. 8 is a schematic diagram of a form of apparatus which may conveniently be employed in obtaining the data shown in Figs. 1–7.

Referring to the drawings, in Fig. 1 there is shown the relationship between the ZZ′ angle and the temperature at which the frequency-temperature coefficient is zero, both for the conventional AT-cut and for the modified AT cuts with ZZ′ angles much larger than the conventional AT cuts. The lower portion of the graph is divided from the upper portion by a dotted line indicated at **1.** The dotted line **1** drawn at −50° C. represents the approximate lower limit on the data heretofore available on the temperature characteristics of quartz crystals. The range of temperature characteristics as shown by the lower portion of the curve have also been extended down to near liquid helium temperature. As can be seen from Fig. 1, applicants have discovered that the well-known parabolic configuration centering at about 24° C. and occurring at a ZZ′ angle of about 35° 21′ has a smaller counterpart of opposite sign in a region centering at about −228° C.

Fig. 2 shows on an enlarged scale the lower portion of Fig. 1 covering the temperature range from −170° C. to −270° C. It will be noted from Fig. 2 that the curve shows an infinite slope at about −228° C.

The temperature of the turnover point or zero temperature coefficient, plotted as the ordinate in each of Figs. 1 and 2, is that temperature on a frequency versus temperature curve at which the curve passes through zero slope. Stated differently, the turnover point is that temperature at which the frequency will not change or will change only very slightly for small changes in temperature.

A better understanding of the curve shown in Figs. 1 and 2 may be had by reference to Fig. 3 which shows a graph of frequency versus temperature for a series of crystals having different ZZ′ angles in the temperature range shown in Figs. 1 and 2. The ordinate of the graph shown in Fig. 3 is in cycles per second and is plotted as the frequency change from a reference frequency corresponding to the boiling temperature of liquid nitrogen. The turnover points shown in Figs. 1 and 2 are taken from the curves of Fig. 3 at the point where each curve in Fig. 3 represents maximum frequency stability with respect to temperature. Such a point occurs where the slope of an individual curve in Fig. 3 passes through zero. Mathematically the curves shown in Figs. 1 and 2 represent the locus of the points on the curve of Fig. 3 wherein the first derivative equals zero. It can be seen that for angles less than 40° 37′ the frequency versus temperature curves shown in Fig. 3 have zero slope at two different temperatures and hence have two turnover points. For angles greater than about 40° 37′ the frequency versus temperature curves have no point at which the slope equals zero. Consequently, for crystals having larger ZZ′ angles there are no turnover points. Figs. 1 and 2 therefore provide the information necessary for selecting a proper ZZ′ angle at which there will be a zero temperature coefficient of frequency at any desired operating temperature.

Fig. 4 is a graph of frequency versus temperature for an AT-cut crystal having a ZZ′ angle of 40° 38′. The graph shows a limited portion of the curb for an angle just beyond the critical value of 40° 37′. As can be seen from Fig. 4, there is no point on the curve at which the slope equals zero, and hence this curve exhibits no turnover point. Both Figs. 1 and 2 facilitate selection of the proper orientation at which to cut a crystal in order to achieve a zero temperature coefficient of frequency at any selected operating temperature within a given range.

Fig. 5 is a similar curve for a ZZ′ angle of 40° 36′, such angle having a value just below the critical value of 40° 37′. The curve of Fig. 5 exhibits two turnover points approximately 5 degrees apart. It should be noted from the curves shown in Figs. 4 and 5 that in both curves there is a considerable range of temperatures (a range of several degrees) centering at about −228° C. where the frequency does not change by more than one part in 10^7. Because of such characteristic it is apparent that even a cryostat of limited sensitivity when operating in this temperature range can give excellent frequency stability. For practical purposes, however, a unit designed for use at temperatures near that of liquid nitrogen is employed because of the availability of thermostats or cryostats which operate satisfactorily in the liquid nitrogen temperature range.

Figs. 6 and 7 show the frequency versus temperature characteristic of AT crystals having ZZ′ angles of 39° 49′ and 39° 48′ respectively. The temperature variation was obtained by varying the pressure on the liquid nitrogen employed as the furnace. In this manner it was possible to obtain a controllable 3° C. variation in the normal (75.5° K. at Boulder, Colorado) temperature defined by the boiling point of liquid nitrogen. The crystal units described by the curves of Figs. 6 and 7 were designed for use in connection with frequency calibrations based on the cesium beam and normally operate at a frequency of 5.158 mc. To provide greater precision of measurement the frequency was multiplied by a factor of 20 before measuring so that the indicated frequency in Figs. 6 and 7 is in the 103 mc. range.

Fig. 8 shows a partially cut-away cross section of the apparatus used in obtaining the low temperature data represented by the graphs shown in Figs. 1 through 7. A copper cylinder **2** is supported within a cryostat dewar flask **3** enclosed at the top by a glass wool plug **4**. A lower portion **6** of copper cylinder **2** is supported in flask **3** by a styrofoam cushion **7**. Centrally disposed within cylinder **2** is an evacuated glass envelope **8** housing a quartz crystal plate **9**. Electrical contact is made to quartz crystal **9** by means of a pair of gold electrodes, one on each side of the crystal. One such electrode is indicated at **11**. Wires **12** act as a support for crystal **9** and also serve to make electrical connection from electrodes **11** by way of insulated leads **13** and pins **14** to crystal energizing lead **16**, shown in Fig. 6 as a conventional TV lead-in cable. Cylinder **2** is surrounded by a heater coil **17** which may be coupled to an external power source by way of leads **18**. A pair of wires **19**, one of Alumel and the other of Chromel, are joined to form a thermocouple junction **21**, and are affixed to the outer surface of glass envelope **8** by means of tape **22**, the thermocouple junction **21** being used to indicate the temperature of the glass envelope **8**. The outer ends of leads **19** go to a reference cold junction connected to a device for measuring electrical potential generated by the thermocouple. Thermocouple leads **19** pass through the top of cylinder **2** inside a pair of ceramic spacer elements **23**. Three circular mica spacer plates **24** maintain the crystal **9** and its supporting wires **12** in correct position in the evacuated glass envelope **8**. Support and electrical lead-in wires **12** pass through each of the spacers **24** and are securely fixed thereto.

The following procedure was followed in obtaining the frequency-temperature characteristics of the various crystals illustrated in Figs. 1–7. All were rotated AT-type crystals. In accordance with IRE nomenclature the crystals are designated YXL wherein the length (L) equals the width (X) equals the diameter equals 32 mm. (circular crystals) with a ϕ (Greek letter phi, the ZZ′ angle) having values from 39° 0′ to 41° 30′.

The particular crystal to be tested enclosed in its glass envelope was inserted into the cylindrical copper container and the various connections made as shown in Fig. 8. Dewar flask **3** was then filled with liquid nitrogen and closed by glass wool plug **4**. Enough time was allowed for the crystal to come to temperature equilibrium as shown by a constancy of the frequency reading. The frequency readings were taken by a frequency counter connected to an oscillator which in turn was coupled to the crystal by means of the twin crystal lead **16** shown in Fig. 8. The time required for such equilibrium to be reached was in the order of 1½ to 2 hours. Frequency and nitrogen temperature were then observed and recorded. The liquid nitrogen was then removed and the Dewar flask **3** refilled with liquid hydrogen. A frequency reading was again recorded at liquid hydrogen equilibrium temperature, such reading being obtained in less than ½ hour. The liquid hydrogen was then removed and the Dewar flask again refilled, this time with liquid helium. A stable frequency was reached at liquid helium temperature in about 10 minutes. Frequency and temperature were again recorded. Subsequently, increasing amounts of energy were applied to heater **17** and the various frequency values recorded as the crystal temperature rose. Frequency and thermocouple readings were generally taken at one-minute intervals.

Some difficulty was first encountered due to the lag of the crystal temperature behind the temperature of the thermocouple taped on the outside of the evacuated glass envelope. This lag was completely overcome by sealing off the crystal unit with a small amount of gaseous helium inside the envelope.

From the above results, it is apparent that the present invention provides a novel rotated AT crystal unit for optimum performance in a low temperature range. Such crystals have heretofore been operated near room temperature with a ZZ′ angle near 35° 21′. The present invention provides a modified AT crystal having much larger ZZ′ angles and further having unexpected frequency stability in the cryogenic temperature region. Such a crystal employed in a crystal unit maintained at this low temperature provides an improved piezoelectric resonator device having greatly improved frequency stability with respect to both temperature variations and residual drift.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made within the scope of the invention as defined in the appended claims.

What is claimed is:

1. For use as a resonator at a temperature lying within a range extending from about −268.9° C. to about −50° C., an AT quartz crystal having a ZZ′ angle in a range from approximately 35° 30′ to 40° 41′.

2. A piezoelectric crystal resonator unit comprising a rotated AT-cut quartz crystal having a ZZ′ angle in a range of approximately 39° 30′ to 40° 41′ and means for operating said crystal resonator at a temperature lying within a range extending from −268.9° C. to about −50° C.

3. The invention of claim 2 in which the ZZ′ angle is 39° 49′ and means for operating said crystal resonator at a temperature within ±5° of −195.8° C.

4. The invention of claim 2 in which the ZZ′ angle is 40° 38′ and means for operating said crystal resonator at a temperature within a range of −226° C. to −230° C.

5. The invention of claim 2 in which the ZZ′ angle is 40° 36′ and means for operating said crystal resonator at a temperature within a range of −226° to 230° C.

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