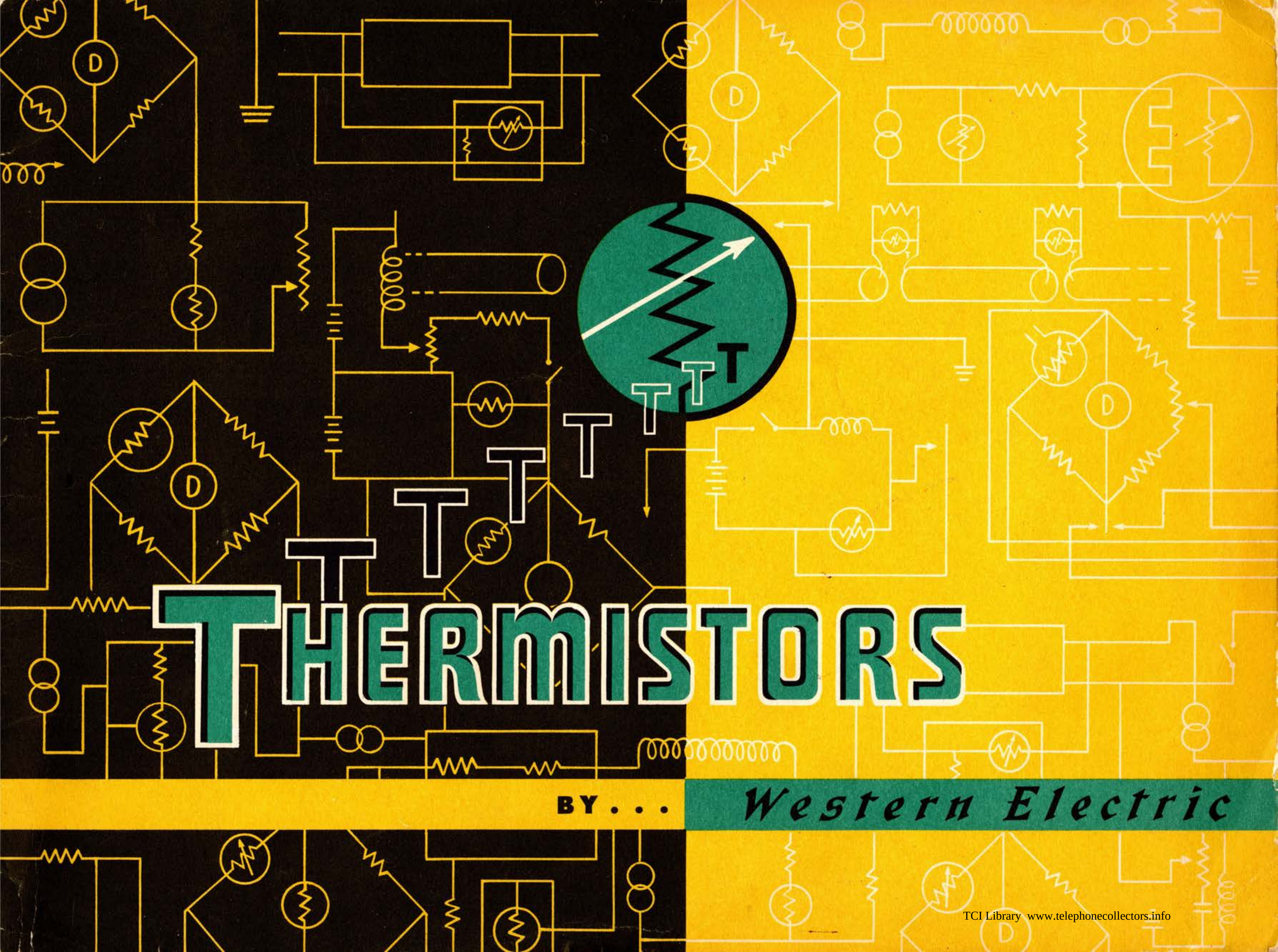
THERMISTORS

BY . . . *Western Electric*



Western Electric THERMISTORS

• Bell Telephone Laboratories, Inc., largest research organization in the world, has pioneered many of the outstanding developments in radio and wire communications.

• At intervals, achievements of this organization have been found to have applications, not only to communications, but to other fields in which electronic circuits can or do play a part.

• Such is the case with Thermistors whose many wartime uses greatly accelerated their emergence as an important factor in peacetime equipment design.

• Research developments of Bell Telephone Laboratories are manufactured by the Western Electric Company, for more than seventy-five years the leading producer of electrical sound transmission apparatus.

THERMISTORS
Their Future in Electronics

As the war-stimulated science of Electronics "comes of age" in a peacetime world, the rapid extension of its promised benefits—throughout Industry and into the home—will depend in large measure on the widespread use of simple, reliable and *economical* techniques by means of which physical energy can be automatically detected, measured, utilized and controlled.

Although much progress has been made in past years in the development of electronic control devices, the continued use of existing apparatus, as applied to the broad anticipated requirements of the future may prove in many respects both cumbersome and costly.

As a means of providing a simplified approach to such problems, the Western Electric Company invites attention to a group of sensitive control elements called Thermistors—developed by Bell Telephone Laboratories—which are proving experimentally adaptable to a wide range of industrial uses.

By comparison with devices which they are designed to replace, Thermistors are small, inexpensive, flexible in application, need little servicing and have indefinitely long life.

In addition to their regulatory functions, Thermistors exhibit certain "creative" characteristics similar to those of electron tubes in that they can, in association with appropriate electronic circuits, alter the form or intensity of energy passing through them. While these creative applications are for the most part still in the laboratory stage, they may prove to have far reaching effects in the industrial and electronic communications fields.

Outlined in this brochure are some of the salient characteristics and suggested uses for these new elements. Potential peacetime fields of application include: Broadcasting, Television, Wire Communications, Air, Sea and Land Transport, Housing and Household Appliances, Manufacturing and Assembly Line Operations, Chemical and Food Processing, Power Plant Operation, Mining and Metal Fabrication and all other fields where temperature variations exist or can be produced. Thermistors are licensed under Bell System patents for all purposes except public service communications.

If a study of your post-war design problems reveals a need for elements of this type, further discussion with a Western Electric or Distributor representative is cordially invited.

WHAT IS A THERMISTOR?

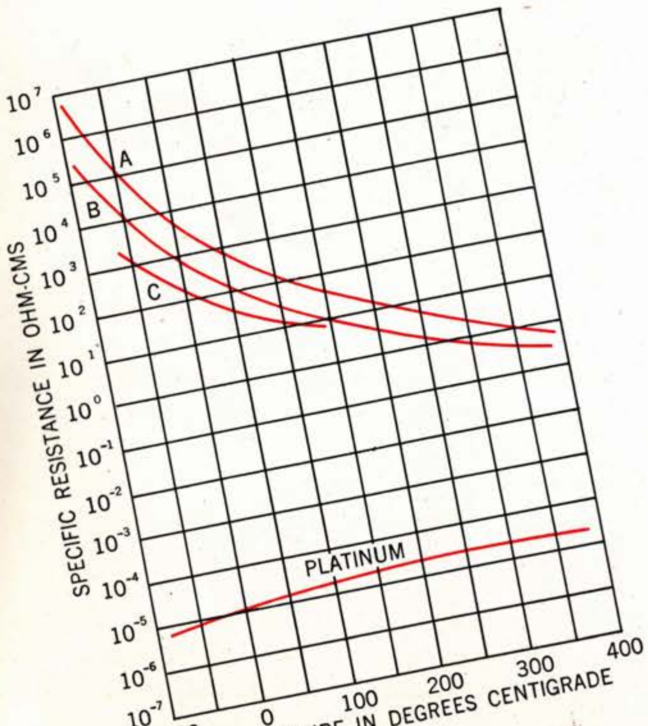


FIG. 1

Briefly, a Thermistor (Thermally Sensitive Resistor) is a new type of circuit element in which electrical resistance varies widely with changes in temperature. Made of a class of materials known as semi-conductors — that is, materials whose conductivity lies between that of conductors and insulators—one basic distinction between these and other variable resistance materials lies in their extreme sensitivity to relatively minute thermal manifestations.

Figure 1 demonstrates the changes in resistance which can be produced in three of the more commonly used Thermistor materials over a 500 Centigrade degree range of temperature, as compared to a representative metal. In some types of Thermistors, resistance may be doubled with a temperature change of as little as 30 degrees Fahrenheit.

In further contrast to metals, which have small, *positive* temperature coefficients of resistance, Thermistors respond *negatively* to temperature variations, i.e., resistance *decreases* as temperature rises; *increases* as temperature falls. Their large negative temperature coefficients give rise to unusual non-ohmic characteristics which endow them with unique regulatory powers.

Physical Characteristics

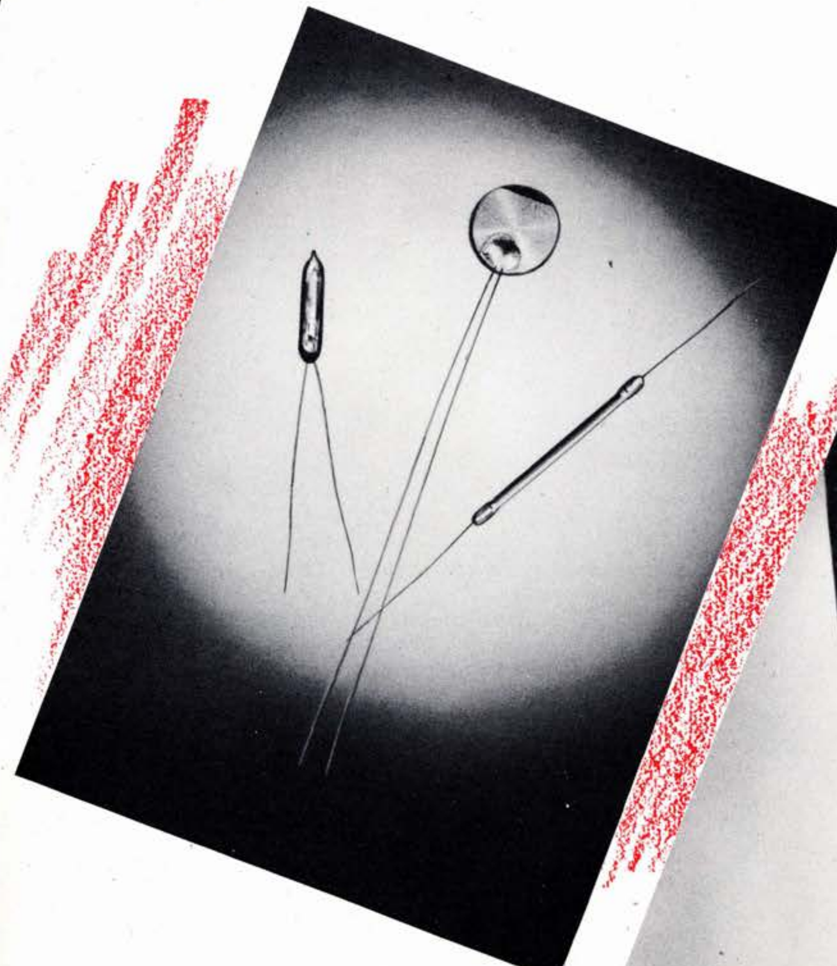
Although knowledge of the behavior of semi-conductors is not new, experimental investigations having been made by Michael Faraday more than one hundred years ago, it has remained for Bell Telephone Laboratories research to produce stabilized combinations which could be reproduced in quantity, capable of long and dependable service, and suitable for use with either a-c or d-c circuits.

Thermistors today are made in three main types: Discs, Rods and Beads. All are made with the same basic methods. The materials of which they are composed—manganese, nickel, cobalt, copper, uranium and other oxides, are milled and mixed in various proportions to provide the specific resistance vs. temperature and other characteristics desired for particular applications. They are then formed into the desired shape and lead wires are attached.

Firing, under carefully controlled atmospheric and temperature conditions results in a hard ceramic-like product which may be mounted in a variety of housings depending on mechanical, electrical and thermal requirements, as in the surrounding illustrations.

In all cases, mountings and enclosures are designed to assure dependable performance and long life. Tests on numerous types extending to more than 500,000 heating and cooling cycles have effectively demonstrated the stability of their thermal characteristics.

T Y P E S O F



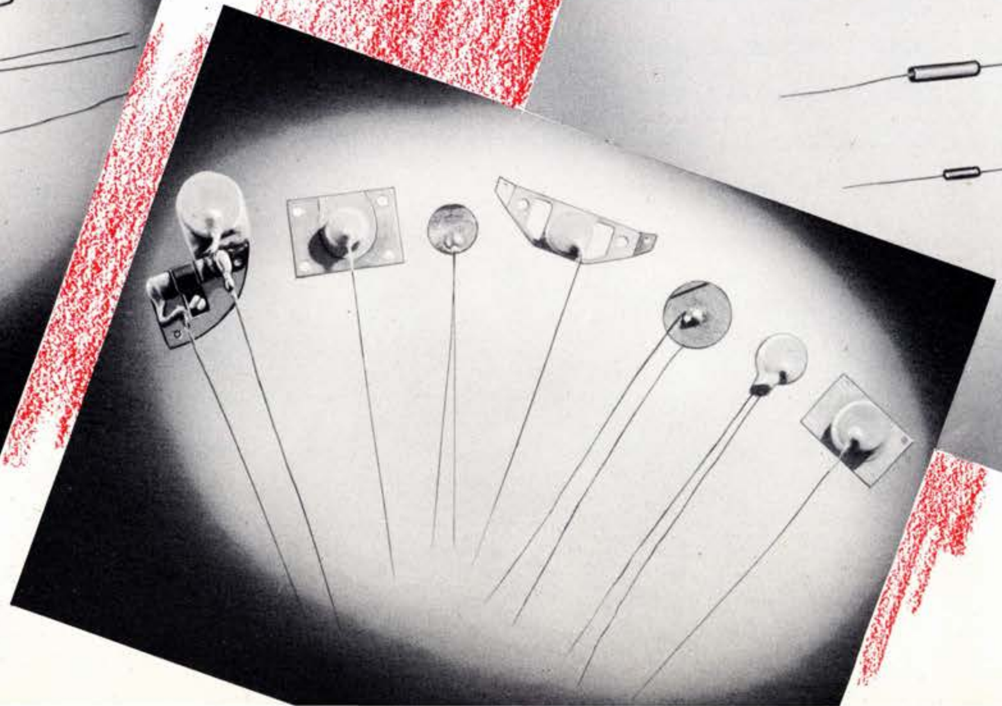
Disc, Rod and Bead Thermistors. The three basic types.

Bead thermistor elements are almost microscopically small. They are formed at specified intervals on twin strands of fine wire, which when cut apart, serve as the connecting leads.

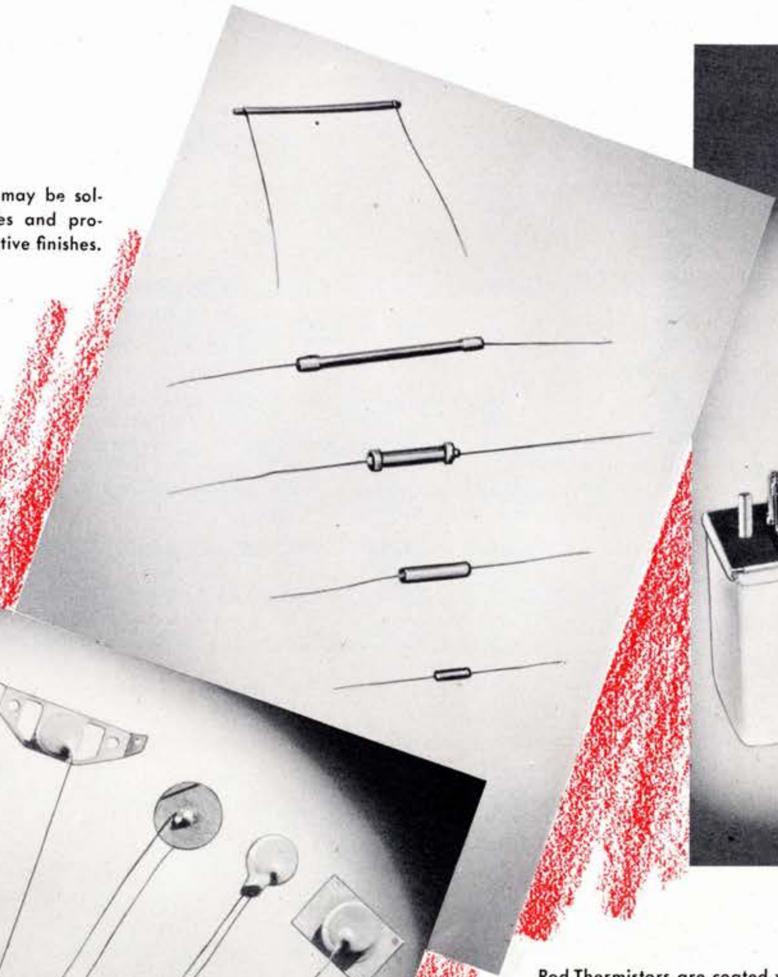
THERMISTORS

Testing one type of potted Thermistor. An airborne unit subject to rapid and extreme changes in temperature.

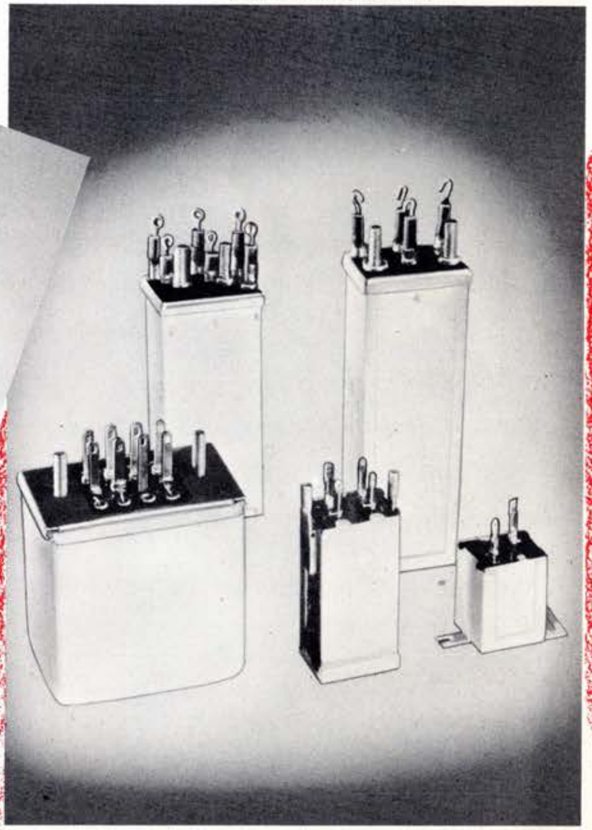
Bead Thermistors are often mounted in small, sealed glass bulbs which may be evacuated or gas-filled depending on thermal requirements.



Disc thermistor elements may be soldered to Mounting Plates and provided with suitable protective finishes.



Rod Thermistors are coated with glass or other electrical insulating material, and, where necessary, are furnished with an additional protective housing.



Where various combinations of Thermistors are used simultaneously in specific applications they may be enclosed in metal containers to simplify mounting and connection problems.

OPERATING CHARACTERISTICS

In operation, temperature variations affecting Thermistor resistance may be brought about in three ways:

1. Externally — by changes in the surrounding elements; air, water, etc.
2. Internally (or Directly) — where current passing through the Thermistor heats the element, thereby reducing its electrical resistance.
3. Indirectly—by means of a separate heating coil surrounding the Thermistor element, which produces a controlled ambient temperature condition.

Externally controlled Thermistors usually are of the disc or rod type, whereas the internal or indirectly heated elements normally are in the form of beads. A sectional view of one form of indirectly heated element is shown in Figure 2. This type of unit has particular merit in that the heater and resistance element are electrically isolated, permitting their insertion in separate circuits. Control is thus obtained thermally without electrical inter-action.

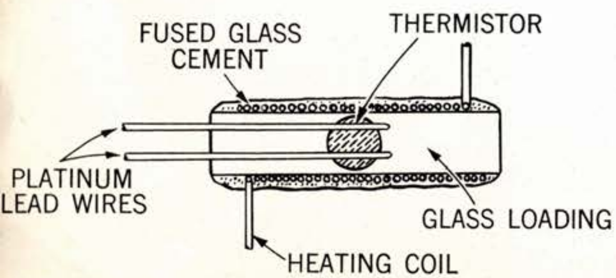


FIG.2

The 4 FUNDAMENTAL CHARACTERISTICS of these elements may be outlined briefly as follows:

TEMPERATURE-RESISTANCE CHARACTERISTICS (Fig. 3). The temperature-resistance characteristics of three of the more commonly used thermistor materials are shown in Figure 3, in terms of their specific resistance and inverse absolute temperature. A variety of other thermistor materials have also been developed for certain types of measurement and control applications where other characteristics were found desirable. Specific resistances ranging from 100 to 450,000 ohm-centimeters at 25°C can be produced, thus permitting a wide latitude in design. As a measure of temperature sensitivity, Thermistors have been developed having temperature coefficients of resistivity as high as 2.7% per degree Fahrenheit at room temperature. This compares with 0.20% per degree F. for a representative metal such as platinum.

The development engineer will be interested in the mathematical relationships describing the temperature characteristics of Thermistors. The resistance R of thermistor materials, in general, approximates the following relationships over limited temperature ranges:

$$R = R_o e^{\beta\left(\frac{1}{T}-\frac{1}{T_o}\right)}$$

$$\text{and } \alpha = \frac{1}{R}\frac{dR}{dT} = -\frac{\beta}{T^2}$$

where T = absolute temperature of Thermistor

R_o = R at T = To

α = Temperature coefficient of resistance

e = 2.718 . . . the naperian base

It will be observed that β is the slope of the curves shown on Figure 3. The values of β at 25°C. for three thermistor materials are listed at the upper left. The value of β at other temperatures can be determined from the slope of the curves. Given β and the resistance of a Thermistor at a specific temperature, the resistance at other temperatures, for the range that β is constant, can be readily determined.

VOLTAGE-CURRENT CHARACTERISTICS (Fig. 4). Current passing through a Thermistor causes a self-heating effect which is readily shown by its static voltage-current curves. A representative characteristic of one type of Thermistor is shown in Figure 4. At low currents, the effective change in temperature is small and Ohm's law is obeyed, i.e., the current is proportional to voltage and the characteristic is a straight line. With increasing current the effects of self-heating become evident and the temperature of the Thermistor rises with a resultant decrease in its resistance. Thus, as the current increases, the points for the steady-value voltage deviate more and more from a straight line. At some particular current, the voltage attains a maximum value and for larger currents, the voltage actually decreases. At still greater currents, the voltage becomes of the same order as the voltage drop in the connecting leads and thereafter the voltage increases. Voltage and current range can be greatly extended by proper design.

This voltage-current characteristic is of fundamental importance in the application of Thermistors to a great variety of voltage regulating networks.

RESISTANCE-POWER CHARACTERISTICS (Fig. 5). The self-heating effect caused by passing a current through a Thermistor can also be described in terms of the power dissipated within the element.

The useful changes in resistance brought about in one type of Thermistor at room temperature by the power dissipated within it are shown in Figure 5. If a small enough current is supplied so as not to heat it appreciably, it will offer a resistance of approximately 50,000 ohms. As additional power is dissipated, the element heats up and its resistance decreases. With 18 milliwatts dissipation, the resistance value will be approximately 18,400 ohms—a decrease of 31,600 ohms. With a dissipation of 100 milliwatts, an even greater proportional drop occurs, the resistance decreasing to approximately 800 ohms.

Note that the static resistance-power characteristics of a Thermistor are also presented on Figure 4 by the use of an additional set of coordinates. This method of plotting is commonly used since it presents the complete static characteristics of a Thermistor.

CURRENT-TIME CHARACTERISTICS (Fig. 6). The change in resistance of a Thermistor with change in current does not occur instantaneously. If a Thermistor is placed in series with a source of voltage, a delay will occur in building up the current, due to the thermal capacity of the Thermistor. The current-time characteristics of a representative Thermistor is shown in Figure 6. The initial current, which is determined by the cold resistance of the Thermistor, is small and rises slowly at first, then more rapidly as the Thermistor becomes hot so that the final current is limited by the circuit resistance. By suitable design and choice of circuit, it is possible to vary the time delay from a few milliseconds to several minutes. This time delay property of Thermistors is a distinct advantage in many applications, since it provides an action which, if obtained by other techniques, would involve much more complex and costly components.

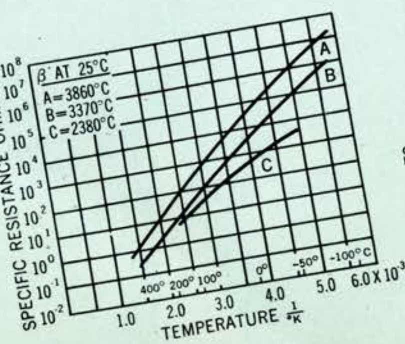


FIG.3

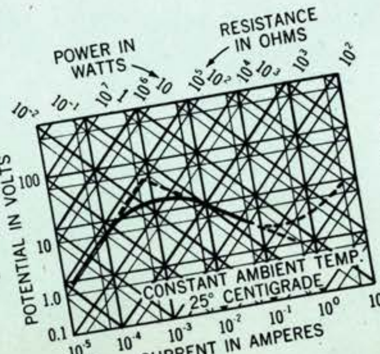


FIG.4

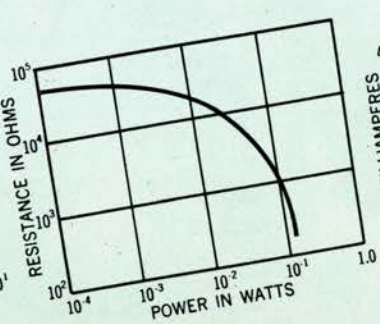


FIG.5

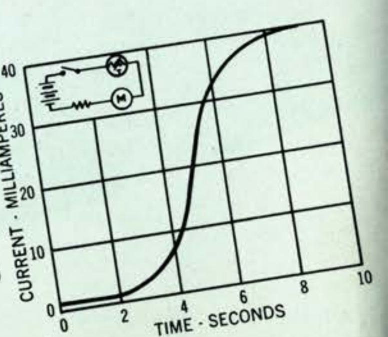


FIG.6

BASIC CIRCUIT APPLICATIONS of THERMISTORS

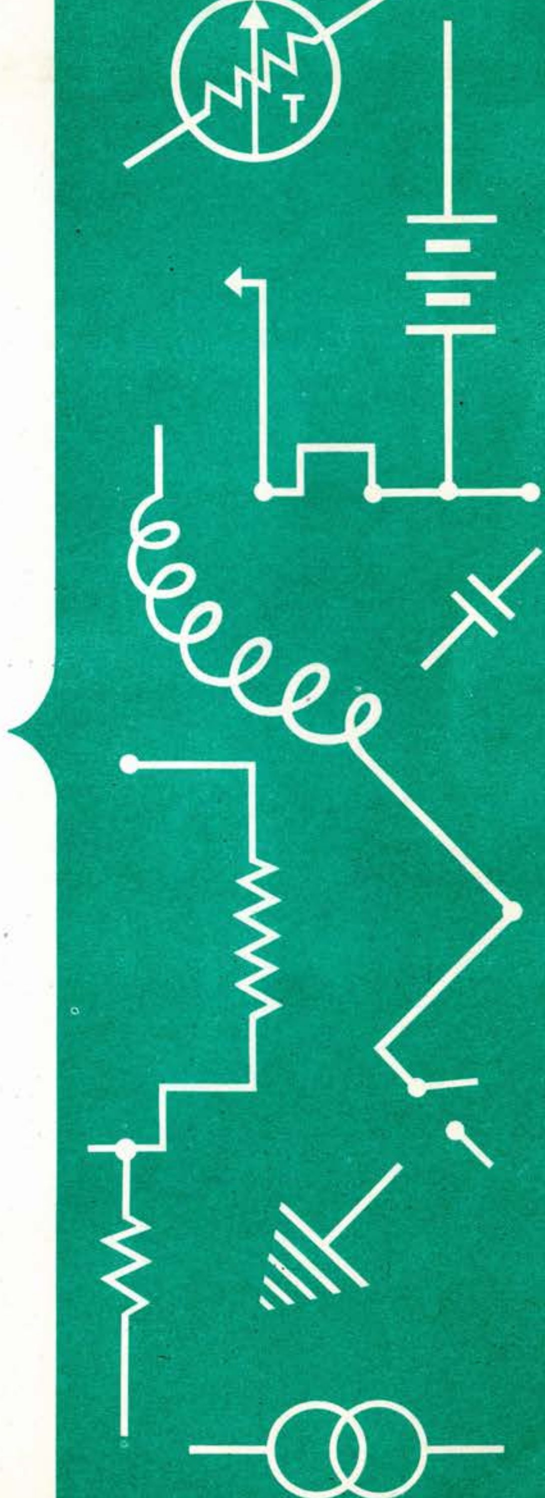
Current applications of Thermistors are divided into two broad categories depending on whether the element is controlled by ambient temperature or whether it is heated by the circuit with which it is associated. The first field includes uses such as temperature measurement, temperature compensation, and temperature control.

When used as resistance thermometers, precision greater than that of thermocouples may be obtained. As temperature compensators, Thermistors are frequently used to neutralize the effects of temperature variations in other electrical circuit components, meters or conductors possessing positive temperature coefficients of resistivity.

A much larger number of applications is found in the second field in which the present and prospective uses for Thermistors grow out of various combinations of the voltage-current, resistance-power and current-time characteristics. One group includes flow meters, anemometers and vacuum gauges. Another class of applications utilizes Thermistors as slow actuators for relays or circuits, overload protective devices and timing mechanisms.

As power responsive, variable resistance devices, Thermistors have important uses in the measurement of small amounts of power, in automatic transmission regulating networks and in signal and characteristic shaping networks, such as speech volume limiters, compressors or expanders. In a related type of use they may serve as oscillation amplitude stabilizers and as voltage regulators.

On the following pages are outlined a number of basic circuit ideas and diagrams which may help the executive or development engineer to visualize how Thermistors can best be adapted to his own particular design problems.



TEMPERATURE MEASUREMENT

In this application the Thermistor is used as a resistance thermometer. The measuring current is kept so low that it produces no appreciable heating and the thermistor resistance is dependent solely upon the ambient temperature.

A conventional bridge circuit is commonly used in such resistance thermometer applications as shown in Figure 7a. Other types of resistance measuring circuits can also be used. Figure 7b shows a bridge circuit employed to provide differential measurements of temperature, such as are commonly used in calorimetry.

Because of their high resistance compared to other temperature measuring devices, thermistor elements can be located remotely from their associated circuits thus permitting great flexibility in their application. Numerous industrial and meteorological applications have been developed in which temperature indications provided by Thermistors can be transmitted automatically from remote locations to control points by wire lines or radio.

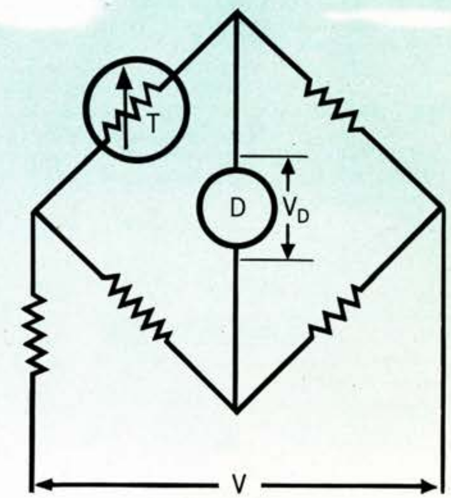


FIG. 7 A

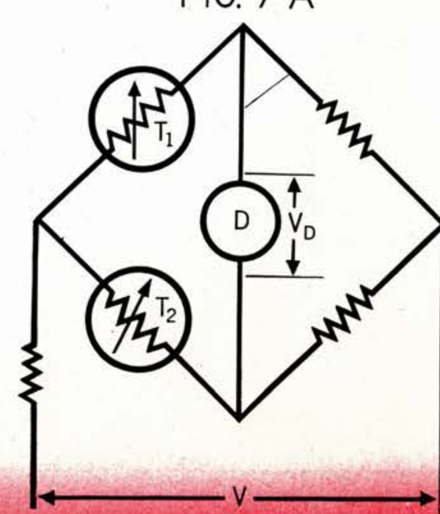
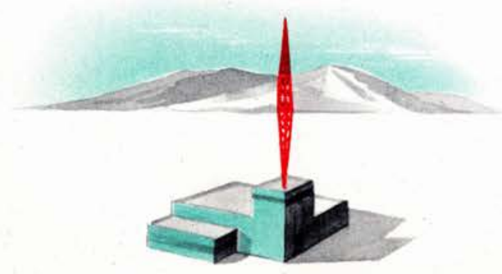


FIG. 7 B



TEMPERATURE COMPENSATION

As temperature compensating devices, the negative temperature coefficients of resistance of Thermistors are used to offset the positive coefficients of resistance usually encountered in electrical circuits and components.

Ideally, if a Thermistor of resistance T and temperature coefficient α_T is placed in series with a circuit or component of resistance R and temperature coefficient α_R, then the total resistance will be independent of temperature if:

$$R\alpha_R + T\alpha_T = 0$$

A practical application of this principle is illustrated in the temperature compensation of telephone cables exposed to variable ambient temperatures as shown in Figure 8A. In this application, the Thermistor is shunted with a resistor to provide the desired negative temperature characteristic. The net effects are shown in Figures 8B and 8C. The same principle can be applied to correct errors in aircraft instruments, meters or other circuit components due to extreme temperature conditions. By using various series and parallel combinations of Thermistors and resistances, a wide variety of neutralizing characteristics can be obtained.

In applications of Thermistors utilizing the effects of self-heating caused by the current passing through them, it is frequently necessary to provide temperature compensation to obviate undesirable effects of varying ambient temperatures. This may be accomplished readily by the use of an indirectly heated Thermistor and a disc Thermistor as suggested in Figure 9. The disc Thermistor under the influence of the ambient temperature, changes the heater current to overcome the effect of the ambient temperature on the bead thermistor element. Thus, a controlled and constant ambient temperature condition surrounding the bead can be produced.

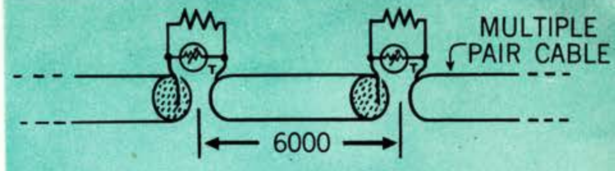


FIG. 8A

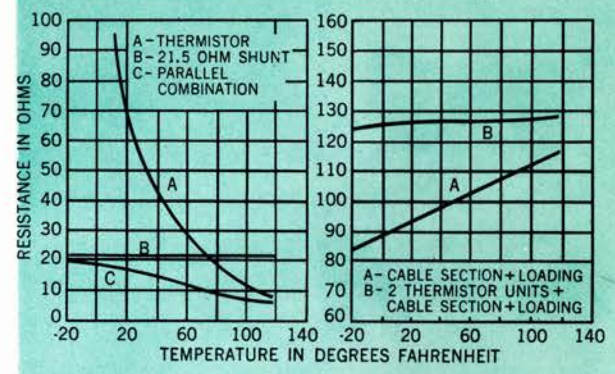


FIG. 8B

FIG. 8C

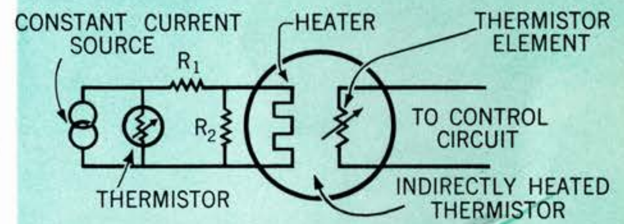
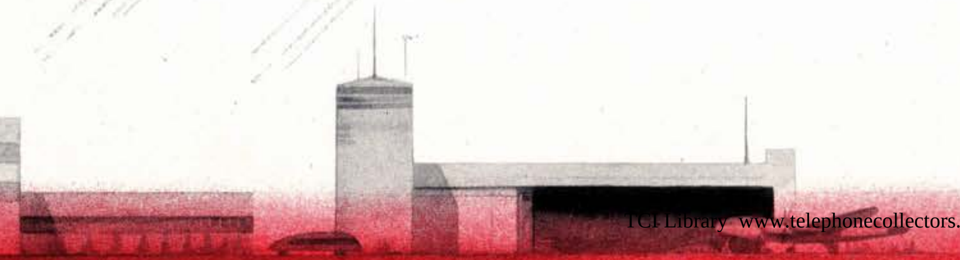


FIG. 9

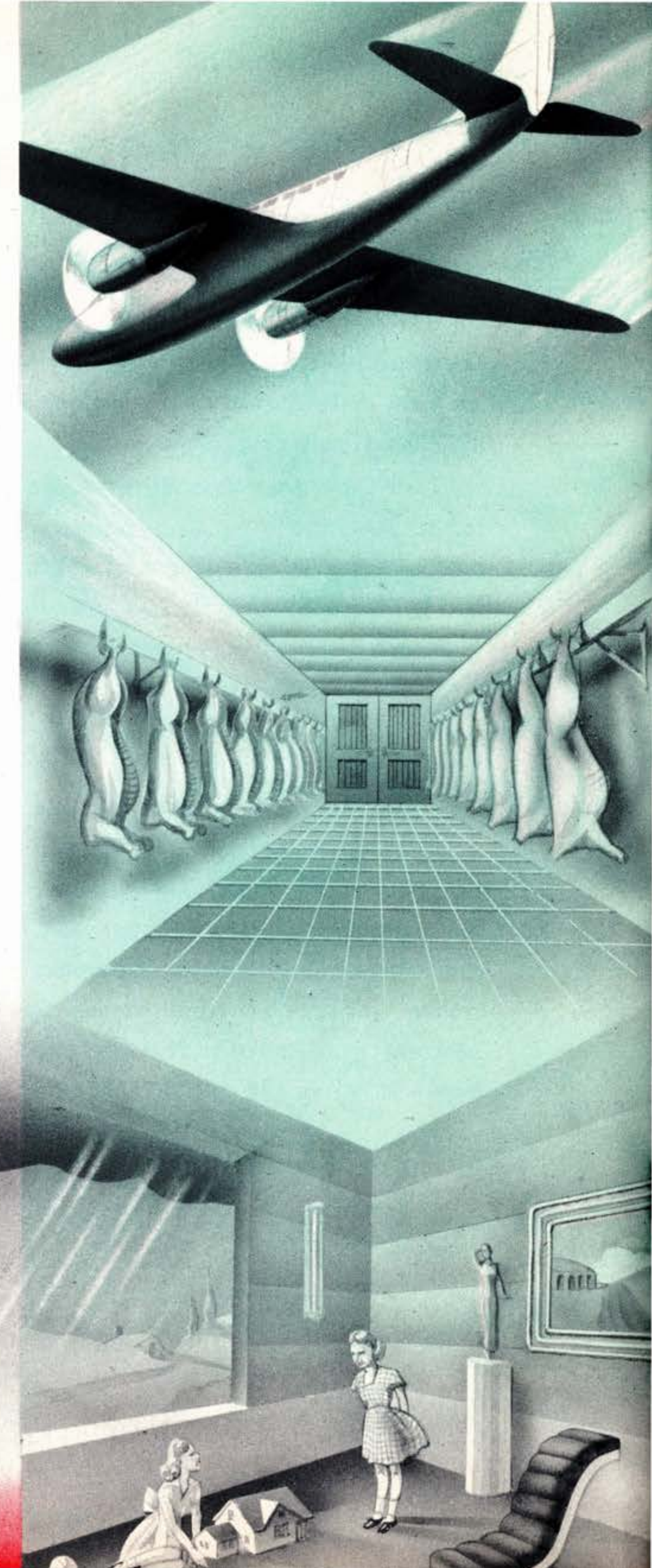


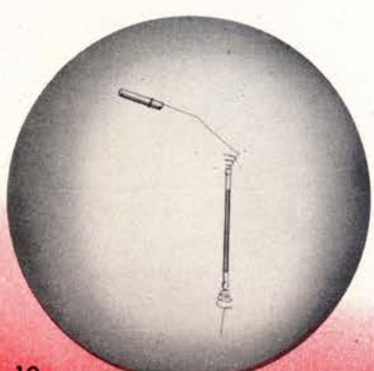
TEMPERATURE CONTROL

Temperature control by Thermistors is an obvious corollary to their use as temperature measuring and compensating devices. The principles of application are essentially the same except for the method of utilizing the changes in resistance to provide a means of control.

One suggested use involves the control of aircraft engine temperature by means of a Thermistor inserted in a simple relay circuit, which automatically governs the rate of flow of a cooling medium. The same principle may be employed to control cabin temperatures, as well as in the automatic regulation of air-conditioning, heating or refrigeration systems. Where more precise thermal control is required, as in chemical or food processing, Thermistors can be made to respond to very minute changes in the surrounding element.

In all of these control applications, Thermistors, by substantially reducing the size and complexity of their associated equipment, materially lower operating costs.





VACUUM GAUGE

If a Thermistor is directly heated by passing a current through it, its final equilibrium condition will be determined by the transfer of heat to or from it. On the basis of this principle, a Thermistor can be used as the sensitive element of a vacuum gauge instrument. The advantage of a Thermistor in such an instrument is in the high temperature coefficients of resistance available over other devices depending on the same heat transfer principle.

A conventional bridge circuit arrangement for this application is shown in Figure 10.

A second Thermistor having substantially the same characteristics as the measuring Thermistor connected to the vacuum system is provided to compensate for variations in the ambient temperature. The representative characteristics of a Thermistor suitable for this application are shown in Figure 11.

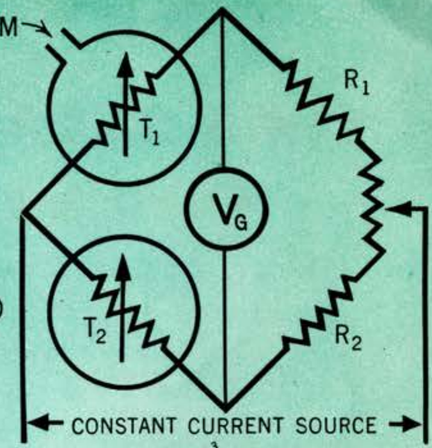


FIG. 10

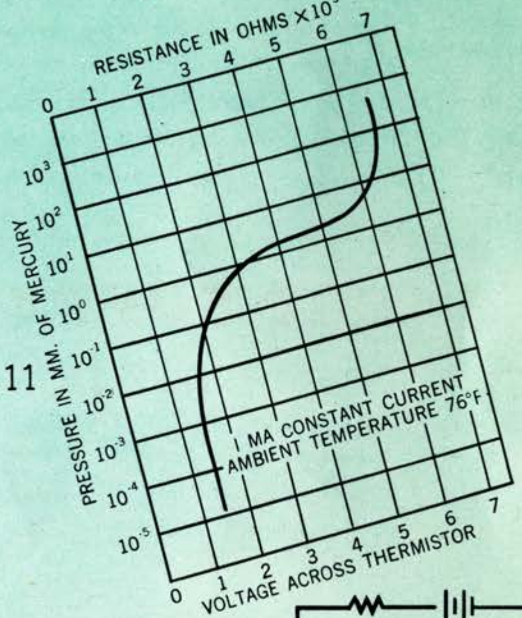


FIG. 11

FLOW METER

On the basis of this same heat transfer principle, a Thermistor provides a sensitive element for use in a flow meter. In this application, the temperature equilibrium of the measuring Thermistor exposed to the flow of gas or liquid will be determined by the rate of flow. As before, a second Thermistor exposed to the gas or liquid, but not subjected to the flow, is used for ambient temperature compensation. One form of circuit arrangement for this type of application is shown in Figure 12.

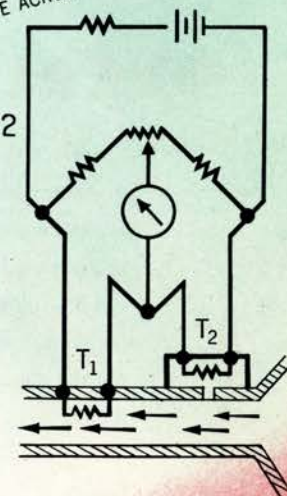


FIG. 12

POWER INDICATOR

The resistance versus power characteristics of Thermistors make them useful as sensitive current and power measuring devices. Inasmuch as they can be designed to have extremely small electrical capacity, they are well adapted to the measurement of either low or ultra-high frequency power.

In this application, the unknown power to be measured is dissipated in the Thermistor with consequent rise in temperature. The thermistor resistance which is dependent upon its temperature then becomes a measure of the power dissipated. This resistance may be determined by means of an ohmmeter resistance substitution circuit or a Wheatstone bridge such as is illustrated in Figure 13. When a-c or r-f power is measured, the resistance measuring circuit may be operated on d-c, or, conversely, for measuring d-c power, an a-c measuring circuit is used with suitable isolating elements in the circuit.

In cases where wide ambient temperature ranges are encountered, temperature compensating Thermistors are commonly employed in the measuring circuits.

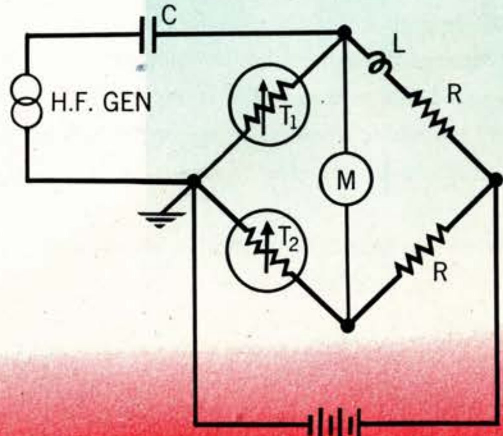


FIG. 13

TIME DELAY DEVICES

The time-current characteristics of Thermistors find numerous time-delay applications. The gradual lowering of resistance which results when a Thermistor is self or directly heated by the current passing through it, can be employed to delay the operation of a relay or any other electrically operated mechanical component.

The magnitude of the delay depends on the thermistor characteristics, the circuit constants and operating conditions. With a given thermistor material, the smaller the heat losses due to convection, conduction and radiation, and the smaller the thermal mass, the smaller the inherent time delay of the Thermistor during its operation. Net time delays from a few milliseconds to several minutes may be obtained by suitable design and choice of circuits.

In such applications, it is evident that to obtain the same delay a second time, the Thermistor must be allowed to cool before reapplying voltage to it. The relay circuit shown in Figure 14 suggests a method for obtaining this cooling time by short circuiting the Thermistor as soon as the relay has pulled up. In this case, if the relay remains closed long enough to permit the Thermistor to cool, the latter is available for immediate duty after de-energizing the circuit.

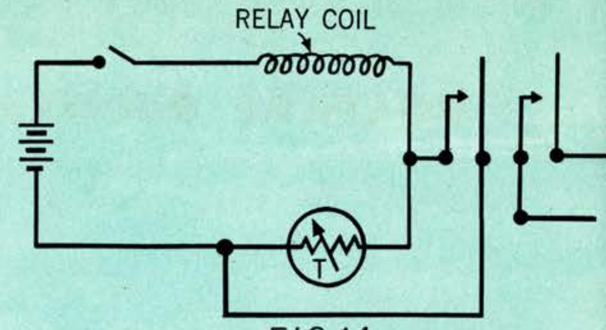
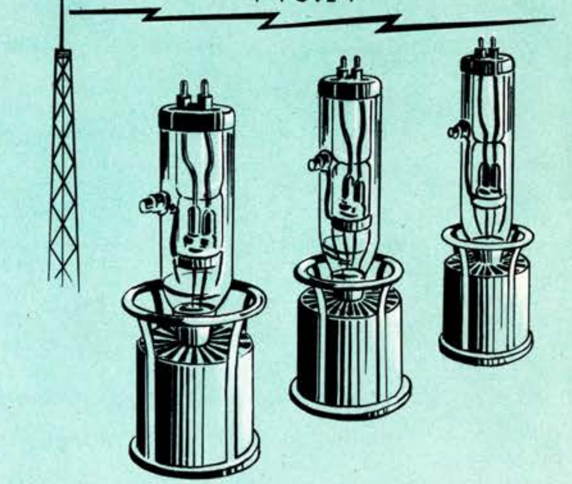


FIG.14



SURGE SUPPRESSION

The time-delay characteristic of Thermistors may also be used to prevent false operation of relays or other devices caused by transient voltages. Thermistors may be designed so that their thermal inertia, together with their high initial resistance, discriminate against high voltage surges of short duration. This selective action, however, does not interfere with the normal operation of the relay or other devices at lower potentials of longer duration.

OVERLOAD PROTECTORS

Closely allied to surge suppression is the application of Thermistors as overload protectors. Some types of equipment may be damaged by continued overloads, such as could occur at the output of an amplifier if the input was increased and maintained at a higher than nominal value. A suitable Thermistor inserted in the output circuit can provide the desired overload protection.

An example of this type of protection is shown in Figure 15. Here, an indirectly heated Thermistor is connected between the output and the input of an amplifier to provide "thermal feedback". An increase of output voltage raises the temperature of the heater which, in turn, raises that of the thermistor element, thus reducing its resistance. The result is a lowered voltage at the input of the amplifier which reduces the amount of power delivered into the load. A disc Thermistor is used in shunt across the heater for ambient temperature compensation.

In this particular application, the time constant of the thermistor element is selected to pass pulses of short duration, but to discriminate against continuously maintained high level signals.

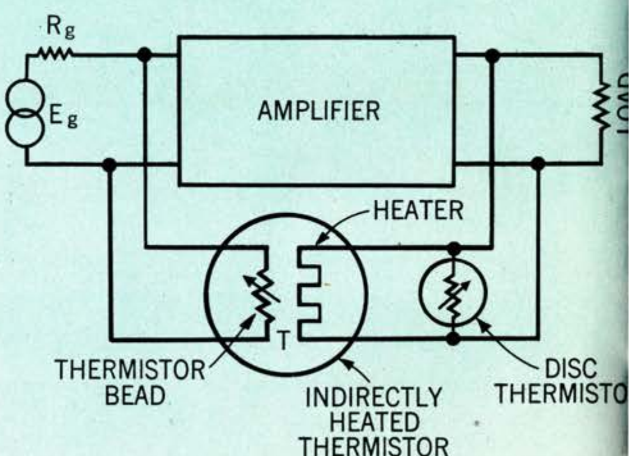


FIG.15

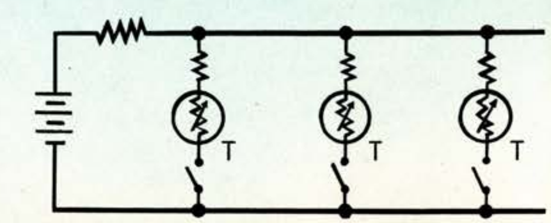


FIG.16

VOLTAGE REGULATORS

Thermistors may be used to stabilize the output voltage in circuits in which the input voltage varies over a considerable range.

Referring to Figure 17, it will be observed that the voltage current curve of a Thermistor has a negative slope over part of its current range. If a suitably chosen value of ohmic resistance is placed in series with a Thermistor, the voltage across the combination can be maintained very nearly independent of current over a wide range. A combined unit of this character is used as a shunt element in a simple circuit as shown in the accompanying figure.

This principle finds useful application in the voltage regulation of both a-c and d-c power supplies. As the power handling capacity of Thermistors is limited, it is possible in heavy duty power supply units to use this basic circuit as a voltage reference to control in turn, an electronic circuit to balance the output voltage and maintain it constant. This application has numerous advantages over conventional voltage regulator circuits using constant voltage transformers or cold cathode tubes. Among other things, it provided better regulation, and substantially negligible distortion and is independent of the power supply frequency.

SWITCHING DEVICES

As previously demonstrated (Figure 4, Page 6) the voltage across a Thermistor rises to a maximum value, then decreases rapidly with increasing current. This phenomenon permits various applications of Thermistors analogous to those of gas-filled tubes which also possess this "breakdown" voltage feature. One suggested use for these units deriving from their rapid change from very high to very low resistances is as substitutes for simple switching devices. This application is particularly adaptable to the communications field where, for example, a Thermistor may be connected in series with a device, such as a lamp or selective ringer, bridged across a transmission line. The Thermistor "breaks down" in response to signal current but returns to its high resistance state when the signal stops, thereby preventing speech current losses when the bridge is not in use.

This "breakdown" voltage characteristic of Thermistors also suggests their employment in assembly or test applications as "lock-in" or "lock-out" switches, depending on the circuit arrangement.

To operate as a lock-in switch, the Thermistor is incorporated in a circuit whose normal voltage is less than the breakdown voltage. The brief application of a breakdown voltage effectively "locks in" the circuit, permitting a relatively large current to continue to pass until the low voltage circuit is opened.

A simple "lock-out" arrangement is illustrated in Figure 16 in which three Thermistors are connected in parallel. When any one key is closed, its associated Thermistor breaks down, reducing the voltage in the circuit to such an extent that no other Thermistor can break down until the circuit has returned to its normal state.

Voltage selective systems have also been devised in which the value of the applied voltage determines which one of a group of Thermistors in a circuit will break down and lock out all the others.

At present, the lock-in, lock-out and selective applications of Thermistors are largely experimental. However, it is evident that their small size, durability and the fact that they have no contacts to deteriorate, gives them distinct advantages over other currently used switching devices.

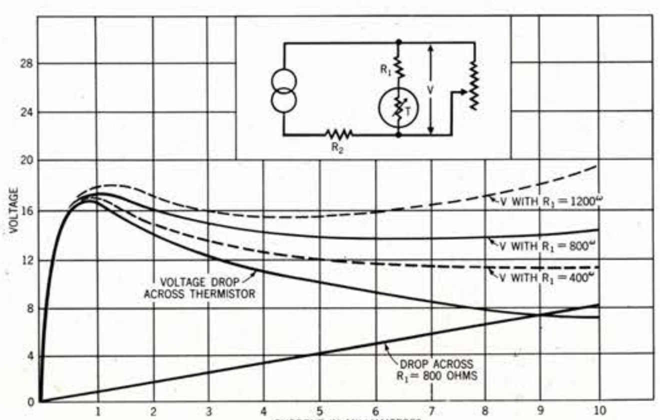
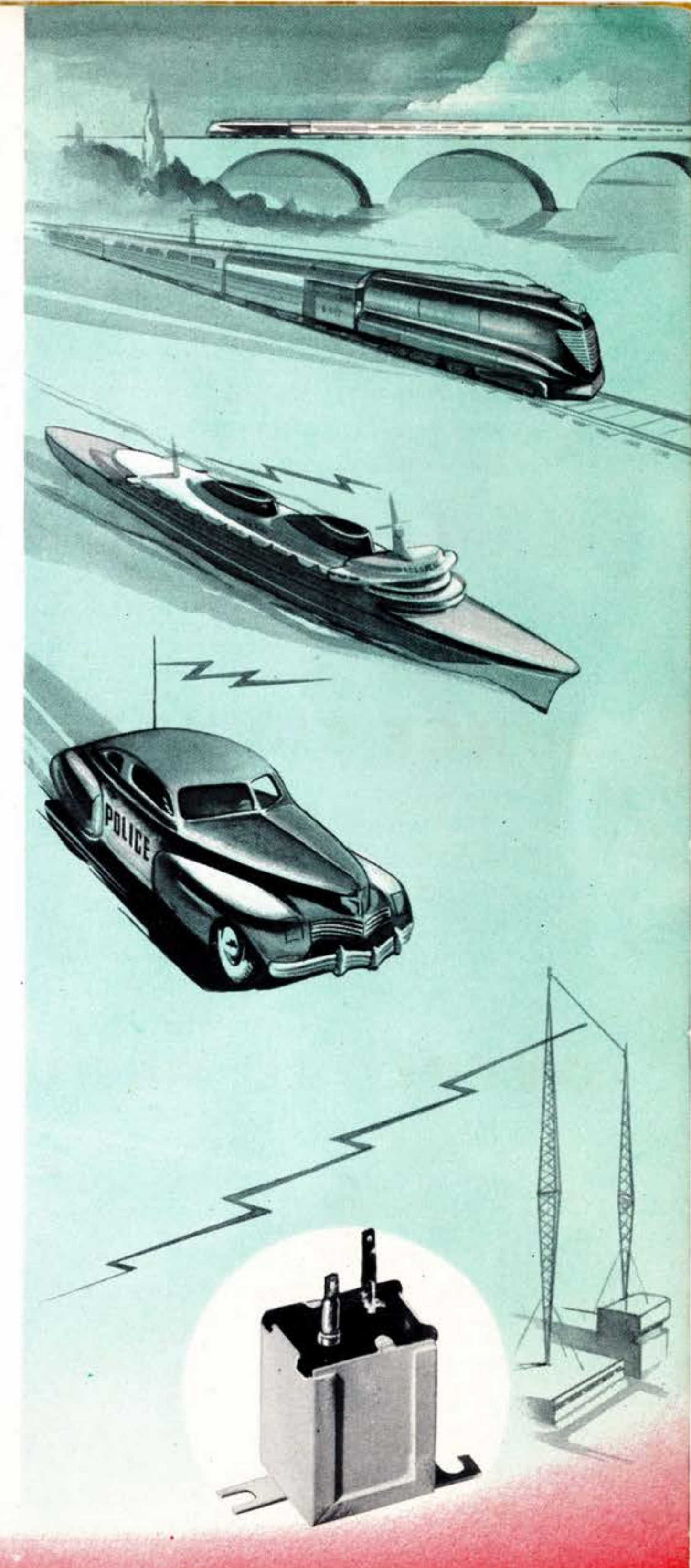


FIG. 17



VOLUME LIMITER

The application of Thermistors as volume limiters in speech and other circuits utilizes the same basic principles as in voltage regulation.

In Figure 18, the Thermistor and associated resistors provide a linear relationship between input and output voltages over the lower ranges. With increasing input voltage, the output voltage departs from linearity because of the subsequent non-ohmic behavior of the Thermistor. By proper selection of the associated resistors, the output voltage can be made to approach rapidly a constant, or limiting value. Thermistor volume regulators can accommodate large volume changes without producing wave form distortion. In audio-frequency speech circuits, this is an important advantage over conventional instantaneous "peak choppers."

COMPRESSORS AND EXPANDERS

Variations of the volume limiter principle also can be used for audio-frequency signal compression or expansion purposes.

It is evident that by proper choice of circuit components, the departure from linearity of the curves of input and output voltage can be controlled over wide limits. Referring to Figure 18A, values of R_1 greater than those required for limiting action, will produce compression characteristics. This compression action is provided without distortion of the signal.

Expansion characteristics can be obtained by placing the thermistor element in series with the generator and the load. This is shown in Figure 18B.

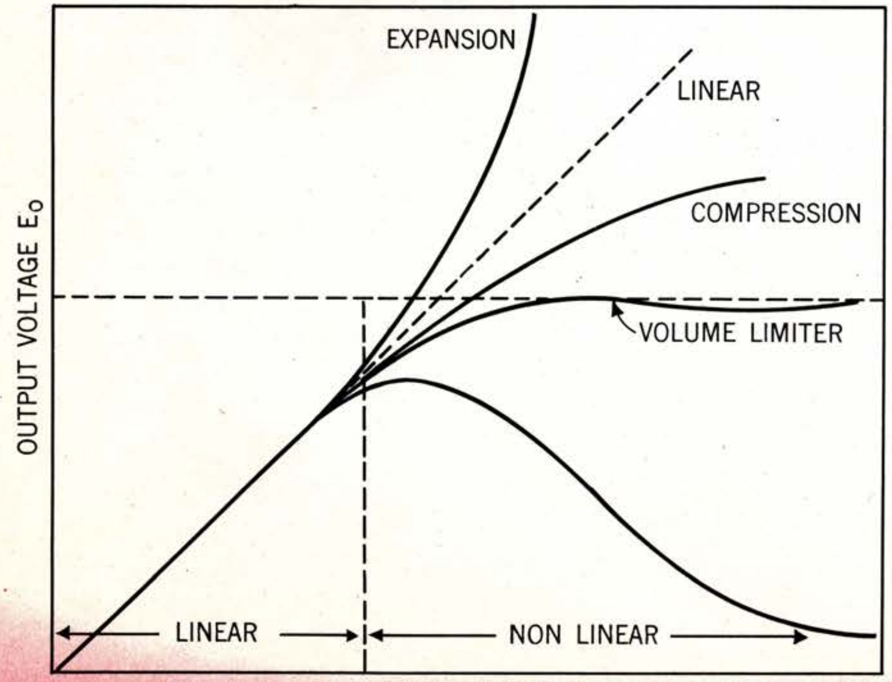
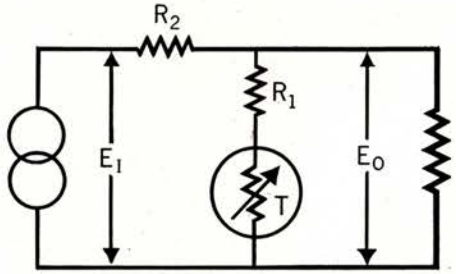
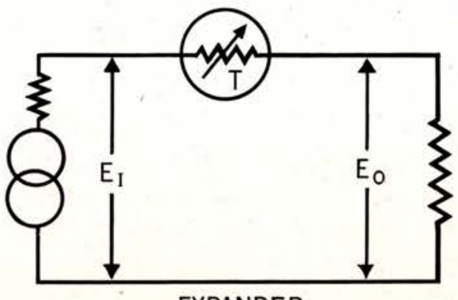


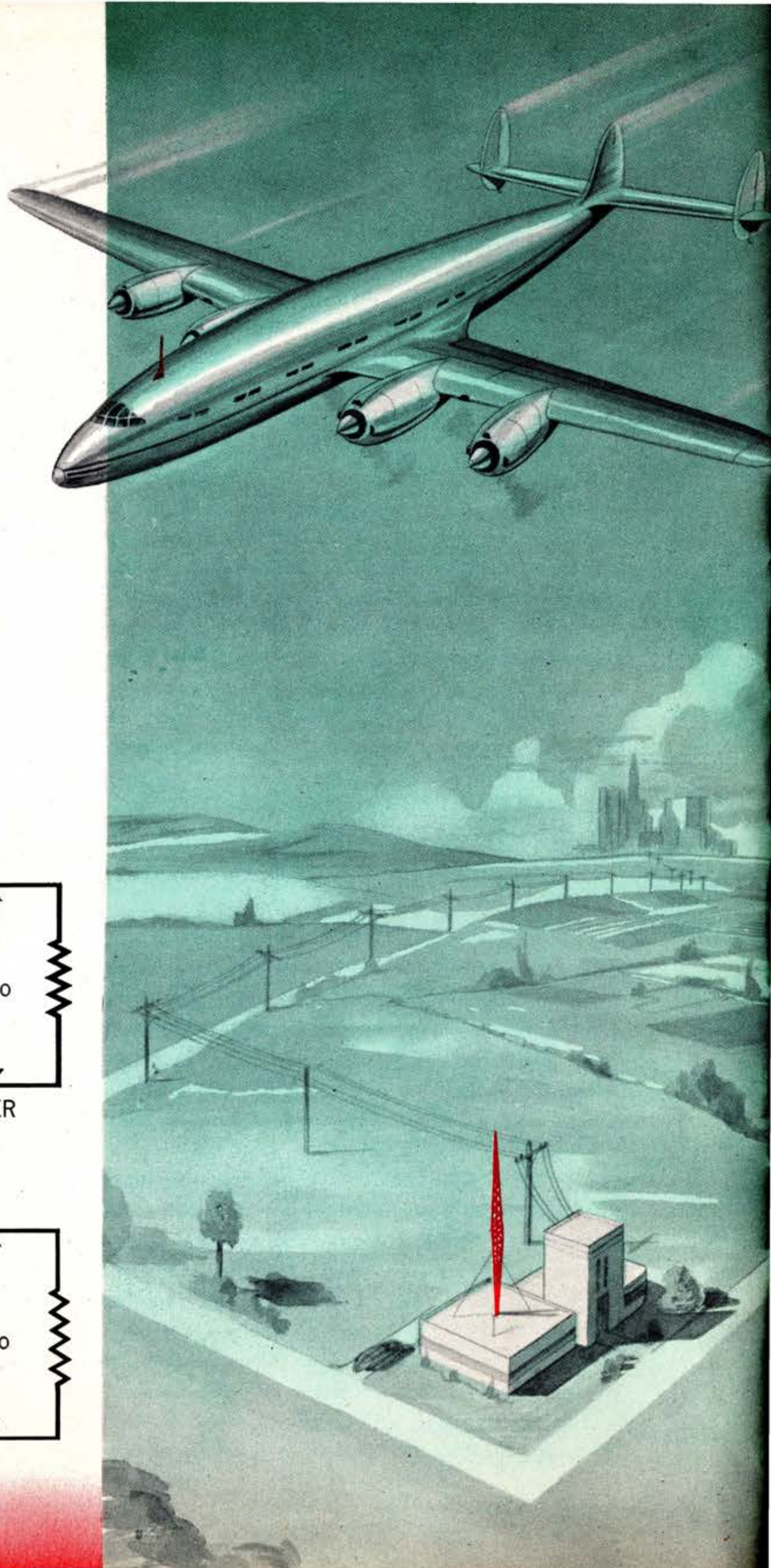
FIG. 18



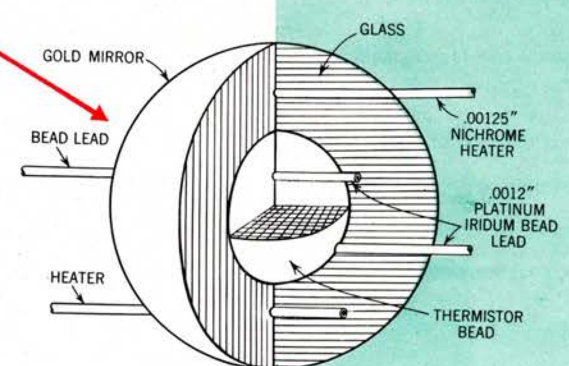
COMPRESSOR OR LIMITER
FIG. 18 A



EXPANDER
FIG. 18 B



Left: Heater type Thermistor bead element mounted inside an evacuated tube. Below: Cross-sectional view showing typical construction of heater type bead element.



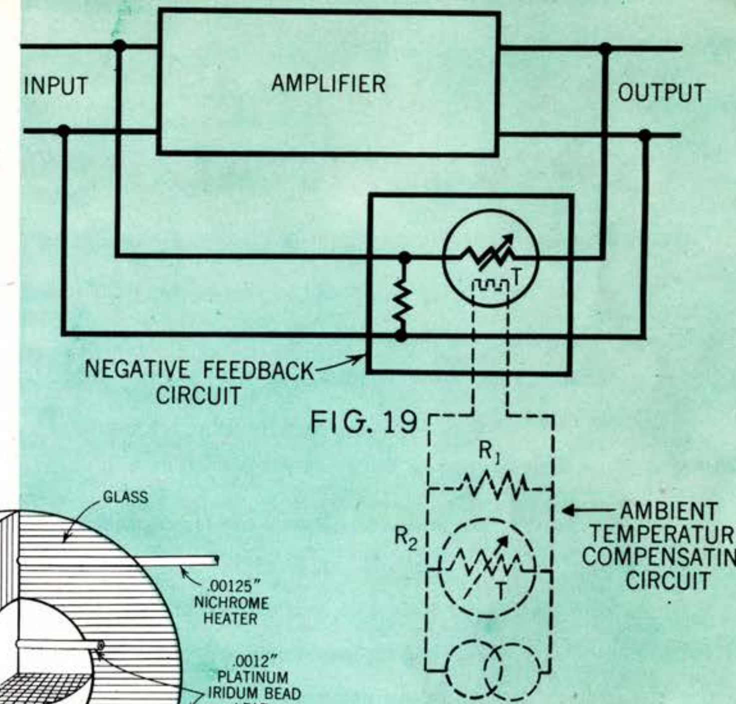


FIG. 19

AUTOMATIC VOLUME LEVEL OR GAIN REGULATION

A further important use for Thermistors, either of the directly or indirectly heated types, is the completely automatic and continuous volume level or gain regulation of amplifiers and transmission networks. Numerous applications of Thermistors have been made in carrier telephone systems to provide automatic transmission regulation and eliminate conventional moving mechanisms such as sliding contacts, rotary switches, and other similar devices.

In applications of this type, Thermistors can be used in a variety of ways. In one principle application, properly designed Thermistors are used in negative feedback circuits to control the net gain of the amplifier as shown in Figure 19. The output of the amplifier is regulated by the directly heated Thermistor in the feedback circuit which varies its resistance with output in such a way that the amount of feedback is varied to compensate for any change in output. In this type of application, it is evident that the directly heated Thermistor as a thermally sensitive device, will react to the ambient temperature as well as the current passing through it. This may be overcome by using an indirectly heated Thermistor and connecting the heater in an auxiliary circuit containing a temperature compensating disc Thermistor.

Indirectly heated Thermistors, in particular, have found a wide variety of applications in gain control problems. Since the heater and thermistor element are electrically isolated, the heater can be operated and controlled from remote locations or from other circuits, which in turn, vary the thermistor resistance, thus providing a convenient, simple and effective method of controlling the gain and output of amplifiers or other similar devices.

EXPERIMENTAL APPLICATIONS

The foregoing illustrations of basic control circuits afford ample evidence that the Thermistor, as a control element, is adaptable to almost every kind of industrial electronic requirement. Because this field is so vast, however, many of these adaptations are still in the "idea" stage or have not yet been fully explored.

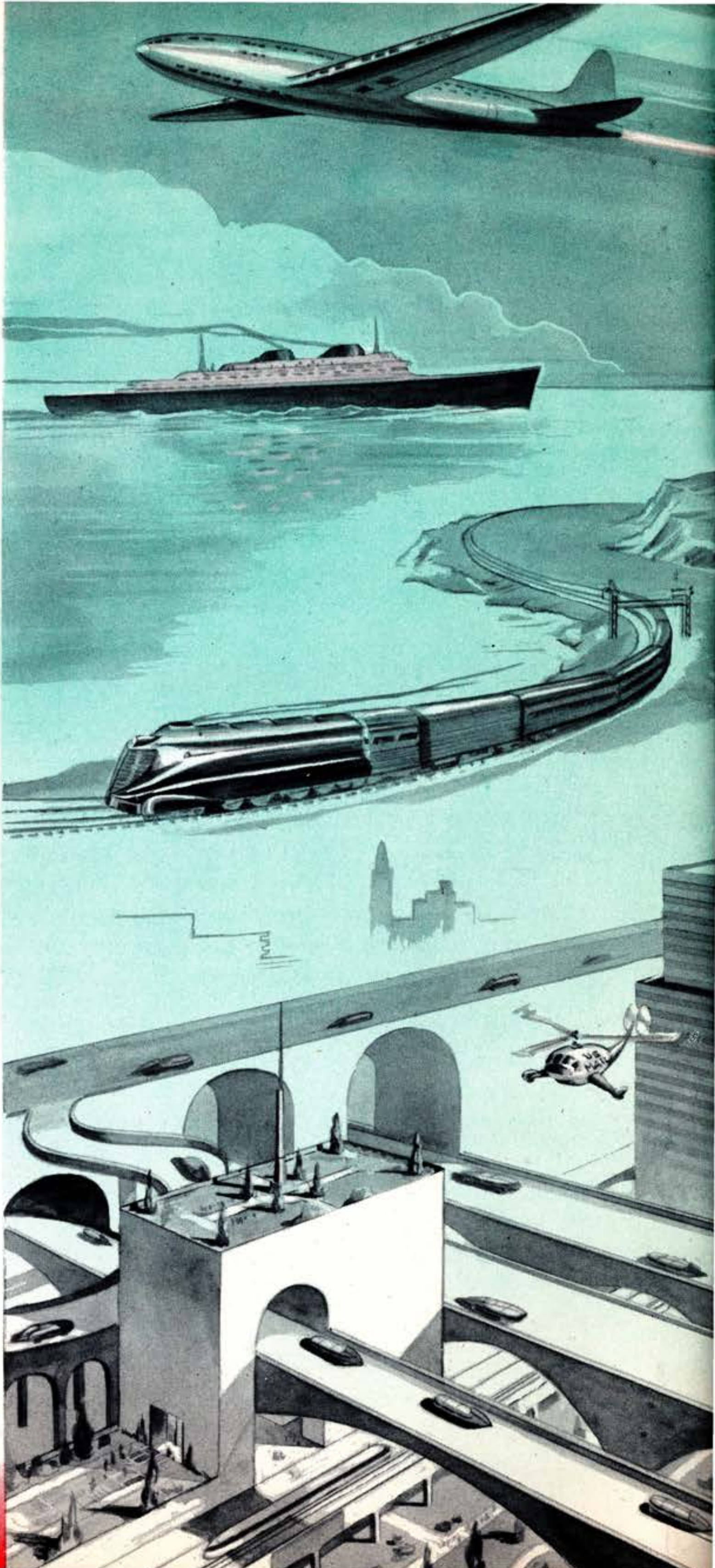
Among the more obvious of these experimental applications is the utilization of the temperature — resistance current-time characteristics of Thermistors in the development of fire alarms, gas detectors and other types of safety devices. Closely allied to these uses are their applications in pyrometry, chemical analysis and quality control.

Less obvious, yet highly interesting to the communications specialist are the "creative" applications growing out of the negative resistance characteristics of these elements. At the present time it must be emphasized that these developments are distinctly in the laboratory stage and that extensive research will be required before units suited to such uses can be offered commercially. However, a brief glimpse of a few of the possibilities can be given here.

For example, the voltage current characteristic exhibited by directly heated Thermistors suggests their use as generators of low frequency alternating voltages, as low frequency power modulators and as amplifiers for various purposes. Specially designed Thermistors have been made to oscillate over the entire voice frequency range when placed in appropriate circuits. This characteristic also suggests their possibilities as low frequency filters, capable of replacing large and cumbersome components. Again, Thermistors of the directly heated type have provided an effective method of amplitude stabilization for both low and high frequency oscillators.

Today there is little doubt that these and many other as yet unconceived uses for Thermistors will ultimately emerge in response to Industry's requirements. Originated as a result of a particular need within the telephone plant for a more efficient means of sound level control, Thermistors, because of their small size and adaptability, within a few years found many other applications throughout the Bell System. During wartime, new and extensive demands by the Armed Forces demonstrated their utility, ruggedness and dependability under the most adverse operating conditions.

Today the Thermistor, already proved both in peace and in war, is ready to play its biggest role in helping the industrial development engineer pave the way toward the electronic world of tomorrow.



CURRENT AND PROSPECTIVE THERMISTOR APPLICATIONS BY INDUSTRIES

CHEMICAL AND FOOD PROCESSING

Local and Remote Temperature Indication
Chemical Analysis
Automatic Temperature Control
Gas Detectors
Refrigeration Control
Pyrometry
Vacuum Gauges
Temperature Compensation
Calorimetry

COMMUNICATIONS*

Automatic Gain Regulators
Volume Limiters
Overload Protectors
Compressors and Expanders
Power Indicators
Ambient Temperature Compensation
Amplitude Stabilized Oscillators
Voltage Regulators
Switching Devices
Remote Controlled Resistances
Time Delay Devices
Negative Resistances
- Oscillators
- Amplifiers
- Transmission Networks

TRANSPORT*

Engine Temperature Measurement and Control
Cabin Temperature Control
Meteorological Equipment
Flow Meters
Test Equipment
Switching and Signalling Devices
Differential Temperature Controllers
Fire Protection and Safety Devices

HOUSING AND HOUSEHOLD APPLIANCES

Air Conditioning Systems
Automatic Room Temperature Control
Fire Protection Devices
Automatic Switches
Gas Detectors
Furnace Controls
Oven Temperature Control
Refrigeration Control
Thermal Insulation
Thermal Conductivity

MANUFACTURING OPERATIONS

Quality Control
Temperature Measurement and Control
Fire Protection Devices
Pyrometry
Automatic Switching and Time Delay Devices
Voltage Regulators
Surge Suppressors
Anemometry
Vacuum Gauges
Flow Meters
Differential Temperature Controllers

MINING AND METALLURGY

Fire Protection and Safety Devices
Gas Detectors
Local and Remote Temperature Measurement and Control
Pyrometry
Quality Control
Calorimetry
Time Delay Devices
Geological Temperature Surveys

PUBLIC UTILITIES*

Voltage Regulation
Switching Devices
Time Delay Devices
Power Indicators
Warning Devices
Temperature Compensation of Instruments
Gas Detectors
Pyrometry
Calorimetry
Flow Meters
Anemometry
Chemical Analysis and Control

* Not licensed for Public Service Communication

For specific recommendations regarding types of Thermistors, characteristics and circuits suited to particular applications, write to:

Radio Division, WESTERN ELECTRIC COMPANY
120 Broadway, New York 5, N. Y.

or contact local offices of the Graybar Electric Company,
(Northern Electric Company, Ltd., in Canada).

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November 12, 1946

Mr. J. W. Martin, Serv. Dept.
Wells-Gardner & Co.
Chicago 39, Ill.

Dear Mr. Martin:

The attached brochure describes the operating principles and characteristics of a relatively new group of miniature electronic control devices called "Thermistors".

Installed in appropriate electrical circuits, Thermistors are providing manufacturers and design engineers with economical, efficient, and space-saving solutions to many knotty control problems.

A list of current and prospective uses for these new elements appears on the inside of the back cover of this book. However, if you or your engineers have a specific control problem, perhaps an examination of one or more of the basic Thermistor circuit applications described elsewhere in this brochure will point the way toward a new approach.

Design and manufacture of a variety of Thermistors that will form the framework of a complete, standard stock-line is now underway. Where these units do not fit your specific needs, custom-built elements can be furnished at costs proportionate to the volume involved.

Whether your present product designs are in an advanced or merely embryo-stage, we urge you to investigate the possibilities of these highly sensitive devices. At your convenience, we shall be glad to discuss control circuits with you and to demonstrate more specifically how Thermistors can solve your current problems and fit into your future plans.

Very truly yours

R. W. Colledge

:EBS

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