OSCILLOSCOPIC MEASUREMENT OF ABSOLUTE TEMPERATURE BY MEANS OF TRANSISTOR

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Abstract

Direct measurement of absolute temperature by means of transistor is acheaved by this method. The basic principle is oscilloscopic presentation of the time derivative of the short-circuit collector current v.s. emitter-base voltage, when it exponentialy varies in time. Presented curve possess maximum, whose location on the voltage axes is directly related to the absolute temperature.

1 Introduction

As it is known, the current that conducts P—N junction strongly depends on the temperature of the junction. This dependence is disadvantageous for the commercial semiconductor devices, but it can be used as temperature sensor or thermometer (N. Sclar et al. 1972). The transistor has been used as absolute thermometer on the bases of the temperature dependence of the currenvoltage characteristic of the base emitter circuit, and the lin near dependence of the short-circuit collector current (I_{cs}) on the diffusion component of th emitter-base current (A./A. Felimban et al. 1974). Theoreticaly and experimentaly has been proved (Sah 1962) that I_{cs} depends on the emitter-base$_0$voltage (V_{eb}) through the diffusion component of the emitter-base current, according to the relation

$$I_{cs} = I_{cso}(T)\left[\exp\frac{eV_{eb}}{kT} - 1\right]. \qquad (1)$$

Where I_{cso} — is temperature but not voltage dependent, and $\frac{kT}{e}$ — temperature of the emitter-base junction in volts.

On the bases of relation (1) the transistor has been used as asbolute thermometer (A. A. Felimban et al. 1974). For very high values of V_{eb} the relation (1) has been aproximated by

$$I_{cs} = I_{cso} \exp \frac{eV_{eb}}{kT},$$

from which the temperature of the transistor has been calculated from the plot of log I_{cs} v.s. V_{eb}.

In this work, a method for direct measurement of the absolute temperature by means of an oscilloscope, is described.

2. Theoretical Base of the Method

In this method, instead of presenting I_{cs} or log I_{cs} v.s. V_{eb}, one present the time derivative of I_{cs} ($\dot{I}_{sc}$) v.sc. V_{eb}; for the case when the emitter-base voltage (V_{eb}) is time dependent according to the relation

$$V_{eb} = V_m \left[1 - \exp\left(-\frac{t}{\tau}\right)\right]. \tag{2}$$

The general expression of $\dot{I}_{cs}$ is

$$\dot{I}_{cs} = \frac{e\dot{V}_{eb}}{kT} I_{cso} \exp \frac{eV_{eb}}{kT}, \tag{3}$$

where $\dot{V}_{eb}$— is time derivative of the emitter-base voltage (V_{cb}). If one takes that V_{eb} is given by (2) the corresponding $\dot{I}_{cs}$ will be

$$\dot{I}_{cs} = \frac{eV_m}{kT} \frac{I_{cso}}{\tau} \exp\left(-\frac{t}{\tau}\right) \cdot \exp \frac{eV_{eb}}{kT},$$

which by the use of (2) can be rearranged in the form

$$\dot{I}_{cs} = \frac{I_{cso}}{\tau}\left(\frac{eV_m}{kT} - \frac{eV_{eb}}{kT}\right) \cdot \exp \frac{eV_{eb}}{kT}. \tag{4}$$

A graphical presentation of $\dot{I}_{cs}$ v.s · V_{eb} will give a curve with maximal value of I_{cs}, which will be obtained for

$$V_m - V_{eb} = \frac{kT}{e}. \qquad (5)$$

From (5) it follows, that the location of the maximum on V_{eb} axes, counted from V_m, is uniquely determined by the absolute temperature of the transistor. This fact gives a possibility for direct read-up of the absolute temperature on the screen of an oscilloscope. Therefore, a voltage proportional to $\dot{I}_{cs}$ should be connected to the one axes of the oscilloscope (in our case X-axes), and periodical voltage, which varies in time according to (2) within one period, should be connected to the other axes (in our case y_1 — axes which was callibrated in millivolts).

3. Experimental Arrangement

The experimental arrangement we have used in our measurements is presented in fig. 1. As a voltage source for V_{eb} we have used a pulsgene-

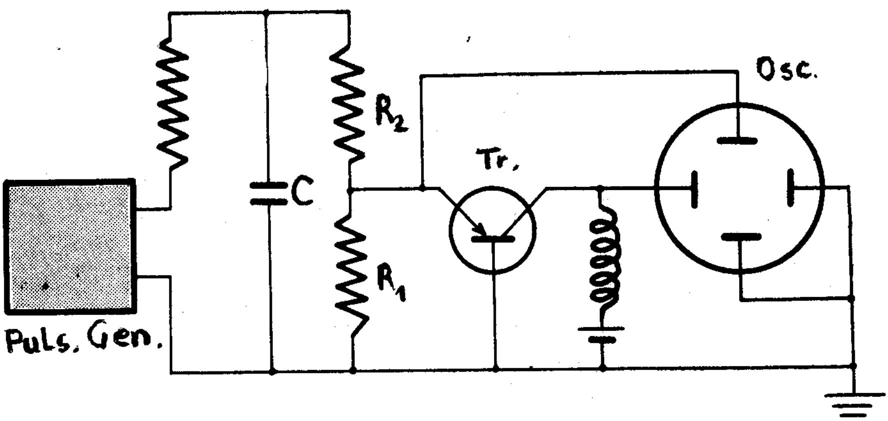

Fig. 1

rator, parallelly connected to *a* RC-circuit. The charge and discharge of C by the pulses from the generator gives the voltages.

$$V_1 = V_m\left[1 - \exp\left(-\frac{t}{\tau_1}\right)\right] \text{ and } V_2 = V_m \exp\left(-\frac{t}{\tau_2}\right),$$

where τ_1 and τ_2 are the time constants of the charging and discharging circuit respectively. For the measuring procedure we have used the voltage V_1 ($V_{eb} = A\ V_1$). The main problem has been the connection of the emitter and base of the transistor to the voltage source, since the input impedance of the emitter-base configuration is very low and nonlinear, and the direct connection would change the characteristics of V_1. In order to overcome this difficulty we have used two variants of connection. In the first one we have used emitter follower, and in the second one we have used potentiometric division of the voltage V_1 by resistors $R_1=10$ ohms and $R_2=1000$ ohms. The voltage drop on R_1 has been used as V_{eb} and so we have had a voltage source with characteristics (2) and very low internal resistance. The second variation, though simpler than the first one, has given better results. As absolute thermometer we have used the transistors *AC*—530, *AC*—540 and *BC*—183. The time derivative of short-circuit collector current has been obtained as a voltage drop on an inductive coil with 1000 turns and 10 ohms resistance.

The time derivation with operational amplifier has given the same results. An oscillogram, taken at $T=273{,}2\,K$ is presented on fig. 2. As we can

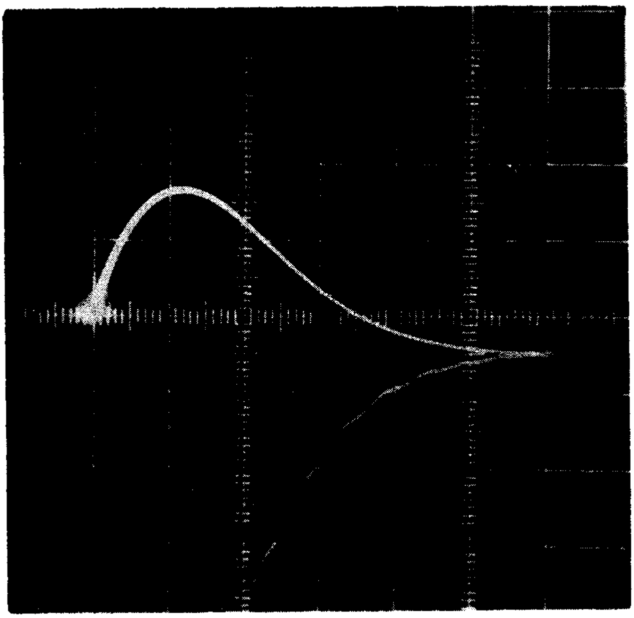

Fig. 2

see the right trace which correspond to the $V_{eb} = AV_1$, $\left(A = \dfrac{R_1}{R_1 + R_2}\right)$ possess maximum, whise location on Y-axes measured from the top (V_m), determines absolute temperature in millivolt. Calculation in Kelvins is straightrorward procedure by multiplicating by the factor 11,6.

4. Experimental Measurements

In the measuring procedure, it was important to have thermal equilibrium of the transistor with the medium under the measurement. For this reason it was neccesery to keep the emitter current to the lowest possible value, in order to prevent the heating of the transistor. In our experiments we have taken the value of V_{eb} from 30—100 mV, which depended on the measured temperature. The performed measurements on different temperatures has given the following results:

Absolute temper. measured by conventional thermom.	location of the max. measured from the top Vm in mV	calculated temp. from the location of max.
90	8 mV	92,8 K
191	16,6	192,5
273,2	23,8	276,1
307,8	26,8	310,4
336	29	336,4
348	30	348

As we can see the results obtained by transistor are a little higher, which is probably due to the lack of good thermal equilibrium.

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ОСЦИЛОГРАФСКО МЕРЕЊЕ НА АПСОЛУТНА ТЕМПЕРАТУРА СО ПОМОШ НА ТРАНЗИСТОР

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Резиме

Со овој метод е постигнато директно мерење на апсолутна температура со помош на транзистор. Тој се базира на осцилографско представување на временскиот извод на струјата на кусо споен колектор во зависност од напонот помеѓу база и емитер (V_{eb}), кој за овој случај има експоненцијална временска зависност. За така избран емитерски напон временскиот извод на струјата на кусо споен колектор ќе биде дадена со изразот (4). Осцилографско представување на (4) во зависност од емитерскиот напон (V_{eb}) дава крива што има максимум за $V_{eb} = \frac{kT}{e}$ каде што е V_m — максималната вредност на емитерскиот напон.

Шематски приказ на експерименталната опстановка е даден на л. 1, а осцилограм на изразот (4) во зависност од напонот за 273,2 K е даден на сл. 2. Методов беше исползуван за мерење на ниски температури од 90—348 K. Резултатите беа споредувани со конвенционални термометри при што се доби одлично сложување.