Clinical engineering projects: A comparison of semiconductor temperature transducers and an electrical safety study

by

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INTRODUCTION

Clinical engineering is rapidly becoming a recognized field of engineering and the need for the services of the clinical engineer is becoming more apparent to health care facilities. The services of the clinical engineer include supervision of electronic technicians in repair and maintenance of equipment, setting up electrical safety programs and advising the medical staff on the purchase of equipment. It is up to the clinical engineer to provide responsible service to the patient and health care professionals as to their use of, and contact with, biomedical equipment. The clinical engineer must be trained in areas ranging from electrical engineering to physiology because of the many areas in which he must function.

This thesis consists of two projects, both of which are typical examples of what a clinical engineer might be asked to do. One is the comparison of semiconductor temperature transducers. The other is an electrical safety study at a local nursing home.

Five semiconductor temperature transducers were tested to see if they met manufacturers' specifications and to gain some familiarity with temperature measurement. Diode thermometers, transistor thermometers, resistance thermometers, thermistors, thermocouples and the five semiconductor temperature transducers are discussed.

The five semiconductor temperature transducers include the Analog Devices AD590, the National Semiconductor LX5700, the Precision Monolithics REF-02, the National Semiconductor LM335, and the Motorola MTS102.

The Celsius temperature scale was used, where possible, for ease of comparison and understanding.

In the modern health care facility, it is possible to find a patient connected to as many as 8 to 10 different pieces of electronic equipment. This increase in the use of electronics provides better health care, but introduces the hazard of electric shock. It is the responsibility of the clinical engineer to provide an electrically safe environment for the patient. Training of the operators of medical equipment and device testing are important parts of this responsibility.

An electrical safety study was conducted covering a large area of the nursing home. A report containing a summary of the results was given to the nursing home director. It is hoped that some action will be taken on the basis of this report. The goal of these projects was to increase the author's understanding and knowledge of the problems and methods of operation of a modern health care facility.

TEMPERATURE SENSORS

Temperature Sensing Techniques

Diodes

Voltage varies with temperature across a forward conducting p-n junction (McNamara, 1962). The diodes tested over the -40°C to +90°C range included 1N270, 1N56A, 1N38AG, 1N457, 1N459, and FD300. This group included both silicon and germanium, and both glass and plastic encapsulated diodes. Voltage versus temperature was plotted. The Ge diodes had a mean slope of -1.83±0.07 mV/°C and the Si diodes had a mean slope of -2.11±0.06 mV/°C. These values were found to agree well with results found by other workers.

Table 1 contains a comparison of characteristics of temperature transducers (Riezenman, 1974). The silicon temperature transducer column was modified. A list of manufacturers of solid state temperature sensors, thermistors, thermocouples and RTDs is available on request from Instruments and Control Systems Journal (Hall, 1979).

Forward voltage versus temperature characteristics were presented for silicon diodes in the -230°C to 27°C temperature range (Sclar and Pollock, 1972). The usual technique of sensing temperature with a diode by measuring its forward voltage drop at a constant supplied current was used. The current used was 100 μA. The three types of diodes investigated were the FD200, FD300 and FJT1000. These are high conductance, low-leakage diodes manufactured by Fairchild Semiconductor Company. The forward voltage of the diodes exhibits a linear dependence on temperature, the slope of which

Table 1. Characteristics of temperature transducers

Parameter	Thermistor	Resistance-temperature device	Thermocouple	Silicon temperature transducer
Sensitivity/°C	-4%	+0.4%	+60 μV	+200 nV to +100 mV
Linearity	Highly exponential	Very linear	Somewhat nonlinear	Very linear
Room temperature resistance range available	5Ω to 20 MΩ	10Ω to 1 KΩ	NA	NA
Minimum temperature	-185°C	-185°C	-185°C	-100°C
Maximum temperature	300°C	750°C	3000°C	+150°C
Minimum size	0.13 mm dia beads	1.5x3x30 mm	Small wire	IC chip-miniature ceramic package
Room temperature error	Typically ±20%	±0.25°C	About 2°C	0.1°C to 8°C
Cost	$5	$25	$2	$1 to $30

depends on the current used and the type of diode. For a given diode, good repeatability in voltage vs. temperature was observed.

Silicon diodes as temperature sensors have the advantage of high linearity and low time constant (Anonymous, 1975). The temperature sensing circuit described in this paper can be used from -50°C to 200°C. The diode voltage must be measured precisely, so a stable reference source was needed. A 723 IC voltage regulator was used to obtain a stable power source for the diode and the rest of the circuitry. A constant current was supplied to the 1N4148 sensing diode. This arranagement is necessary because the diode is, in effect, a voltage source with a finite internal resistance, and any variation in the current flowing through it would therefore produce a change in the voltage which would be incorrectly interpreted as a change in temperature. It is necessary to calibrate this circuit for proper operation. The output of this thermometer circuit was a temperature dependent voltage, which was read with a voltmeter.

A 1N914 temperature sensing diode was used to convert temperature to a numerically equivalent frequency for direct display or for instrumentation (Williams and Durgavich, 1975). The circuit provided 0.1°C resolution from 0°C to 100°C with an accuracy of ±0.3°C. A 1 mA current was sent through the temperature sensing diode. A 2N2222 transistor and its associated components provided an output pulse that was compatible with transistor-transistor logic. While in operation, the circuit functioned as a voltage-to-frequency converter. A LM301A op amp was used, and the only variable voltage available to it was the temperature-dependent -2.2 mV/°C potential from the sensing diode. The calibration procedure must be repeated two or three times until the adjustments cease to interact. Once the circuit is adjusted, its output frequency is 10 times the sensed temperature. For example, if the temperature is 27.5°C, the meter will read 275 Hertz. The output frequency can be counted by TTL counters.

A remote temperature sensing probe was built using four 1N914 diodes in series as the temperature sensing element (Elmore, 1976). The probe sensed temperature by the change in voltage drop across the four forward-biased silicon diodes. As the temperature increased, the voltage across the sensing diodes decreased at the rate of -2 mV/°C for each diode in the probe. A zener diode and transistor regulated the voltage to the probe so that voltage readings were relatively independent of battery voltage fluctuations.

A simple temperature-to-voltage converter was made, based on the 741 op amp (Turner, 1977). It used a minimum of components and despite its simplicity, it was capable of producing an output voltage proportional to temperature over the range -20°C to 120°C. The circuit described in this paper used a diode as the temperature sensing element and its voltage varied linearly with temperature if it was driven by a constant current. Once the zero control was set, the diode current was fixed. The output voltage could be set to zero at any desired temperature, so calibration in either degrees Centigrade or Fahrenheit was very simple. The output scaling was determined by some resistors. For the resistor values used, an output voltage change of +1 mV/°C could be expected. The approximately -2 mV/°C temperature coefficient of the diode was changed to +1 mV/°C output through the use of a negative-gain amplifier and a resistor network.

A low power LM324 quad op amp and a diode probe were the central elements of an electronic thermometer (Nezer, 1977). An op-amp in conjunction with an LM113 reference diode, produced a constant 1.5 V output which was virtually independent of variations in battery voltage. This supplied the sensing diode with a constant current of about 0.5 mA. A simple calibration procedure must be performed for proper operation. If a wide range of temperatures (0°C to 150°C) is to be measured, a transistor diode (base and collector connected) is often preferable to a diode, because its properties better approximate an ideal p-n junction. But in applications where temperature variations are small, a glass encapsulated diode is more convenient (Nezer, 1977). This glass encapsulated diode thermometer is sensitive enough for medical applications where there are small temperature variations. When stray capacitances are minimized at the probe, precision is better than 0.1°C.

A diode sensor and an analog-to-digital converter were used to build a thermometer which measured temperature digitally (Wurzburg and Hadley, 1978). No buffers or op amps were used, so that temperature drift errors associated with amplifiers were eliminated. Unlike its analog counterpart, the circuit described in this paper remained calibrated over a wide temperature range from -199° to +100° in either the Celsius or Fahrenheit scales. The 3 1/2 digit A-D converter limits the circuit resolution to 0.1°C. An MC14433 converter chip changed the output voltage of the 1N4148 silicon temperature sensor diode into a binary-coded-decimal number. An MPSA20 transistor and associated network operated the sensing diode. This circuit must be calibrated to read the proper temperature on the display.

An MC14511 BCD-to-seven-segment decoder driver and an MC1413 hexadecimal inverter were used to display the BCD-number on an HP5082 display. The error of the system was limited to no greater than 1.0°C through the use of a standard diode sensor. Diode sensors with an error of less than 0.6°C are available on a special order basis from Motorola.

An empirical approach rather than the constant current principle of diodes was used by Treharne and Riley (1978) in order to extend the linear range to ±200°C. A forward biased DA1703 diode was the sensor. Some other components of the system included an RCA CA3085 op amp, resistor network for calibration and a DVM for readout. The relationship they obtained was

$$V_0 = m(T_C \pm 0.5 \text{ mV})$$

where V_0 is the output voltage and the slope, m, was chosen to be 1 mV/°C. Thus, any 3 1/2 digit ±200 mV digital voltmeter could be used. T_C is the measured temperature in °C. The calibration procedure and circuit design allow for easy interchangeability of the sensing diode with a maximum uncertainty no greater than ±0.5°C.

A pair of germanium diodes was made to serve as a differential temperature comparator by exploiting a much less used temperature diode property--the logarithmic variation with temperature of the reverse saturation current (DeKold, 1974). For unmatched type 1N270 diodes, the current doubles for every 13°C rise in temperature. The doubling is highly regular producing a nearly linear semilog plot over a temperature range of about 20°C to 120°C. When a diode is reverse biased, it in effect becomes a temperature dependent current source. When the diodes' temperature differential exceeded a threshold, it was sensed by an op amp configured as a comparator. This arrangement caused the output to go from low to high.

Transistors

A transistor with its base and collector connected is often preferable to a diode because its properties better approximate an ideal p-n junction (Nezer, 1977).

A low-leakage CIL511 silicon planar transistor was used as a temperature sensor (Supe, Patil and Agarwal, 1969). The emitter current, I_E, of a transistor operated at a constant V_{BC} is given by

$$I_E = Ae^{\frac{-q(Eg - V_{BE})}{kT}}$$

where A = a constant for the transistor material

q = the electron charge

k = Boltzmann constant

T = temperature in °K

Eg = ionization potential corresponding to the forbidden energy gap of the transistor material

V_{BE} = base-emitter voltage

V_{BC} = base-collector voltage

Rearranging,

$$V_{BE} = Eg + \frac{kT}{q} \ln \left(\frac{I_E}{A}\right)$$

then

$$V_{BE} = Eg + CT$$

This equation indicates that if V_{BC} and I_E are held constant, V_{BE} is linearly dependent on temperature. For silicon, this linear dependence is valid over the temperature range of -60°C to +150°C.

The CIL511 transistor was operated at a constant emitter current of 0.1 mA. The sensor output was compared to a reference and the difference was fed to a low-drift differential amplifier. This output was connected to a voltmeter. After calibration, readings were taken in the 20°C to 100°C temperature range. No hysteresis was observed.

An OC200 silicon sensing transistor was used in a circuit measuring temperature in the range -80°C to +150°C (Pallett, 1963). The principle used was that of constant current biasing with respect to the base-emitter voltage.

The sensing transistor formed the first stage of a dc amplifier and the voltage V_{BE} was derived from a voltage divider across the output of the amplifier. The results were linear to within 1% over the range ±100°C. The transistor of the temperature measuring probe could be interchanged with one of the same type.

A low-cost electronic medical thermometer was constructed using a transistor sensor (Henry, 1972). Any of these four NPN silicon transistors was acceptable for use as the sensing transistor in this design: an MMT3904, a 2N4124, a 2N718A or a 2N2222. The base-emitter junction resistance of all silicon transistors varies with temperature changes. The sensing transistor not only served to detect temperature but also provided some amplification of its own. After calibration, the output was accurate enough so that it did not vary more than 0.05°C.

A digital thermometer using a low-cost transistor sensor was designed, built and tested (Box and Neil, 1976). The principle used was that of constant current biasing with respect to the base-emitter voltage. The collector and emitter of the BC109C sensing transistor was connected as one arm of a bridge circuit. When the temperature of the sensor increased, its internal impedance decreased and its current increased upsetting the balance point of the bridge. Balance was returned by decreasing V_{BE} to return I_C to its preset level. This was achieved by rotating the wiper of a potentiometer calibrated in °C. The bridge balance was sensed with a comparator and two light-emitting diodes. This instrument had a range of 0°C to 100°C and a resolution better than 0.05°C. A three-digit dial with one-tenth increments on the last digit was fixed to the balance potentiometer and provided a digital readout. The instrument could be converted to operate over any range between the limits of -100°C and +180°C.

Three 2N706A transistors were used as sensors for temperature monitoring and control in a central heating system (Thomas, 1977). The relationship of V_{BE} varying linearly with temperature for a constant collector current was used. The transistors monitored the room temperature, boiler temperature and outside temperature and their outputs were summed with a 741 op amp.

A remotely located 2N2484 transistor was used as a temperature sensor (Ruehle, 1975). The circuit described in his paper was based on the fact that if emitter current is held constant, V_{BE} becomes a linear function of temperature. This circuit had a highly linear output which was adjustable from 10 mV/°C to 360 mV/°C. The linearity of the circuit was typically within ±0.05%.

Silicon diodes such as the FD200 have been used as temperature sensors. Pease (1972) found a temperature coefficient of approximately -2 mV/°C. This diode was used in an op amp circuit, where the amplifier functioned as a follower with positive gain. The output sensitivity was +100 mV/°C, providing a full-scale range of ±10 V for the ±100°C temperature range. A problem with this circuit was that the reference voltage must be stable since a 50 mV shift in the supply would cause a 1°C apparent change at the output. An alternative circuit was designed, which used silicon planar transistors such as 2N930, 2N1613 or 2N3903 as the temperature sensing elements (Pease, 1972). With the modified circuit, linearity was typically within 0.01°C over a 0°C to 20°C range and better than 0.1°C from -50°C to +100°C.

Two different temperature sensing circuits were designed and built by Koch, 1976. One circuit used a transistor as the temperature sensing element and the other circuit used a diode as the temperature sensor. The voltage across either the diode or the base-to-emitter junction of the transistor changes at -2.2 mV/°C if the current through the junction is held constant. The thermometer circuits described in this paper were both linear and accurate to within 0.05°C. Self-heating of the sensors was small since they both operated at about 50 μW power levels. An AD811 sensing transistor and a Fairchild μA748 op amp were used in this circuit.

Two adjustments were necessary for calibration, and since they were interdependent, they must be repeated two or three times. For the diode circuit, a Fairchild FD300 diode was the sensor, and two Fairchild μA748 op amps were also used. The first op amp was a constant current source for the sensing diode. Since most temperature measurements are made in the 0°C to 100°C temperature range, the second op amp was used to choose whatever temperature range was desired. Compared to the transistor circuit, the diode circuit was a little harder to fabricate and shield effectively. The diode had two advantages though. It had a simple calibration procedure and was about half as sensitive to reference voltage changes as the transistor sensor circuit.

Resistance thermometers

In the literature, resistance thermometers also go by the name resistance temperature detectors or devices (RTDs). In these devices, very pure wire is wound in a coil to serve as the sensing element (Fluke Manufacturing, Inc., 1974). Resistance changes are monitored using various bridge circuits to provide temperature data as a direct function of current flow. RTDs are perhaps the most accurate and linear temperature sensors available over a wide temperature range and are therefore often used as laboratory standards. The signal from an RTD is simply a change in resistance.

Signal strength from an RTD is sufficient enough that high-gain amplifiers are not required. This, in turn, reduces the chance that electromagnetic interference will introduce errors into the output signal

(Sandford, 1976). When unusually high accuracy is required, the RTD can be combined with a device to produce a linearized output voltage.

The choice of metal depends on several factors; the most important being the ease of obtaining a pure metal, and the capability of drawing it into a fine wire. Also, it must have a repeatable temperature coefficient, be linear, and have a relatively high rate of resistance change. At present, five metals are commonly used: platinum, tungsten, copper, nickel and the alloy Balco. Rhodium, iridium, silver, iron, and tantalum are occasionally used. Platinum is the most widely used and nickel and copper are the second choices.

Platinum has a high melting point, resists oxidation and is chemically stable. It can be contaminated by gases in a reducing atmosphere and can act as a catalyst when certain hydrocarbons are present. Therefore, good platinum sensors are usually encapsulated. Nickel also is available in nearly pure form. It has the highest resistance change of any metal between 0°C and 100°C. The sensitivity decreases sharply above 285°C and the resistance change is quite nonlinear. Copper oxidizes rapidly and loses its purity, which makes it less desirable than the others. However, it is easy to refine and draw into uniform wire and it absorbs heat uniformly.

As temperature increases, the resistance of the platinum RTD increases; therefore, it has a positive temperature coefficient (PTC). Figure 1 shows a typical circuit arrangement for a platinum sensor having a three-lead probe. The precision of the measuring device, e.g., the galvonometer, must be as good as that of the sensor.

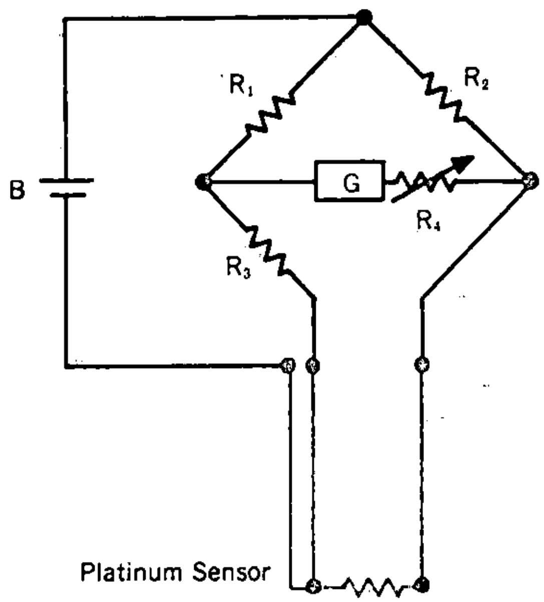

Figure 1. Typical circuit arrangement for a platinum RTD (Sanford, 1976)

Knowing the resistance of the RTD and the temperature coefficient, the temperature can be determined from tables of resistance vs. temperature. There are two commonly used temperature coefficients. A coefficient of 0.003916 ohm/ohm/°C is referred to as an SAMA curve and is generally used in the United States. A second coefficient, 0.00385 is referred to as the DIN 43760 curve and is the International and European Standard (Hall, 1978). The two curves are not interchangeable. Minco Products, Inc., Minneapolis, Minnesota points out that manufacturers of platinum RTDs have not standardized resistance-temperature relationships (Sandford, 1976). As a result, serious errors can occur from intermixing RTDs from several suppliers.

RTD systems provide high accuracy over narrow spans (6°C). They can yield accuracies of thousandths of a degree. Compensation is not required and RTDs can be very small in size. Sometimes RTDs can be fragile, expensive and difficult to mount.

A recent development in platinum resistance thermometry is based on the refinement of film deposition techniques combined with automated methods of trimming. This has led to a new generation of small flat detectors with the temperature precision measuring capability of wire-wound devices (Walko, 1976). These detectors are less expensive than the devices which use platinum wire. These new devices also are called thin film detectors. The sensors are at least the equal, technically, of the existing wire products. Also, because of their smaller size, there is a greater variety of possible applications for temperature measurement by platinum resistance thermometry. Detectors manufactured by Rosemount Engineering, England are called Platfilm. They are 3 mm wide, 30 mm long and 1.5 mm thick. They operate in the range -50°C to 500°C and have a metal sheath. Platfilm also is packed into a cylindrical ceramic sheath and is 4 mm in diameter and 32 mm long. Another company which should presently be manufacturing such a detector is Heraens (England), which has a glass encapsulated platinum layer on a ceramic substrate. These are called Thin Film Detectors. Matthey (England) also produces thin film detectors, as robust replacements for thermocouples and platinum resistance detectors. These are called Thermafilm detectors. Some of these thin film detectors are made with resistances of $100 \pm 0.1\ \Omega$.

Thermistors

Thermistors are electronic sensors made from semiconducting materials such as metal oxides. They are pressed and sintered pellets made from oxides of metals such as nickel, iron, and titanium. In temperature sensing, they are usually one leg of a Wheatstone bridge circuit, as seen in Figure 2. Their resistance is a direct function of absolute temperature, decreasing as temperature increases. Most thermistors have a negative temperature coefficient, but some have a positive one. The thermistor has an exponential curve for its resistance versus temperature transfer function. At very low temperatures, most thermistors approach infinite resistance, and conversely, at high temperatures, very low resistance. Interchangeability is still somewhat of a problem, but low cost is an asset. Thermistors that initially have certain resistance values at a given temperature will sometimes vary widely from that value after prolonged use (Mangum, 1977).

The thermistor is well-suited for sensing small changes in temperature over a narrow range. Very slight changes in the temperature being monitored produce very large negative changes in electrical resistance (a high NTC). Thermistors have the disadvantage of requiring calibration when they are interchanged. Thermistors are designed for accuracies of 0.2°C.

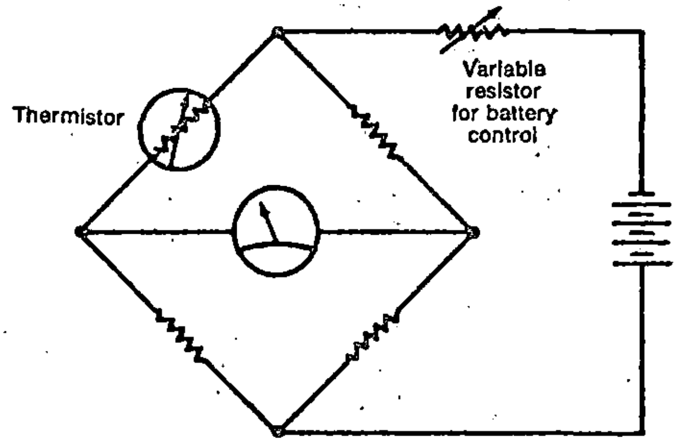

Figure 2. A typical thermistor circuit (Sandford, 1976)

A typical application of thermistors is to compensate temperature in electrical circuits. Since most electrical conductors have a positive electrical resistance change, the NTC thermistor in the same circuit compensates in the opposite direction. The result is to hold circuit resistance constant over a wide temperature range.

Thermistors are rugged and provide a relatively high degree of stability over a long life span (Hall, 1978). They are available with resistances of 0.5 Ω to 80 MΩ. Standard forms include discs, washers, rods, beads and probes. The thermistors' relatively large resistance change per degree change in temperature provides good accuracy and resolution. A typical 2000 Ω thermistor with a temperature coefficient of 3.9%/°C at 25°C will have a resistance change of 78 Ω/°C compared to only 7.2 Ω for a platinum resistance bulb with the same basic resistance.

A typical thermistor bridge does not require amplification. The voltage output of the typical thermistor bridge at 25°C will be 18 mV/°C with a 4000 Ω thermistor.

Thermocouples

A thermocouple is a junction between two dissimilar metals at which a voltage develops when exposed to heat. To obtain useful data, two junctions must be used in a thermocouple circuit. The sensing junction that produces a signal proportional to the sensed variable is connected to a reference junction maintained at a specific temperature. The resultant output of both junctions is then directly related to temperature.

Two disadvantages of thermocouples are the low-level output signal and the requirement for extension wires for remote readout. The latter is a critical cost factor since most thermocouples use fairly expensive metals for wire. Copper extensions can be used in many cases, without significant loss of accuracy. A thermocouple signal requires circuitry to amplify its 20-70 μvolt/°C signal.

Thermocouples provide moderate accuracy, suitability over a broad temperature range, ruggedness, high reliability, low cost and great versatility of application. In practice, the temperature of the reference junction is held at a constant known value. The temperature of the measuring junction is determined accurately by measuring the circuit voltage and referring to calibration tables for the particular thermocouple materials. Since the voltage generated by a thermocouple circuit is a function of the difference in temperature between the measuring junction and the reference junction, it is important that the reference junction be maintained at a constant, known temperature. This can be accomplished with a temperature-controlled furnace, an ice bath or an electrical means of simulating a known temperature. Electrical temperature simulation is the most convenient and popular means of providing reference junction compensation.

Aside from low output, reference junction drift also is a problem with thermocouples. These problems can be avoided by using inexpensive linear CMOS chips as low-level signal conditioners, and a bucking voltage for reference junction compensation (Ben-Yakov and Sanandagi, 1976). The complex electronics and temperature control of past designs are no longer needed, making thermocouples attractive transducers even in the 0°C to 100°C temperature range.

Although many materials can be combined to produce a thermoelectric effect, certain pairs have become more widely used than others. The National Bureau of Standards gives reference tables for the thermocouple material combinations that are most commonly used in the United States. Some common thermocouples are listed in Table 2.

Procedure for Testing the Temperature Sensors

Physical description of sensors

Five temperature sensors were tested. They are pictured in Figure 3. From left to right, the five temperature transducers are: Analog Devices' AD590K two-terminal IC temperature transducer, National Semiconductor's LX5700 temperature transducer, Precision Monolithic's REF-02 +5 V precision voltage reference, regulator and thermometer, Motorola's MTS102

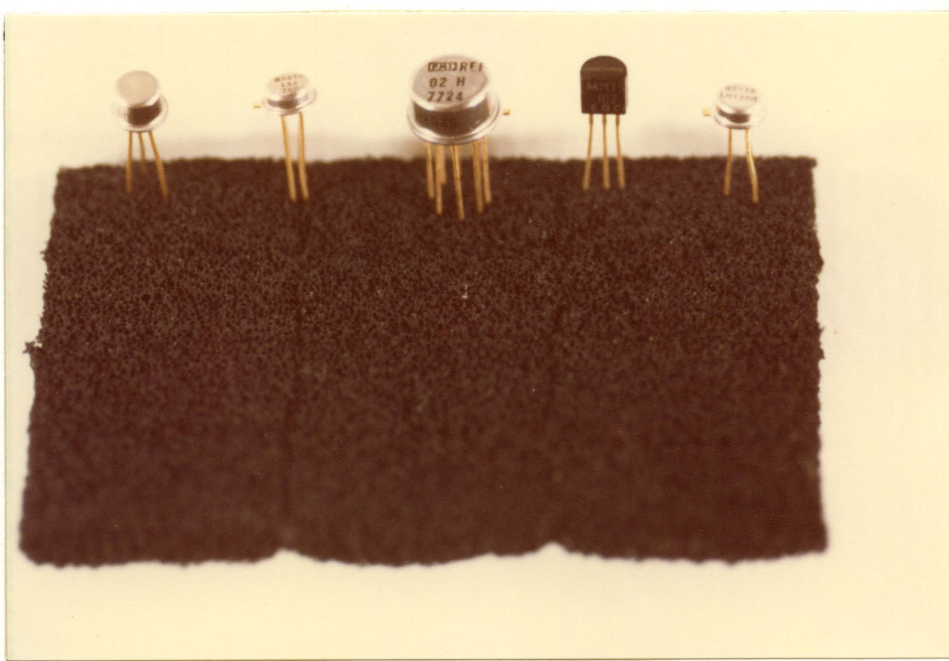

Figure 3. Photograph of the five temperature sensors tested

Table 2. Common thermocouples (Gould, Inc.)

ISA[a] type	Conductor: Positive	Conductor: Negative	Temperature range °C	Limits of error: Standard	Limits of error: Special	Application notes
J	Iron	Constantan	0 to 275 275 to 760	±2.2°C ±3/4%	±1.1°C ±3/8%	Reducing atmosphere recommended
T	Copper	Constantan	-185 to -60 -100 to -60 -60 to +95 95 to 370	- ±2% ±0.83°C ±3/4%	±1% ±1% ±0.42°C ±3/8%	Excellent in oxidizing and reducing atmosphere within its temperature range
K	Chromel	Alumel	0 to 275 275 to 1260	±2.2°C ±3/4%	±1.1°C ±3/8%	For oxidizing atmosphere
E	Chromel	Constantan	0 to 315 315 to 870	±1.7°C ±1/2%	- -	Highest output of common thermocouples
S	Platinum 10% rhodium	Platinum	0 to 540 540 to 1480	±2.8°C ±1/2%	±1.4°C ±1/4%	Laboratory standard, highly reproducible
R	Platinum 13% rhodium	Platinum	0 to 540 540 to 1480	±2.8°C ±1/2%	±1.4°C ±1/4%	Oxidizing atmosphere recommended

[a]Instrument Society of America.

silicon temperature sensor and National Semiconductor's LM335H precision temperature sensor. The Analog Devices' AD590 was in a three-pin metal can package and the National Semiconductor LX5700 was in a four-pin metal can package. The Precision Monolithic's REF-02 was in an eight-pin metal can package and the National Semiconductor LM335 was in a three-pin metal can package. The Motorola MTS102 is not manufactured with a metal can package--a three-pin plastic package is available.

Test apparatus

A photograph of the apparatus which was used to test the sensors is in Figure 4. From left to right is: the Hewlett-Packard Model 3476B digital multimeter, Analog Devices Model 904 ±15 V power supply, testing circuit, water bath, and Koldwave Products beverage dispenser. The sensors were secured in styrofoam cups which were placed in the water

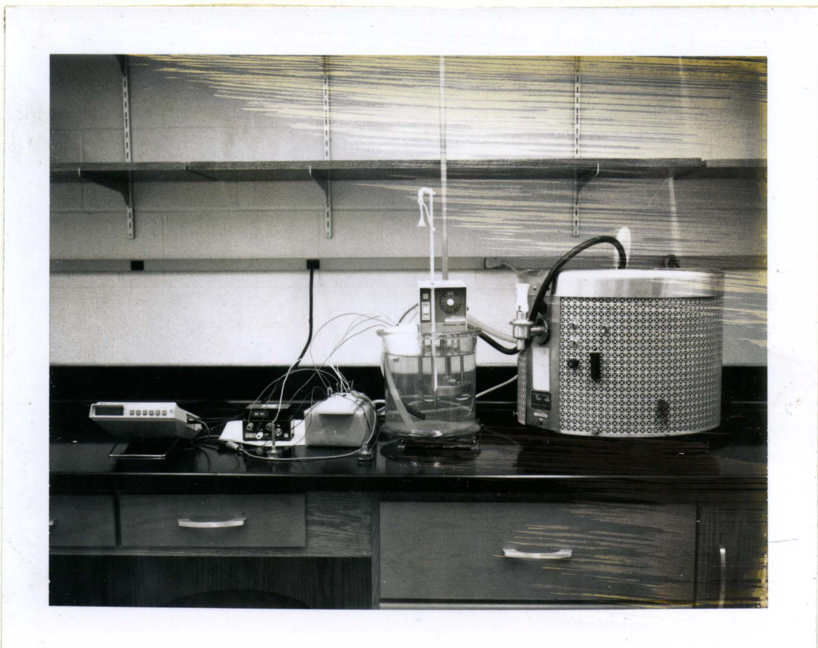

Figure 4. Photograph of the testing apparatus

bath as shown in Figure 4. The Koldwave Products beverage dispenser had a pumping mechanism and was used to cool the temperature of the water bath. A Thermomix 1440E Bronwill Constant Temperature Circulator and Fisher 1500A mercury thermometer can be seen in the water bath of Figure 4. The Thermomix unit was used to raise the temperature of the water bath. The Fisher mercury thermometer was accurate at 0.1°C and was used to determine the actual temperature of the water bath.

Manner in which sensors were secured during testing

Figure 5 shows the styrofoam cup with the precision Monolithics REF-02 temperature sensor sealed into place. Initially, the sensors were glued onto the styrofoam cups and then an attempt was made to put the sockets onto the bottom of the sensors. Lining up the sensors' pins with

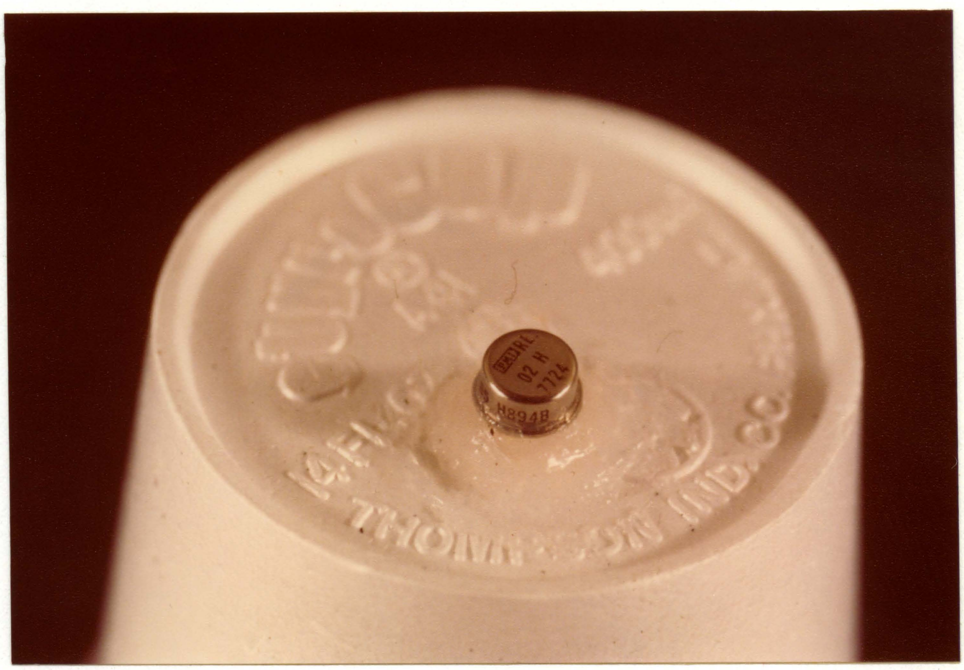

Figure 5. Styrofoam cup with temperature sensor

the socket holes proved to be extremely difficult. Changing the technique of securing the temperature sensors proved to be more successful. First, a circular, flat, one-inch diameter piece of styrofoam was cut from the bottom of a cup. Then, the sensor pins were pushed through this piece and the sensor was inserted into its socket. Then, a small hole was cut into the bottom of a new styrofoam cup, just large enough so the sensor could fit through. The waterproof sealer which was used to glue the sensor and flat tab of styrofoam into place was Dow Corning Silastic Medical Adhesive Silicone Type A. During curing, approximately 6.4% acetic acid is evolved, so it is preferable to do this in a ventilated area.

Test circuits and calibration (where required)

The circuit used for testing the Analog Devices AD590 is diagrammed in Figure 6. V_T, the output voltage is 1 mV/°K. When the AD590 was calibrated at 50°C, the output was set equivalent to 273°K + 50°K or 323°K, which was 323 mV.

Figure 7 shows the circuit used to test the National Semiconductor LX5700. The supply voltage was 15.17 V. To determine the value of R_s, the following equation was used:

$$R_s = (V^+ - 6.8\ V) \times 10^3\ \Omega$$

$$R_s = (15.17 - 6.8\ V) \times 10^3\ \Omega$$

$$R_s = 8370\ \Omega$$

A 1/4 W, 5% tolerance, 8200 Ω carbon resistor was used for R_s. The output is 10 mV/°K.

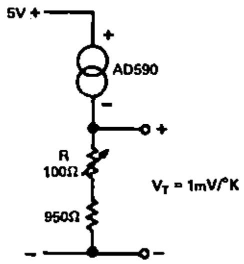

Figure 6. AD590 test circuit (Analog Devices Inc., 1977)

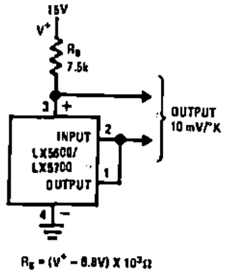

Figure 7. LX5700 test circuit (National Semiconductor Corp., 1973)

The circuit used for testing the Precision Monolithics REF-02 is shown in Figure 8. Table 3 provides the user with three possible output scales. Once the choice is made, the table provides resistor values for the test circuit. The scaling factor chosen was s = 10 mV/°C.

R_a was a 9.02 KΩ, 1/2 W, IRC ±1% metal film resistor. R_{b1} consisted of two 0.75 KΩ, 1/4 W, IRC ±1% metal film resistors in series. R_c was a 10.1 KΩ resistor in parallel with a 10.3 KΩ resistor resulting in a 5.15 KΩ resistance. These two were also 1/4 W IRC ±1% metal film resistors. R_{BP} was a 200 Ω potentiometer. The op amp used was a Precision Monolithics OP-02.

To test the REF-02, a calibration procedure had to be used. Step one consisted of measuring the ambient temperature, T_A, in °C and measuring V_{temp}. T_A was 23.0°C and V_{temp} was 641 mV. Step two consisted of calculating the calibration ratio r.

$$r = \frac{V_{temp}(\text{in mV})}{s(T_A + 273)}$$

$$r = \frac{641}{10(23.0 + 273)}$$

$$r = 0.2166$$

Step three consisted of turning off the power, shorting the V_{REF} terminal to ground, and applying a precise 100 mV to the V_{out} terminal.

The precise 100 mV was obtained by using a dual 5 V power supply.[1] To obtain the precise 100 mV, the circuit of Figure 9 was used. A 1 KΩ

[1]Model 500 dual power supply manufactured by Spar Electrostatics, San Diego, California.

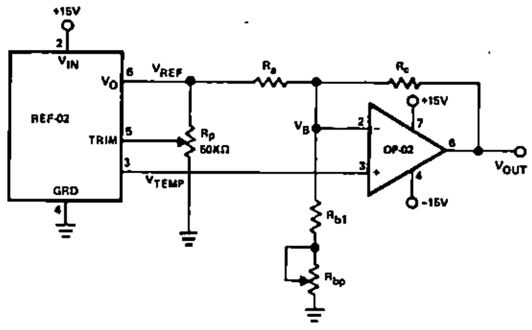

Figure 8. REF-02 test circuit (Precision Monolithics Inc., 1976)

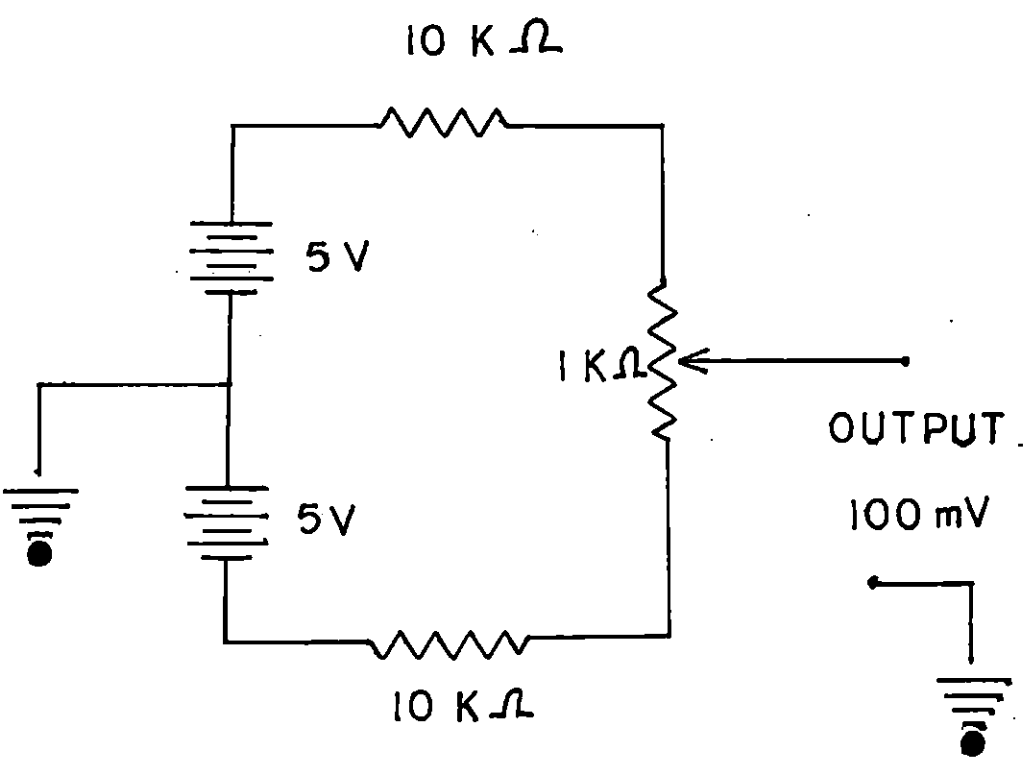

Figure 9. Circuit used to obtain 100 mV

Table 3. Resistor values for the REF-02 test circuit[a]

TCV_{out} slope (s)	10 mV/°C	100 mV/°C	10 mV/°F
Temperature range	-55° to +125°C	-55° to +125°C	-67°F to +257°F
Output voltage range	-0.55 V to +1.25 V	-5.5 V to +12.5 V	-0.67 V to +2.57 V
Zero scale	0V @ 0°C	0V @ 0°C	0V @ o°F
R_a (±1% resistor)	9.09 KΩ	15 KΩ	7.5 KΩ
R_{b1} (±1% resistor)	1.5 KΩ	1.82 KΩ	1.21 KΩ
R_{bp} (potentiometer)	200 Ω	500 Ω	200 Ω
R_c (±1% resistor)	5.11 KΩ	84.54 KΩ	8.25 KΩ

[a]Precision Monolithics Inc., 1976.

potentiometer and two 10 KΩ resistors were used. A voltmeter was used to check the output, and the potentiometer was adjusted so that 100 mV was obtained.

After the 100 mV was applied to the output terminal of the test circuit, step four of the calibrating procedure was performed. In step four, R_{bp} is adjusted so that:

$$V_B = r(100 \text{ mV}) = (0.2166)(100 \text{ mV}) = 21.66 \text{ mV}$$

As R_{bp} is adjusted, the loading effect on the circuit used to obtain the 100 mV changes. Therefore, V_{out} and V_B are monitored. The 1KΩ potentiometer has to be adjusted to maintain a 100 mV output at V_o. Then, R_{bp} is adjusted to obtain the desired value for V_B. After this, the short at V_{REF} to ground is removed.

Step five included turning the power on and adjusting R_p so that V_{out} equaled the correct value at ambient temperature. R_p was adjusted so that V_o was equal to 230 mV at 23°C. Calibration for the REF-02 was then complete.

Figure 10 shows the test circuit used with the National Semiconductor LM335. R_1 is a 10.1 KΩ resistor. It is a 1/4 W Dale metal film precision (1%) resistor. V^+ was chosen to be a 12 V power supply. The LM335 has less than 1 Ω dynamic impedance. Since the Hewlett-Packard digital voltmeter has a very slight loading effect and the LM335 operates between 400 μA and 5 mA, the values for R_1 and V^+ put the LM335 in its operating range. The output is 10 mV/°K.

Figure 11 shows the test circuit used with the Motorola MTS102. A 12 V power supply was used. To make up the 110 KΩ, two resistors were used in series. These were 100 KΩ and 10 KΩ and both resistors were 1/4 W Dale 1% tolerance metal film resistors.

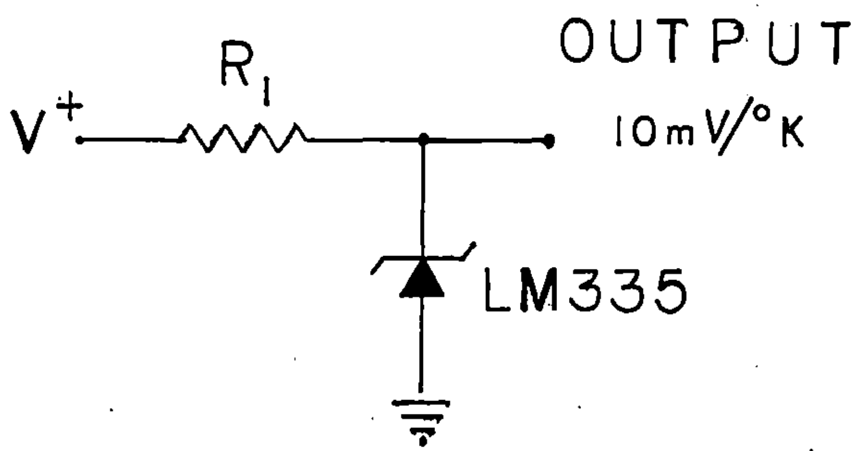

Figure 10. LM335 test circuit (National Semiconductor Corp., 1973)

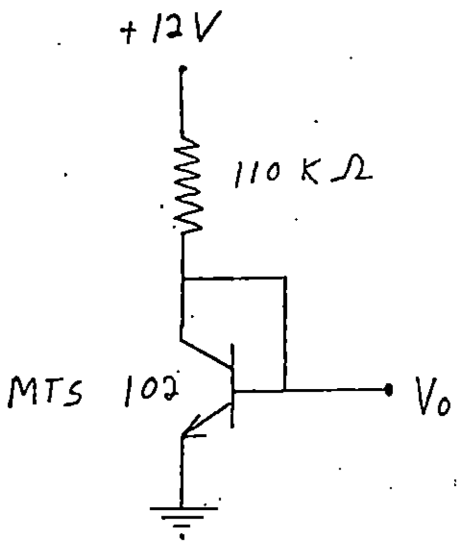

Figure 11. Test circuit for MTS102

<u>Actual testing</u>

All of the temperature sensors were tested three times from 50°C to 0°C at 5°C intervals. These three test runs were averaged. Also, all of the temperature sensors were tested for hysteresis effect by testing them from 0°C to 50°C at 5°C intervals. A Fisher 1500A mercury thermometer accurate to 0.1°C was used as the standard.

Transducer Operating Principles; Experimental Results; Discussion

<u>Analog Devices AD590</u>

The Analog Devices AD590 is an IC temperature transducer with an operating range of -125°C to +200°C. Analog Devices guarantees the AD590K for a -55°C to +150°C range. Overall absolute accuracies of ±0.5°C have been obtained over that temperature range.

The AD590, which is fabricated using laser trimmed thin-film-on-silicon technology, is a calibrated temperature-dependent current source. For supply voltages between +4 V and +30 V, the device acts as a constant-current regulator, passing 1 μA/°C.

In the circuit schematic seen in Figure 12, Q_9, Q_{10}, and Q_{11} are the critical temperature sensing transistors. These are located at the opposite end of the chip from the main power-consuming components Q_1, Q_2, Q_3, Q_4, Q_7 and Q_8. The temperature sensing principle used is that if two identical transistors are operated at a constant ratio of collector current densities, Ic_1/Ic_2, then the difference in their base-emitter voltages (ΔV_{BE}) will be (kT/q) ln (Ic_1/Ic_2). Since k and q are constants, the resulting voltage is directly proportional to absolute temperature (PTAT). The PTAT voltage is converted to a PTAT current by low-temperature-coefficient thin-film resistors. The total current of the device is

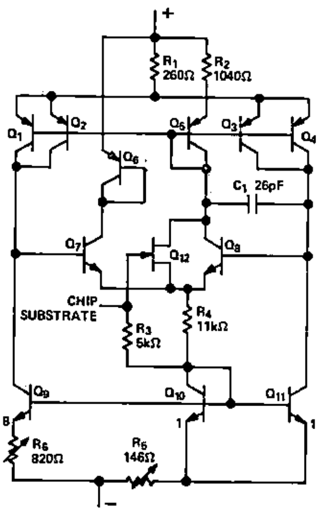

Figure 12. Schematic diagram of the AD590 (Analog Devices Inc., 1977)

then forced to be a multiple of the PTAT current. Transistors Q_9 and Q_{11} produce the PTAT voltage. R_5 and R_6, which are laser trimmed on the wafer to calibrate the device at 25°C, are also used to convert the voltage to current. Q_{10} supplies all the bias for the rest of the circuit, forcing the total current to be PTAT. Figure 13 shows a typical V-I characteristic of the circuit at +150°C, +25°C, and -55°C. At 25°C, power requirement for the AD590 operating at 5 V is 1.5 mW (Analog Devices Inc., 1977).

As tested, the AD590 had excellent results, as can be seen in Appendix A and Figure 14. There was no hysteresis effect and it was well within the claimed ±1.0°C absolute error with +25°C calibration. There was no slope error. It also was within the ±0.5°C claimed nonlinearity. Referring to Table 4, it can be seen that the AD590 had a least squares linear regression coefficient of 1.00000. Appendix A contains the data of

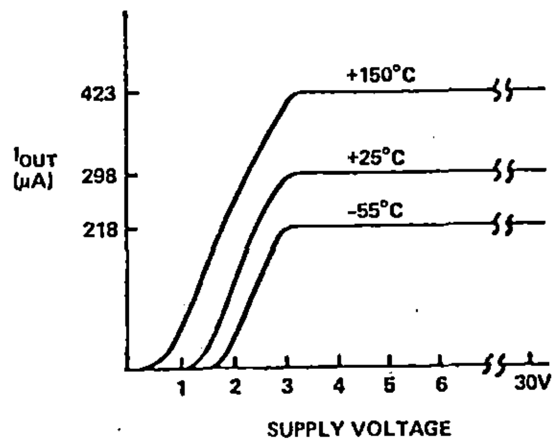

Figure 13. V-I characteristic of the AD590 (Analog Devices Inc., 1977)

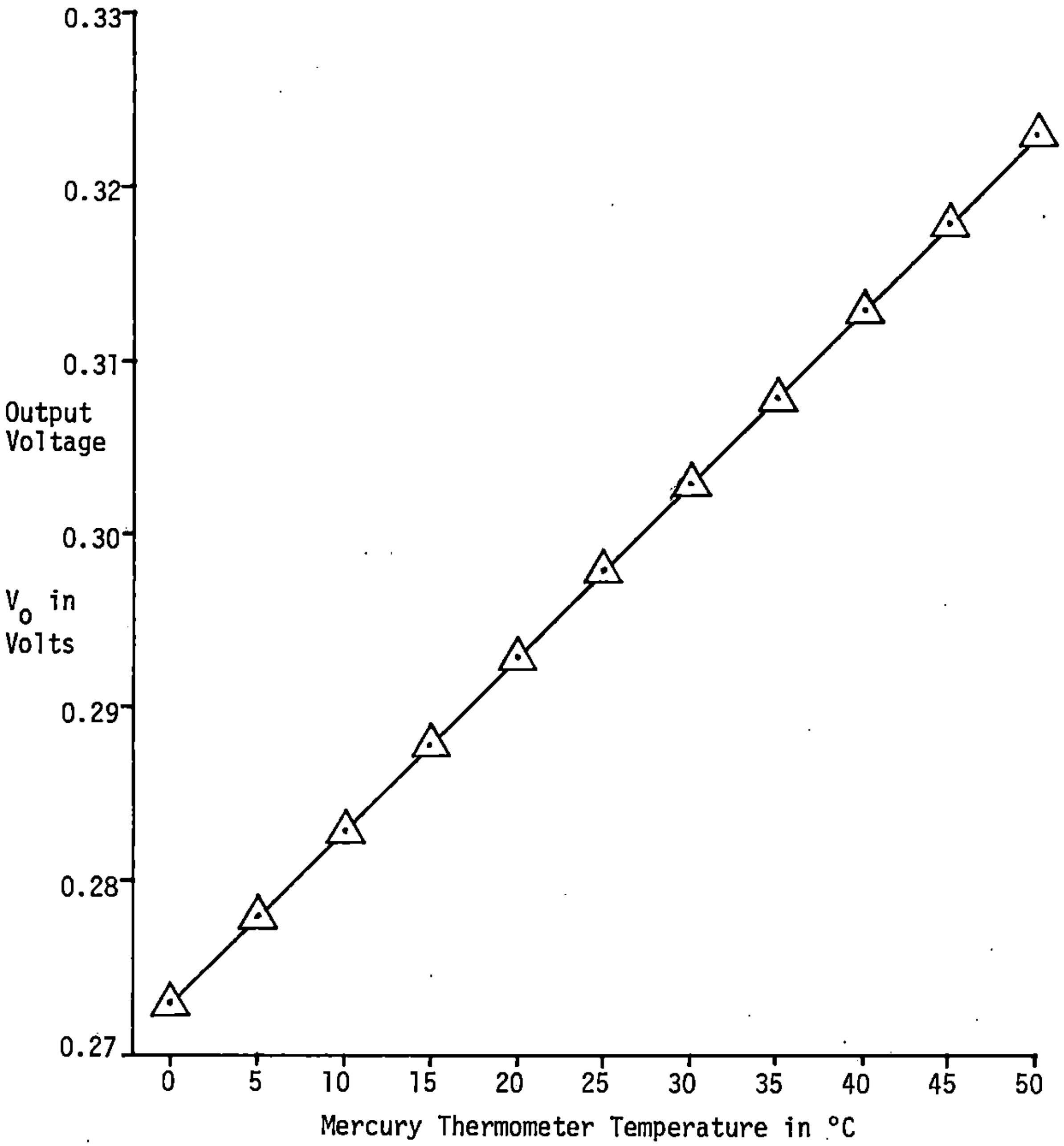

Figure 14. Plot of temperature vs. output voltage for the AD590

the five temperature sensors. The first column shows the temperature, as read from the standard (the mercury thermometer). The next three columns are the three test runs, and the average column is a mathematical average of the three test runs. The last column is the temperature determined by the sensor, as calculated from the output voltage.

Because the AD590 is a current source with only two active leads, the sensor is virtually free from noise pick up even when remoted over hundreds of feet of cable (Owen, 1978). The AD590 should presently be available in a miniature ceramic packaged version, which, if it were a biocompatible ceramic, would make the AD590 an excellent temperature sensing device for implantation.

National Semiconductor LX5700

The LX5700 temperature transducers are accurate over the -55°C to +125°C temperature range. Figure 15 shows the block diagram of the LX5700. The LX5700 exploits the temperature sensitivity of the emitter-

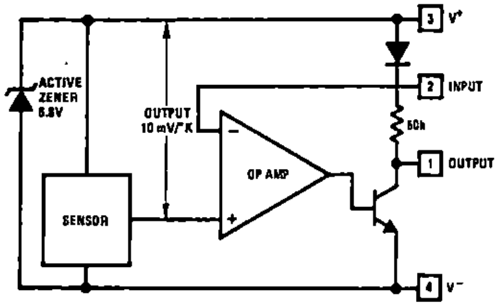

Figure 15. Block diagram of the LX5700 (National Semiconductor Corp., 1973)

base voltage. It uses a pair of matched transistors operating at different collector currents. The difference in their base-emitter voltages is proportional to the absolute temperature of the transistors and to the natural logarithm of the ratio of their collector currents.

The 6.8 V active zener diode of Figure 15 provides a stable voltage reference for the thermal sensing circuit and for the input stages of the amplifier and it also provides a 6.8 V reference between leads 3 and 4, available for external use. As tested, leads 1 and 2 were connected, which makes the operational amplifier a unity-gain voltage follower.

When the op amp is connected as a comparator, the output will switch as the temperature crosses the set point making the device useful as an on-off temperature controller. The output collector can be brought back to a voltage higher than 6.8 V allowing the LX5700 to drive lamps and relays.

A low cost digital thermometer using the LX5700 IC and a digital panel meter kit was designed and constructed (Swift, 1979). The thermometer's resolution was 0.1°C and total parts cost was less than $55. The LX5700 temperature sensors are not interchangeable, unless the thermometer is recalibrated. A simple electronic thermometer having accuracy and resolution better than 1°C was designed and built by Box, 1974.

The results for the LX5700 in Appendix A are well within the initial ±4°C accuracy. No hysteresis was observed. Figure 16 is a plot of temperature versus output voltage for the LX5700. The plot shows excellent linearity (99.98%). The linear regression coefficient (R^2) for the LX5700 is 0.99967. Slope was (3240 mV - 2750 mV)/(50°C - 0°C) = 9.8mV/°C and the

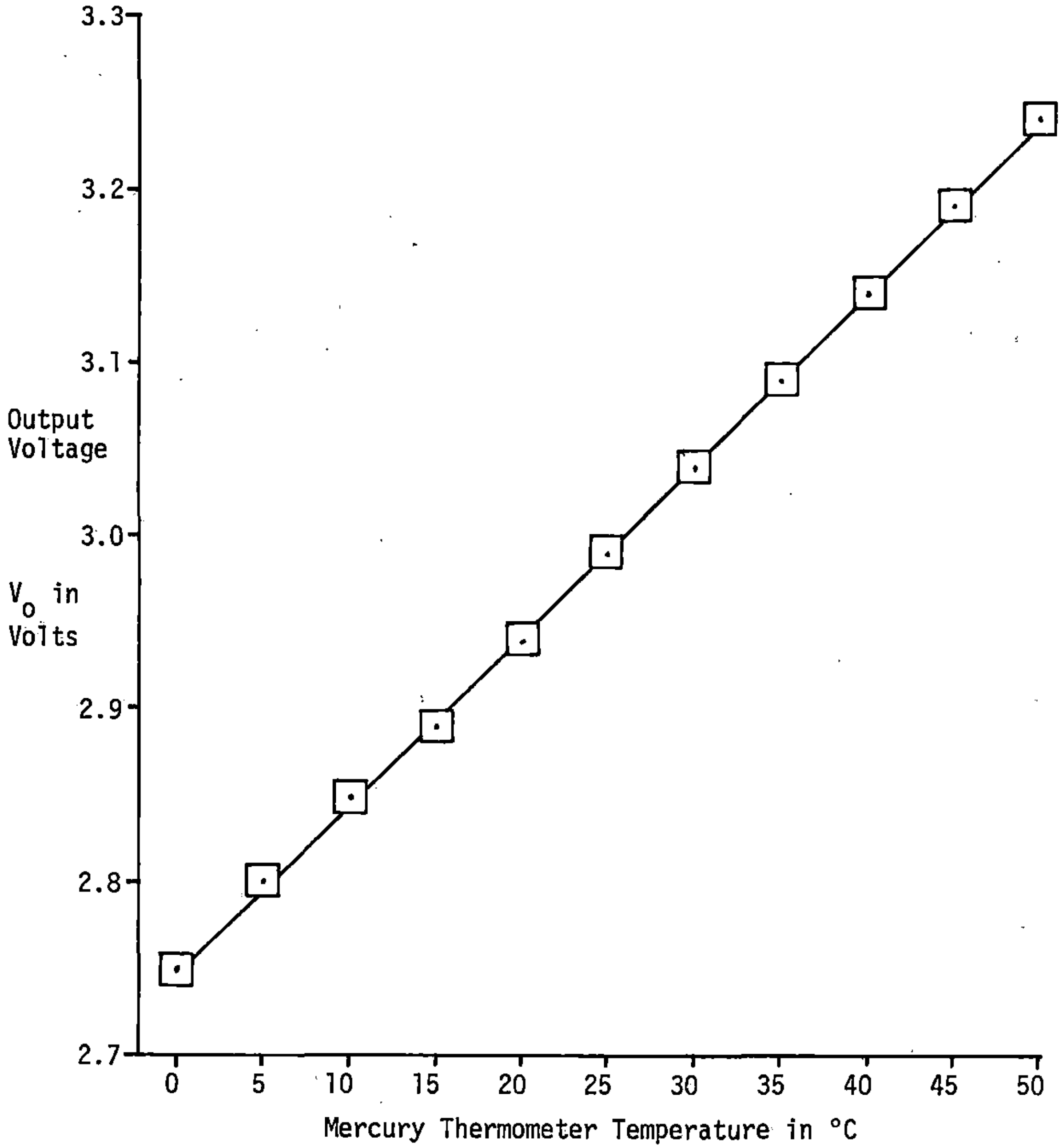

Figure 16. Plot of temperature vs. output voltage for the LX5700

slope error (in percent) = [(10 mV/°C - 9.8 mV/°C)/(10 mV/°C)] x 100 = 2%. At 1.0 mA operating current, the LX5700 has a 7.0 mW power dissipation.

Precision Monolithics REF-02

A simplified schematic of the REF-02 circuit is shown in Figure 17. The REF-02 offers the versatility of being able to choose a temperature scale, such as 10 mV/°C, 100 mV/°C or 10 mV/°F. It also allows direct voltage readings, such as -0.25 V at -25°C, 0 V at 0°C, and +1.15 V at +115°C.

The REF-02 uses bandgap voltage reference theory from semiconductor physics to generate a constant voltage. The base-emitter voltage of a transistor has a current density dependent negative temperature coefficient of about -2.1 mV/°C. The difference between base-emitter voltages of two transistors operated at different current densities results in the equation:

$$\Delta V_{BE} = \frac{kT}{q} \ln \frac{I_1}{I_2}$$

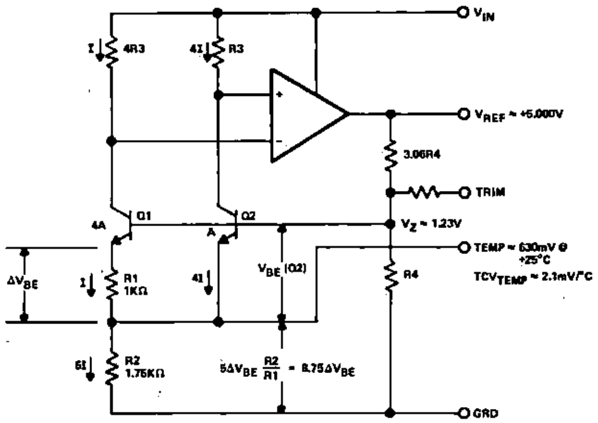

Figure 17. Simplified schematic of the REF-02 (Precision Monolithics, Inc., 1976)

This relationship has a positive temperature coefficient. Two different approaches account for the difference in negative and positive slopes of the MTS102 as compared to the other four temperature transducers. Q_1 and Q_2 are the temperature sensing transistors. The REF-02 trim terminal can be set to 5V ±300 mV. This allows the system designer to trim system errors by setting the reference to a voltage other than 5 V. V_{REF} can be set to exactly 5.000 V or to 5.12 V for binary applications.

The REF-02 is calibrated in free air at room temperature. The small (2°C) rise in chip temperature of the REF-02 above ambient temperature, serves as an error cancelling factor of some second-order effects internal to the REF-02 design (Erdi, 1976).

The REF-02 is guaranteed to perform over the -55°C to +125°C range. A large number of devices were measured and found to be functioning satisfactorily over the -150°C to +170°C range with only a slight degradation in accuracy (Erdi, 1976).

The REF-02 has a high load driving capability of 20 mA. The REF-02 can operate at 15 mW of power and its maximum power dissipation is 500 mW.

The REF-02H, which was tested, is guaranteed to be accurate over the 0°C to +70°C temperature range. Claimed typical system accuracy for the REF-02H is within ±0.6%. This accuracy is calculated with respect to room temperature at which the REF-02 is calibrated. For example, the REF-02 was calibrated at 23°C and the output voltage at 50°C was 0.497 V. So, the percent accuracy is within:

$$\frac{50°C - 49.7°C}{50°C - 23°C} \times 100 = 1.1\%$$

As can be seen from this calculation, this point did not fall within the claimed typical system accuracy. Only 17 of the 44 test points were within the ±0.6% claimed typical accuracy. A slight hysteresis effect was noted for the REF-02. It had excellent linearity, as seen in Table 1, with a linear regression coefficient (R^2) of 0.99999.

Figure 18 is a plot of temperature versus output voltage for the REF-02. Slope for the REF-02 was [497 mV - (-1.3 mV)]/[50°C - 0°C] = 9.966 mV/°C and the slope error (in percent) = (10 mV/°C - 9.966 mV/°C) x 100 = 0.34%.

National Semiconductor LM335

The LM335 is accurate over the -10°C to +100°C temperature range, while the better grade LM135 is accurate over the -55°C to +150°C temperature range. The LM335 IC precision temperature sensor operates like a zener diode with less than 1 Ω dynamic impedance in the reverse breakdown region of the V-I characteristic curve. See Figure 10. It operates with nearly constant current and the voltage is read as a temperature. The low impedance and linear output make interfacing to readout or control circuitry especially easy. The LM335 can be calibrated using a single-point calibration because the sensor is proportional to absolute temperature with the extrapolated output of the sensor going to 0 V output at 0°K.

As can be seen from the results in Appendix A, the maximum temperature error was ±2°C. This is well within the claimed uncalibrated temperature error of ±4° C. Errors in the output voltage versus temperature are only in slope or scale factor, so a slope calibration at one temperature corrects at all temperatures. The slope error was calculated in the

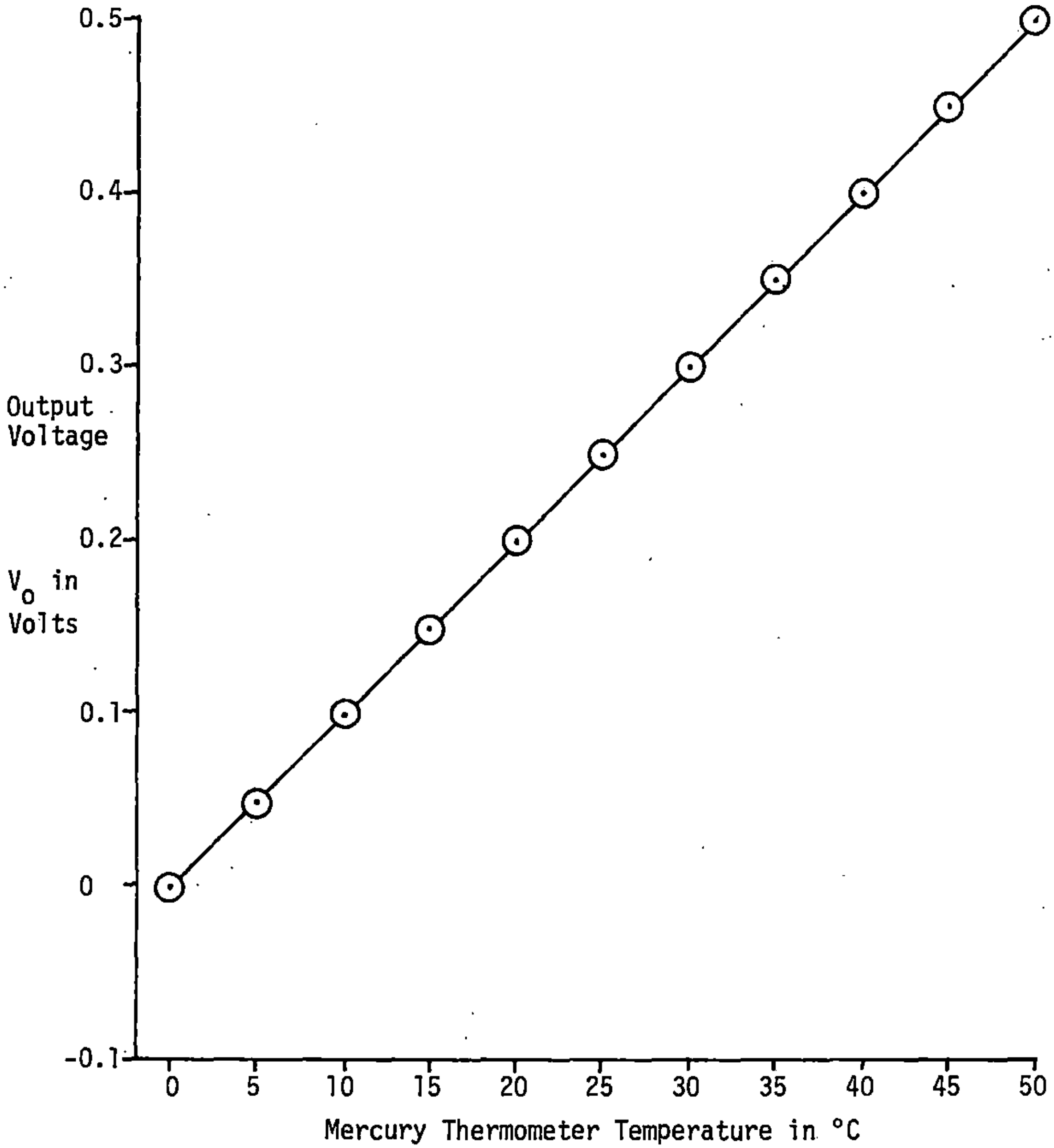

Figure 18. Plot of temperature vs. output voltage for the REF-02

following manner, using the end points at 0°C and 50°C: slope = (3210 mV - 2720 mV)/(50°C - 0°C) = 9.8 mV/°C and slope error (in percent) = [(10 mV/°C - 9.8 mV/°C)/10 mV/°C] x 100 = 2%.

The LM335, like any temperature sensor, can have reduced accuracy as a result of self-heating, so precautions should be taken to operate the sensor at a low current for the application. The LM335 operates over a current range of 400 μA to 5 mA. While testing, it was operated at a current level of approximately 1.2 mA. The least squares linear regression coefficient (R^2) for the LM335 is 0.99968, which shows that the LM335 has excellent linearity. A slight hysteresis effect was noted for only one point. Figure 19 is a plot of temperature versus output voltage for the LM335. At 25°C, power dissipation was 8.1 mW.

Motorola MTS102

The Motorola MTS102 has an accuracy of ±2°C. Motorola also offers less expensive transistors for temperature monitoring. These are the MTS103 and 105 which have accuracies within ±3°C and ±5°C, respectively. Claimed power dissipation for the MTS102 was 625 mW at 25°C.

Transistors would seem to be ideal temperature trandUcers. Their sensitivity, low cost, linearity and ability to operate consistently over long periods all recommend them for this use. A problem in using transistors for this purpose has been that of finding transistors with characteristics matched closely enough to allow them to be used interchangeably. If it were not for this difficulty, their use as temperature sensors would be much more widespread.

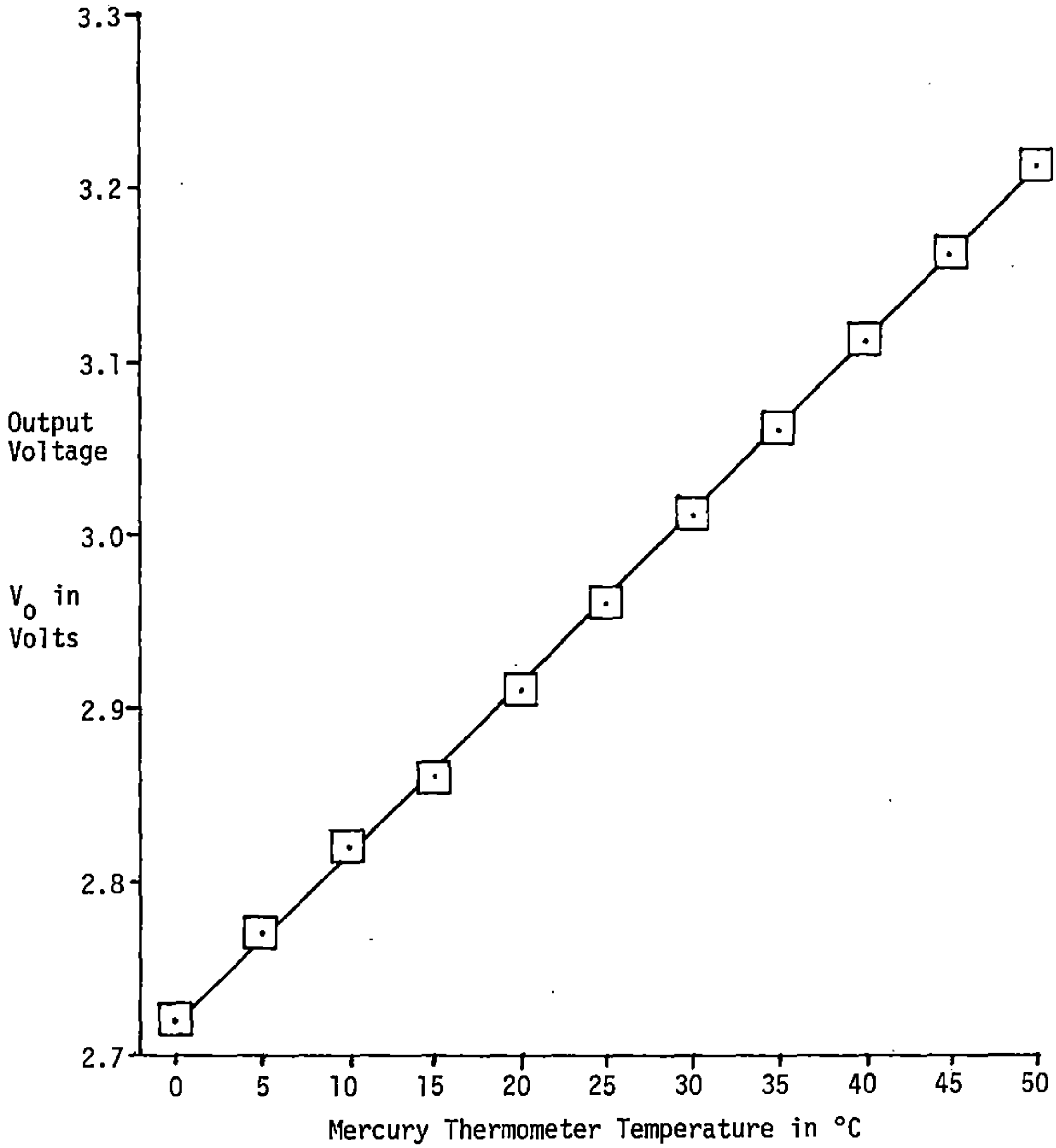

Figure 19. Plot of temperature vs. output voltage of the LM335

In search for interchangeable semiconductor sensors, manufacturers have built sensors that employ laser trimming to equalize circuit parameters and monolithic integrated circuits whose output is the difference of two junctions with differing current densities. Improvements in production line capabilities make it possible to produce discrete transistors with tightly controlled and matched geometries. The Motorola MTS family is a series chosen specifically for temperature sensing. The MTS102 is accurate over the range from -40°C to +150°C. The nominal V_{BE} is any value from 580 to 620 mV. Circuits can be built using the MTS102 that provide accuracies within ±0.1°C. One such circuit has a reference voltage source, sensor circuit, squaring circuit, and an output standardization circuit (O'Neil and Derrington, 1979). Through the use of a more complex and precise squaring circuit and three-point calibration, an uncertainty of ±0.01°C can be obtained.

The Motorola MTS102 has an accuracy within ±2°C and when tested, three of 44 points were not within this accuracy. To determine temperature from the voltage obtained, an equation, which is given in an application note (Motorola, 1978), can be used, or a calibration curve can be plotted and temperature can be read directly from it. Slope for the MTS102 is (545 mV - 648 mV)/(50°C - 0°C) = -2.06 mV/°C and the slope error (in percent) = [(2.00 mV/°C - 2.06 mV/°C)/(2.00 mV/°C)] x 100 = 3%. Linearity for the MTS102 was 99.996%. A slight hysteresis effect was noted, as can be seen in Appendix A. Figure 20 is a plot of temperature versus output voltage for the MTS102.

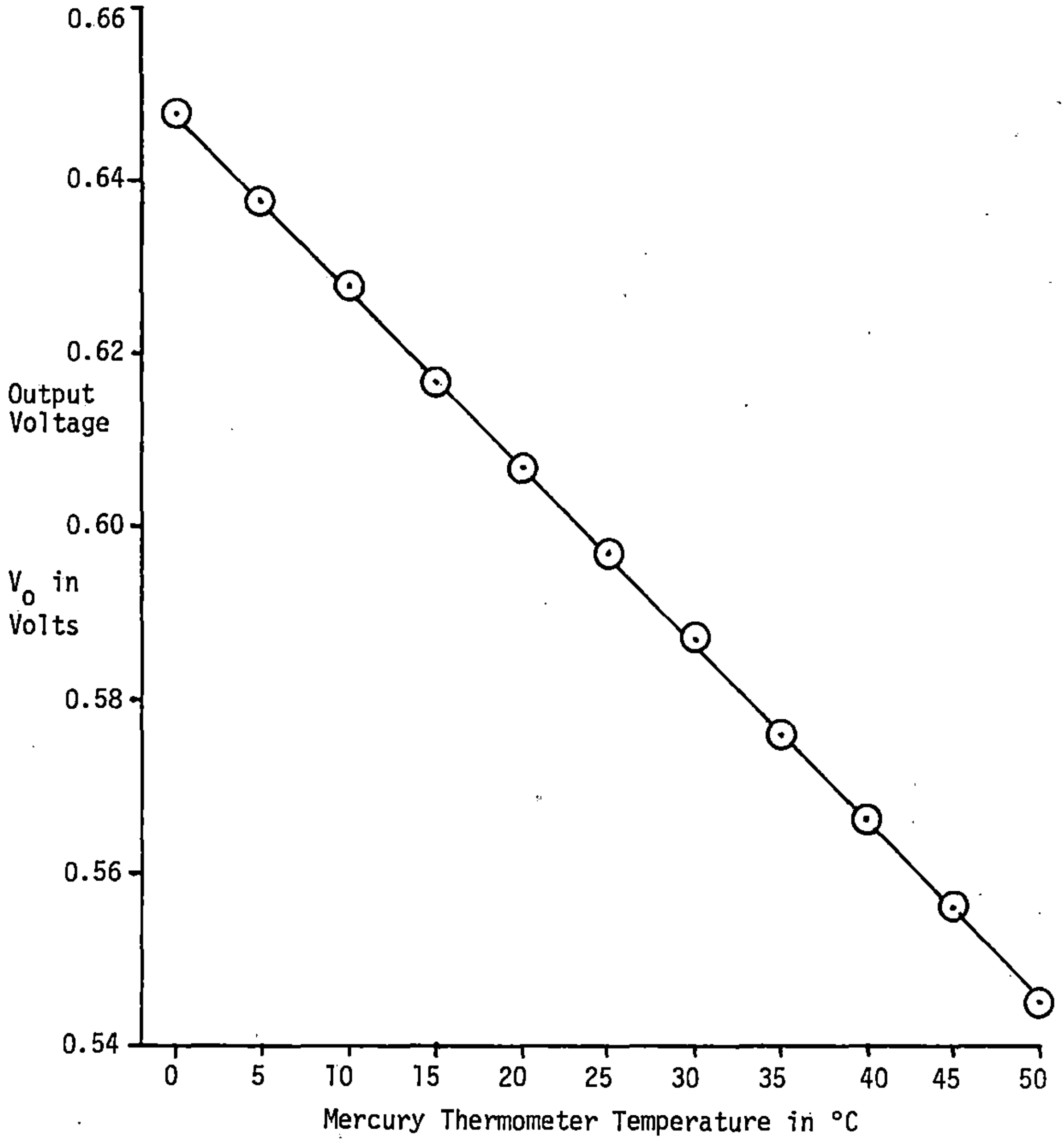

Figure 20. Plot of temperature vs. output voltage for the MTS102

Results

Figure 21 shows the measured nonlinearity for an MTS102 transistor along with typical nonlinearity curves for a type T thermocouple and a platinum resistance thermometer. The regression coefficients for a least squares fit to a straight line, where $R^2 = 1.00000$ for a perfectly linear device, were calculated. These can be seen in Table 4. This indicates that the five temperature sensors tested are superior to the type T thermocouple and thermistor and that the AD590, REF-02 and MTS102 are approximately equal in capability to the more expensive platinum resistance thermometer.

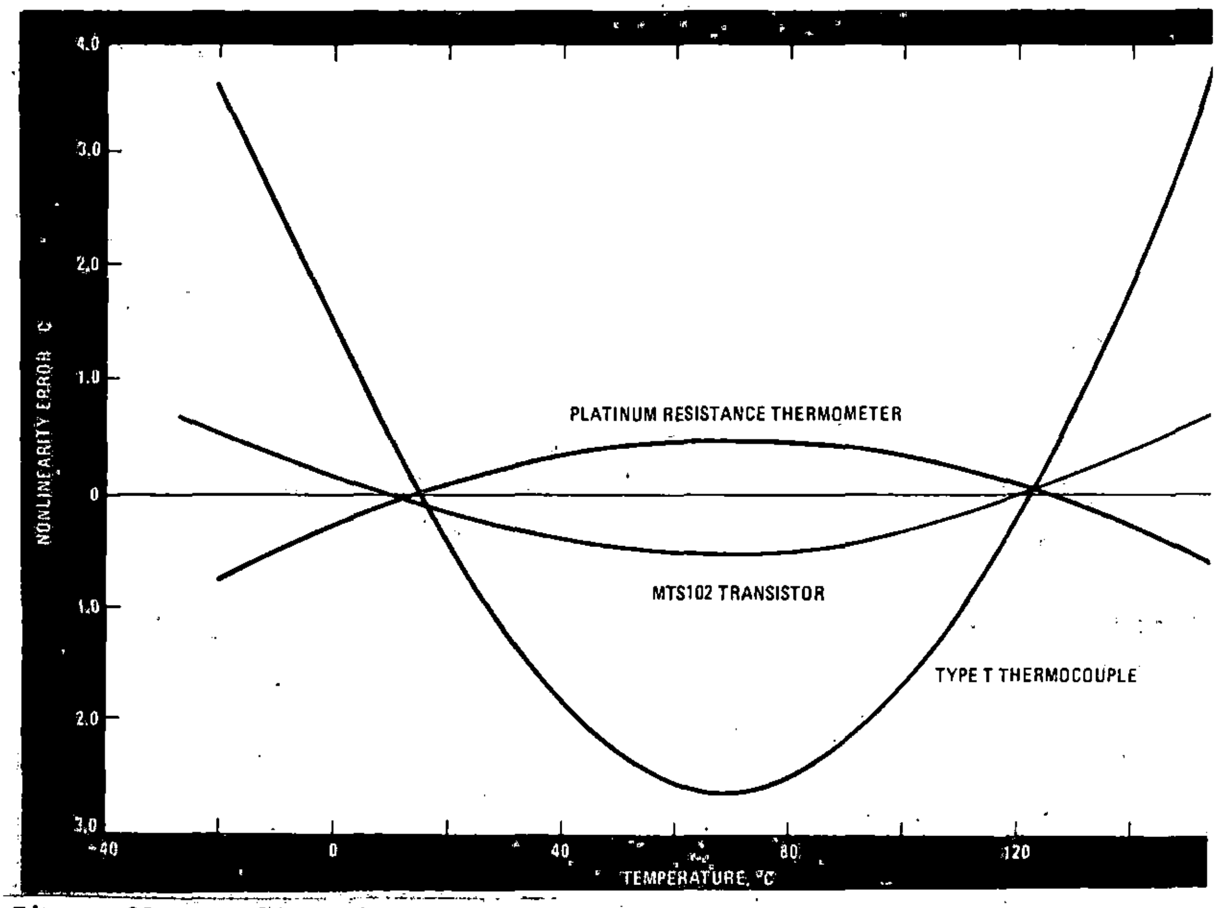

Figure 21. Nonlinearity curves for three types of sensors (O'Neil and Derrington, 1979)

Table 4. Regression coefficients for temperature sensors

Device	Regression coefficient (R^2)
AD590	1.00000
LX5700	0.99967
REF-02	0.99999
LM335	0.99968
MTS102	0.99992
Type T thermocouple	0.99866[a]
Platinum resistance thermometer	0.99999[a]

[a] O'Neil and Derrington, 1979

As tested, the MTS102, LX5700 and LM335 did not require calibration. The AD590 and REF-02 were calibrated. Even with calibration, only 17 of the 44 test points of the REF-02 were within the ±0.6% claimed typical accuracy. A slight hysteresis effect was noted for the REF-02. For the LM335, a slight hysteresis effect was noted for only one point. For the MTS102, three of the 44 points were not within the claimed ±2°C accuracy. Also, a slight hysteresis effect was noted for the MTS102.

Table 5 contains the slope errors for the five devices tested. The AD590 had no slope error, and no hysteresis was noted. The AD590 had a linear regression coefficient (R^2) of 1.00000. The AD590 was well-within the claimed ±1.0°C absolute error and it was also within the ±0.5°C claimed nonlinearity. As tested, of the five devices, the AD590 is the state of the art of semiconductor temperature sensors.

For temperature sensing applications of circuit components, platinum resistance thermometers are more useful, since there is no need to worry that the sensor will fail before the semiconductor circuit components.

Table 5. Slope error of the five temperature sensors

Device	Slope error (in percent)
AD590	0.0
LX5700	2
REF-02	0.34
LM335	2
MTS102	3

The addresses of the four companies whose semiconductor temperature transducers were tested, are in the list of references.

ELECTRICAL SAFETY STUDY

Effect of Electrical Shock

Current, rather than voltage, is the cause of physiological effects of electricity. Any current of 10 mA or more may be fatal. Currents between 75 mA and 4 amperes are probably fatal from heart discoordination and those above 5 amperes may be fatal from severe burns (Lee, 1971). Table 5 shows physiological effects of different amounts of current. Ohm's Law determines the amount of current traveling through the human. It is actually the variable resistive element of the body which is the controlling factor given constant voltage.

Some of the variables, which determine human resistance, include the skin, area of contact, tightness of contact, dryness or wetness of skin, cuts, abrasions and blisters. Excluding the skin, human resistance is 250 Ω per arm or leg, and 100 to 500 Ω from shoulder to shoulder or hip (Lee, 1971). Skinny arms or legs, and those made up mostly of fat, have higher resistance than muscular limbs. Bone also has high resistance. Total human circuit resistance is the sum of two contact resistances and the internal body resistance. A value of 500 Ω is commonly used as the minimum resistance of the human body between major extremities. Table 6 shows human resistance values for various skin contact conditions. Table 7 shows resistance values for various materials.

Above approximately 240 volts, the high voltage punctures the skin and the only resistance which impedes current flow is the internal body

Table 6. Current range and effect on 68 kg man (Lee, 1971)

Current (60 Hz)	Physiological Phenomena	Feeling or lethal incidence
<1 mA	None	Imperceptible
1 mA	Perception threshold	
1-3 mA		Mild sensation
3-10 mA		Painful sensation
10 mA	Paralysis threshold of arms	Cannot release hand grip; if no grip, victim may be thrown clear (may progress to higher current and be fatal
30 mA	Respiratory paralysis	Stoppage of breathing (frequently fatal)
75 mA	Fibrillation threshold 0.5 percent	Heart action discoordinated (probably fatal)
250 mA	Fibrillation threshold 99.5 percent ($\geq$5 second exposure)	
4A	Heart paralysis threshold (no fibrillation)	Heart stops for duration of current passage. For short shocks, may restart on interruption of current (usually not fatal from heart dysfunction)
$\geq$5A	Tissue burning	Not fatal unless vital organs are burned

resistance. At around 2400 volts, burning is the major effect. Below this, ventricular fibrillation and/or asphyxiation are the usual effects.

Continuous currents in excess of the let-go current passing through the chest may produce collapse, unconsciousness, asphyxia and death. It is believed that ventricular fibrillation in a normal adult worker is likely if the shock intensity is more than $116/t^{1/2}$ mA where t is in seconds (Dalziel, 1972). Currents of the order of amperes may produce fatal damage to the central nervous system.

Table 7. Human resistance for various skin-contact conditions (Lee, 1971)

Condition (area to suit)	Resistance, ohms	
	Dry	Wet
Finger touch	40 k-1 M	4-15 k
Hand holding wire	15-50 k	3-6 k
Finger-thumb grasp	10-30 k	2-5 k
Hand holding pliers	5-10 k	1-3 k
Palm touch	3-8 k	1-2 k
Hand around 1 1/2-inch pipe (or drill handle)	1-3 k	0.5-1.5 k
Two hands around 1 1/2-inch pipe	0.5-1.5 k	250-750
Hand immersed	-	200-500
Foot immersed	-	100-300
Human body, internal, excluding skin ohms		200 to 1000

Table 8. Resistance values for equal areas (130 cm^2) of various materials[a]

Material	Resistance, ohms
Rubber gloves or soles	More than 20 M
Dry concrete above grade	1-5 M
Dry concrete on grade	0.2-1 M
Leather sole, dry, including foot	0.1-0.5 M
Leather sole, damp, including foot	5 k-20 k
Wet concrete on grade	1 k-5 k

[a]From Lee (1971).

Electrical Shock - Microshock and Macroshock

The human body is mainly an electrolyte solution surrounded by skin. Since the high resistance shell surrounds the low resistance solution, two separate shock hazards exist, depending upon whether the electrical shock is introduced externally or internally.

Macroshock hazards are those circumstances where the current must pass through the skin. When macroshock hazards cause ventricular fibrillation, the current must pass either from a hand to foot contact or from a hand to hand contact. The amount of current which causes ventricular fibrillation is dependent on the individual's body weight (Strong, 1973).

Microshock hazards occur when a current is applied internally. Death may result from currents, such as 10 to 100 μA, which are too small to perceive by the average person.

The hospital areas where microshock hazards are most likely to occur are the coronary care units, surgical intensive care units and catheterization laboratories. Hazards in hospitals are due to inadequate hospital wiring, electrodes being placed inside the body of the patient and insufficient knowledge of the possible electrical hazards by doctors and hospital personnel. Capacitive coupling from the primary transformer and 110 volt or 220 volt power line of any instrument is the major source of potentially fatal leakage currents.

Another type of hazard, is from high frequency equipment. Electrocautery, neurosurgical lesion generators, radio-frequency diathermy and microwave therapy are all used in treatment of patients. Burns caused by arcing can occur if an insulated wire or cable inadvertently comes in contact with the patient, constituting a return to ground. High frequency currents flowing through body tissues can be conducted directly to equipment having input electrodes on or in the patient, or to implanted sensors. The performance of implanted pacemakers may also be disrupted. Details of these problems are outlined in a manual, "High-Frequency Electrical Equipment in Hospitals, 1970, No. 76CM," published by the National Fire Protection Association.

Possible Means of Eliminating Electrical Shock Hazards

A potential shock hazard is present when electrical devices are used in the vicinity of grounded objects, especially when there is a possibility of wet contact conditions attributed to water, coffee or other liquids found in the hospital environment. Few people are aware that currents too small to be perceived by the fingers may produce electrocution if they flow on or in the heart. Education of hospital personnel in basic electricity is important. There is no substitute for intelligent use of electrical apparatus and careful preventive maintenance is essential.

Inspection and acceptance testing of each new piece of apparatus when received should be performed. Comparing test results with the manufacturer's specifications and operating instructions is important. Special hospital grade plugs should be used in which the connections between the pins and the wires are clearly visible. If periodically inspected, a broken ground lead can be easily detected.

A good grounding system is the main protection against electrical hazards. The conventional three-prong plug with a longer grounding pin allows for connection with ground before power contact is made and after power contact is broken, ground is then disconnected. Ground fault circuit interrupters or isolation transformers with line isolation monitors are also useful in eliminating electrical shock hazards in surgical areas. Unfortunately, no automatic mechanisms are available for protection against microshock currents, and reliance is placed upon excellence in design, materials, construction, and maintenance of isolation transformers, instruments, and proper grounding.

The electrically controlled hospital bed is one of the greatest potential hazards in the modern hospital. This hazard is substantially reduced when a double insulated model is used. The shock hazard in the ordinary model is not only that the bed is connected to the electrical power system, but that the bed frame is grounded. A patient may be connected to an assortment of instruments and he should not be able to contact a grounded bed frame. The more electrical equipment connected to a patient, the greater the danger. Double insulation in this case means that the motor and its wiring are insulated from the metal bed and the electric control push buttons are water tight. A doubly insulated bed should protect both against macroshock and reduce the hazard from microshocks.

Electrical Safety Standards

Currently, there is some disagreement in the clinical engineering field as to what constitutes safe limits for the various electrical tests. The 1981 National Electrical Code (ANSI/NFPA 70) and the "Standard for the Safe Use of Electricity in Patient Care Areas of Hospitals" (NFPA 76B-

1977) (both of which are written by the National Fire Protection Association, NFPA) were the chosen "standards" for this work. The Underwriters' Laboratories standard UL-544 "Medical and Dental Equipment" (July 1976) and the Association for the Advancement of Medical Instrumentation (AAMI) December 1978 standard "Safe Current Limits for Electromedical Apparatus," which is accepted by the American National Standards Institute (ANSI), were also used. The 1980 Accreditation Manual for Hospitals (AMH) written by the Joint Commission on Accreditation of Hospitals (JCAH) also was used.

The AAMI/ANSI December 1978 standard, the NFPA 76B-1977 standard, the UL-544 standard are all in reasonably good agreement concerning leakage current. They recommend 500 μA for equipment not likely to contact patients, 100 μA for equipment likely to contact patients and approximately 10 μA for equipment with patient-connected leads. The Hewlett-Packard 4655A is an instrument used to measure equipment leakage current and is also used to measure ground wire resistance. The HP 4655A instruction manual recommends 0.2Ω and the NFPA 76B-1977 standard recommends 0.15Ω as the safe limit for ground wire resistance.

The AMH recommends that hospitals have voluntary surveys done by the JCAH to assess the degree of compliance with the JCAH standards. For a survey, a hospital must have a current license to operate, as required by its appropriate governmental jurisdiction and it must have been in operation for at least six months prior to the survey so that a record of performance exists that can be evaluated. The hospital need not meet 100% compliance, but should be in compliance with most items, and after a given period must show record of improving items not in compliance. Accreditation is usually for one or two years. If accreditation is for two years, the hospital must supply a self-survey for the interim year. The extent of compliance with each item of the standards is assessed in at least one of the following ways:

1) Statements from authorized and responsible hospital personnel
2) Documentary evidence or certification of compliance provided by the hospital
3) Answers to detailed questions concerning the implementation of an item, or examples of its implementation, that will enable a judgment of compliance to be made
4) On-site observations by surveyors

Accreditation after the one- or two-year period is not automatic. The hospital must apply for and schedule a new survey.

According to the Accreditation Manual for Hospitals, all personnel must be instructed in the safe use of electricity. The increased variety, quantity, and complexity of electrical and electronic equipment in use in diagnostic and therapeutic patient support, particularly when multiple units are used on the same patient, have magnified the safety problem and have increased the need for expanded knowledge and additional caution. All new equipment should be evaluated prior to its use and all medical equipment should be periodically checked and in no case should the testing interval exceed six months.

According to the JCAH, systematic and periodic evaluation of the electrical power distribution systems and all electrical and electronic non-patient-care equipment including receptacles should be performed at least annually.

The JCAH recommends that there is an isolated power system in each anesthetizing location. Also, such a power system should have a continually operating line isolation monitor that has both audible and visible signals. Line isolation monitors should be tested weekly when the areas are not in use, and a permanent record of this testing should be maintained. The findings of electrical and electronic tests with corrective recommendations should be distributed to the responsible department heads. Operators' instruction booklets should be kept with individual pieces of equipment, with a master file copy available in a designated location at all times.

All personnel involved in direct patient care of those patients particularly sensitive to electrical hazards should be educated in the proper use of electromedical equipment in special care areas. Special care areas include cardiac care units, intensive care units, surgical areas, and cardiac catheterization laboratories. A defibrillator and resuscitative equipment should be at bedside when new equipment is connected to patients in special care areas. An accurate log of the use of all battery-operated pacemakers should be kept, including the date of manufacture or the date of purchase, and the hours of use.

In implementing electrical safety programs, some hospitals follow certain existing standards, while some hospitals follow the acceptable safe levels given in the instruction booklets provided by manufacturers of the electrical safety test equipment being used. Other hospitals write their own standards and procedures for electrical safety testing.

Materials Used for Testing and Test Procedures

An electrical safety study was conducted at an Ames area nursing home. Appendix B contains the data sheets used during this study. The equipment used for electrical safety testing in the nursing home included the following:

1) Hewlett-Packard Model 4655A ac hazard detector
2) Dearborn ground monitor
3) Simpson voltmeter model 260
4) 100 W light bulb
5) Daniel Woodhead Model 1760 outlet tension tester

Outlet Testing

To check the power distribution system, the outlets were tested for polarity using the Dearborn ground monitor. Hot-to-neutral, hot-to-ground and ground-to-neutral voltages were measured using the Simpson voltmeter. For proper polarity, the hot-to-neutral voltage is 120, the hot-to-ground voltage is 120 and the ground-to-neutral voltage is zero. Improper polarity occurs when the power distribution system is improperly connected to the transformer. Reversed polarity is present when the hot-to-ground voltage is zero and the neutral-to-ground voltage is 120. A case of non-conventional polarity is in a balanced wiring system. Here, the hot-to-ground and neutral-to-ground voltages are each 60 V.

A 100 W light bulb was placed between the hot-to-ground contacts to see if the ground conductor would be capable of carrying a fault current of approximately 1 ampere. The Daniel Woodhead Model 1760 outlet tension tester was used to measure the outlet mechanical tension in ounces. Ten ounces or more was acceptable, below 10 ounces was not. Outlets were also checked for physical condition and the circuit breaker boxes were checked for proper labelling.

Appliance Testing

The Hewlett Packard 4655A hazard detector was used to measure the leakage current of appliances in microamperes. It was noted whether or not appliances had a strain relief on the casing, and where applicable, ground wire resistance was measured in ohms. Appliances and their power cords were inspected as to their physical condition.

Results

All of the outlets checked had the proper polarity. Hot-to-neutral, hot-to-ground and ground-to-neutral voltages were all 120, 120 and zero, respectively. All the outlets had ground conductors capable of carrying a fault current of approximately 1 ampere. Some of the labelling on circuit breaker boxes was incorrect. Mechanical tension of hot, neutral and ground conductors was poor for a number of outlets. Also, some outlets had broken cover plates.

A number of appliances had power cords which were badly bent. One television had a broken on-off switch. Cube taps and extension cords were found. Table 9 contains a summary of the results of the electrical safety study. An elaboration of these conditions and their locations can be found in Appendix C.

Table 9. Summary of results of electrical safety study

Safe conditions

All wiring was conventional.
Ground conductors were capable of carrying approximately one ampere of fault current.
Air conditioner power cords were safe.
The floor buffers had acceptable leakage currents.
Most circuit breaker boxes were properly labelled.
Some television sets had one-way plugs.
Hospital grade plugs were present on some appliances.

Unsafe conditions

Poor mechanical tension was found on many outlets.
Some outlets had broken cover plates.
Several sharply bent power cords were noted.
Broken power switches on some appliances were seen.
A power cord was placed along the back of a sink.
One outlet had no electrical ground connection.
Some cube taps were in use.
Some extension cords were in use.
One uninsulated screw-type plug was found.
An outlet was located too close to a paper towel dispenser.
One air conditioner had a broken front panel.
The strain relief on one floor buffer was in poor condition.

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I would like to thank my parents, Mr. and Mrs. Werner Schilling, especially my wife, Marilyn, and also her family.

APPENDIX A: DATA OBTAINED FROM TESTING THE FIVE TEMPERATURE TRANSDUCERS

AD590

Mercury thermometer °C	V_0 in volts 1st test	V_0 in volts 2nd test	V_0 in volts 3rd test	V_0 in volts average	AD590 temperature °C
50	0.323	0.323	0.323	0.323	50
45	0.318	0.318	0.318	0.318	45
40	0.313	0.313	0.313	0.313	40
35	0.308	0.308	0.308	0.308	35
30	0.303	0.303	0.303	0.303	30
25	0.298	0.298	0.298	0.298	25
20	0.293	0.293	0.293	0.293	20
15	0.288	0.288	0.288	0.288	15
10	0.283	0.283	0.283	0.283	10
5	0.278	0.278	0.278	0.278	5
0	0.273	0.273	0.273	0.273	0

Mercury thermometer °C	V_0 in volts (hysteresis test)
0	0.273
5	0.278
10	0.283
15	0.288
20	0.293
25	0.298
30	0.303
35	0.308
40	0.313
45	0.318
50	0.323

LX5700

Mercury thermometer °C	V_O in volts 1st test	V_O in volts 2nd test	V_O in volts 3rd test	V_O in volts average	LX5700 temperature °C
50	3.24	3.24	3.24	3.24	51
45	3.19	3.19	3.19	3.19	46
40	3.14	3.14	3.14	3.14	41
35	3.09	3.09	3.09	3.09	36
30	3.04	3.04	3.04	3.04	31
25	2.99	2.99	2.99	2.99	26
20	2.94	2.94	2.94	2.94	21
15	2.89	2.89	2.89	2.89	16
10	2.85	2.85	2.85	2.85	12
5	2.80	2.80	2.80	2.80	7
0	2.75	2.75	2.75	2.75	2

Mercury thermometer °C	V_O in volts (hysteresis test)
0	2.75
5	2.80
10	2.85
15	2.89
20	2.94
25	2.99
30	3.04
35	3.09
40	3.14
45	3.19
50	3.24

REF-02

Mercury thermometer °C	V_0 in volts 1st test	V_0 in volts 2nd test	V_0 in volts 3rd test	V_0 in volts average	REF-02 temperature °C
50	0.497	0.497	0.497	0.497	49.7
45	0.449	0.448	0.449	0.449	44.9
40	0.399	0.398	0.400	0.399	39.9
35	0.348	0.348	0.350	0.349	34.9
30	0.297	0.298	0.300	0.298	29.8
25	0.248	0.248	0.250	0.249	24.9
20	0.199	0.198	0.200	0.199	19.9
15	0.148	0.149	0.150	0.149	14.9
10	0.0974	0.0972	0.0993	0.0980	9.8
5	0.0481	0.0477	0.0497	0.0485	4.85
0	-0.0011	-0.0015	-0.0013	-0.0013	-0.13

Mercury thermometer °C	V_0 in volts (hysteresis test)
0	-0.0040
5	0.0482
10	0.0980
15	0.149
20	0.200
25	0.249
30	0.299
35	0.349
40	0.399
45	0.449
50	0.499

LM335

Mercury thermometer °C	V_O in volts 1st test	V_O in volts 2nd test	V_O in volts 3rd test	V_O in volts average	LM335 temperature °C
50	3.21	3.21	3.21	3.21	48
45	3.16	3.16	3.16	3.16	43
40	3.11	3.11	3.11	3.11	38
35	3.06	3.06	3.06	3.06	33
30	3.01	3.01	3.01	3.01	28
25	2.96	2.96	2.96	2.96	23
20	2.91	2.91	2.91	2.91	18
15	2.86	2.87	2.86	2.86	13
10	2.82	2.82	2.82	2.82	9
5	2.77	2.77	2.77	2.77	4
0	2.72	2.72	2.72	2.72	-1

Mercury thermometer °C	V_O in volts (hysteresis test)
0	2.72
5	2.77
10	2.82
15	2.87
20	2.91
25	2.96
30	3.01
35	3.06
40	3.11
45	3.16
50	3.21

MTS102

Mercury thermometer °C	V_0 in volts 1st test	V_0 in volts 2nd test	V_0 in volts 3rd test	V_0 in volts average	MTS102 temperature °C
50	0.545	0.545	0.545	0.545	48.0
45	0.556	0.556	0.555	0.556	43.1
40	0.566	0.566	0.566	0.566	38.7
35	0.576	0.576	0.577	0.576	34.3
30	0.587	0.587	0.587	0.587	29.4
25	0.597	0.597	0.597	0.597	25.0
20	0.607	0.607	0.607	0.607	20.6
15	0.617	0.617	0.617	0.617	16.2
10	0.628	0.627	0.628	0.628	11.3
5	0.638	0.638	0.638	0.638	6.86
0	0.648	0.648	0.648	0.648	2.43

Mercury thermometer °C	V_0 in volts (hysteresis test)
0	0.649
5	0.638
10	0.627
15	0.617
20	0.607
25	0.596
30	0.586
35	0.576
40	0.566
45	0.555
50	0.545

APPENDIX B: DATA SHEETS USED FOR THE CARE CENTER ELECTRICAL SAFETY TEST

DATA SHEET FOR OUTLET TESTING

Room ________ Date _________

Outlet	Polarity Test	G.I.T.[a]	Power Distribution System (Volts)			Mechanical Tension in Ounces			Physical Appearance and Comments
			H-N	H-G	G-N	H	N	G	

[a]Ground Integrity Test with 100 watt light bulb.

Room floor plan: location of outlets

DATA SHEET FOR APPLIANCE TESTING

Room __________ Date __________

Device	Leakage Current in μA		Reversed Plug		Type of Plug	Strain Relief on Casing	Ground Wire Resistance in Ohms
	Off	On	Off	On			

Room floor plan: location of appliances

APPENDIX C: REPORT TO CARE CENTER ADMINISTRATOR

OWA STATE
JNIVERSITY

Biomedical Engineering Program
Ames, Iowa 50011

Telephone 515-294-6520

Dear Sir:

Clinical Engineering is rapidly becoming a recognized field of engineering and the need for the services of the clinical engineer is becoming more apparent to health care facilities. Some of the services of the clinical engineer include supervision of electronic technicians in repair and maintenance of equipment, setting up electrical safety programs, and advising the medical staff on the purchase of equipment.

As part of a preventive maintenance program, an electrical safety study should be undertaken at regular intervals. The safety and general well-being of the patients and the health care facility staff depends upon this maintenance. Defective wiring or appliances could cause severe burns to a patient, could be a fire hazard or may even cause ventricular fibrillation and probable death. Allowing me to conduct an electrical safety test helped increase my understanding and knowledge of the problems and methods of operation of the modern health care facility.

In conducting the electrical safety test, I first checked the outlets for proper wiring and mechanical condition. Electrical equipment and appliances were checked for leakage current, power cord strain relief on the equipment casing, ground wire resistance (where applicable) and physical condition. Floor waxing buffers were checked and circuit breaker boxes were checked for proper labelling.

Following this letter is a summary of the results of the electrical safety test. I would like to express my appreciation for allowing me to conduct the electrical safety test and thank you for the valuable experience gained. If you have any questions concerning the details of the tests and results, please call me or Dr. Curran S. Swift of our department.

Sincerely yours,

Ralph W. Schilling

Electrical Safety Study

In conducting the electrical safety test, two to three rooms per wing were completely checked. The remaining rooms in the wing were spot checked, usually one outlet per room. The outlets are numbered I, II, III, etc., going clockwise around the room. Socket I is the first outlet to the left of the door as you enter the room.

To check the power distribution system, the outlets were tested for polarity. All of the outlets checked had the proper polarity. Also, hot-to-neutral, hot-to-ground and ground-to-neutral voltages were measured. These were all 120 volts, 120 volts and 0 volts, respectively. A 100-watt light bulb was placed between the hot-to-ground contacts to see if the ground conductor would be capable of carrying a fault current. All the outlets had good ground conductors. In summary, all five wings of the nursing home had proper electrical wiring and no sockets had reversed polarity or balanced wiring systems. Balanced wiring systems occur when the power distribution system is improperly connected to the transformer. The hot-to-neutral voltage is still 120 volts, but the hot-to-ground and neutral-to-ground voltages are each 60 volts.

The A and B wing circuit breaker boxes were checked and they were both properly labelled. The C, D and E wing circuit breaker boxes also were labelled, but they still used the "old" numbering system. These labels should be changed to the "new" numbering system.

Currently, there is some disagreement in the clinical engineering field as to what constitutes safe limits for the various electrical tests. Both the Ames fire inspector and electrical inspector use the National

Electrical Code (NEC), which is written by the National Fire Protection Association (NFPA). I used the 1981 National Electrical Code (ANSI/NFPA 70) and the "Standard for the Safe Use of Electricity in Patient Care Areas of Hospitals" (NFPA 76B-1977). I also used the Association for the Advancement of Medical Instrumentation (AAMI) December 1978 standard "Safe Current Limits for Electromedical Apparatus," which is accepted by the American National Standards Institute (ANSI) and I used Underwriters' Laboratories standard UL-544 Medical and Dental Equipment (July 1976). The AAMI/ANSI December 1978 standard, the NFPA 76B-1977 standard, and the UL-544 standard are all in reasonably good agreement concerning leakage current. They recommend 500 microamperes for equipment not likely to contact patients, 100 microamperes for equipment likely to contact patients and approximately 10 microamperes for equipment with patient-connected leads.

The instrument used to check for electrical hazards was the Hewlett-Packard 4655A Hazard Detector. The Hewlett-Packard 4655A instruction manual recommends 0.2 ohms and the NFPA 76B-1977 standard recommends 0.15 ohms as the safe limit for ground wire resistance. NFPA 76B-1977 states "All appliances are subject to deterioration. It is essential that a test program be established to detect the deterioration of appliances, or the presence of a fault, so that the appliance can be repaired." It also states "The appliance shall not be used if inspection of the cord, cabinet, switches, knobs, or dials discloses obvious mechanical damage."

The outlets were also checked for mechanical tension. Ten ounces or more was acceptable, less than ten ounces was not.

Mechanical tension is important for a good electrical connection to the power line. Also, in the event a fault current occurs, there is then a low resistance path for the current to travel, rather than traveling through a patient or staff member as a connection to ground. NFPA 76B-1977 states "Specific procedures shall be developed for reporting and repair of equipment found to be damaged."

The leakage current of devices was measured. It was noted whether or not devices had strain relief on the casing, and where applicable, ground wire resistance was measured. Devices and their power cords were inspected as to physical condition.

A-Wing

Room A-5 Outlet I had a loose connection, so a voltage reading was not attainable. Also, neutral and ground had poor mechanical tension. Outlets II, III, and IV were good except that the grounds had poor mechanical tension. Outlet V had poor neutral and ground tension, and it was loose, exhibiting lateral movement. The electric shaver, clock, television and two wall lamps were in good condition except that the north side wall lamp had a bent wire at the plug.

Room A-7 Outlet II was in good condition. Outlets I, III and IV had poor ground tension. Outlet V had poor neutral and ground tension. The clock, electric shaver, television and the wall lamps were all in good condition. There was a standing floor lamp with three bulbs and a three-way switch on the north side of the room. It has either faulty wiring or a faulty switch because, when the switch is touched, two of the three lights would turn off.

Room A-10 Outlet II was in good condition. Outlets I and III had poor ground tension and outlet I had a cube tap. Outlet IV had poor neutral and ground tension. The clock, bed and table lamps were all in good condition. The radio on the south side of the room had a bent wire at the plug.

The outlets closest to the door in rooms A-1, A-2, A-6 and A-9 all had poor ground tension. Outlet I in room A-3 had poor hot and ground tension. Outlet I in room A-4 had poor neutral and ground tension. Outlet I in room A-8 had no electrical ground connection. Also, on the north wall of room A-8, there were no bare wires but there was an outlet hole in the wall. An outlet cover plate should be placed over the hole.

B-Wing

Room B-4 Outlets I, II and IV have poor ground tension. Outlet III has poor neutral and ground tension. The lamp is in good condition but the television power switch works only in the on position. This should be repaired.

Room B-10 Outlet II is in good condition. Outlet III has poor hot and ground tension. Outlet I has poor ground tension and is loose. The fan, radio, and two wall lamps are in good condition.

The outlets closest to the door in rooms B-1, B-5, B-6, B-7 and B-8 all have poor ground tension. Outlet I in room B-2 has poor hot and ground tension. Outlet I in room B-3 has poor neutral and ground tension.

C-Wing

Room C-5 Outlet I was in good condition. Outlets II, III and IV all had poor ground tension. The two lamps and two television sets were in good condition. The clock power cord ran along the back of the sink to an outlet. This is not recommended. Also, the plug on this cord was of the type which has two screws holding the wires in place and it did not have cardboard insulation covering that section of the plug. The fan had an extension cord.

Room C-9 All the outlets in this room had poor ground tension. The television and wall lamp were in good condition. The cord for the other wall lamp was tied in a knot to shorten it and the cord was bent at the plug.

The outlets closest to the door in rooms C-4, C-6 and C-8 all have poor ground tension. Outlet I in room C-2 has poor hot and ground tension. Room C-1 has the edge of a calendar hanging right where the prongs of a plug insert into outlet I. This calendar should be moved. That outlet also has poor ground tension. The television in this room has a broken antenna which has fallen into the case. This should be repaired. A lamp power cord goes across the back of the sink to an outlet. This is not a safe condition. It should be corrected. Outlet I in room C-7 has poor ground tension and the lower socket is chipped. This outlet should be replaced. Outlet I in room C-3 has poor neutral and ground tension.

D-Wing

Room D-10 Outlet I is in good condition. Outlets II, III and IV have poor neutral and ground tension. The heating pad with hospital grade plug, lamp and television set were all in good condition. The lamp on the north side of the room had a twisted power cord and the television set, also on the north side, had an extension cord.

Room D-20 Outlets II and III have poor ground tension. Outlet I has poor hot and ground tension and outlet IV has poor neutral and ground tension. The radio, clock and two lamps were in good condition and the hospital bed with hospital grade plug was in good condition.

The outlets closest to the door in rooms D-2, D-3, D-5, D-6, D-7, D-8, D-9, D-16 and D-18 all have poor ground tension. Outlet I in room D-1 has poor ground tension. Outlet I in room D-1 has poor neutral tension and outlet I in room D-4 has poor hot and ground tension. The overhead light in room D-12 does not work and outlet I has poor ground tension and the outlet plate is chipped. This outlet plate should be replaced. Outlet II in room D-14 has poor ground tension. The outlet is loose and it has a broken cover plate. The bathroom in D-wing has an outlet right underneath a paper towel dispenser and the outlet also has poor ground tension. The paper towel dispenser should be moved to a location away from the outlet.

E-Wing

Room E-3 Outlets I, II and III are in good condition and outlets IV and V have poor ground tension. The clock and two lamps are in good condition.

Room E-16 Outlet II is in good condition. Outlets I and III have poor neutral and ground tension and outlets IV and V have poor ground tension. The radio, television and two lamps are in good condition.

Outlet I in room E-18 is in good condition but it has a cube tap. The outlets closest to the door in rooms E-1, E-2, E-4, E-5, E-7, E-8, E-10 and E-12 all have poor ground tension. Outlet I in room E-6 has poor neutral and ground tension and it has a cube tap. Outlet I in room E-8 has an extension cord for an electric razor and outlet I in room E-14 has a cube tap. The outlet in the E-wing bathroom has poor ground tension.

Discussion

All of the outlets which have poor tension should be replaced. It may be helpful to instruct the staff when moving furniture to be more careful of plugs, power cords and electrical equipment.

Use of cube taps and extension cords is not recommended. These allow more appliances to be attached to a single outlet, possibly exceeding the current limits for the electrical wiring, presenting a potential fire hazard.

Several of the television sets had the type of two-prong plug which can only be plugged in one way, not reversed. This is beneficial in that there is a decreased amount of leakage current.

The air conditioner in room A-5 had acceptable leakage current. The plastic knobs had been removed. The ground wire resistance at one knob was 3.5 ohms and 0.4 ohms at the other knob. The air conditioner in room A-7 had a broken front panel which had been removed. Also, the switching panel had been removed and the knobs were missing. The air conditioners in rooms A-10 and D-10 had acceptable leakage current and acceptable ground wire resistance. The air conditioner in room A-10 had some accumulated dust. A good practice found on some of the air conditioners was that during the season when they are not used, the power cord was unplugged and wrapped up and put inside of the unit.

A floor waxing buffer was checked in the A-wing storage closet. It had acceptable leakage current. The ground wire resistance was 2 ohms. The bolt on the power cord strain relief was missing. The strain relief should be repaired. The buffer in the service area was also checked. It had acceptable leakage current and its strain relief was fine. It had a 1.4 ohm ground wire resistance.