TWENTYSECOND WEEK.
PIEZO-ELECTRIC CRYSTALS.

G.B.Todd,Rmlc.

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QUESTION #1. What crystals possess piezo-electric properties and which is the best suited for tube transmitters in controlling frequency?

ANSWER #1. Any crystalline body which has double refracting properties and whose atomic structure is unsymmetrical is piezo-electrically active. Included in this class are: Tourmaline, Quartz, and Rochelle salts. Of these quartz is best suited for tube transmitters in controlling frequency because it will retain its physical dimensions if kept at a definite temperature; it will stand considerable abuse which accompanies its use in oscillation test circuits when the crystal is heated momentarily in excess of 45° C. and when it is subjected to frequency washing. The crystals will hold the original oscillation frequency for periods in excess of 10 months when operated continuously in a high-frequency transmitter system. Other exacting tests have proven that quartz is the only material known which is satisfactory for use in crystal-controlled vacuum-tube circuits. The reason for the non-use of the other crystals are: Rochelle salts, although it has ten times the piezo-electric properties of quartz, is not reliable. It is fragile, extremely hard to manufacture, and its physical dimensions can be easily changed by handling, especially when subjected to contact with water. It also will not stand any electrical load. For instance if used as a resonator in connection with the output of an oscillator of a few watts capacity it will break down If the power is increased the salts will return to a liquid state. Tourmaline is too expensive to be considered as a commercial product, and therefore resort has been made to the use of quartz, which can be obtained in reasonable quantities in Brazil, Madagascar, Japan and the United States. Any quartz which has no flaws, intergrowths, or optical twining can be so manufactured that it has excellent piezo-electrical properties.

QUESTION #2. Explain the piezo-electric quartz crystal as used for frequency control.

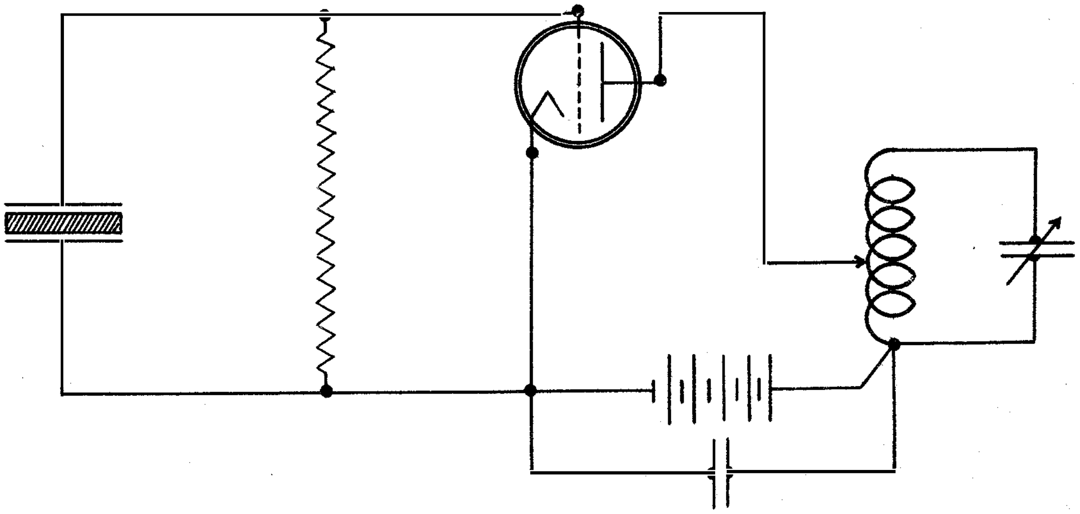
ANSWER #2. The first discovery that a crystal could be used to hold the frequency of self-oscillating circuits constant and also that crystals could be made to control the frequency of a vacuum tube circuit, was mady by Cady. The first circuit in which a crystal was used to control the circuit, consisted of a self-oscillating vacuum-tube circuit with a crystal placed across the grid tuning condenser. When the circuit was adjusted to the resonant frequency of the crystal, there was a tendency in the crystal to keep the frequency of the circuit equal to that of the crystal. If the plate voltage, filament voltage and load remained the same, the crystal would hold constant the frequency of the circuit; but if one or more of the above conditions were changed, the circuit would oscillate at any frequency that the circuit conditions permitted. Later a plate feed back circuit was used in order to obtain a greater piezo-electric voltage for controlling the frequency of the circuit but the operation of this circuit was limited by the same conditions that are cited in the first circuit Any method that depends upon any self-oscillating conditions in a vacuum-tube circuit, in addition to piezo-electric control, is dangerous for two reasons: First, because of the danger of frequency shifting; and, secon because it is very easy to crack or chip crystals in such circuits. This latter trouble is exaggerated when we tie in the crystal oscillating circuit with an unbalanced amplifying system in which the radio-frequency current feed back from the amplifying circuit is sufficient to supply enough additional current through the crystal to cause it to heat up and crack. The first circuit known to the art wherein the crystal with the associated amplifying circuits comprised a system in which the crystal was the only control for the generator frequency, comprised an arrangement wherein the initial piezo-electric charge on the grid was amplified through three stages of resistance coupled amplificatio and by means of a third contact plate on the crystal this amplified charge was applied to the crystal in the right phase relationship to reinforce the initial charge and by the process assist the circuit in generating radio-frequency currents. Professor Pierce later developed a circuit which was capable of generating by the use of crystal control a source of constant frequency. In this circuit, the crystal was placed between the grid and plate of a vacuum tube and a resistance load was inserted in the plate circuit. A grid leak was employed to hold the grid at a certain voltage with respect to the filament. This was slightly modified later by replacing the plate resistance with an inductance. Both of these circuits function in the same manner as the old De Forest ultraudion circuit wherein a tuned circuit is interposed between grid and plate and a choke coil employed as a load in the plate circuit. This choke coil was so constructed that it acted as a capacitive load for all frequencies to which the tuned circuit was resonant. In the Pierce circuits the crystal functions as a tuned circuit having a preponderance of inductance, while the plate load for the condition of oscillation has to be capacitive. To accomplish this end, Pierce used a very large inductance coil in the plate circuit. The true inductance and the distributed capacity of the coil system used in this circuit has to be such that it will be resonant to a lower frequency than that of the crystal before the circuit will oscillate. In the case where resistance is used as in the first Pierce circuit, it is distributed capacity of the resistance together with plate-filament capacity that affords the capacitive reactance required for the oscillation condition. If the proper precautions are observed with the Pierce circuit with respect to the capacitive plate load condition, any crystal can be made to trigger off this circuit into the oscillating condition. In view of the fact that a grid leak is employed and the plate load is a resistance or large inductance, it is not possible to obtain the rated power output from a given tube with this circuit.

ANSWER #2. Continued.

The circuits described heretofore had limitations as to power output, so the Naval Research Laboratory at Belle vue carried on development work to attempt the discovery of any system which could permit a reasonable radio frequency output. The first one discovered was similar to Pierces except that it employed a tuned plate circuit and a variable tap on the inductance. This permitted tuning to any desired frequency thus excluding undesired frequency oscillations. The variable plate tap permitted matching of tube impedance to circuit impedance so that a maximum power transfer was effected. Another circuit developed was known as the fundamental Navy circuit shown in the diagram following. In this circuit the crystal is placed between grid and filament instead of between plate and grid as in the first circuit. With this circuit the load for the plate circuit should be inductive in order that a condition for oscillation be obtained. The action of this circuit with reference to the oscillating condition is similar to the well known Hartley self oscillating circuit. This may be better understood by stating that the crystal being equivalent to an inductance is similar to the grid coil of the Hartley circuit, while the inductance load in the plate circuit of the crystal oscillator is identical to the plate coil of the Hartley system. It was demonstrated that both of these circuits could be made to oscillate with crystals of different frequency ratings. Preference was given to the use of the circuit sketched below instead of the one with the crystal in the plate circuit because in such a circuit there is no tendency for short-circuiting the high voltage plate circuit should the crystal crack or slide out from between the contact plates, thus causing the plates to come in contact with each other. A good output was obtained with high as well as low frequency crystals when employed in the circuit sketched below.

QUESTION #3. Draw a diagram of a crystal-controlled circuit and show where crystal is inserted.

ANSWER #3.



FUNDAMENTAL NAVY CRYSTAL-CONTROLLED TRANSMITTER.

QUESTION #4. Explain in detail an efficient crystal holder as used on naval transmitters.

ANSWER #4. An efficient crystal holder should be a hermetically sealed container where no moisture or dirt can come into contact with the crystal. It is necessary that capacities other than that between the crystal contact plates be kept as small as possible thus eliminating the charging losses occasioned by extraneous shunt capacities. For reliable operation and maximum output the crystal contact plates should be intimately touching the surface of the crystal. Lapped surfaces on these plates are to be preferred while the weight of the upper plate should be kept to a minimum. No restriction of up and down movement of the upper plate should be tolerated. Light spring pressure can be applied to this plate, but for best results no pressure other than the weight of the plate is necessary. Retaining rings of bakelite or other insulating material or brass retaining pegs can be employed to hold the crystal in one fixed position with respect to the sides of the container. A holder having all these features together with means for restricting the tendency for the crystal to jump clear of the retaining pegs when being transported is ideal for use in naval transmitters. Experience has shown that any air gap between upper surface of crystal and the contact plate means a great reduction in output, and when used in the regular power circuit, the air gap causes brushing between the surface of the crystal and the plate, which in turn causes the crystal to heat and crack. Crystals which have been subjected to the brushing effect show a discoloration on the surface of the crystal at the place where the brushing occurred.

QUESTION #5. How is the temperature of a crystal maintained constant?

ANSWER #5. One method is to place the crystal in a hermetically sealed container and by use of thermostat and heating unit in this container maintain the crystal at a predetermined temperature. The second method is to place the crystal in a crystal holder and to secure this holder on a metal plate that can be maintained at a constant temperature. The heat from the plate will be conducted through the lower crystal contact plate direct to the crystal. The metal-heating plate can be kept at a constant temperature.by circulating water through it, or a subcompartment with suitable heating unit and thermostat can be attached to this plate. A thermostat can be employed with the water-circulating system to turn on or off the current in a heating coil which is placed in the water-intake line to the plate. This latter water-cooling method was developed at the naval laboratory. The importance of constant-temperature control is appreciated when operating high-frequency crystals, as a change of 10° C. will change the frequency as much as 1 kilocycle in the 4000 KC band. Extreme temperature changes in temperature met with on board naval ships when cruising change frequency as much as 2 KCS which change is very detrimental. Remedy is to provide thermostatic control which will maintain crystal temperature above that which is ever encountered through out the year.

NOTES ON PIEZO-ELECTRIC CRYSTALS.

The quartz crystal is hexagonal in shape and when in its true form has an apex at each end. The methods of mining and also the process of growing are such that the two apexes are rarely found on crystals which are purchased from the importers. In the majority of cases it is unusual to obtain crystals having sides and one apex which are not chipped or cracked, due to rough handling or poor mining methods.

In the usual crystal the optical axis is parallel to an imaginary line which is drawn between two apexes. The electric axes are of two types, one of which is parallel to a line drawn between the corners of the hexagonal sides and the other is parallel to a line which is drawn between the opposite flat faces of the hexagonal sides. From this we note that there are three electrical axes of the first type and three of the second type and one optical axis. The optical axis is always at right angles or perpendicular to any of the electrical axes.

A slab of quartz is cut from the crystal, making this cut at right angles to the optical axis. Then, in order to obtain a workable crystal, we cut a slice from this slab. This slice is so cut from the slab that the slicing produces a crystal whose sides are parallel to one of the second electrical axes and at right angles to one of the first electrical axes. We now have a crystal whose thickness represents one of the first electrical axes, whose length represents one of the second electrical axes, and the depth an optical axis.

Having completed the cutting of the crystal, which we will term "Curie" or "zero angle cut" we find that there are three frequencies to which the crystal will resonate. One frequency corresponds to the first electrical axis, one to the second electrical axis, and the other to a frequency which is between the two and is termed the coupling frequency and depends on the dimensions of the first two axes.

In round crystals, as shown by one physicist, the first electrical axis will produce 104.6 meters per mm. (millimeter), the second electrical axis 110.5 meters per millimeter, and the coupling frequency is equal to 0.71 of the second electrical axis dimension wave length. In rectangular crystals the meters per millimeter for the first axis varies from 103.5 to 105, while for the second it varies from 110 to 117 meters per millimeter. The meters per millimeter obtained for the coupling frequency can not be stated, because it depends upon the dimensions of the rectangle from which may be square or any shape that the requirements demand.

The foregoing figures are based on the true Curie cut and on crystals whose dimension is between 20 and 28 millimeters. If any cut is made which is at an angle from the Curie cut, the meters per millimeter will be greater, especially for the X dimension oscillation.

Rectangular crystals are to be preferred to round crystals, first because they are cheaper to make, and second, because they will control a greater radio-frequency output without cracking or chipping. The latter condition is probably explained by the uneven stress conditions present in round crystals when they are oscillating under the influence of radio-frequency currents.