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# An Electronic Thermometer for remote-indicating applications

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ABSTRACT. An electronic thermometer designed by the author for remote indicating applications in meteorology uses a p-n-p germanium junction transistor as the sensor element and a D.C. voltmeter calibrated in terms of temperature as the indicator. The principle of its operation, scope and limitations are described in this paper. A wet and dry-bulb thermometer system consisting of two transistor sensors is also described.

## 1. Introduction

Remote indicating thermometers are useful accessories in certain branches of meteorology. One such instrument described by Das and Kapoor (1962) for the measurement of runway temperature uses a pair of thermistors as temperature sensing elements telemetering the data as an audio frequency note whose frequency depends on the temperature. At a modest estimate the initial and operating cost of the equipment described by them is quite high for the intended use. Electronic thermometers using semi-conductor diodes and transistors as sensing elements, are being developed elsewhere and can provide cheap and fairly reliable instruments for certain applications in meteorology. The principle of operation of the transistor thermometer is briefly explained before describing the instrument developed by the author.

## 2. Principle of operation

'Drift' in transistor circuits due to variations in ambient temperature is an undesirable effect in normal transistor circuits and is minimised by proper circuit design. Specifically, the variations in ambient temperature affect significantly (*i*) the leakage current, $I_{c0}$ and (*ii*) the base emitter voltage $V_{be}$ due to changes in the conductance of the base-emitter diode (Mullard manual—1960); whereas the increase in the 'leakage current' with rise in temperature is non-linear, the base-emitter voltage decreases roughly by 2 millivolts per deg. C rise in temperature and this change being almost linear. These two effects in turn cause a drift in the steady value of current at the collector terminal.

One or the other of these effects could be utilised to advantage in the measurement of temperature. Barton (1962) described a D.C. amplifier in the common-emitter configuration in which changes of leakage current are amplified at the collector terminal and the temperature is determined by a 'null' method on a calibrated potentiometer dial. A more elegant method is that described by McNamara (1962) in which the changes in the base-emitter voltage of an n-p-n silicon transistor are magnified at the collector terminal in a common-base D.C. amplifier; the error introduced in the results with this arrangement is negligible as the leakage-current-effect is minimum in this configuration. This arrangement is eminently suited to the needs of surface temperature measurement in meteorology—and also the upper air temperature with suitable modifications to the instrument.

The design procedure outlined by McNamara has been adapted with necessary modifications by the author in the construction of a dry and wet bulb thermometer system using two p-n-p germanium transistors as sensor elements.

## 3. Dry- and Wet-Bulb Thermometer system

(*i*) *The dry-bulb thermometer*—The circuit diagram of the basic dry-bulb thermometer is given in Fig. 1. It is essentially a common-base D.C. amplifier, the $V_{be}$-changes being the input to the amplifier. The potentiometer $R$ in conjunction with $r$ fixes the emitter-

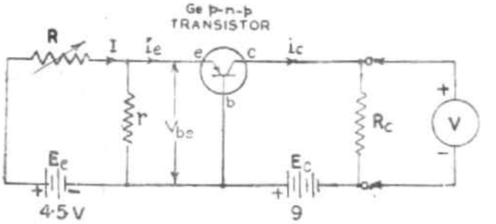


**Fig. 1. Circuit diagram of the basic transistor thermometer**

Typical values for circuit constants using 2SB54 Toshiba transistor, $R=1800\,\Omega$, $R_c=4000\,\Omega$, $r=67\,\Omega$ and $dV/dT=0.103$ V/deg. C

injection current at a given temperature. The $V_{be}$-changes due to variations in ambient temperature change the emitter-injection current $i_e$ ; and hence the collector current $i_c$. The voltage drop across the collector load-resistance $R_c$ changes linearly with temperature. A suitable voltmeter is used to read the voltage across $R_c$ . The component values calculated according to standard design procedure had to be modified to suit the exact requirements in the practical circuit. This is because of the large manufacturing 'spreads' in the values of the transistor characteristics for any particular transistor. A change of 0·1 volt on the indicator for 1 degree-change in the ambient temperature affords convenient indication on a D.C. voltmeter reading 6 volts full scale. The instrument described here was designed for a range of — 10° C to + 50° C; the values of $R_c$ , $r$ and $I$ were adjusted by trial and error to get the exact sensitivity of 0·1 volt per °C. After experimenting with a number of transistors of different makes, a 2SB54 (Toshiba) transistor was chosen for its relatively lower leakage-current and also the lesser variation of current gain $\alpha$ over the range of temperatures to be measured ($I_{cob}$ values for 2SB54 are 3 $\mu$ amp. at 25° C rising to only 28 $\mu$ amp. at 50° C).

(*ii*) *Calibration and performance*—A hot-water bath was used for calibrating the transistor thermometer by keeping the transistor sensor and the comparison thermometer immersed in it close to each other. Fig. 2 is the temperature *versus* output voltage curve for the instrument. The final calibra-

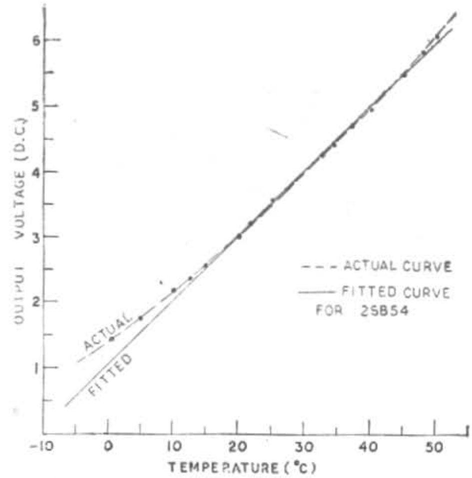


**Fig. 2. Temperature *vs* output voltage for cct. 2SB54 shown in Fig. 1**

tion was done after the sensor element was subjected to about 50 cycles of heating and cooling in the water-bath. The variation of output-voltage with temperature is seen to be almost linear in the range 15–40° C. The actual curve departs from linearity by less than 1° C in the range 40—50° C; the non-linearity increases at the lower end of the scale from just less than 0·1° at 15° C to 0·3 at 0° C. The temperature values read on the indicating meter will have the same errors (positive) in the ranges specified. Non-linearity at the higher limit of the temperature scale is due to the exponential variation of leakage current and can be minimized by using a transistor with relatively low leakage current at high temperatures. At the lower end of the scale, the decrease in the current-gain $\alpha$ due to low emitter-injection current introduces non-linearity. Some improvement can be achieved by using silicon transistors.

'Thermal time-constant' of the sensor element is defined as the time required for the temperature to fall by 63 per cent of the total fall to its equilibrium value. This was determined for the transistor sensor by raising its temperature to 45° C by dipping in hot water and allowing it to cool in air to 26° C

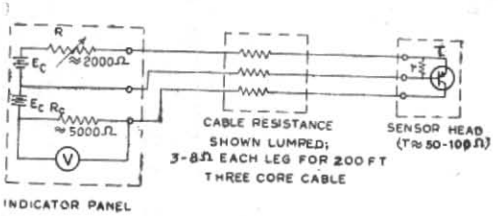


**Fig. 3. Schematic diagram to illustrate the insignificant effect of the cable connecting sensor head and indicator**

when the room temperature was 15° C. The time constants for the mercury thermometer, transistor thermometer and the bimetal thermograph are given below—

| | |
|---|---|
| Mercury thermometer | 105 seconds |
| Transistor thermometer | 65 seconds |
| Bimetal thermograph | 150 seconds |

Incidentally it is to be noted that the range of cooling chosen for the time constant determination is of the same order as that experienced immediately after an afternoon thunderstorm in summer. The time constant, however, does not depend upon the temperature levels chosen for its determination.

(*iii*) *Effect of cable between sensor and indicator*—As the sensor element is intended to be kept at a remote point, the effect of cable resistance on the working of the instrument was studied. The schematic diagram in Fig. 3 shows that the cable resistance being small compared to circuit constants will have insignificant effect provided the resistance $r$ — which determines the initial biassing conditions — is connected directly across the emitter-base terminals as shown. Hence the laboratory calibration will hold good for moderate cable-lengths used in practice for remote indicating equipment.

(*iv*) *Adjustments and maintenance*—The laboratory calibration of the instrument described will be maintained for a long time, if $I$ (in Fig. 2) is maintained constant. If due to emitter battery deterioration, $I$ changes, this can easily be reset to its original value by means of the potentiometer $R$. The battery drain being only of the order of a few milliamperes, the maintenance cost is negligible. The use of batteries with low internal resistance, specially designed for transistor circuits will contribute towards the economical working of the instrument.

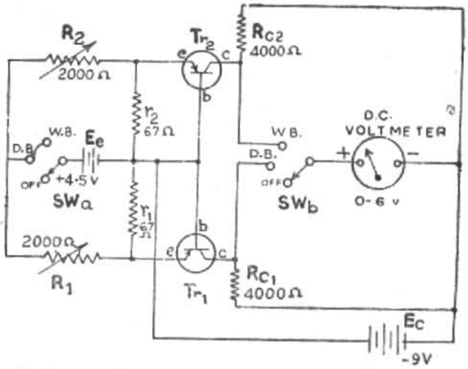


**Fig. 4. Schematic diagram of the 'dry- and wet-bulb' transistor thermometer system**

$Tr_1$ is the dry bulb and $Tr_2$ is the wet bulb transistor sensors. $SW_a$ and $SW_b$ — switches are ganged to operate simultaneously

#### 4. Dry- and Wet-bulb thermometer

Fig. 4 shows the development of the basic circuit in Fig. 1 for a combined dry- and wet-bulb thermometer system using two transistor sensors. In order to achieve 'wet-bulb' conditions the transistor was covered with a wet muslin in the same way as the bulb of the conventional mercury thermometer. The assembled instrument is shown in the photographs in Fig. 5. Initial trials on the completed instrument have been successful and the same is being put to field trials. A comparison of the readings of the transistor and mercury thermometers during a trial under conditions approximating to those in a Stevenson Screen is given in Table 1. Fig. 6 shows the errors during this test run plotted against the transistor thermometer readings (the ordinates being the difference between the transistor and mercury thermometer readings for both dry- and wet-bulbs). It is seen that most of the time the transistor thermometer reads higher and the error is within 0·4 degree Celcius.

Further experiments directed towards 'straightening' the temperature *versus* output-voltage curve at the higher and lower limits of the temperature scale, and field trials are in progress.

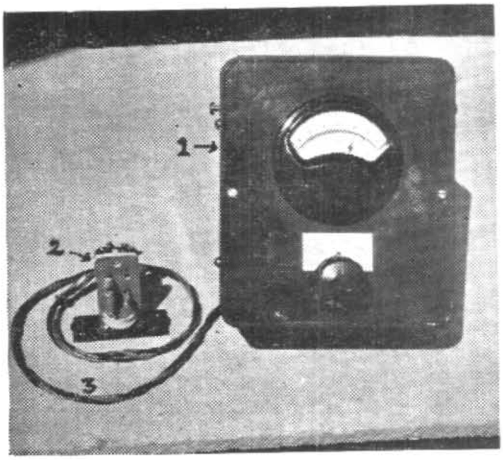


Fig. 5 (a)

1. Indicator panel with facility to switch on dry- and wet-bulb thermometers
2. Sensor head with transistor elements mounted side by side, wet bulb at left and dry bulb at right
3. Connecting cable — 5 core

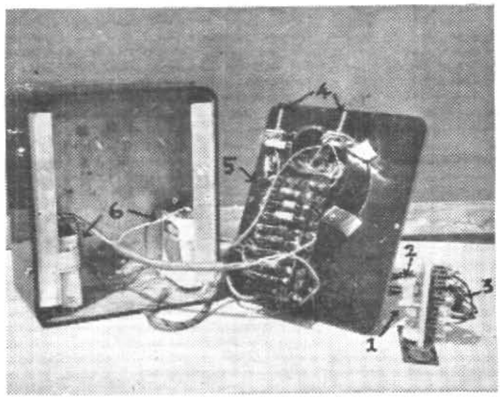


Fig. 5(b)

1. Dry-bulb transistor, 2. Wet-bulb transistor, 3. Emitter-base resistances, 4. Potentiometers, $R_1$ and $R_2$, 5. Collector resistance combination—$Rc_1$ and $Rc_2$, 6. Battery pack for 4·5 and 9·0 volts

**TABLE 1**

**Comparison of transistor and mercury thermometer readings (°C) obtained during a trial run, at different periods of the day on three days, location — Agartala airport**

| Date and time (IST) | Dry bulb | | Wet bulb | |
|---|---|---|---|---|
| | Mercury thermometer (°C) | Transistor thermometer (°C) | Mercury thermometer (°C) | Transistor thermometer (°C) |
| 22 Feb 1963 | | | | |
| 0900 | 25.6 | 25.5 | 17.2 | 17.5 |
| 1000 | 27.8 | 28.0 | 18.1 | 18.5 |
| 1100 | 29.3 | 29.0 | 18.1 | 18.0 |
| 1200 | 30.6 | 30.6 | 18.5 | 18.5 |
| 1300 | 30.9 | 31.0 | 19.2 | 19.5 |
| 1400 | 30.9 | 31.5 | 20.3 | 20.5 |
| 23 Feb 1963 | | | | |
| 1900 | 23.9 | 24.0 | 18.3 | 18.5 |
| 2000 | 20.9 | 21.0 | 17.2 | 17.5 |
| 2100 | 18.5 | 18.3 | 16.1 | 16.5 |
| 2230 | 18.0 | 17.8 | 16.4 | 16.5 |
| 24 Feb 1963 | | | | |
| 0500 | 14.5 | 15.0 | 13.9 | 14.0 |
| 0700 | 19.1 | 19.5 | 16.3 | 16.0 |
| 0800 | 22.8 | 23.0 | 18.0 | 18.0 |
| 0900 | 25.6 | 25.5 | 18.0 | 18.0 |
| 1030 | 28.6 | 29.0 | 17.8 | 17.5 |
| 1100 | 30.0 | 30.0 | 18.6 | 18.5 |

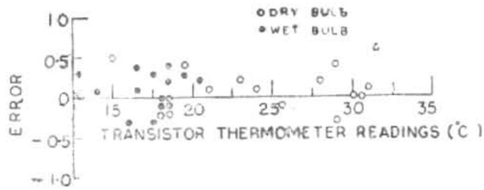


Fig. 6

## 5. Conclusion

The transistor thermometer offers a cheap and reliable instrument for measurement of temperature at a remote point, for instance, the runway temperature for aviation interests; it can easily be adapted for other applications in meteorology by slight modification in the placement of the sensor head, as for instance, in the measurement of earth temperatures or in total radiation thermometers; or, as part of an automatic weather station, the output voltage being utilised for telemetering the temperature data.

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