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STEP CURRENT METHOD IN PROGRAMMABLE TEMPERATURE MEASUREMENT

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Abstract: The temperature is one of most important parameter in many industrial control applications. For measuring temperature's values are many methods using different sensors and transducers. One of these is semiconductor sensors respectively p-n junction into diode or transistor. This paper present possibility to measure temperature using base-emitter junction of a transistor that is operate with two different collector's currents. For every of this currents are determinate a different base-emitter tensions which afterwards are processing by an analog to digital conversion and output send into an 80C51 family microcontroller. Outputs may be metrological signal or a signal which be displayed in numerical format.

Key words: temperature, p-n junction, collector's step current, microcontroller

1. Introduction to temperature measurement

Temperature measurement represents one of more important measurement in industrial control process. The simplest and the most widely used phenomenon for temperature sensing is thermal expansion. For electrical transduction, different of sensing are employed. Among them are: resistive, thermoelectric, semiconductive, optical and piezoelectric detectors.

Talking a temperature essentially requires the transmission of a small portion of the object's thermal energy to the sensor, whose function is to convert that energy into an electrical signal. When a contact sensor is placed inside or of the object, heat conduction takes place through object and sensor that warms up or cools down i.e. it exchange heat with the object. Any sensor, no matter how small, will disturb the measurement site but this disturbance is much small if sensor is much small.

A contact temperature measurement is complete when there is no thermal gradient between object and sensor. This process makes take significant time, because, after the probe placement, reaching thermal equilibrium between the object and the sensor is a slow process.

In a contact sensing, amount of transferred heat is proportional to a temperature gradient between the transducer's sensing element of instantaneous temperature T and that of the object T_1:

$$dQ = a \cdot A \cdot (T_1 - T) \cdot dt \qquad (1)$$

where a is the thermal between the object and the sensor and A is the heat transmitting surface. If the sensor has specific heat c and the mass m, the absorbed heat is:

$$dQ = m \cdot c \cdot dT \tag{2}$$

Equations (1) and (2) yield a first order differential equation:

$$(T_1 - T) \cdot dt = \tau_T \cdot dT \tag{3}$$

where denote thermal time constant τ_T as:

$$\tau_T = \frac{m \cdot c}{a \cdot A} \tag{4}$$

and considering the case when the object has a thermal mass several orders of magnitude than that of the sensor and thermal conductivity the object is high (*infinite heat source*) has a solution:

$$T = T_1 - K \cdot e^{-t/\tau_T} \tag{5}$$

where K is a constant.

The time response of temperature T that corresponds to the above solution is shown in fig.1.a.

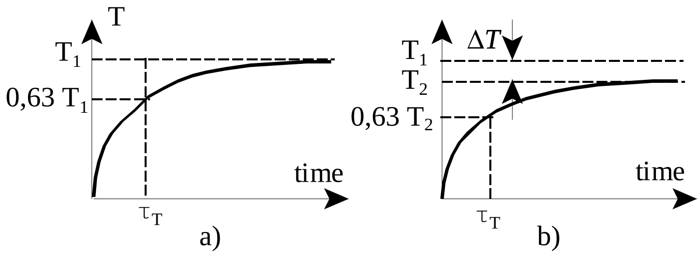

Fig. 1. Temperature change of a sensor

Theoretically, it takes infinite time to reach a perfect equilibrium between T_1 and T, however for the most practical case, a quasi-equilibrium state may be considered after 5 to 10 time constant. In addition, if a sensor is coupled with object an additional error may be introduced because the object temperature is modified by the sensor temperature and fig.1.b. show that the equilibrium is set on a lower level T_2 that is smaller by a difference ΔT corresponding to heat loss.

2. Junction p-n in temperature measurement

A semiconductor p-n junction in a diode (fig.2.a.) and a bipolar transistor (fig.2.b.) has a strong thermal dependence. If the junction is connected to a constant current generator the resulting voltage, provide a measure of the junction temperature whit a high degree of linearity (fig.2.c.).

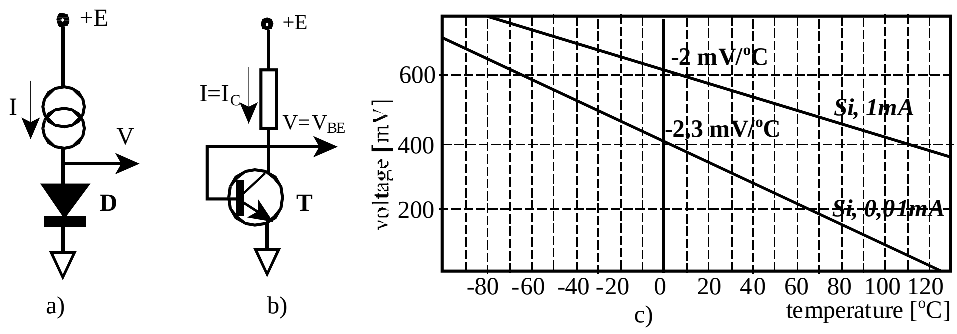

Fig.2. Temperature-to-voltage conversion and voltage-to-temperature dependence

The current-to-voltage *V* equation of a diode p-n junction can be expressed as:

$$I = I_0 \cdot exp(qV / 2kT) \qquad (6)$$

where I_0 is the saturation current, *q* is the charge of an electron, k is Boltzman constant

$$V = \frac{E_g}{q} - \frac{2kT}{q} \cdot (\ln K - \ln I) \qquad (7)$$

and T is absolute temperature and this yield the temperature-dependent voltage across the junction:
where E_g is the energy band gap for silicon at 0K (absolute zero).
The current-to-voltage $V = V_{BE}$ equation of a transistor p-n junction can be expressed as:

$$V_{BE} = \frac{kT}{q} \cdot \ln \frac{I(= I_C)}{\alpha_F I_{ES}} \qquad (8)$$

where α_F represent direct current factor, I_{ES} represent saturation current for base-emitter junction and that represent a linear dependence between base-emitter voltage V_{BE} and temperature *T*.

According to (6) and (7) because when the temperature increase, voltage *V* drops which results in a minute increase in current *I*, this causes some reduction in sensitivity, which is manifested as nonlinearity. However, the nonlinearity may be either small enough for ordinary applications.

This makes a transistor (diode) temperature sensor a very attractive device for many applications, due to its simplicity or low cost.

Transistor employment sensing element conform (8) involve a very good stability for resistor R parameters and inter-changeability between transistor into the same class.

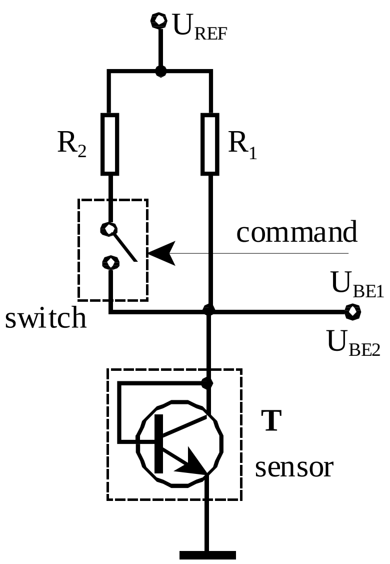

Fig.3. Principle of step current method

The last function required is pull off thanks, too factory dispersion effect and is necessary to make up this effect.

3. Current step method

One of the methods to compensate factory dispersion effect is by using fundamental properties of transistor to produce voltage based to relationship between base-emitter voltage and collector current (eq.8), which produce a linear semiconductor temperature sensor.

It forced two different collector currents I_{C1} and I_{C2} who determine two base-emitter voltages (eq.8) V_{BE1} and V_{BE2} into the same transistor that represent temperature sensor. It is well known, that the transistor's collector current is very little dependent on collector voltage. The difference between these two base-emitter voltages ΔU_{BE} will be:

$$\Delta U_{BE} = U_{BE1} - U_{BE2} = \frac{kT}{q} \cdot \ln \frac{I_{C1}}{\alpha_F \cdot I_{ES}} - \frac{kT}{q} \cdot \ln \frac{I_{C2}}{\alpha_F \cdot I_{ES}} = \frac{kT}{q} \cdot \ln \frac{I_{C1}}{I_{C2}} \qquad (9)$$

Principle of this method is shown in fig.3. were considering that the transistor's collector current is very little dependent on collector voltage, the collector currents I_{C1} and I_{C2} are determined by stable resistors values R_1 and R_2 and power supply V_{REF}.

Measuring operation has forth steps:

- in first step switch is open and in transistor (sensor) collector is connected only resistor R_1 who determine an collector current I_{C1},
- in second step switch is closed and in transistor (sensor) collector is connected parallel group R_1 and R_2 ($R_1 || R_2 < R_1$) who determine an collector current I_{C2} ($I_{C2} < I_{C1}$),
- in third step is calculate by an corresponding circuit value ΔU_{BE}
- in last step is determinate relation between temperature T and base-emitter voltage variation ΔU_{BE} in according with relation (9):

$$T = \frac{\Delta U_{BE} \cdot q}{k \cdot ln\frac{I_{C1}}{I_{C2}}} = \frac{q}{k} \cdot \left(-ln\frac{I_{C2}}{I_{C1}} \right) \cdot \Delta U_{BE} = -K \cdot \Delta U_{BE} \qquad (10)$$

were I_{C1} and I_{C2} represent fixed collector currents of the sensor and also:

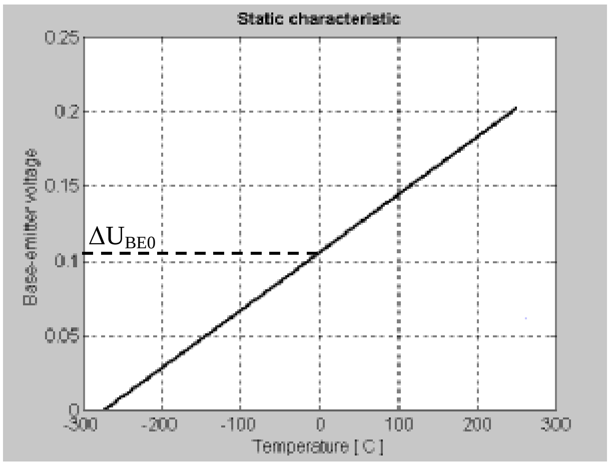

Fig.4. Static characteristic of the sensor

$$K = \frac{q}{k} \cdot \left(ln\frac{I_{C2}}{I_{C1}} \right) \qquad (11)$$

is a constant that represent characteristic slope of the sensor.

Considering fixed collector currents I_{C1} and I_{C2} the static characteristic (realized in) for the temperature range [-50…+200] ^{o}C is shown in fig.4. This characteristic may be use to compute the values to complete a look-up table used for display these values.

4. Programmable solution for current step method

For generate the command to connect or disconnect appropriate collector current, for command programmable gain amplifier, for analog to digital conversion and

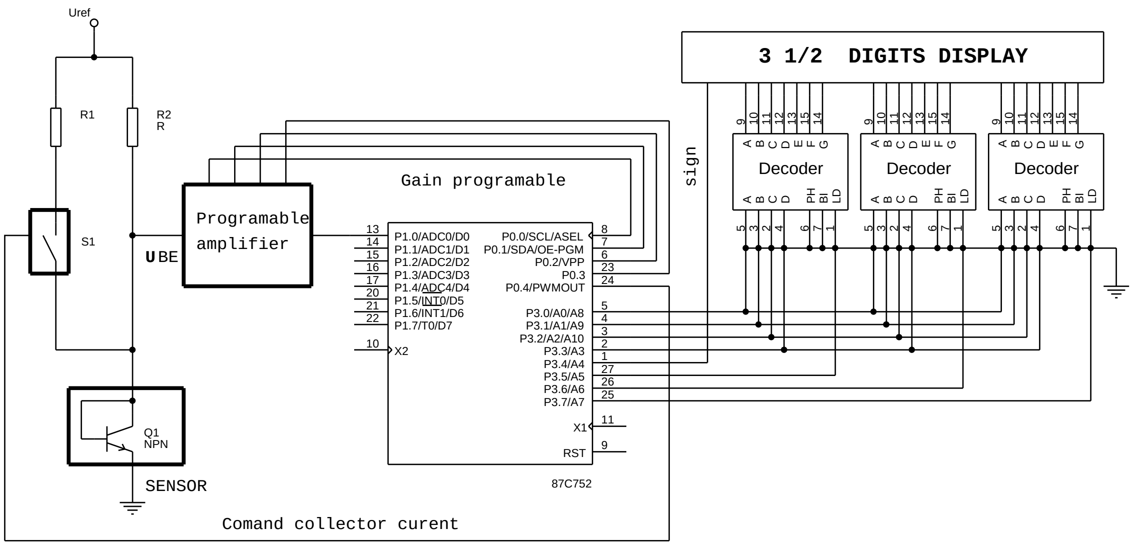

Fig.5. Principle of the programmable temperature measurement schematic

for command the display device is necessary to use an microcontroller. The acceptable unit is 87C752, a Philips 80C51 family device and this connection is shown in fig.5.

The main control unit of the system measurement is microcontroller 87C752 witch contains:

- an internal A/D converter with 5 channels multiplexed, 8 bits resolution, a relatively great input impedance (Zi = 9 kΩ) for one channel;
- one analog output, PWM type with 8 bits resolution;
- 16-bit auto reloadable counter/timer;
- 2k x 8 EPROM;
- 64 x 8 RAM

According to relation (10) and static characteristic (fig.4.) for temperature range [-50…+250] ^{o}C and collector currents I_{C1} = 3.125 μA respectively I_{C2} = 2.5 μA the output signal (ΔU_{BE}) range is [0.085…0.202] V. It is known that voltage input range for A/D converter inside microcontroller is [0…5] V which impose magnification by a programmable amplifier of the sensor outputs values. Necessary amplifier gain is 25 witch determine the sensor outputs values [2.14…5.00] V for temperature range [-50…+245] ^{o}C thus are not come A/D converter over range. Because the sensor null output corresponding to the temperature zero absolute the effectively temperature range is [-273.15…+245] ^{o}C. For other collector currents results other outputs values and in these cases if is necessary the gain amplifier can be setting by port P0 (lines P0.0… P0.3) of the microcontroller. The line P0.4 of the same port are using for command collector current I_{C1} or I_{C2}.

Base-emitter voltages U_{BE1} and U_{BE2} are collected by line P1.0 of the port P0 that represent one of the inputs of the inside A/D converter. By program resident in EPROM memory is compute binary ΔU_{BE} and by way that is setting address in look-up table

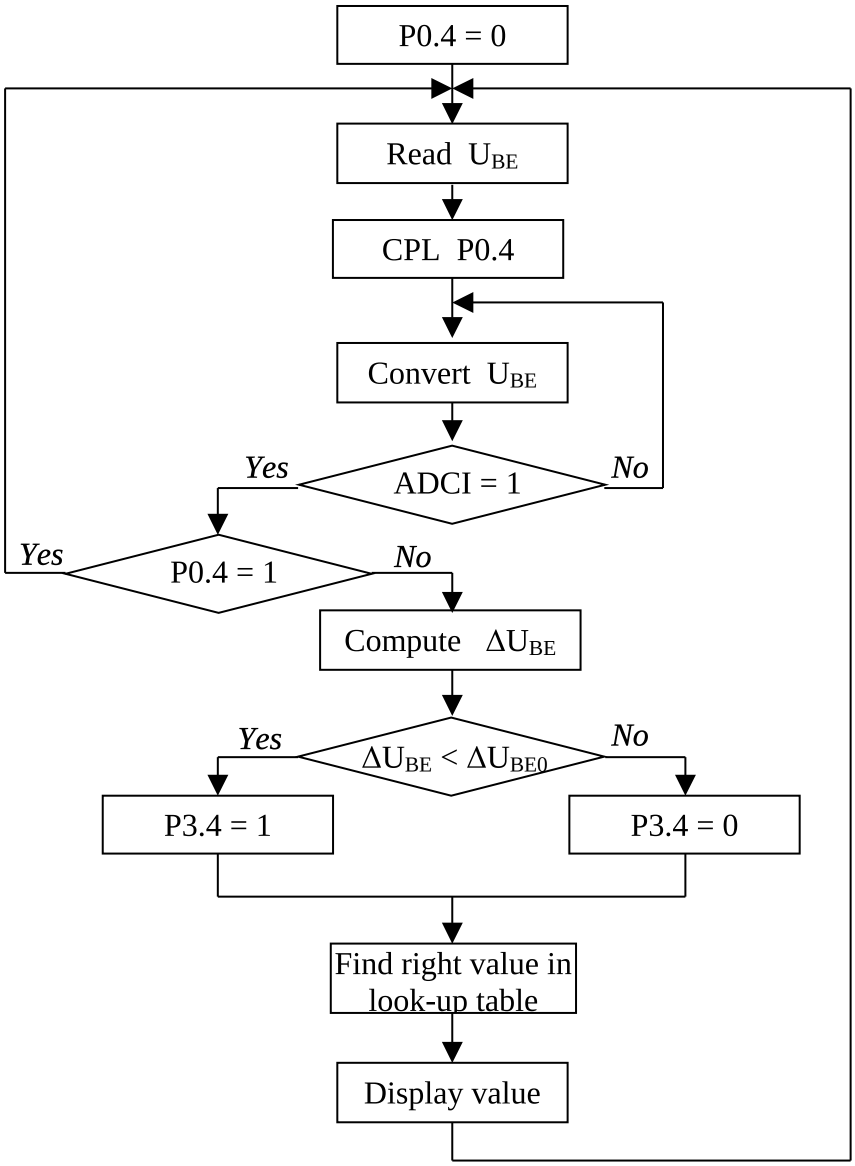

Fig.6. Functionally algorithm

where are stored the digits corresponding of the temperature value. These digits are sequential transmitted towards display by appropriate decoder.

The functionally algorithm for step current method in programmable temperature measurement is presented in fig.6. where firsts blocks represents acquisition and analog – to – digital conversion of the base – emitter tensions U_{BE} corresponding of the two collector's currents I_{c1} and I_{c2}. Acquisitions of these tensions are achieved by corresponding set of the microcontroller selection output P0.1 that control the S1 switch. The next steps in functionally algorithm compute ΔU_{BE}, adjust this value with characteristic slope of the sensor (11) and establish the sign of the value through output P3.4 of the microcontroller by comparing that with ΔU_{BE0}, which correspond at 0^{o}C temperature. The right value of the temperature is extract from the look-up table and for this is used the digital value of the ΔU_{BE} like a displacement into an instruction MOV A, A+@DPTR where register DPTR contain first value of the look-up table and general register A contain digital value of the ΔU_{BE}. The value extract now from look-up table where are stored in corresponding digits can be used for display the temperature value.

5. Conclusions

Concerning measuring temperature with programmable semiconductor transducers results some conclusions such as:

- § semiconductor transducers on account of little mass have less the other time constant and additional error;
- § for fixed collector currents is possible to change transistor sensor without precision affect;
- § in concordance with collector currents is possible to setting the gain for programmable amplifier thus ensure input level for A/D converter and a good precision;
- § utilize an appropriate static characteristic is possible to create an look-up table necessary to digital display temperature values;

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