The Lenkurt Demodulator

NEWS FROM LENKURT ELECTRIC

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The Theory and Applications of

PIEZOELECTRIC CRYSTALS

The piezoelectric property of certain crystals has been recognized for about 75 years. However, this property was not fully utilized until after the start of World War II. Since then, millions of crystals have been used in various electronic devices such as oscillators, filters, frequency standards, microphones, and phonograph pickups. Although piezoelectric crystals are widely used, there is relatively little non-technical information on their characteristics and processing.

The purpose of this article is to discuss the source of piezoelectric crystals, their characteristics, and how they are prepared. Some of their applications are also mentioned.

The terms piezoelectricty is derived from the Greek word *piezein,* meaning *to press.* Hence, a piezoelectric crystal is one capable of producing an electric charge when it is deformed by an external force.

Certain crystalline materials have piezoelectric properties, and are capable of converting mechanical force into an electrical charge or vice versa. These materials are often used in various devices to change sound waves into electrical waves.

In addition to the piezoelectric property, crystals may also have a very sharp resonance to certain frequencies of vibration. These two properties are used in electronic oscillators to generate closely controlled frequencies by electrically coupling the oscillator to a stable mechanically-vibrating crystal.

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FIG. 1. A well-formed quartz crystal. This raw crystal is about 5 inches long and weighs one pound and three ounces.

A quartz crystal sealed in a vacuum tube to eliminate damping of its vibrational motion due to the surrounding air. The dark line is a division of the metal coating which was plated on the surface of the crystal. The coating is divided to obtain a balanced pair of electrodes on each side of the crystal.

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Early History

The piezoelectric effect was first discovered by Pierre and Jacques Curie in 1880, when they put a weight on a quartz crystal and detected an electric charge on its surface. The converse effect—that a charge applied to the surface of a crystal will cause it to deform—was predicted and verified a year later.

Many different crystals—for example, quartz and Rochelle salt—exhibit piezoelectric properties. If two tinfoil electrodes are properly placed on a Rochelle salt crystal and connected to a neon lamp, the lamp can be flashed by striking the crystal with a hammer. In fact, up to 5000 volts can be generated if the crystal is struck sharply.

The converse effect can be demonstrated by placing two Rochelle salt crystal strips together in such a manner that when a voltage is applied to them, one expands and the other contracts. This produces an effect that causes the crystal to bend. For a crystal that is ten-thousandths of an inch thick and four inches long, a 90-volt potential will displace the end of the unit more than ¼ inch. Reversing the polarity of the voltage reverses the direction of displacement.

First Practical Uses

The piezoelectric effect remained a scientific curiosity for many years, and no practical use was found for it until the first World War. At that time, the French Government initiated a project to devise a method of detecting submarines by the sound waves they produced in the water. As a result of this project, it was found that quartz crystals would generate measurable electric potentials when subjected to the pressure of sound waves. A submarine detection device using quartz crystals was not perfected until after the war, but application was then found for it as a sonic depth finder.

After this development, considerable

effort was spent on studying the properties and uses of piezoelectric crystals. Nicolson, of the Bell Telephone Laboratories, used Rochelle salt crystals to make simple loudspeakers, microphones, and phonograph pickups. He was also the first to use a crystal as the controlling element in an electronic oscillator.

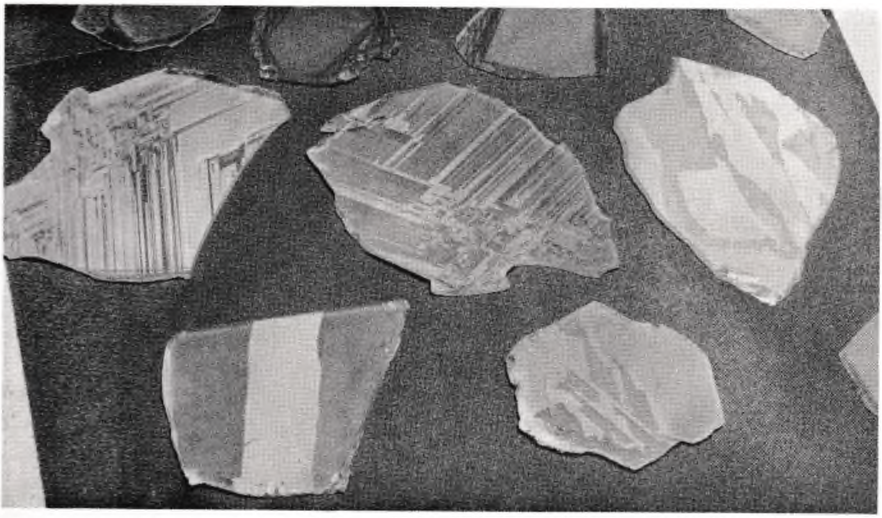
Physical Properties

A crystal is formed when a compound solidifies in such a way that its molecules are *locked* in an orderly pattern. The symmetrically-arranged plane surfaces of a crystal are external expressions of its uniform internal structure. The well-formed crystal shown in Fig. 1 is quartz, the most abundant piezoelectric material.

Quartz is used in jewelry, heat and chemical resistant dishes, and optics; however, this article will consider only quartz commercially used for its piezoelectric property. Although many kinds of crystals exhibit this property, quartz is used almost exclusively.

Most usable quartz crystals are found in the interior of Brazil. These crystals range in size from about one-half pound to five pounds. Their color may vary from perfectly clear to almost opaque. The opaque, or dark, crystals are called *smoky* quartz.

The smokiness, which is caused primarily by impurities, may be confined to areas within the crystal or be uniform throughout. Also, irradiating a clear crystal with X-rays may cause it to become smoky. Fortunately, smokiness can usually be cleared by heating the crystal to a temperature of from 350°C to 450°C for a short time. Smokiness



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Specimens of optical and electrical twinning in quartz wafers. Electrical twinning affects relatively large sections of the crystal. The electrical twins can usually be separated to obtain smaller usable crystals. Optical twinning generally makes a crystal unusable.

makes a crystal undesirable because it is difficult or impossible to observe other imperfections that may be present within the crystal.

Crystal Imperfections

Raw quartz crystals often contain certain imperfections that interfere with their preparation and operation. The more common imperfections are electrical and optical twinning, cracks, and inclusions.

Electrical and optical twinning are imperfections caused by an abnormal growth condition during the formation of the crystal. A crystal has electrical twinning when it does not generate the same polarity of charge throughout its structure. Usually only one section of a raw crystal is of the opposite polarity, and smaller usable crystals can be obtained if the electrical twins are properly separated. Optical twinning is a reversal of molecular structure within the crystal. This reversal of structure takes place alternately throughout the crystal, and makes it unusable.

Many crystals contain cracks. These cracks may have been caused by rough handling, abnormal conditions during formation, extreme temperature changes, or other natural causes. The large cracks are easily seen, but others may be so fine that they are nearly invisible. A cracked crystal must be treated with special care because it may fracture if subjected to mechanical or thermal shocks.

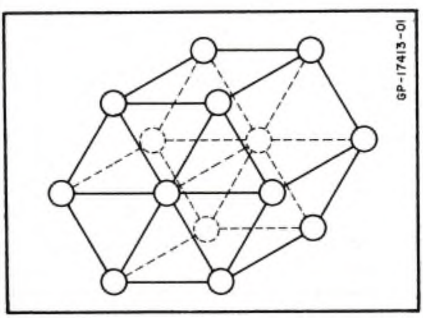


FIG. 2. The circles represent molecules of a quartz crystal, and the lines represent the forces holding the molecules in the symmetrical arrangement.

Inclusions are solid, liquid, or gaseous materials within the crystal. They may vary in size from those easily seen with the naked eye to others that are nearly invisible. In some cases, they may be bubbles that are filled with carbon dioxide, water, or a salt solution; or else microscopic inclusions may form in a group that gives an outward appearance of needles, veils, or clouds within the crystal. Raw crystals with inclusions are seldom used; consequently, little is known about what effect inclusions have on a finished crystal.

Piezoelectric Theory

A model of quartz crystalline structure proposed by Lord Kelvin in 1893 is still useful in explaining the reasons for piezoelectricity, but is not rigorously correct. Kelvin developed the theory that the molecules in a quartz crystal are arranged in a symmetrical hexagonal manner, such as is shown in Fig. 2. The six-sided appearance of this model corresponds very closely with the appearance of a well-formed quartz crystal.

Lord Kelvin also thought that the silicon and oxygen atoms composing the crystal's molecules are arranged in the same manner (Fig. 3). In this figure, the silicon atoms are labeled with plus signs and the oxygen atoms with minus signs.

If the atoms are arranged symmetrically as shown, the lines connecting the three silicon atoms form an equilateral triangle. The same is true of the lines connecting the oxygen atoms. The midpoints of these two triangles are coincident at the exact center of the molecule. Therefore, the center of charge of the three silicon atoms coincides with the center of charge of the oxygen atoms, which has the effect of neutralizing the molecule's charge.

If a force is now applied to this molecule in the Y direction, it will be deformed and appear like Fig. 4a. In this case, the centers of charge have moved because of the deformation, and no longer coincide. The molecule has now acquired an electric charge at right angles to the applied force.

If the force is applied in the X direction, the molecule will also be deformed (Fig. 4b). In this case, the charge separation still takes place along the same axis, but is of the opposite polarity as before. The axis along which this charge appears is called the "X" or electrical axis of the crystal. Perpendicular to the X axis is the "Y" or mechanical axis. Extending up out of the paper (perpendicular to the other two) is the "Z" or optical axis.

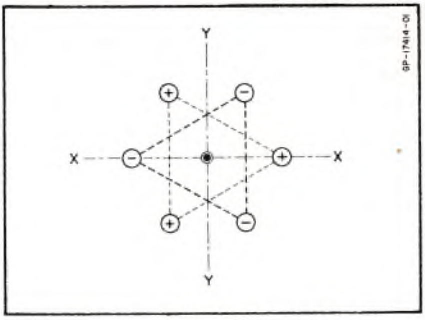


FIG. 3. A model of one molecule of a quartz crystal. The silicon and oxygen atoms are represented by plus and minus signs respectively. The centers of charge of the atoms are coincident.

A mechanical force is developed when an electric charge is introduced into a molecule. The charge upsets the electrical balance of the crystal and causes the atoms to separate. For example, a voltage applied along the X axis will produce a charge displacement

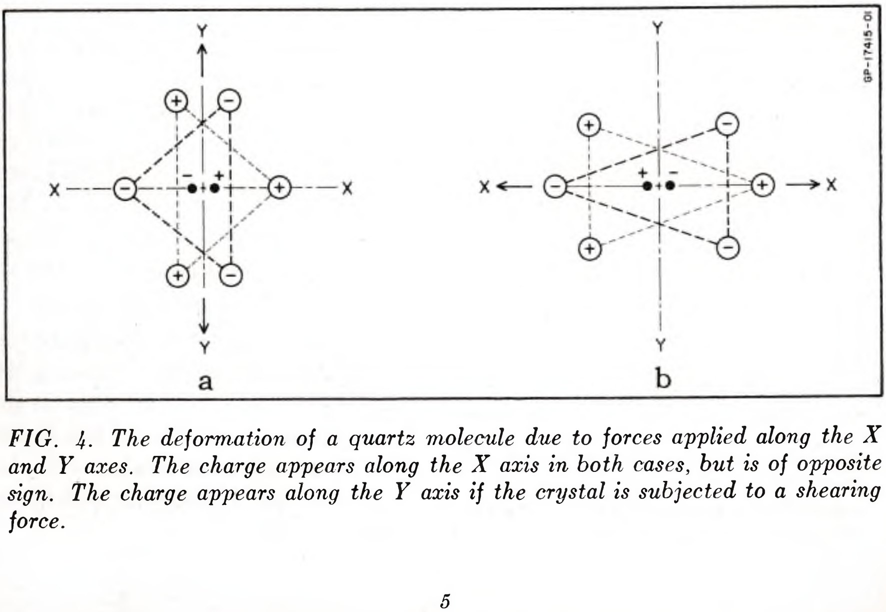


FIG. 4. The deformation of a quartz molecule due to forces applied along the X and Y axes. The charge appears along the X axis in both cases, but is of opposite sign. The charge appears along the Y axis if the crystal is subjected to a shearing force.

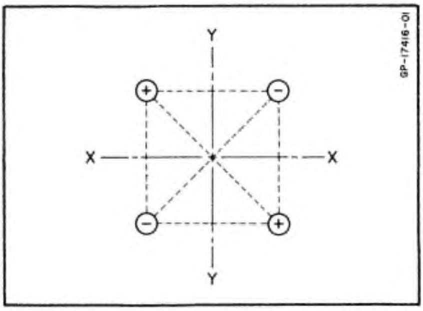


FIG. 5. A molecular structure that has no charge separation when deformed. A crystal composed of this type of molecule has no piezoelectric property.

and consequently a stress along the Y axis. This stress will set up a motion (or wave) along the Y axis.

There are many crystals which do not have piezoelectric properties. The requirement for a piezoelectric crystal is that it must have a certain kind of molecular symmetry. If the centers of charge of a molecule remain together during deformation, the crystal will remain neutral when a force is applied.

For example, consider a molecule made up of atoms located in the symmetry shown in Fig. 5. A crystal composed of these molecules will not generate piezoelectricity because regardless of the direction of an applied force, the molecule will not undergo a charge separation.

Crystal Transducers

In a piezoelectric crystal, electrical charge is transformed into mechanical force, or vice versa. A crystal may, therefore, be classed as a device capable of changing one form of energy into another. A device of this kind is called a *transducer*.

One common use for crystals is transducing the mechanical force of sound waves (or their impressions in phonograph records) into electrical waves. When used as an element in a microphone, the crystal is attached to a diaphragm that vibrates when exposed to sound waves. The stress thus applied to the crystal causes voltages to be generated that are electrically equivalent to the original sound waves. A phonograph pickup is much the same, except that a needle transmits the varying forces to the crystal.

In the opposite sense, if an electrical wave is applied to a crystal, a sound wave can be generated. In this manner a crystal can be used as an earphone or a loudspeaker. When a crystal is used to reproduce sound, it cannot have a strongly resonant frequency or it will introduce severe distortion. A crystal used in a microphone, for example, must be designed so that its resonant frequency lies outside of the range of frequencies it must reproduce. This is accomplished by using specially designed crystals, or piezoelectric materials other than quartz.

The ability of a quartz crystal to convert electrical energy into mechanical energy, combined with its very strong mechanical-resonance characteristic, makes its use desirable for controlling the frequency of high-precision oscillators. Such oscillators are used extensively in carrier, radio, and other fields of communication.

Both properties of a quartz crystal—mechanical resonance and electro-mechanical coupling—are important when the crystal is to be used as the controlling element of an oscillator. Mechanical resonance is desirable because it is usually much sharper than the electrical resonance obtained from combinations of inductance and capacitance. Therefore, the frequency of a mechanically vibrating crystal is more accurate and stable over a period of time than the frequency of an LC oscillator.

The electro-mechanical coupling of a crystal makes it possible to utilize its mechanical resonance in an electronic circuit. In a crystal-controlled oscillator, an electronic circuit supplies energy to a mechanically-vibrating crystal. The frequency of vibration is very constant and is used to stabilize the output frequency of the oscillator.

Electrical Equivalent

Fig. 6a shows the impedance versus frequency characteristic of a crystal as observed from its connecting terminals. Two resonance frequencies are apparent. One frequency (F_{sr}) is that at which the crystal appears as a series-resonant circuit. At a little higher frequency (F_{pr}), the crystal appears as a parallel-resonant circuit. An electrical circuit that has this same characteristic is shown in Fig. 6b, which is the *equivalent circuit* of a crystal. The electrical operation of a piezoelectric crystal, especially near the resonance points, is very well approximated by this circuit.

The impedance of a crystal is low at its series-resonant frequency and extremely high at its parallel-resonant frequency. Since the spacing between F_{sr} and F_{pr} is always small (it may be only one-fourth of one percent), the impedance of a crystal changes rapidly in this region. This rapid impedance variation can be used to maintain the output frequency of an oscillator at the resonant frequency of the vibrating crystal.

The "Q" of a crystal (the ratio of a crystal's reactance to its resistance) is extremely high. Q is inversely proportional to the power lost in a system, and may range from less than ten to over 400 for conventional electrical circuits. Since little power is lost in the oscillation of a crystal, its Q may range from *ten thousand to several hundred thousand.*

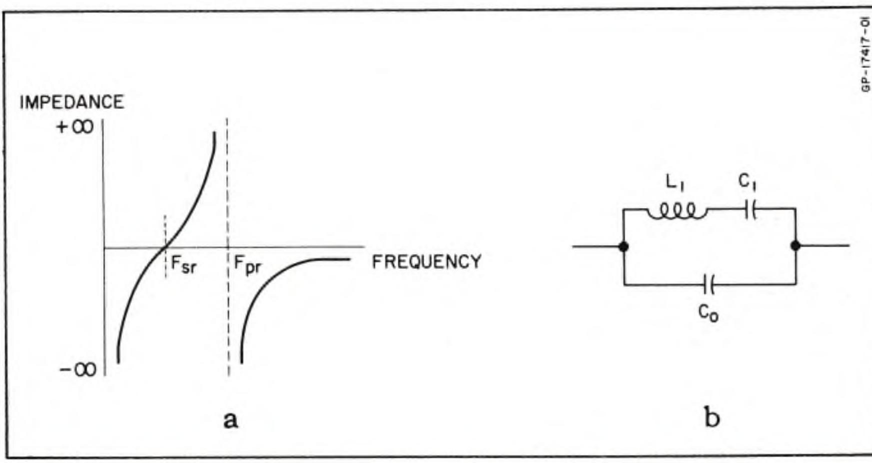


FIG. 6. The impedance-frequency characteristic of a quartz crystal, and its electrical equivalent. The frequencies F_{sr} and F_{pr} are always very close together.

The losses of a crystal are in its internal dissipation, through its mounting, and the damping of its motion by the surrounding air. The sum of these losses is very small compared with the loss in the resistance of an electrical circuit.

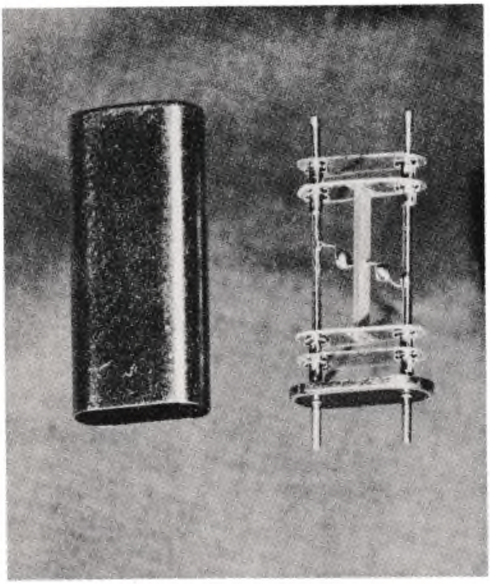
A conventional oscillator using an inductance-capacitance tuned circuit will stop oscillating almost instantaneously when the power is removed. A crystal oscillator, however, will continue to oscillate until the energy in the crystal is dissipated, which takes about one-half of a second. If the crystal is mounted in a high vacuum, it may take up to eight seconds for it to stop oscillating. This is equivalent to a Q of about 330,000.

Manufacturing a Quartz Crystal

A number of problems are involved in the process of manufacturing quartz crystals. Among these are locating the three axes, avoiding the imperfections in the raw crystal, adjusting the crystal to resonate at the desired frequency, the elimination of undesired temperature effects, and mounting the crystal without disturbing its characteristics.

It is of prime importance to locate the three axes accurately because the resonant properties and temperature characteristics of a crystal are dependent upon its orientation. The optical axis can be determined by inspecting the crystal with polarized light. A face is then ground on the raw crystal parallel to this axis. After further adjustment to assure that this face is properly oriented, the electrical axis is located by an X-ray process. The mechanical axis is then known to be perpendicular to these two axes.

When the axes have been located, the individual crystals can be cut. A crystal that is cut to a particular orientation with respect to the three axes, and to



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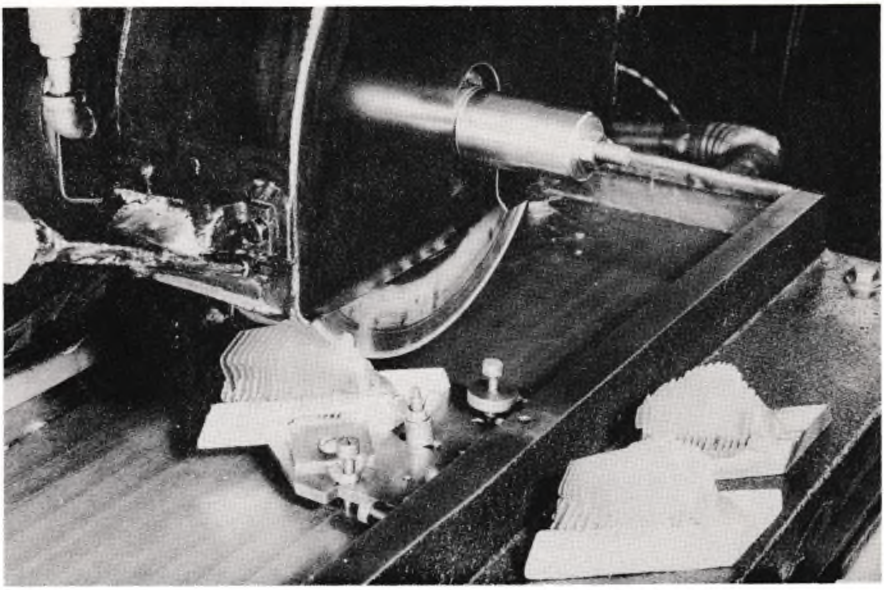
The construction of a quartz crystal using the longitudinal mode of vibration; that is, the crystal lengthens and shortens at its resonant frequency. The connecting wires are soldered to opposite sides of the crystal. The solder balls on the connecting wires are used to reflect back the motion that may be transmitted from the crystal to the wires.



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The quartz sawing process. A multiple blade saw is used to cut a raw crystal into the desired thickness and orientation.

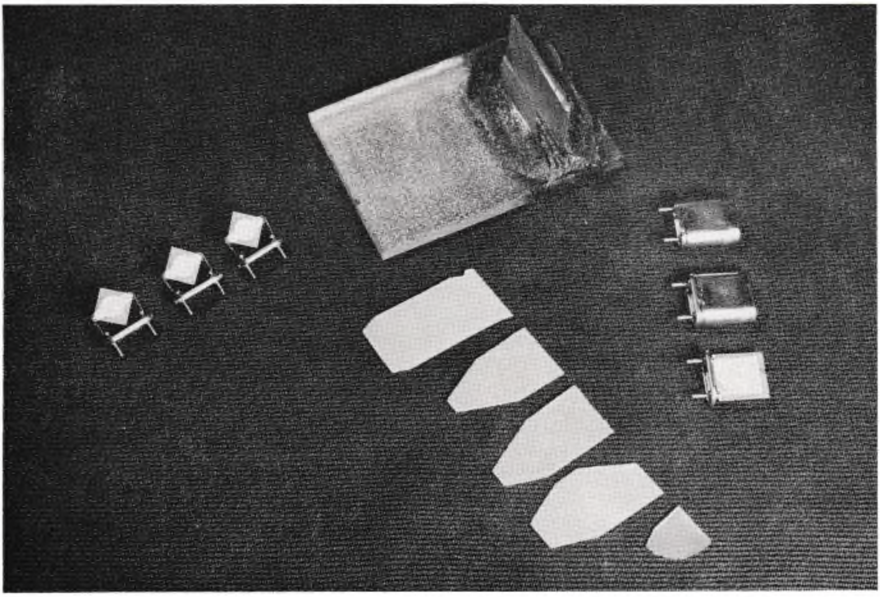
different physical dimensions can have any one of a variety of possible characteristics. The crystals with different orientations and proportions are specified by letter names such as AT, BT, CT, or GT.

For example, one orientation (the GT cut) is important because it maintains a very constant frequency over a wide temperature range. The resonant frequency of this crystal varies about *one part in a million over a 100°C temperature change.* To illustrate the accuracy to which this crystal must be manufactured, it must have a ratio of width to length of .859 and must have an angle of rotation about the X axis of 51 degrees 7.5 minutes. This crystal is used extensively in frequency and time standards, and for filters requiring very accurate and stable characteristics.

The crystal cannot be completely finished until it is mounted because the presence of the mounting may change its characteristics. The usual mounting employs wires soldered to two faces of the crystal. These wires serve as a means of fastening the crystal to a holder, and also as a connection between the crystal and the external circuit.

Before the wires can be soldered to the crystal, it must be prepared. This is done by placing spots of silver paste on opposite faces of the crystal where the wires are to be attached. These spots are placed at *nodes*—sections of the crystal where there is little vibration—so that energy will not be lost through the mounting. The unit is then heated to about 700°F to join the silver to the crystal. The wires are then soldered to the silver spots.

Soldering the wires to these spots is a delicate operation, because the wire



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The various stages in the manufacture of hermetically sealed crystals. A raw crystal is cemented to a block, sawed to the desired dimensions, separated and ground to the final size, mounted, adjusted, and sealed.

must be firmly attached with as little solder as possible. This is done by preforming the amount of solder to be used, fastening it to the wire, and then soldering the wire to the crystal (while the wire is held in a jig) with a blast of of hot air. These wires are then attached to heavier wires connected to the crystal holder. This is done in such a way that the crystal is protected from severe shocks.

After the wires are fastened to the crystal, it must be adjusted to its final operating frequency. This is done by alternately checking the frequency and removing quartz from one edge until it meets its specifications. The resonant frequency can be increased, but not decreased by this method. The crystal must therefore be cut to a lower frequency than is ultimately desired. After receiving its final check, the crystal is ready to be encased.

Conclusion

A piezoelectric crystal has several properties that make it valuable to the electronic industry. Among these are its accuracy, stability, and small size. Because of these characteristics, crystals have an important application in the carrier and radio communication field. They are also widely used in other devices such as filters, frequency and time standards, and band-switching receivers and transmitters. In fact, many present-day accomplishments in the field of electronics would not be practicable without the use of piezoelectric crystals.

Introducing Type 72C

A WIDEBAND MICROWAVE SYSTEM

Type 72C is a new addition to Lenkurt's 72-class of radio systems which provide reliable radio transmission for large numbers of telephone channels. The Type 72C system transmits up to 360 voice channels on a radio path over three radio channels. Each of the three separate radio channels is capable of transmitting a total of 120 toll-quality voice channels. Where a station is a hub with several radiating systems, up to 720 voice channels can be operated from that point.

In common with other 72-class systems, a single 72C system can economically transmit groups as small as 12 or as large as 360 channels over distances as short as 10 or 15 miles. When repeatered, over-all system lengths up to about 600 miles can be achieved.

Type 45BX channelizing equipment is available for use with 72C microwave and provides up to 120 voice channels for each radio channel. The 45BX system is designed so that no more than 24 channels will be affected by individual circuit failures or trouble conditions within the channelizing equipment. Also, great system reliability can be achieved by operating one radio channel as a standby to avoid service interruptions. A typical terminal arrangement providing 360 voice channels is shown in Fig. 1.

Features

Important features of 72C microwave are large channel capacity, high quality transmission, and reliability. In addi-

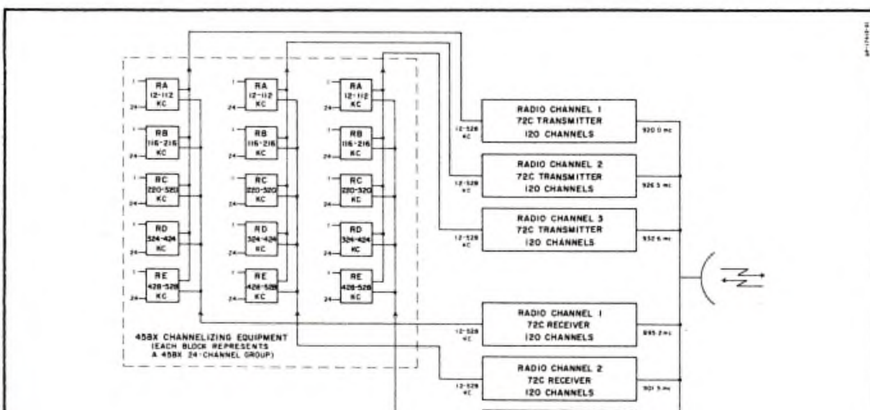


FIG. 1. A typical terminal arrangement of a completely equipped 360 channel 72C microwave system.

tion, channel groups can be dropped or inserted at repeater stations, and the system can be expanded in convenient-sized groups of channels to its maximum capacity.

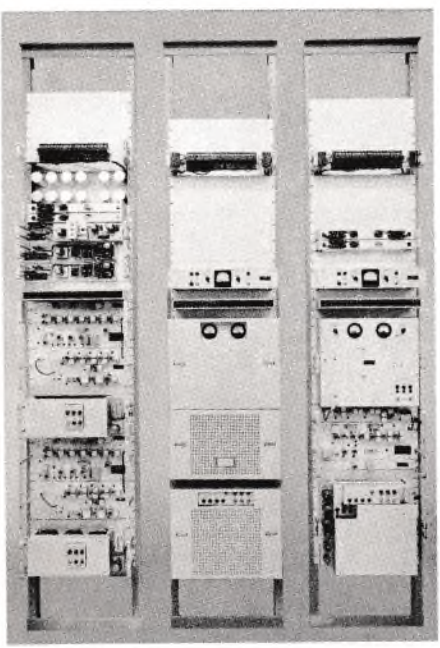
Standard Type 72C equipment includes: (1) modulator, converter, and power output panels for the transmitter; (2) converter and demodulator panels for the receiver; and (3) transmitting and receiving service-channel panels. The repeaters for this system consist of radio receivers and transmitters connected back-to-back. A variety of other optional features is available, such as automatic transfer between parallel sets of transmitters or receivers, and equipment to provide remote control and supervision.

The radio-frequency panels have been specially designed to provide for the wide-band, low-distortion operation required in multi-channel radio telephone communication systems. When equipped with the proper crystals for frequency generation, the 72C system operates on any frequency between 890 and 960 megacycles.

Performance

Performance of the new system, with respect to noise and crosstalk, is comparable to that obtained from toll-quality open-wire and cable carrier facilities. Operation over routes of up to ten sections with individual spans of 25 to 30 miles is feasible without compandors.

When compandors are provided, the resulting noise advantage can be used to employ longer sections, more repeaters or smaller antennas, or to increase the over-all length of the system to about 600 miles.



A typical arrangement of transmitting and receiving equipment to permit transmission of up to 240 channels over a single antenna.

The microwave transmitter accepts a baseband input of 4 to 552 kilocycles. Lenkurt Type 45BX provides 120 voice channels within this baseband frequency allocation. In the transmitter, the baseband is frequency-modulated to obtain an output with a high signal-to-noise ratio and low distortion. A converter and several doubler and tripler stages increase the frequency deviation to the desired value and provide the final carrier frequency in the range from 890 to 960 megacycles. The outputs of up to three transmitters are then combined and transmitted to the receiver or repeater.

The transmitters and receivers employ a common antenna. The incoming signals are separated from the others present by means of radio-frequency directional filters. In the receiver, the microwave channel is converted to a lower frequency and detected to obtain an amplitude-modulated carrier-frequency baseband. The baseband then goes to conventional channelizing carrier equipment.

A recently issued publication, Form 72C-P4, describes the new system and gives basic application information. A technical summary lists the pertinent operating and design characteristics. Copies of Form 72C-P4 are available from Lenkurt's distributors.

NEWS BRIEFS

EXPORT DIVISION—As a result of expanding activities in the Latin American market, an Export Division has been formed to give more comprehensive service to present and potential customers in that area. Weston C. Fisher, who has 16 years of experience in communications, has been appointed manager of the new division. He formerly handled Lenkurt matters relating to Bell System and Canadian sales. That responsibility now is assigned to Robert E. Graham, formerly with A.T.&.T. Long Lines 21 years, who has been in charge of sales and engineering services at Lenkurt.

FLORIDA RADIO NETWORK—Work is progressing in Florida on a microwave installation extending from Ocala to Leesburg, Dade City, Tampa, Bradenton and Sarasota, with a 45A wire-line carrier branch from Leesburg to Tavares. This project is the first part of an extensive radio network planned by Independent telephone companies in Florida. The installation will use Lenkurt Type 72 microwave and 45BX carrier equipment for channelizing purposes. The new facilities are expected to be in service early next year.

LENKURT OF CANADA—Now nearing completion in the Vancouver suburb of Burnaby is the new office and manufacturing building being constructed by Lenkurt Electric Co. of Canada, Ltd. Occupancy of a 15,000 sq. ft. building will enable the company to increase the scope of production activities and meet the steadily increasing demand for carrier and microwave equipment in Canada. Heading the Canadian operation is William H. Heflin, who was elected Vice President and General Manager on November 1. During his seven years at Lenkurt, Heflin has handled various positions in sales, engineering and production, and most recently was manager of the Procurement Division.

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Recently Issued Publications

Among the significant features of Lenkurt's 45-class carrier equipment are the arrangements available for transferring from one system to another on a carrier frequency basis. Such arrangements are advantageous from a transmission standpoint and tend to reduce costs substantially.

Product Information Letter No. 20, describing a number of types of interconnection, is now available. Copies of this letter can be obtained from Lenkurt's distributors.

Lenkurt ELECTRIC CO. SAN CARLOS, CALIF VANCOUVER, B. C.

The Lenkurt DEMODULATOR is a monthly publication circulated to individuals interested in multi-channel carrier, microwave radio communication systems and allied electronic products. Permission to reproduce material will be granted upon request.

Editor . . . . P. C. DeMuth

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