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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A CRYSTAL MODE INDICATOR

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● ONE OF THE MOST TROUBLESOME EFFECTS encountered in the production of quartz plates for frequency control is that of "spurious" or "coupled" frequencies. These are due to modes of vibration giving unwanted response frequencies near the desired frequency. Changes in temperature can cause the interfering frequencies to move nearer to, or farther from, the desired mode, in which case the normal response may decrease or increase as the temperature changes. If the quartz plate is used in an oscillator, the amplitude of oscillation will change as the temperature changes, and sometimes oscillations cease altogether at a particular temperature.

To examine a crystal by point-by-point measurements is extremely difficult and tedious, to say the least. Such measurements are of but little value for production control since they must be repeated for each change made in the dimensions of the quartz.

During the war, an instrument for rapidly examining the response spectrum

Figure 1. Panel view of the crystal mode indicator.

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of quartz plates was suggested by Prof. K. S. Van Dyke, of Wesleyan University, to several manufacturers, but no instrument was produced. At the close of the war, workers at the Signal Corps Laboratories and at colleges, under Signal Corps contracts, developed instruments, one of which, built by the Signal Corps Laboratories, was exhibited at the I.R.E. Convention in New York in March, 1948.

This equipment utilized frequency modulation of an oscillator, produced by electronic means controlled by the sweep voltage of an oscillograph. The oscillator output was applied to a quartz plate and the rectified response was displayed on the cathode ray oscillograph. The shunt capacitance of the holder was balanced out, so that the pattern represented the admittance of the quartz element alone.

A simplified arrangement, utilizing a General Radio Type 700-A Wide-Range Beat Frequency Oscillator, with a small motor-driven (or manually operated) variable capacitor as the frequency modulation means, is easily assembled and is very useful for testing quartz plates in the range from 500 to 5000 Mc.

This crystal mode indicator, now in use in the General Radio Company's crystal grinding laboratory, is shown in Figure 1. At the top of the rack is a General Radio Type 700-A Wide-Range Beat Frequency Oscillator. One connecting wire is brought out at the rear, from the fixed oscillator tuned circuit, for connection to the frequency sweeping capacitor described below.

At the bottom of the rack are the control panel and the cathode-ray oscilloscope. The oscilloscope shown here is a Dumont Type 250, with a five-inch super-persistence tube. This model is particularly convenient, since d-c amplifier connections are available by use of selector switches on the panel. (A Dumont Type 208-B unit was used previously, where d-c amplifier connections are available by changing the internal wiring in accordance with instructions given by the manufacturer.)

The control panel has a rest at the upper left-hand corner for the heater unit used in bringing the temperature of the test crystal up through the normal operating temperature. The unit is a heavy aluminum cup in which are buried two cartridge-type heaters operating at a total power of 50 watts. At the upper center of the control panel is the test crystal, which plugs into jacks mounted in a polystyrene plate. Below the test crystal is the dial on the shaft of the frequency sweeping capacitor, with an adjustment knob (just to the right of the dial) for altering the spacing of the plates. This provides for altering the range of the frequency sweep.

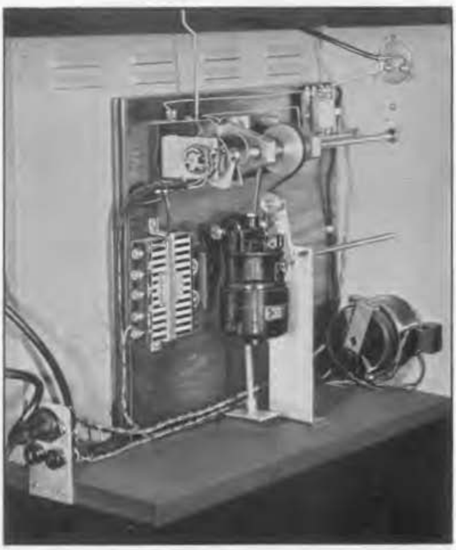


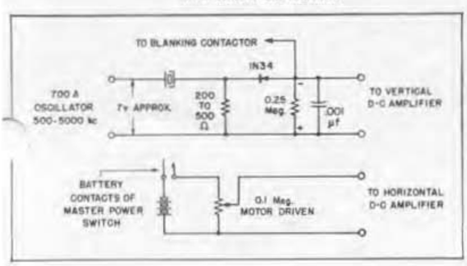
Figure 2. Rear view, showing the motor drive and frequency-sweeping capacitor.

Below these is the clutch control knob, operating a spring pressed idler wheel to be either free of the belt or to press on the belt connecting the drive motor and sweep frequency capacitor shaft. When disengaged, the sweep can be operated manually by rotating the dial. Where much routine use is made of the equipment, a motor drive is desirable. For occasional use, or for demonstration purposes, manual operation is entirely satisfactory.

At the bottom of the control panel is the Variac knob for controlling motor speed, the motor power switch, and a master power switch, which controls the battery and line supplies to the entire assembly.

In Figure 2, a view of the apparatus behind the control panel is shown. The motor, clutch-idler, belt, and the shaft of the frequency-sweeping capacitor are readily identified. On the shaft, from left to right, are (1) the potentiometer, for producing the synchronized horizontal d-c sweep voltage, (2) the blanking contactor which short-circuits the d-c vertical deflecting voltage during 120° of the rotation, and (3) the sweeping-frequency-capacitor moving plate, which gives a quite linear change in frequency for 240° of the rotation. The motor gear reduction and the applied voltage give sweep rates adjustable from about one per second to about one in twenty-five seconds. If too rapid a sweep is used, difficulty is encountered from "ringing" in the crystal.

Figure 3. Schematic diagram of the electrical circuit.



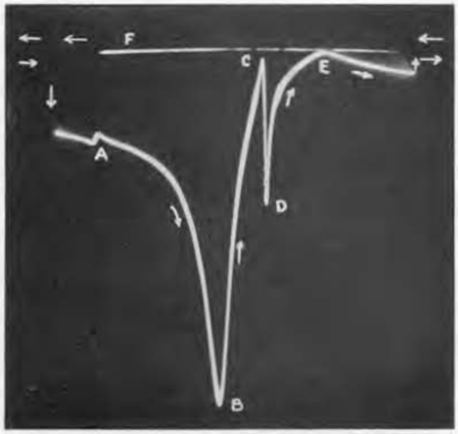


Figure 4. Oscillogram of the response of a quartz plate with two spurious response frequencies.

The fixed plate of the frequency-sweeping capacitor is a sector 15° wide supported on a guided block on the vertical base. By means of a threaded shaft this plate can be moved toward or away from the rotating plate to change the range of frequency sweep. A scale and pointer are provided so that the sweep range can be reset to desired values without the need of recalibration.

At the upper right are mounted the resistors, by-pass capacitor, and germanium rectifier used for obtaining a rectified d-c response voltage from the quartz crystal under test. The essentials of the circuit are shown in the schematic diagram of Figure 3. (For convenience in viewing, the germanium rectifier is poled to give negative deflections on the screen.)

An unretouched photograph of the response of a 1400 kc *AT*-cut quartz plate, before edge grinding, is shown in Figure 4. The sweep cycle starts at the

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upper left, with the spot moving to the right. As the blanking contact is closed, there is no vertical deflection. When the blanking contact opens, the spot drops downward along a vertical line, the distance depending on the shunt capacitance of quartz crystal and holder and on the frequency. Then as the spot moves to the right, in synchronism with the change in frequency, the response of the quartz crystal is traced. At the right edge of the figure the spot jumps up to the zero line when the blanking contact closes and finally returns along the zero line, *F*, to the initial position.

The response of a normal quartz crystal consists of a smooth curve from region *A* to a minimum, at series resonance, at *B*, followed by a smooth rise to a maximum at parallel resonance, at *E*, followed by a smooth drop.

In Figure 4, a small spurious response is indicated at *A*, and a larger one at *D*. Both of these move toward the left (toward lower frequencies), with respect to the principal resonance *B*, as the temperature is increased. The response at *D* increases rapidly in magnitude, with rising temperature and at some temperature *D* reaches the same level as *B*. The quartz crystal then has two response frequencies where the series impedances are low and equal. Any slight change in temperature then causes one response to be larger than the other. Under these conditions the frequency of an oscillator in which the quartz crystal is used will jump from one value to another. At *E* parallel resonance occurs between the quartz plate (acting as an effective inductance) and the total shunt capacitance. The impedance is high as evidenced by the spot returning to the zero line.

Suitable edge grinding causes the responses *A* and *D* to move to the right (toward higher frequencies). To produce a satisfactory quartz crystal, the grinding must be continued until response *A* has been carried clear through the operating region to a frequency well above the region shown in the photograph. All this is very straightforward, but the practical difficulties sometimes pile up when such edge grinding brings in additional responses, from the lower frequency side of the picture, which must, in turn, be moved out at the high frequency side — which brings in more low frequency responses, which must, in turn, . . . etc.

Only one difficulty has been experienced in setting up and operating this equipment, and that is frequency modulation of the oscillator output produced by mechanical vibration. Possible causes lie in the power supply of the instrument, where transformer vibration mechanically modulates some part of the two oscillator circuits, and in vibration transmitted from the motor or Variac to the sweep frequency capacitor, connecting wires, or to the oscillators of the source. The amount of such frequency modulation is minute, but, on a very steep portion of a quartz crystal response curve, it is readily observed as a lengthening of the spot. This difficulty is greatly reduced by use of sponge rubber mountings.

— J. K. Clapp

The crystal mode indicator described in the foregoing article is not manufactured for sale by the General Radio Company. The oscillator, oscilloscope, Variac, and motor are standard commercial products, as are many of the other parts. The complete assembly can be built in a well-equipped model shop, and crystal manufacturers will find it a valuable production tool.

— Editor

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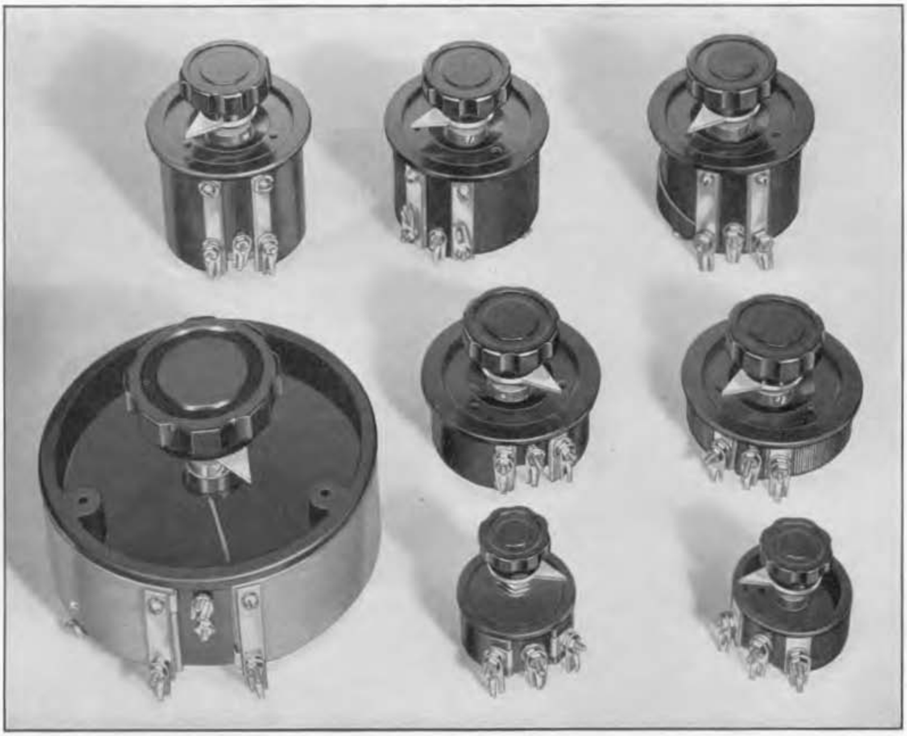
THE VERSATILE VOLTAGE-DIVIDER

PART I

A wire-wound potentiometer, or more accurately a voltage-divider, is superficially a very simple device. It consists of nothing more than a little resistance wire, wound around a supporting mandrel, with some sort of traveling brush arrangement to adjust the position at which contact is made to the wire. But the simple appearances are deceptive. This gadget is really insidious in its potential complexity. The circuit designer optimistically sees in it a panacea for all his troubles. He wants a potentiometer that will meet myriad requirements, many of which turn out to be mutually contradictory. He may want small size, high operating temperature, extreme linearity, very high resistance value, and a closely held curved relationship between resistance and rotation, which is often a curve having very steep portions.

When one of these "impossible" specifications comes to a potentiometer designer, he has to make up his mind whether to regard it as a challenge, or just to let the little men in the white coats come and get him. What he really does is to determine, with the circuit engineer, the best compromise between what is wanted and what can economically be done, probably dreaming up some new method or dodge under the pressure of the compromise to approach more closely the ideal desired.

Figure 1. A group of General Radio potentiometers showing the various sizes available.



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Potentiometers were among General Radio's earliest products. In producing them, the policy has been to aim for the quality rather than the quantity market, supplying highly critical users with a product for applications where the quality of materials and workmanship should be high with correspondingly long life, or where rigorous electrical specifications are to be met. Potentiometers, which can, of course, be used as rheostats by a change in connections, are stocked in standard resistance values which are decimal multiples of 1, 2, and 5. For specialized applications, units can be built to order, when the quantity desired is large enough to permit economical design and manufacture.

FEATURES

These potentiometers currently offer a number of features to provide flexibility of choice for the circuit designer, although combinations not listed in our current catalog are available only on special order:

1. *Sizes.* Molded bases are available having drum diameters, around which the flat-wound resistance strips are bent for attachment, between 1⅝″ and 5″.

Figure 2. A 5-inch-barrel potentiometer with justifying mechanism. This resistor is used in the Type 650-A Impedance Bridge.

The larger sizes are used where more resistance or more power-handling capacity is needed. Sometimes, as will appear later in this article, one of the larger sizes is also needed where a steep resistance-rotation curve is to be met.

2. *Mandrel Widths.* Different widths of mandrel, that is, depth behind panel, are available. In particular, the 2½″ barrel-diameter bases are available with four mandrel widths. The reasons for changing widths are similar to those for changing sizes of base, with the additional reason that the width required is dependent on whether the takeoff brush is a single one riding on a narrow flat edge, or a multifingered one traversing part of the inside cylindrical surface.

3. *Shafts.* ⅜″ O.D. shafts are regularly available in centerless-ground stainless steel, paper-base phenolic tubing, or steel-cored phenolic. For special purposes, of course, shafts of other materials could easily be used such as brass, aluminum alloy, solid phenolic rod, etc. ¼″ O.D. shafts are generally available only in centerless-ground stainless steel.

4. *Resistance Alloys.* There are many resistance alloys available having controlled composition and resistivity. These vary in resistivity from 10.6 ohms per circular-mil-foot for copper, up to 800 ohms per circular-mil-foot for Evanohm or 331 Alloy. In general, as the resistivity of the alloy increases, the hardness, wear-resistance, and tensile strength increase, and the temperature coefficient of resistivity decreases. The higher-resistivity alloys are employed where high total resistance is desired without using too fine a wire. The low-resistivity alloys are used where it is important that the resistance per turn be low, or, in other words, that there be fine adjustment of the potentiometer because the total number of turns is large.

5. *Justifying Mechanism.* The largest, or TYPE 433, potentiometer, having a 5″ diameter barrel, can be provided with an adjustable justifying mechanism (see Figure 2). This mechanism provides a means by which the contact arm can be made to travel at a different rate from the driving shaft. This enables the user to make the potentiometer track more closely a predetermined (perhaps etched) scale than it would as it comes from normal manufacture. The justifying mechanism consists of a flexible cam, the shape of which can be altered by screwdriver adjustments (see illustration).

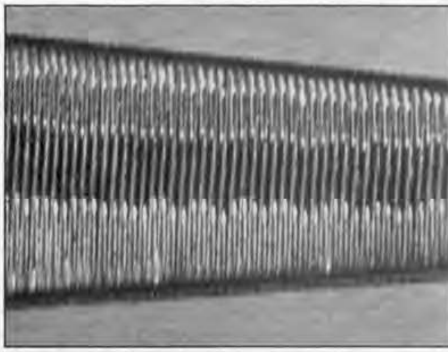

Figure 3. Close-up view of an Ayrton-Perry non-inductive winding on a tapered form.

6. *Range.* By changing the many parameters that will effect the total, resistance values from 1 ohm (or even below) to 1 megohm can be obtained.

These parameters include:

a. Wire size.
b. Use of ribbon instead of round wire.
c. Spacing of wires.
d. Wire alloy.
e. Size of molded base.
f. Shape of winding mandrel.

7. *Accuracy.* For catalog models, the accuracy specification is ±5%. By using a continuously variable speed changer to drive the carriage feed on the winding lathes, and by continuous monitoring of the results, it is possible to maintain an accuracy of ±1% in total resistance. However, for some extreme mandrel shapes, which are discussed later, not even the catalog accuracy of ±5% can be guaranteed.

8. *Linearity.* If linearity of voltage division is an important property, this can be improved by close attention to dimensions of parts and by keeping the winding lathe free of looseness, or lash.

9. *Materials and Dimensions.* A number of the details of these voltage-dividers have been given particular attention in order to secure superior performance.

Shafts are all centerless ground to control diameter closely, are made of stainless steel if of metal, or of a special grade of wrapped molded phenolic paper-base tubing having surface hardness controlled to resist damage from the points of set screws. The shafts run in journals of brass molded into the bases, which practice allows the shaft hole to be cylindrical and to be controlled for diameter better than a hole molded into the base. Shortly, when equipment now under construction is available, these shaft holes will be bored, rather than reamed, for still better control of size and direction (±0.0005″) on the diameter.

The mandrels on which the resistance wire is wound are made from a special grade of linen-base (rather than paper-base) phenolic sheet, in order to guarantee better flexibility for forming the mandrel around the molded base without cracking. Where bend radius is small, or where the mandrel has a narrow portion, a more expensive, nylon-fabric-base phenolic sheet is used, which has much better flexibility and tensile

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strength. A woodworking molder has been adapted to machine-finish the edges of these mandrels, assuring straightness and parallelism of the two long sides and a controlled smooth contour thereof, approximately semicircular.

These controls of width and edge contour are important if extreme linearity of voltage division is to be obtained (when a very linear voltage-divider is needed) or a particular curve is to be tracked accurately. It is also necessary to add another operation for turning the outside barrel of the molded base concentric with the shaft bushing, in order to remove eccentricity and molding taper, and to control the barrel diameter.

If accurate tracking of a resistance-rotation curve other than a straight line is to be attained, it is necessary also to control closely the thickness and the width of the mandrel (actually what needs to be controlled is the sum of thickness and width, which determines the length of wire per turn at a given rotation). If a number of voltage-dividers are to be gang mounted, it is sometimes necessary that the base of the molding be machined to be normal to the axis, in order to minimize the inevitable difficulties in such a structure in getting the shaft to run smoothly and easily.

10. *Non-Inductive Winding.* Where it is important to minimize inductance of the unit, the Ayrton-Perry method of winding can be employed (see Figure 3).

— P. K. McElroy

(To be continued)

This is Part I of a three-part article by Mr. McElroy on the design, performance, and application of wire-wound potentiometers. The other two parts will be published in early issues of the *Experimenter* and will cover such subjects as design tricks, limitations, economics, and examples of use.

— Editor

COAXIAL CONNECTORS FOR RG-8/U CABLE

We have received a number of inquiries about Type 874 Coaxial Connectors to fit the widely used Army-Navy Type RG-8/U concentric cable, and we are glad to announce that these are now available, as listed below. They are identical with the standard connectors for General Radio Type 874-A7 Cable previously announced,* except that the transition pieces, which connect to the cable, are designed specifically to fit RG-8/U cable.

Type		*Net Weight*	*Code Word*	*Price*
874-C8	Cable Connector	1¼ oz.	COAXCORDER	$2.00
874-P8	Panel Connector	2¼ oz.	COAXPUTTER	2.25
874-PC8	Panel Connector with Cap	2¼ oz.	COAXTOPPER	2.75

This connector is licensed under U. S. Patent No. 2,125, 816.

*W. R. Thurston, "A Radically New Coaxial Connector for the Laboratory," *General Radio Experimenter*, October, 1948

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