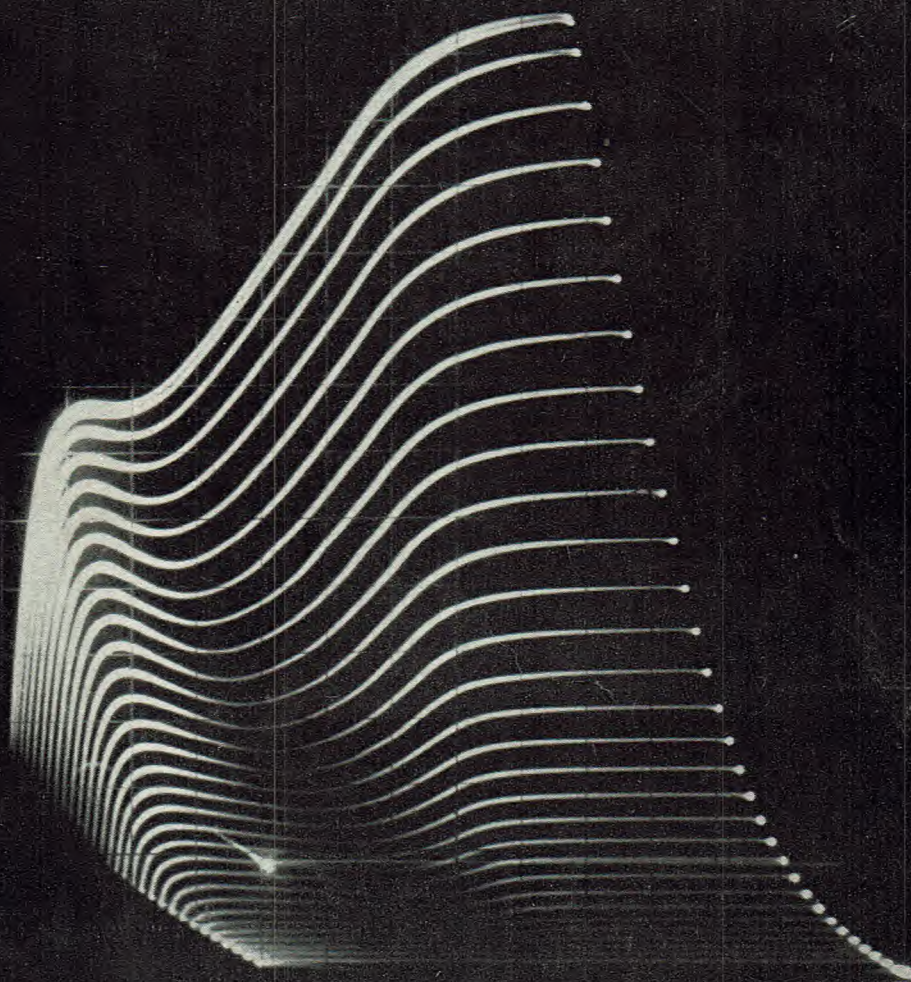


THE
OSCILLOGRAPHER



Vol. 13, No. 3

JULY - AUGUST, 1952



THREE-DIMENSIONAL TUBE CHARACTERISTICS

SEE PAGE 2

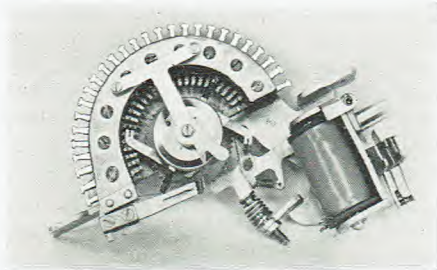


Figure 8. Stepping switch

In oscillography, switches are generally used to indicate limits, to start sweeps, to count, to create marker signals, and to select input circuits. To these ends rack and circular cams are employed frequently to actuate the switches. Actually, any protrusion on a rack or disc can be made to operate them.

The stepping switch, as shown in Figure 8, is sometimes employed to select input or output circuits. These switches may have 100 or more positions and many banks. Most of these switches are continually rotatable but some types return to their starting point by means of a spring after a certain number of operations. This type of switch is more commonly found in the form of a stepping-relay, that is, the switch is moved from position to position by means of a relay. Such relays can be operated from micro-switches, and when used in this manner, little direct mechanical power is required to operate them.

SPRINGS

A recent addition to the transducer field is the spring resistor. This device consists of a gold-plated wire, wound either helical or conical so that the tension varies along its length. When the spring is stretched, the turns separate one by one. This device, when tested by the National Bureau of Standards, showed that the resistance varied continuously either linearly or non-linearly (depending on the method of winding the spring) as the turns of the spring were separated.

The sensitivity of the device is excellent. Measurements of as little as 0.0001 inch displacement were made with

it without the use of amplifiers. With amplification displacements of several magnitudes less could be made readily.

Two methods of using this unit suggest themselves. It could be used as a leg of a balanced bridge and displacement could be determined by the change required to return the bridge to balance. Or, as its sensitivity is high, it could be connected in series with a resistor and the series combination connected to a battery or power supply. (See Figure 9.) In the latter application the signal is taken from across the spring resistor and fed into a high-gain cathode-ray oscillograph, such as the Du Mont Type 304-A Cathode-ray Oscillograph, or into some other measuring device.

A spring resistor is capable of faithfully following the displacement of a body to which it is connected up to its self-resonant frequency, and in addition, it generates a voltage which is an accurate reproduction of its elongation. As the resonant frequency of a spring is determined by its mass and compliance, the self-resonant frequency of a small spring can be made quite high.

MECHANICAL NON-LINEAR TRANSDUCERS

When fine granules of carbon are loosely packed and a voltage applied through them, they will pass a current which varies directly with the pressure applied to them. Such granules placed between a heavy plate and a diaphragm formed one of the earliest types of microphones, the carbon microphone. The variation in current obtainable from such a device is quite large.

Except for inexpensive microphones,

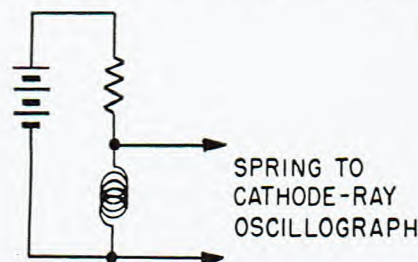


Figure 9. Method of using a spring resistor as a transducer element

the carbon "mike" is no longer used where faithful reproduction is required because the current variation is not strictly proportional to the applied pressure. It is rarely used as a transducer element for the same reason. However, this lack of linearity does not justify its rare use, for many transducer elements in common use are non-linear, indeed much more so than this element. In addition, the device is reliable, trouble free, and approximately linear over small ranges. Above all, the large voltage variations appearing across a series resistance (which makes amplification unnecessary) make it well suited for many applications.

If carbon granules are to be used as a transducer element, special "microphone carbon" is available. Where low pressures are encountered, the granules should not be tightly packed, and the chamber which contains the carbon is best left barely filled.

Another device which varies its resistance with mechanical pressure or strain is nickel wire (plus a few other metals). A current passed through the wire will vary as the wire is either bent or twisted. Since the current variation is small, the device is generally used as one leg of a bridge. This is necessary unless amplifica-

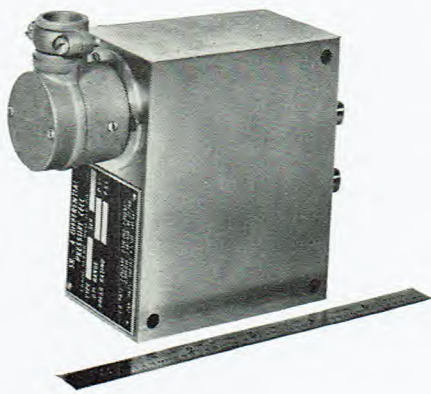
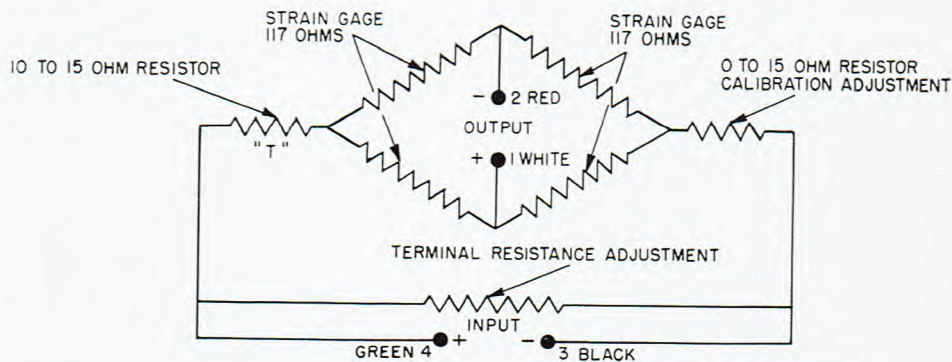


Figure 10. Pressure cell (strain gage) with schematic. Shown with 6-inch rule. (Courtesy of Baldwin-Lima-Hamilton Corporation)



120.0 ± 0.2 OHMS AT 70°F. INCREASES APPROX. 1 OHM FOR 50°F. RISE IN TEMP.

NOTE-

RESISTOR "T" VARIES WITH TEMPERATURE TO COMPENSATE FOR THERMO-ELASTIC COEFFICIENT OF PICK UP METAL.

RECOMMENDED INPUT VOLTAGE 6 VOLTS A.C. OR D.C. MAXIMUM INPUT VOLTAGE 10 VOLTS A.C. OR D.C.

OUTPUT VOLTAGE 2.00 ± .005 MV./V. INPUT.

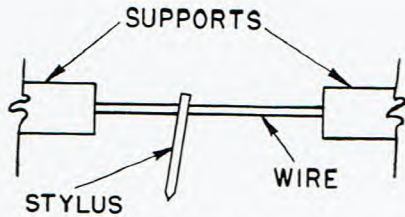


Figure 11. Phonograph pickup which uses nickel wire as the transducer element

tion or very sensitive measuring instruments are employed.

Such wire, when folded and backed by a piece of felt and covered by paper, is commonly used as a "strain gage." A pressure cell, which employs more than one strain sensitive element, is shown in Figure 10. A phonograph pickup similar to this which uses nickel wire as the transducer element is on the market. As shown in Figure 11, this pickup uses a flat strip of nickel clamped tightly between two blocks. The stylus, attached to the wire, twists the wire, thereby varying the resistance of the nickel.

However, the strain gage finds its chief use as a transducer in a balanced bridge arrangement. (See Figure 12.) As is well known, if a-c is applied across a bridge, the bridge can be balanced by varying the potentiometer (C). To measure the strain of a plate or other device with the balanced bridge the strain sensitive elements (A) and (B) are glued to opposite sides of the plate with the output of the bridge connected to a measuring device such as a high-gain cathode-ray oscillograph (the Du Mont Type 304-A, for example) or other measuring instruments. (If a single strain gage were attached to the plate, the bridge output, of course, would be halved.) With a-c power applied, the output signal will appear on the oscillograph as an envelope when the plate is placed under stress. If this type of signal is undesirable, direct current can be applied to the bridge and a high-gain d-c amplifier, such as the Hanover Type 104, can be employed to preamplify the signal. (Also, the a-c envelope can be removed by means of a

"lock-in" amplifier to be described later in the article.)

The envelope consists of sinewaves of the power frequency whose amplitude is varied by means of the strain sensitive elements causing the bridge to vary its balance. The amplitude of the envelope is a linear function of the strain, and, therefore, the bridge may be calibrated if accurate measurements are to be made. Because this amplitude is a function of the strain and is not dependent on its direction, care must be taken in interpretation of data. Since the phase of the output signal is a function of the direction of strain, the lock-in amplifier, which is sensitive to phase, will indicate both amplitude and direction.

Because the envelope consists of waves of the power frequency, no variation in strain approaching the power frequency can be relied on to give accurate data. For example, if a strain occurs whose duration is $1/60$ of a second and the power frequency is 60 cps (or, in other words, one cycle of the power frequency is $1/60$ of a second) the strain may reach maximum amplitude at the instant the input power goes through zero with the result that the output signal will be zero at the moment the peak strain occurs. Therefore, the observed data will be false. To avoid this, the power frequency should be at least ten times the maximum strain frequency.

Another way of employing strain sensitive elements is shown in Figure 13. In this application Elements A and B must

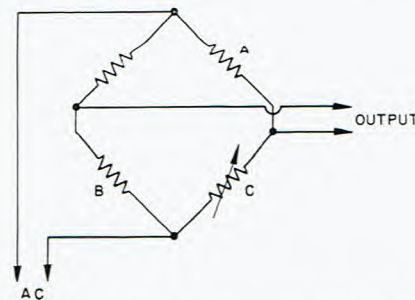


Figure 12. Strain gage employed with bridge

be arranged to be displaced in opposite directions. The voltages to the elements, each applied through its independent dropping resistor, should be approximately the same value but of opposite sign. The resistor R2 should be greater than R1. With no strain applied R2 should be varied until zero reading is obtained. (For any cathode-ray oscillograph with a-c amplifiers, such as the Du Mont Type 304-A, the cathode-ray beam should show little or no displacement when the transducer is disconnected from the oscillograph.) This transducer application indicates both amplitude and direction of strain and will operate over any frequency range likely to be encountered with mechanical devices. However, if the distortion of the strain sensitive elements is very small, preamplification will be necessary.

PHYSICAL NON-LINEAR TRANSDUCERS

Some substances when exposed to a specific condition will show a varying ability to conduct an electric current. Thus, selenium prepared properly will show an increasing ability to carry current as more light strikes it. Again, some salts, even common table salt, will exhibit greater current carrying capacity as the humidity of the surrounding atmosphere increases. The same is true of solutions of chemicals in some solvents.

The properties of these materials can be used advantageously to make transducer elements. They can be employed in any of the circuits previously described.

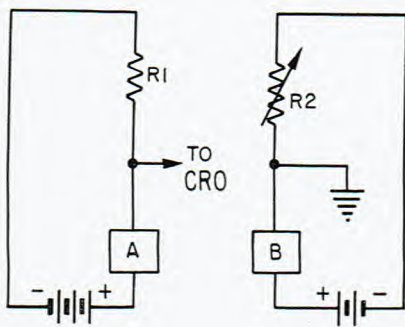


Figure 13. Alternate method of using strain sensitive elements

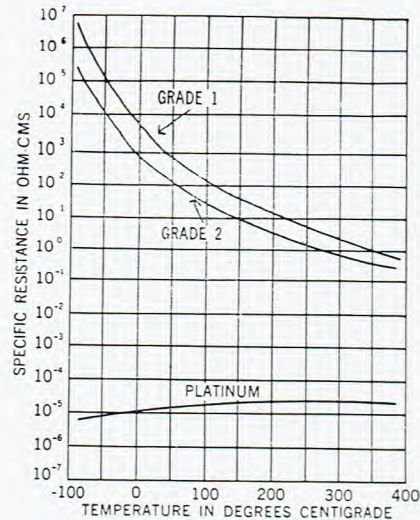


Figure 14. Graph of resistance versus temperature in degrees for General Electric thermistor. (Courtesy of Carboly Department of General Electric Company)

THERMISTORS AND NEGATIVE TEMPERATURE COEFFICIENT RESISTORS

Generally speaking, the resistance of metal wires increases in resistance as their temperature is raised, that is, the coefficient is positive. Platinum possesses the quality of varying its resistance more uniformly than other metals — i.e., it will have more nearly the same resistance when returned to the same temperature. For this reason, it is commonly employed in one arm of a bridge and used as a thermometer. The variation in resistance of metals with heat is small and either sensitive instruments or amplifiers must be used with them.

In recent years new materials have appeared on the market under the trade name "thermistors," "negative temperature coefficient resistors," etc. They exhibit increasing conductance with temperature, a characteristic directly opposite to metals. In Figure 14 a graph of resistance versus temperature is shown for one of these devices, and as may be seen, the variation of resistance with temperature is large. The range over which they can be employed is large, from -60° to 300° C.

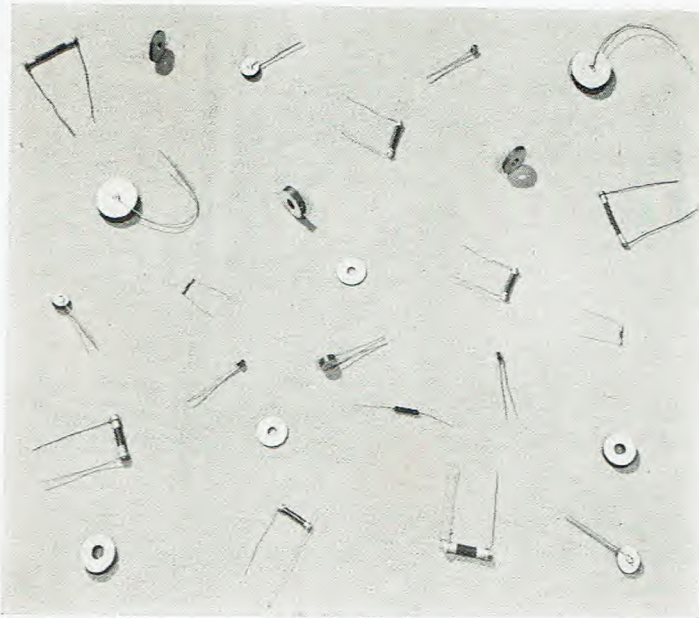


Figure 15. Thermistors available on the market. (Courtesy of Carbonyl Department of General Electric Company)

Thermistors and negative temperature coefficient materials (N. T. C. M.) are manufactured in many forms as shown in Figure 15. The small units which are manufactured as beads or flakes have a small time lag before a temperature change affects their conductance. This time lag in air is in the order of .008 seconds. Beads sealed in glass are reported capable of measurements accurate to $1/10^{\circ}$ F over a long period of time without recalibration, but at this date the information is not confirmed. These units may be obtained from the manufacturer in any resistance from less than 1 ohm to more than 1 megohm at 70° F. When ordering, resistance and temperature ranges should be specified.

The small time lag of the sealed bead unit makes them useful in obtaining data hitherto unavailable or obtained with difficulty with sensitive, fragile and expensive instruments. The latter is especially true in region below 300° or 400° C.

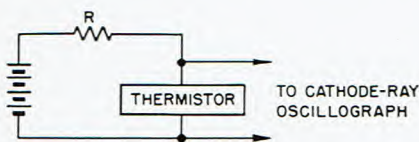


Figure 16. Method of using thermistor

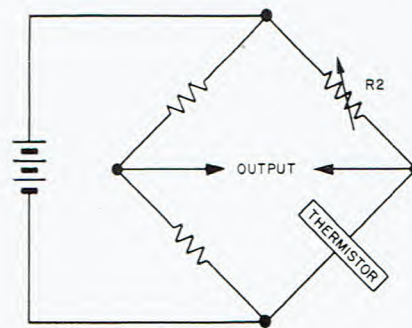


Figure 17. Alternate method of using thermistor

Above this region radiation sensitive devices may be employed.

Because of their large temperature and resistance ranges these thermistors, et al, may be employed in simple circuits. Where a large range is desired, the series circuit shown in Figure 16 may be used. Where a short range is required, the bridge shown in Figure 17 is better. Care must always be taken to limit the current flowing through the sensing element; as this element is essentially a resistance, excessive current will cause it to heat and thus affect readings. Thermistors and N. T. C. M. can be used to start a second device after a predetermined time, as

shown in Figure 18. With switch S1 closed, the flow of current causes the thermistor to heat, decreasing its resistance and permitting a further increase in current. At a predetermined point the current will attain a level sufficient to operate the current sensitive device. The current will not multiply indefinitely as the heat is radiated or conducted to the surrounding medium, and at some point equilibrium will occur. If the current sensitive device in Figure 18 is replaced by a resistor, the voltage across the resistor can be used to operate a voltage sensitive device.

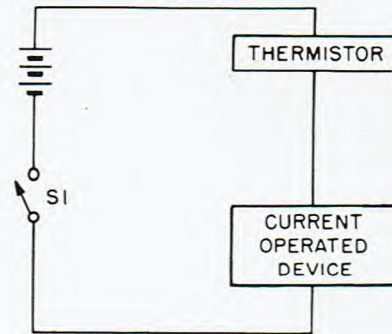


Figure 18. Method of obtaining time delay

THYRITE

At or about the same time thermistors were introduced, another device appeared on the market under the trade-names "thyrite" or "varistor." The resistance of these devices varies with voltage. Because their resistance is variable they are rated at a given current and voltage. A graph of their characteristics is shown in Figure 19. One of the characteristics can be replotted to show how resistance varies with

voltage. The current flow to be expected with a change in voltage is approximately by $I = kE^n$, where E is the applied voltage, k a constant, I the current and n an exponent between 1 and 7. This law is not exact, and inspection will show this current to be a logarithm of the voltage. The reader should note that this is only an approximation, for these devices are semi-logarithmic.

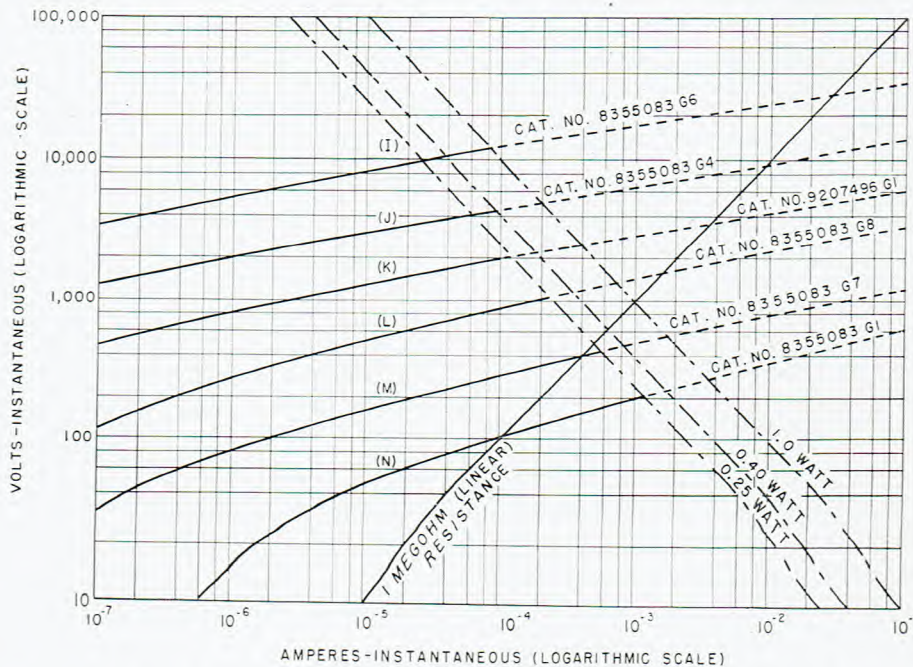


Figure 19. Graph of voltage plotted against current for thyrite. (Courtesy of General Electric Company)

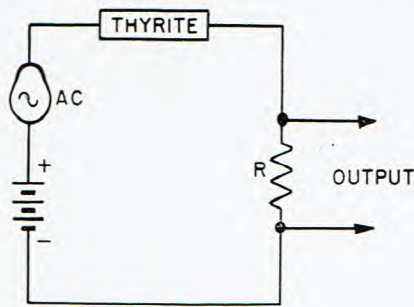


Figure 20. Thyrite used as coupling element

The use of varistors has been somewhat limited to equipment which operates over small temperature ranges because their characteristics vary with changes in temperature much more than most resistors. Where they are intended for use over a wide temperature range, some method of compensation should be employed.

Near the maximum voltage rating of thyrite the resistance changes relatively slowly. This property can be of great use when needed. It can be used to protect against a rise in voltage from a medium or high impedance source, or, as in Figure 20, it can be used as a coupling device displaying high d-c impedance and low a-c impedance. If the resistance, R, is of comparable resistance to the thyrite when biased by the d-c voltage, E, and a small a-c voltage applied in series, most of the applied a-c will appear across resistor R because resistance of the thyrite varies in such a manner as to aid the current change. If the a-c signal is small compared to the d-c by a factor of 10 or more, the thyrite will tend to act as a nearly linear coupling element.

As a transducer element thyrite probably finds its greatest single use as a logarithmic attenuator. For many applications in biologic, psychologic and other research a logarithmic response is more desirable than a linear response, especially where the range is very great and compression is required. To build such an attenuator, the circuit given in Figure 21 may be employed. In this schematic diagram two sections are shown with a dashed line separating the sections. By

careful choice of values two and a half decades (500:1) or more range may be achieved. Adding more sections will further extend the range. As both the input and output impedance of such a device are not constant, it may be found desirable for applications where constant impedance is required to shunt the input and/or output with a resistance whose value is low compared to the network terminal.

The attenuator shown in Figure 21 is single ended, i.e., a single signal is attenuated logarithmically. For many applications such a device is not sufficiently versatile; it is often necessary to obtain data from two fluctuating signals and measure the logarithm of their difference. For such applications the circuit of Figure 22 is suggested. The two signals to be compared are fed into the grids of the triodes (which may be in a single envelope). The output of the logarithmic attenuator, which is connected between the cathodes as shown, is not at ground potential and therefore the indicator may not be grounded. As the output impedance is low, a few hundred ohms at most, no difficulty from pickup should be encountered. The simplicity and stability of this circuit make its use desirable for many applications. However, if great accuracy is required, the thyrite elements should be maintained at a reasonably constant temperature, $\pm 5^\circ$ C or less.

BOLOMETERS

Bolometers are radiation detecting devices, which detect radiation by its heating effect. From this it is readily apparent that they are very sensitive devices.

A bolometer element may be a wire through which a fixed current is passed and the voltage across it is measured. (See Figure 23.) As usually operated, the bolo-

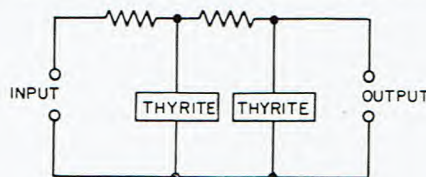


Figure 21. Logarithmic attenuator

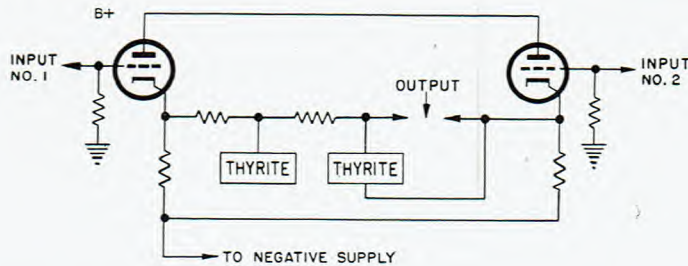


Figure 22. Circuit to measure log of difference of two fluctuating signals

meter element, a very fine wire, has constant current flowing through it, while a potentiometer in series serves to regulate the current and act as a load resistor. The current should be large enough to heat the wire, the sensing element, because it is most sensitive to radiant heat under this condition. The voltage drop across the sensing wire is measured.

Radiation causes the wire to heat, increasing the wire's resistance, and therefore the voltage across it. Air surrounding the element causes cooling, especially moving air. Thus, if accurate measurements are to be made, the air surrounding the bolometer wire must be motionless, or better yet, the wire should be in a vacuum. The temperature of the case will

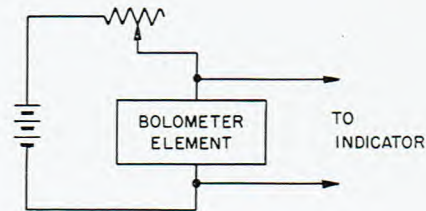


Figure 23. Bolometer

also affect the re-radiation of the wire and should be maintained constant.

Because a moving medium causes greater cooling than a stagnant medium, bolometers are often used to measure gas flow. They are even employed as air speed indicators in aircraft by measuring air flow as a function of cooling.

(To be continued)

"A Compilation of Analog Transducers" Published by Instrument Division

Over a long period of time, engineers of the Instrument Division have been called upon to advise industry in oscillographic techniques and applications. In the course of these activities, it has become increasingly apparent that a major stumbling block to the effective application of the cathode-ray oscillograph to non-electrical studies is the problem of selecting a suitable transducer.

To aid in this selection, the Instrument Division has published "A Compilation of Analog Transducers" which comprises 68 pages, and lists more than 500 transducers together with their more important characteristics. For radiation studies, a special section on Geiger-Mueller tubes is included. Another section contains a listing of pertinent reference materials quoting author and date of publication.

The "Compilation of Analog Transducers" is available from the Instrument Division (See address on Page 2) at a cost of 50 cents per copy.

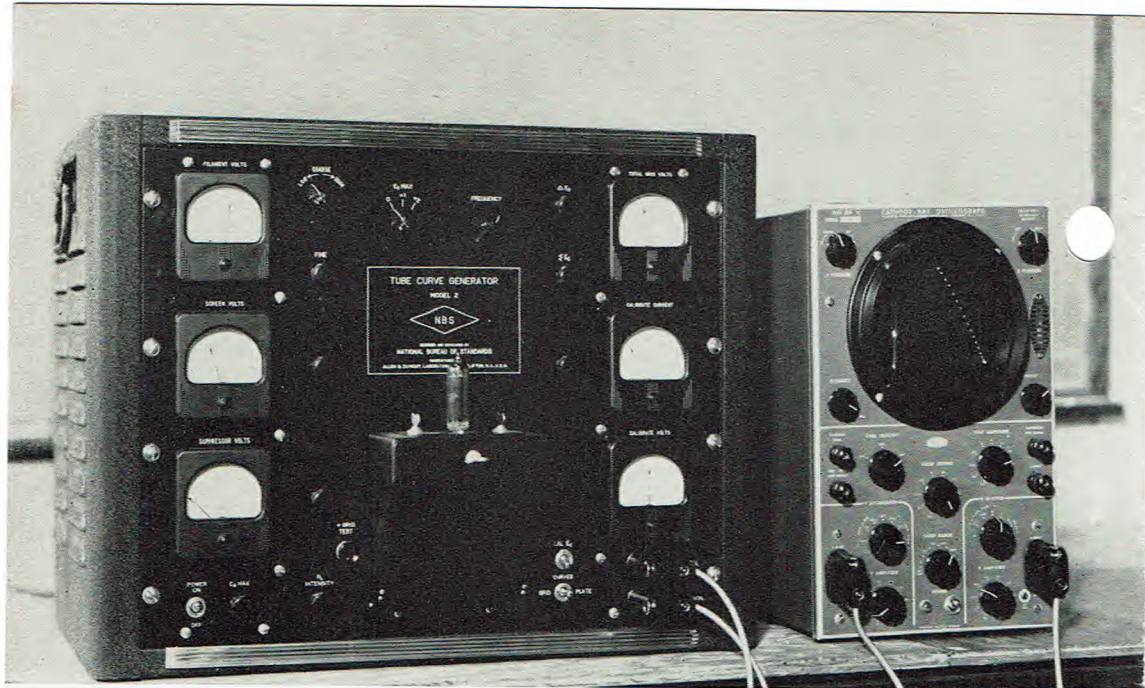


Figure 1. The new Electron-tube Characteristic Curve Generator. (Now designated the Du Mont Type 2590 Tube Characteristics Plotter)

A New Electron-tube Characteristic Curve Generator

Electron-tube characteristic curves are generally obtained by plotting meter readings of the desired parameters, such as plate current, for successive static values of other parameters, such as grid bias. Such a process is exceedingly wasteful of time, particularly for multi-electrode tubes; and the length of time required to take a reading might sometimes prohibit measurement of characteristics in regions exceeding dissipation or other ratings. Moreover, once a tube is incorporated in a circuit its dynamic characteristics may deviate quite widely from the previously obtained static measurements. Thus it may be seen that means for determining the dynamic characteristics of a tube rather than the steady-state performance are needed.

To accomplish this, M. L. Kuder, of the National Bureau of Standards, has developed a new Electron-tube Characteristic Curve Generator, the first model of which was manufactured by the Allen B. Du Mont Laboratories, Inc. The Electron-

tube Characteristic Curve Generator is used with a Du Mont Type 304-H Cathode-ray Oscillograph* and a Du Mont Type 297 Oscillograph-record Camera.¹ (See Figure 1.) With this combination a photographic record of tube characteristics may be obtained in less than two minutes.

A number of tube characteristic curve plotters using cathode-ray oscillographs have been constructed from time to time, but they have left important problems unresolved. For example, in measurements of this type one is faced with the problem of calibrating the oscillograph, since the scale may be slightly non-linear. Also, the input signal may be in error owing to the non-linearity of the Electron-tube Characteristic Curve Generator. Therefore, it has been necessary in the past to put the calibrating signals through the complete circuitry to compensate for this accumulative non-linearity, or to photograph the oscillograph scale and the tube characteristics separately. The

*Now succeeded by Type 304-A.

trouble in the latter instance is that the tube-plotter characteristics might change with variations in line voltage, drifts, changes in ventilation, etc., in the period between exposures.

To obviate these difficulties the new Electron-tube Characteristic Curve Generator presents both the tube characteristics and the calibrating voltage on the cathode-ray screen in 1/60 of a second. The presentation is locked to the power frequency so that effects of line-voltage hum and stray fields are held substantially constant.

The new Electron-tube Characteristic Curve Generator is designed to test the normal range of small receiver tubes including sub-miniature sizes. The tube is connected into the circuit by an adapter for each type of tube socket. The leads in this attachment are carefully shielded from external effects.

The oscillograph for this application must have satisfactory transient response for both X and Y deflections in order to avoid distortion. The Type 304-H was chosen for this purpose.

Meters are provided in the Electron-tube Characteristic Curve Generator for setting the filament or heater voltage, the maximum grid voltage, the screen, sup-

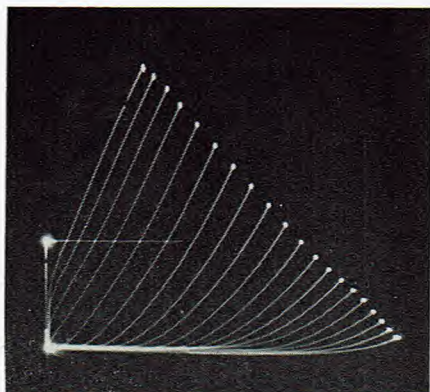


Figure 2. Family of I_p - E_p curves for 6SN7 tube. E_b max = 300 volts; ΔE_c = 1 volt; $E_c +$ max = + 1 volt; I_b std = 6 ma; E_b std = 100 volts. The value of R_L is 12,000 ohms

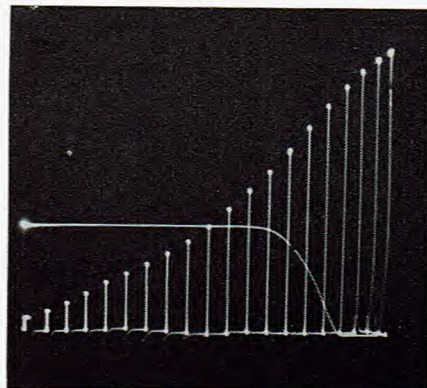


Figure 3. Family of I_b - E_c curves for 6SN7 tube, E_b max = 300 volts; ΔE_c = 1 volt; $E_c +$ max = + 1 volt; I_b std = 7 ma; R_L = 12,000 ohms

pressor and plate voltages. From additional meters amplitudes of voltage- and current-standardizing wave-shapes may be read. The type of display obtained is shown in Figure 2 for a type 6SN7 tube.

In addition to the normal display of a family of plate-characteristic curves, a curve may be plotted stepwise of I_b versus E_c at an adjustable maximum value of E_b .

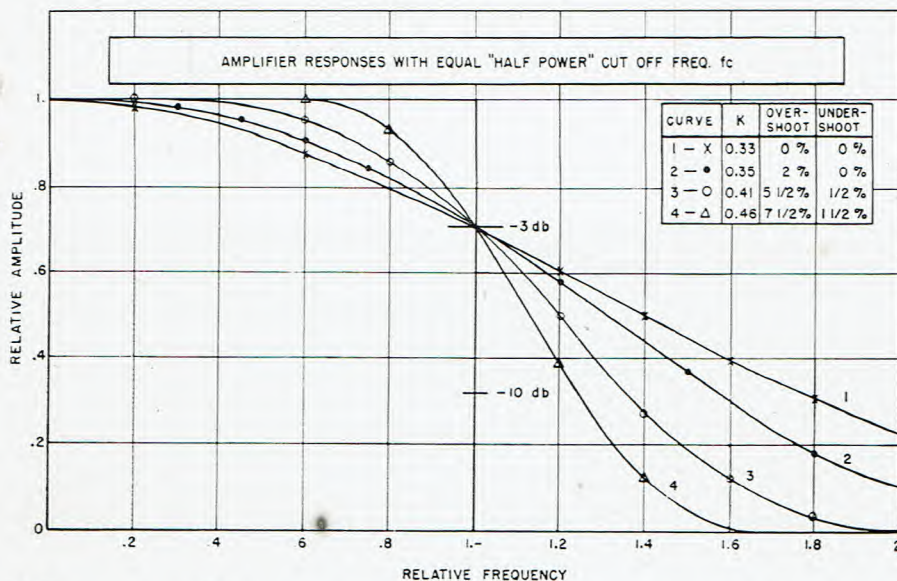
Circuits and controls are provided for indicating the value of E_c up to a maximum grid voltage of +1 volt. This value of grid voltage is shown in Figure 3.

Although the Electron-tube Characteristic Curve Generator is designed to test tubes, with modifications it may be possible to display I versus E characteristics of other devices, such as varistors, thermistors, crystal diodes, transistors, etc.

At its present stage of development the electron tube is a complex device, requiring a mass of data for accurate reproducibility. What the Electron-tube Characteristic Curve Generator does is to gather this data rapidly. For this reason, the Electron-tube Characteristic Curve Generator offers a great potential contribution to electron-tube technology in promoting better tubes with greater reproducibility.

As a service to industry, the Instrument Division offers its engineering and manufacturing facilities to those interested in

Correction



THE OSCILLOGRAPHER

A publication devoted exclusively to the cathode-ray oscillograph, providing the latest information on developments in equipment, applications, and techniques. Permission for reprinting any material contained herein may be obtained by writing to the Editor at address below.

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ON THE COVER

Family of $E_p-I_p-e_g$ curves for 6AG7 tube, tetrode-connected, taken with a Du Mont Type 296 Oscillograph-record Camera from the face of the newly developed Du Mont Type 2590 Tube Characteristics Plotter. This new instrument presents both the tube characteristics and the calibrating voltage on the cathode-ray tube screen in 1/60 of a second. In this display the characteristics are displayed as a function of three variables: plate voltage, plate current and grid voltage. Third-dimensional effect is enhanced by intensity modulation. For further information see Page 18.

We wish to rectify an error made in the Oct.-Dec., 1951, issue of the Oscillographer (Vol. 12, No. 4). On page 14 in the article, "Relating Transient and Amplitude-response Curves without Computation," by H. E. Kallmann, Figure 1 is incorrect. The corrected graph appears above.

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Type 2562- Illuminated Calibrated Scale Kit	20

procuring instruments similar to the Electron-tube Characteristic Curve Generator described above. Each proposal will be considered on its individual merits. Inquiries should be addressed to the Allen B. Du Mont Laboratories, Inc., Instrument Division, 1500 Main Avenue, Clifton, N. J.

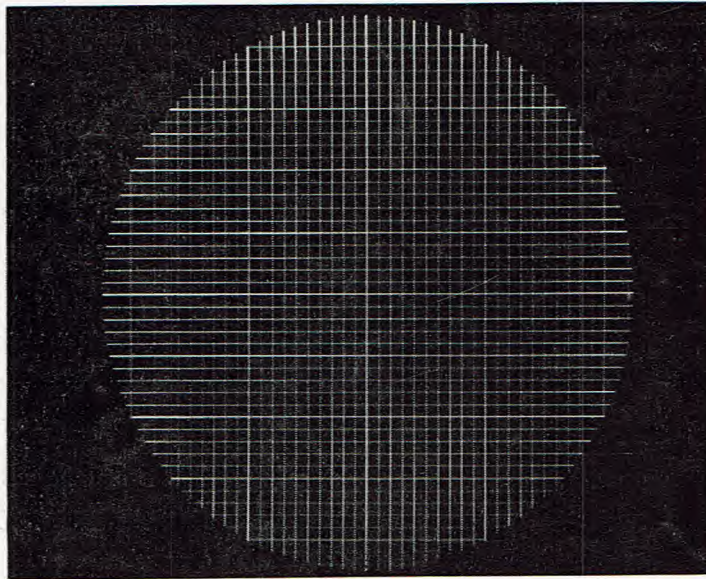
1. Kuder, M. L., "Electron-tube Curve Generator," *Electronics*, March, 1952
2. Arnold, Joseph, "Electronic Tracing of

Tube Characteristics," *The Sylvania Technologist*, Jan., 1951

3. Haegele, Rowland W., "A Visual Transistor Test Method and Its Application to Collector Forming," *The Sylvania Technologist*, July, 1951
4. Von Ardenne, Manfred, "Cathode-ray Tubes," Pitman Publishing Co., 1939
5. Berkley, Carl, "Three-dimensional Representations on Cathode-ray Tubes," *Proc. I.R.E.*, Vol. 36, No. 12, Dec., 1948, P. 1530-1535.

(An article on three-dimensional oscillography will appear shortly in the *Oscillographer*.)

TYPE 2562- ILLUMINATED CALIBRATED SCALE KIT



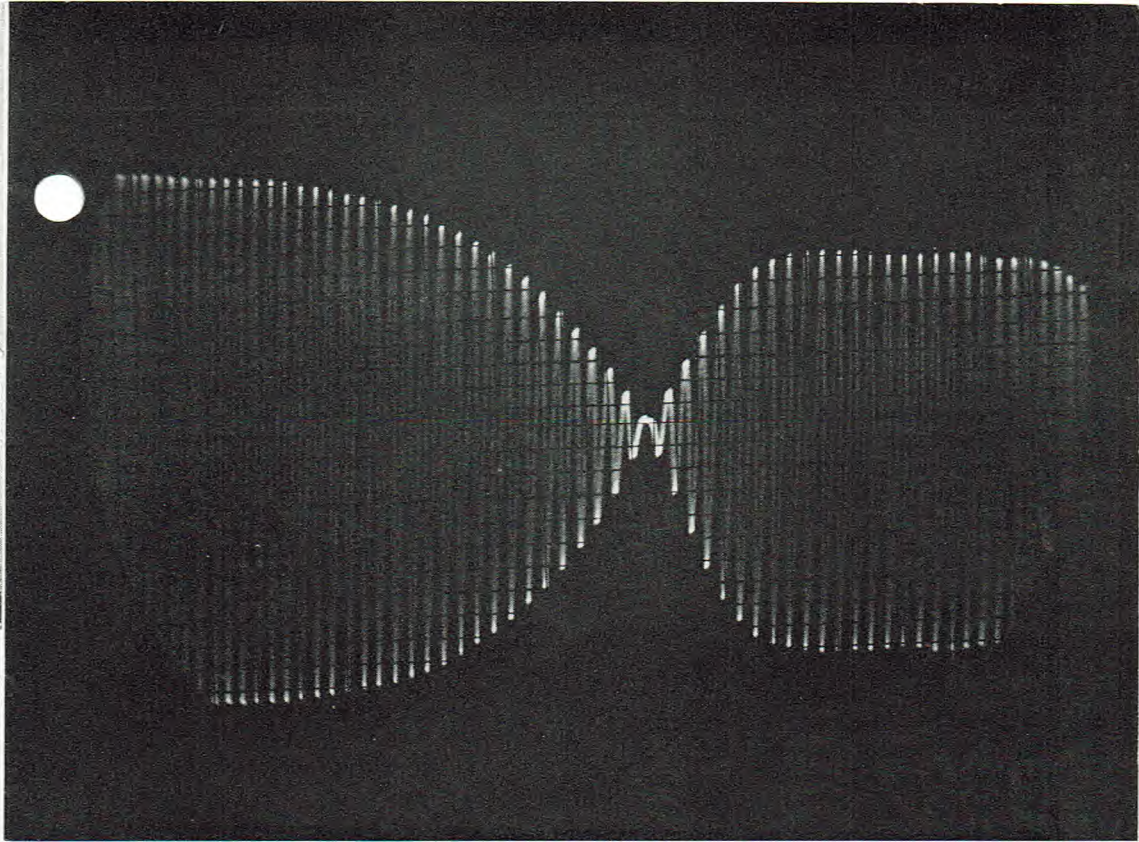
The Type 2562- illuminated calibrated scale as recorded by the Du Mont Type 296 Oscillograph-record Camera.

A new Illuminated Calibrated Scale Kit for users of cathode-ray oscillographs who wish to bring their equipment up to date is now being sold by the Instrument Div., Allen B. Du Mont Laboratories, Inc.

The Type 2562- facilitates amplitude and time calibration for both visual and photographic applications. It is designed to fit any 5-inch cathode-ray oscillograph with the standard Du Mont Type 2501 Bezel, and is especially useful under darkened room conditions or under a

camera hood where a scale without illumination is difficult to discern.

The new kit consists of four incandescent bayonet-type lamps with sockets, a bezel, front and rear masks, a plastic, rectangular-coordinate calibrated-scale, and a color filter. The lines on the clear plastic scale are engraved 10 x 10 to the inch, with one-inch vertical lines and half-inch horizontal lines accentuated. Cat. No. 1604-A (green filter - P1, P2); 1605-A (blue filter - P11); 1606-A (amber filter - P7). Price \$15.50.



The Function and Design of Transducers for Oscillography

By Mark T. Nadir

Part 1

Accurate measurement of quantity is the very essence of engineering. Often, however, the appropriate yardstick for a direct measurement cannot be applied. In such cases those interesting, and often Rube Goldbergian, devices known as transducers are employed.

A good example of the need for a transducer was shown in the testing of razor blade edges for imperfections. Here one would normally suggest placing each razor blade under a microscope to examine its cutting edge. However, on a production line where the blades are moving past the quality control point at six

blades per second, this method of measurement is impractical. The solution in this case was the employment of a photocell transducer and a cathode-ray oscillograph. (This method was described in the Jan.-March, 1950, Vol. 12, No. 1, issue of the Oscillographer.)

Some of the limitations in direct measurement which require the use of transducers are as follows:

1. Where a quantity is too small to measure directly.
2. Where a quantity is too large to measure directly.

3. Where a quantity varies too rapidly to measure directly.

4. Where it is necessary to maintain a suitable distance from the object being measured.

5. Where a special set of conditions makes it impossible for the observer to be included in the experimental area. Examples of this might be where measurement is desired in a special small chamber, one rotating very rapidly, or when the area is radioactive.

Webster's Dictionary defines a transducer as "A device actuated by power from one system and supplying power in the same form to a second system." Increasingly, however, the word "transducer" has come to mean a device for translating a non-electrical quantity into electrical energy, preferably in the form of an electrical potential suitable for measurements. This transformation should take place according to some simple mathematical law (i.e., the relationship between the physical quantity and the output voltage from the transducer should be a function which is linear, logarithmic, trigonometric, differential, etc.) When this is not the case, interpretation of the information presented is difficult, if not impossible.

(A distinction must be made between a transducer and the transducer element. The *element* is that part of the transducer which does the actual conversion of some form of energy into electrical energy. The

transducer, on the other hand, is the total unit, with the element built into it, to perform a specific type of measurement or control.)

The transducers described in this article have characteristics desirable for use with the cathode-ray oscillograph. It does not follow that all of these devices cannot be operated in conjunction with other electrical equipment, such as voltmeters, phasemeters, control devices, signaling units, etc. However, the cathode-ray oscillograph is unique in that it alone can make all the information available, i.e., amplitude, phase, waveshape, peak value, etc. Moreover, such additional information as distance, angle, weight, speed, etc., can be plotted on one axis while some other quantity is plotted on the other axis, and calibrating markers of various types may be applied to facilitate reading.

Transducers have been designed for many purposes. Measurement of acceleration, vibration, pressure, and displacement are well known uses of transducers. Transducers are also employed to measure torque, tension, linear displacement, angular and linear velocity, viscosity, radiation, etc. In general, *any* physical quantity can be transduced into an analogous electrical signal.

In the design of a transducer, many factors must be taken into consideration. When a physical quantity is to be converted into electrical energy and the energy it possesses is small, a major consid-

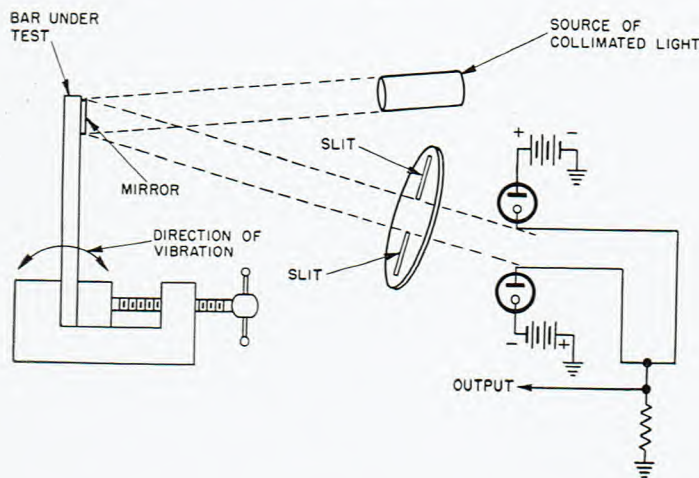


Figure 1. Indirect method of determining amplitude of oscillation of bar. Method of setting bar into oscillation is not shown

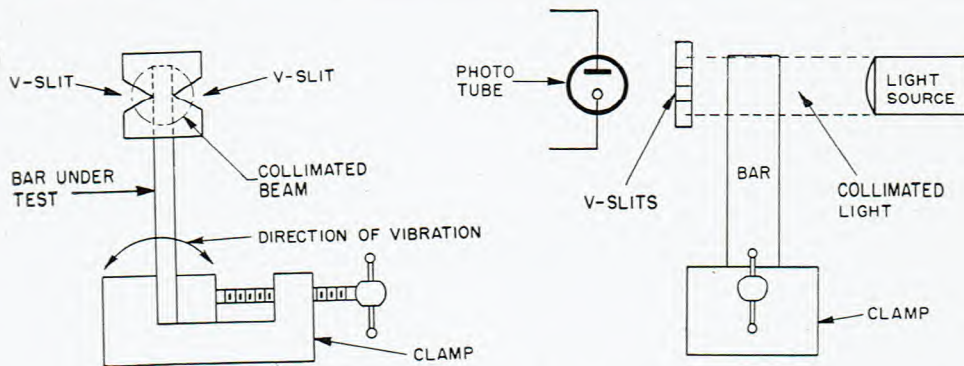


Figure 2. Alternate indirect method of measuring amplitude of vibration with phototubes connected as in Figure 1. Phototubes behind slit not shown in Figure 2a. Figure 2b is the same setup as Figure 2a from a 90° angle. One phototube is shown. Bar vibrates in and out of the plane of the page

eration is the magnitude of the energy which can be derived from the system without substantially loading it and significantly changing its operating characteristics. In this case it may be necessary to obtain a special transducer and amplify its output by means of an externally powered device. Thus, a comparatively large signal may be made available from a small controlling source. Some such devices will be described later in the article.

Still another difficulty may be encountered in obtaining data when the physical quantity to be measured possesses a large amount of energy. When testing a destruction by vibration, it is quite possible that the transducer itself will be destroyed before the object under test, with the result that the most vital part of the data is not obtained. However, the problem often can be solved by the employment of non-contact methods of measurement or by making the object under observation part of the transducer.

A good example of non-contact measurement or making the object part of the transducer is the testing of a metal bar with a rectangular cross-section whose length is long compared to its width. The information desired is the amplitude of vibration when one end of the bar is clamped while the other end is set into forced oscillation. Several methods are available to obtain the information, some

admittedly impractical. We shall start with an indirect method of observing the amplitude of motion, as shown in Figure 1.

Here a beam of light whose rays are made parallel to their direction of motion (collimated) is thrown on a mirror fastened to the bar under test (by plating it on, if necessary). The light beam is reflected by the mirror between two slits arranged so that a slight bending of the bar will cause one of them to be illuminated. Behind these slits are placed two phototubes. The anode of one phototube is connected to a positive source of voltage, its cathode is returned to ground through a resistor, and the other side of the voltage source is returned to ground. The anode of the second phototube is connected to the same side of the common resistor as the cathode of the first phototube, and the cathode of this second phototube is wired to a negative source of voltage whose other terminal is returned to ground. The output, taken across the common resistor, is fed into the vertical amplifier of a cathode-ray oscillograph, thus enabling the amplitude and waveform of the oscillating bar to be observed and measured.

An alternate indirect method of measuring the amplitude of vibration is shown in Figure 2.

An example of a method of measuring the amplitude of vibration of a bar by

making the bar part of the transducer is shown in Figure 3. In this case it is necessary that the bar be an electrical conductor or be made surface conductive by some means. The output will operate only into a high-impedance device, such as a cathode-ray oscillograph, and is not linear with displacement, but varies as the reciprocal of the distance between the bar and the charged plate. The metal plate should be as far as practical from the bar to reduce the effects of the inverse distance law. If a charged plate of opposite sign and equal voltage is placed on the opposite side of the vibrating bar at an equal distance from the resting position, a nearly linear output will be obtained. The theory of operation is that the capacity varies with the distance between the charged plates and the oscillating bar.

While four means for obtaining the amplitude of vibration of an oscillating bar have been described, they differ widely in the following important details:

1. Linearity of output
2. Principle of operation
3. Shape and size of the bar from which measurement can be obtained
4. Amplitude of output voltage
5. Impedance
6. Frequency of output signal
7. Ease of obtaining a signal free from noise and pickup

The four methods are by no means the only ways of obtaining the amplitude and waveform of the oscillating bar; the prin-

ciples previously listed may be employed in almost unlimited variations of arrangements.

In designing a transducer to be used to measure a quantity from a large body, it may be found that the quantity varies over or through the body. The important factor to be determined may be the variation of the quantity over a given surface or cross-section, or the direction of flow existing over the cross-section. The data can best be recorded as a graph of distance versus the quantity or its flow in a given direction. From this we see that the transducer must possess two characteristics:

1. The response time must be rapid enough for the transducer element to achieve equilibrium.

2. The element must have directional characteristics — the more the better.

Other design considerations must be mentioned. For example, the response time of the recording instrument must be shorter than any variation in signal received from the transducer. Furthermore, the distance along the abscissa (if distance is plotted on this coordinate) should have some simple mathematical relation to the distance through the body being studied. If this is impossible, markers of some kind must be incorporated to determine the distance.

The use of markers in the design of a transducer to measure the rate and direction of flow of a small body of water is illustrated in Figure 4.

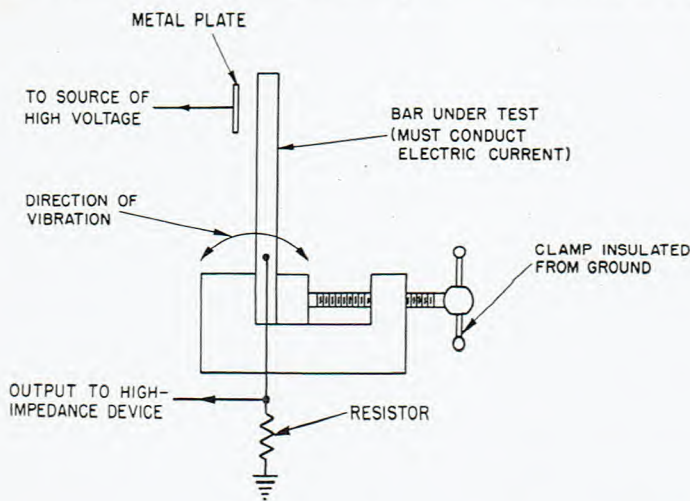


Figure 3. Method of using object under test (vibrating bar) as part of the transducer

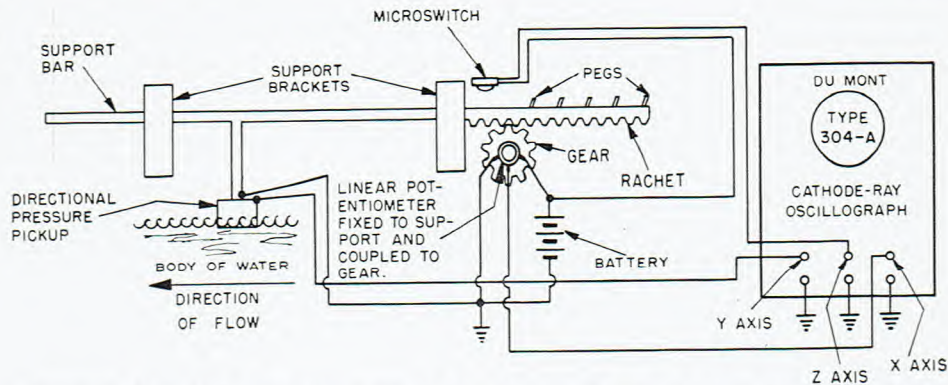


Figure 4. Method of determining rate of flow of a small body of water. Markers to determine distance are supplied by microswitch

In this example a Du Mont Type 304-A Cathode-ray Oscillograph was selected as the measuring instrument because it is d-c coupled on both X and Y axes, the displacement of the fluorescent spot is linear with changes in voltage, and it possesses a Z axis for intensity modulation. The transducer is a linear potentiometer which produces a linear change in voltage with a linear radial displacement. By coupling this potentiometer to a gear and ratchet as shown in Figure 4, the fluorescent spot on the oscillograph screen will be displaced linearly when the output of the potentiometer is connected to the X axis of the oscillograph. If pegs are placed in the support bar and a micro-switch incorporated so that the pegs cause the switch to be tripped in passing, a brighter or darker spot will appear on the waveform, and thus act as a marker. The transducer element itself is a pressure pickup which will respond to very slow changes. Also, the pressure pickup should possess directional characteristics if the direction of flow is to be determined.

It is evident from the above example that a transducer may become a complex of transducers and accessories. The latter are by no means unimportant.

Now that we have investigated some transducers and understand some of their basic features, we are almost ready to describe the basic types of transducer elements in a classified order. First, however, it is necessary to distinguish between the

principle of operation of a transducer and the purpose for which the transducer was designed. For example, the transducer may be designed to measure torque, but the method of measuring this torque might be a variation of resistance in nickel when it is twisted or bent. The quantity being measured here is torque, yet the principle underlying the measurement is a variation of the resistance in nickel resulting from strain.

According to their principle of operation, transducers may be classified as follows:

1. Resistive
2. Electro-magnetic
3. Optical
4. Capacitative

These classifications may be subdivided. For example, electro-magnetic can be subdivided into reluctance, variable flux, magnetostrictive and transformer. A non-linear case can be added with saturable reactors.

TABLE 1	
Resistive Transducer Elements	
1.	Potentiometer
2.	Switches
3.	Springs
4.	Mechanical Non-linear
5.	Physical Non-linear
6.	Thermistor
7.	Thyrite
8.	Bolometer

Examination of Table 1 shows that the resistive elements are made up of a surprisingly large variety of elements with a diversity of physical characteristics. These elements possess the ability to measure a wide group of phenomena directly — such as displacement (linear and angular), pressure, heat and humidity, etc. It is important to note that an a-c output can be obtained from all of these transducer elements. Whenever an output signal directly proportional to a slow input function is required, a d-c output transducer element must be employed, unless additional means are used to obtain the d-c components. The resistive and photoelectric elements most commonly possess this property, but there are some exceptions.

POTENTIOMETERS

The potentiometer usually consists of a resistive element such as carbon, or wire, either coated or wound on a circular insulator. In wire-wound potentiometers, insulating varnish is applied to the wire, except on the working surface, to keep the turns from shorting to each other. The insulator is not usually a complete circle and generally does not enclose more than 355° , although 360° potentiometers are available. The ends of the resistive element are brought out to two posts with a third post being connected to an arm, free to rotate, which contacts the wire or carbon surface. This arm is coupled to a shaft, and the shaft is brought out through the case which houses the unit.

Potentiometers are commercially available in a wide variety of tapers. The resistance of the wire or carbon coating may vary linearly with the distance from one end of the potentiometer to the arm as the arm is rotated uniformly. Such a "pot" is said to be linear. Other types include logarithmic, trigonometric, and non-mathematical tapers. Special tapers, accurate to almost any percentage, are obtainable from several manufacturers.

When ordering non-linear potentiometers, always be sure to specify whether the resistance is to increase most rapidly with clockwise or counter-clockwise rotation. Moreover, should the arm of the

"pot" impose too great a load on some device, special potentiometers are available that require a small torque to operate them.

The degree of accuracy that may be achieved with wire-wound potentiometers depends upon the number of turns of wire on the circular insulator and the care with which the potentiometer is made (such as uniformity of wire resistance and the spacing between the turns). On the other hand, carbon potentiometers cannot be made as accurately as wire-wound units. Carbon types also show wear sooner than wire-wound "pots." This wear appears as an erratic signal, known as "noise."

Rotational speed of the potentiometer arm is limited, and at high rates the arm tends to break contact with the resistive surface. Naturally, this "bounce" varies widely with the torque required to operate the arm, and among the brands sold commercially.

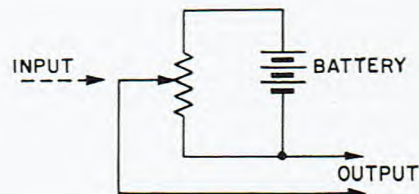


Figure 5. Method of connecting potentiometer as transducer

A common method of connecting a potentiometer as a transducer is shown in Figure 5. A battery of suitable voltage is connected across the potentiometer and the output taken from the arm and one side of the battery. The input is the mechanical rotation of the shaft by some device. It is a matter of choice whether the output is to be taken from the positive or negative terminal of the battery. However, in oscillography, an upward and rightward deflection of the cathode-ray beam is generally understood to mean an increase in voltage, current, etc.

A special type of potentiometer is shown in Figure 6. Essentially, it is a wire-wound rotating card which provides a convenient means of obtaining two signals (sine functions) separated by 90°

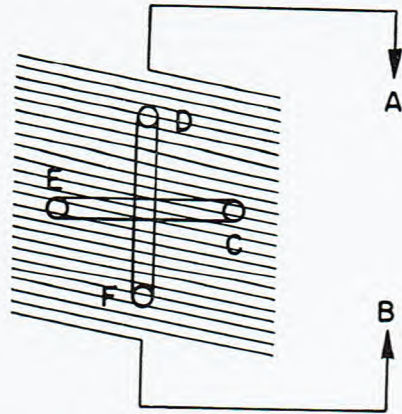


Figure 6. Potentiometer whose output is 2 sinewaves 90° out of phase

electrical and mechanical degrees. The winding itself consists of a simple single layer of close-wound wire. The end terminals "A" and "B," plus "C," "D," "E," and "F," are all brought out to binding posts. The wire-wound card is rotated by means of the shaft which extends through the housing. In operation a voltage is impressed across terminals "A" and "B" while the output is taken from any two contacts 180° apart — either "C" and "E," or "D" and "F." The signals obtained from "C" and "D," or "E" and "F," are 90° apart. When the shaft is rotated mechanically at a uniform rate, the output will be a sinewave or cosine wave whose frequency is the frequency of rotation, or speed, of the shaft. If the impressed voltage across terminals "A" and "B" is varied, the output is proportional to both the shaft angle and the impressed voltage. This is a simple means of obtaining modulation.

SWITCHES

The simplest type of switch is the on-off variety. One of the most common is probably the microswitch. These are actuated by a slight pressure which varies with the make and model, some requiring two grams or less for their operation. These pin and plunger type switches require a small fraction of an inch motion, $1/32$ inch or less, and they return to their orig-

inal condition, either open or closed, when the pressure is released. Some of these switches are equipped with lever arms with springs affixed to pivot or the arms themselves may be springs. Switches with rigid arms may be obtained with rollers fitted at the ends of the arms. Among other features worthy of note are dust-proof housings, supplied by most manufacturers, and, less common, water-proof housings. Where space is limited, un-housed switches or the new small units appearing on the market may be employed. These small switches sometimes possess the unusual property of being free of contact bounce.

Most switches when thrown from the open to closed (contact) position, or vice versa, will "bounce." That is, the switch will not close once and remain closed but will rebound and thus open the contact due to the elasticity of the materials. This is shown in the oscillogram in Figure 7 where the contact was made four times before remaining closed. For most applications contact bounce is not important except as it affects the life of the switch. However, when switches are used to operate into impulse counting devices, or for markers, etc., in oscillography, this phenomenon becomes objectionable, and switches free from bounce should be employed exclusively.

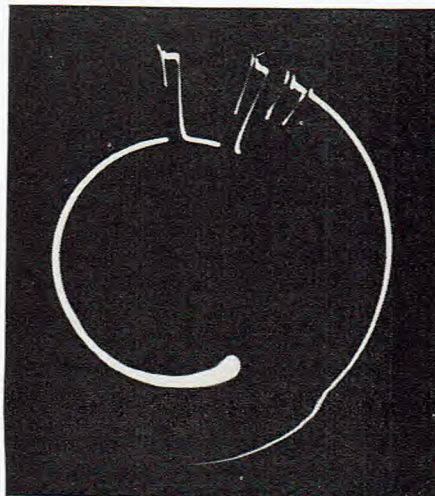


Figure 7. Oscillogram showing contact "bounce"