Technical University of Lodz

Department of Semiconductor and Optoelectronics Devices

WWW.DSOD.PL

ELECTRONIC MEASUREMENT LAB.

Experiment No 5

Measurement of non-electrical quantities

GOAL OF THE EXPERIMENT:

The purpose of this experiment is to familiarize students with methods to measure temperature using sensors and electronic circuits, identification of static characteristics of selected sensors and application of sensors for temperature measurement in non-steady states.

SPECIFICATION OF USED INSTRUMENTS:

Instruments and software used in the experiment.:

Instruments

1) Case moulded thermostatic module equipped with Poliera cell and PID controller to stabilize the temperature and the module with the sensors:
    a) Thermocouple type sensor - Thermocouple of type K
    b) IC LM 335 - electronic integrated circuit temperature sensors
    c) Pt-100 - platinum RTD type sensor,
    d) thermistor based type semiconductor NTC (Negative Temperature Coefficient) with a negative coefficient of resistance changes.
2) Electrical signal conditioners to adjust output of sensors to the voltage required of to the input voltage measuring card of USB-4711 operated by software installed in PC.
3) USB-4711A multifunction ADC card produced by Advantech Co.
4) Power supply of controlled voltage and current (recommended range of 5 V / 3 A)

Software:

1. Software Package ,,PSoC-GRAM-ADDA” handling US4711 ADC card
2. Spreadsheet with the Office for processing data from Data4711
3. LabVIEW (Laboratory Virtual Instrument Engineering Workbench) - graphical programming environment used in the measurement and analysis of data (used optionally)

THEORY

Theoretical basis

Measurement of non-electrical quantities such as pressure, temperature, flow, humidity, etc. are very important in the production process and monitoring of environment.

Temperature measurements cover over 85% of all industrial measurements.

Temperature – physical interpretation

The temperature defines the thermodynamic state of the body. The physical interoperation of temperature is that it defines the concentration of energy whether kinetic or potential in the body in micro scale. The simplest example of such concentration of kinetic energy would be the speed of vibration of individual atoms within a system of atoms (molecules, crystals, plasma, etc.) The extension of this example to subatomic level would indicate the agitation state of individual atoms or the relation between its nuclear components and electronic shelves.

There is a universal tendency for energy to flow from higher state to lower, i.e. a tendency to attain an equilibrium at the lowest state within a closed systems. Thus the heat (the total sum of energy of individual particles) is transferred from hotter (higher state) to colder (lower state) body.

Thermometer – an instrument used to measure temperature

The temperature of any medium can be measured by measuring a particular property of the medium, which varies with temperature. A direct measurement of such variation of the property is difficult without physical contact medium and thermometer. Thus the thermometer submerged into a liquid does not actually measure the temperature a liquid but its own temperate, which may be close to the liquid, but rarely identical. Further, the insertion the thermometer alters locally the state of the liquid. Such facts are difficult to be omitted. The sensitivity and accuracy of any thermometer depends on the speed and closeness to which it approaches the temperature of the measured medium.

Temperature sensors can be classified according to the physical characteristics by which to gain information about their temperature. Use of such physical phenomena as:

- a variation of the volume of liquid, gas or the length of the effect of temperature
- a variation of the resistance of an element such as a conductor or semiconductor
- a variation of properties of semiconductors
- generation of thermoelectric power (STE) at the junction of two different metals joined together when their ends are placed in different temperatures (thermocouples).
- variation of the parameters of thermal radiation

Most commonly used temperature sensors for engineering practice are:

a) RTD sensor - Resistance Temperature Detector
b) Thermocouple type sensor
c) Thermistor a semiconductor based resistors sensor
d) semiconductor junction serving as a sensor being a part of integrated circuit with analogue or digital output

RTD sensor - Resistance Temperature Detector

Resistance thermometers are made in the technology of high-precision thin-film resistors, wound, or whose parameters are set by international standards are respected by all manufacturers. European standard EN 60751 provides that the characteristics of platinum thermometers meet the following relationships for the two temperature ranges:

from -200 °C to 0 °C:

$$R_t = R_0[1+At+ Bt^2 +C(t-100)t^3] \qquad (1)$$

And for the range from 0°C to 850 °C

$$R_t=R_0[1+At+Bt^2] \qquad (2)$$

Where:

R_0 – resistance at t=0°C at which standard resistance R_t=100 Ω

A, B, C coefficients are as follows:

$A=3,9083*10^{-3}\,^{o}C^{-1}$

$B=-5{,}775*10^{-7}\ {}^{o}C^{-2}$

$C=-4{,}183*10^{-12}\ {}^{o}C^{-4}$

Overall the resistance dependence along temperature is standardised, the standard quotes two classes: class A and "B" where the values are within ranges as given in Table. 1:

Tab. 1. Permissible deviations of Pt100 sensors

Temperature °C	**Tolerance**					
	Class A		**Class B**		**Class 1/3B**	
	°C	**Ω**	**°C**	**Ω**	**°C**	**Ω**
-200	±0.55	±0.24	±1.3	±0.56	-	-
-100	±0.35	±0.14	±0.8	±0.32	-	-
0	±0.15	±0.06	±0.3	±0.12	±0.1	±0.04
100	±0.35	±0.13	±0.8	±0.30	±0.26	±0.1
200	±0.55	±0.20	±1.3	±0.48	±0.4	±0.16
300	±0.75	±0.27	±1.8	±0.64	±0.6	±0.21
400	±0.95	±0.33	±2.3	±0.79	-	-
500	±1.15	±0.38	±2.8	±0.93	-	-
600	±1.35	±0.43	±3.3	±1.06	-	-
700	-	-	±3.8	±1.17	-	-
800	-	-	±4.3	±1.28	-	-
850	-	-	±4.6	±1.34	-	-

RTD sensors of standard values of 500 Ω (Pt 500) and 1000 Ω (Pt 1000) at temperature of 0^0 C are available commercially.

The dependence of resistance vs. temperature at the range 0^0C – 100^0C for Pt-100 is presented in Fig. 1.

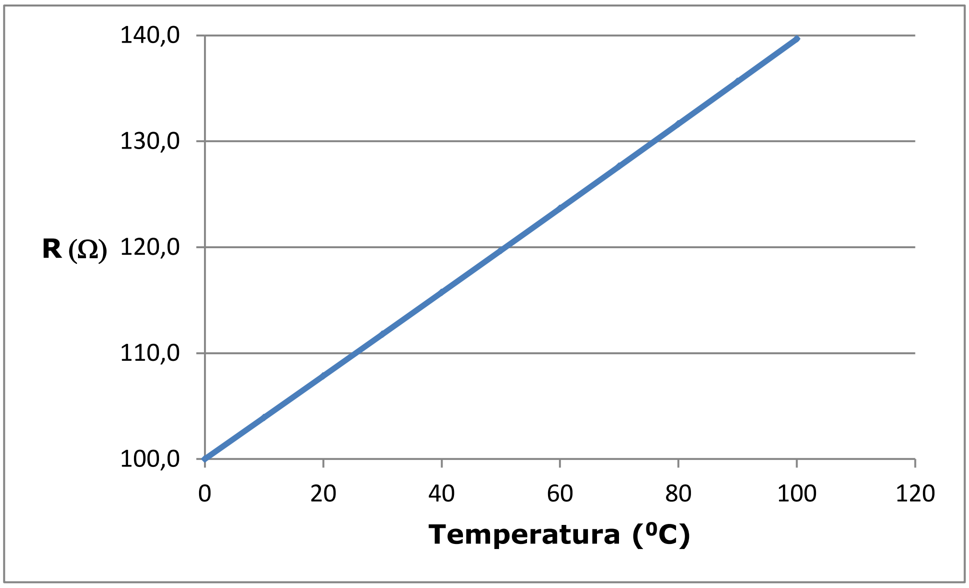


Fig 1. Resistance vs. temperature at the range 0^0C – 100^0C for Pt-100

For each actual value of resistance of RTD sensor, based on A and B coefficients the actual temperature t_{Pt} can be calculated using formula (3).

$$t_{Pt}\left[{}^{0}C\right]=\frac{-AR_0+\sqrt{\left(AR_0\right)^2-4BR_0\left(R_0-R_{Pt}\right)}}{2BR_0}\quad\left[{}^{0}C\right]\tag{3}$$

Where R_0=100 Ω

NTC (Negative Temperature Coefficient) type Thermistor

Thermistor is made of semiconductor material. There are two type of thermistor NTC of which resistance decreases when temperature rises and PTC (Positive Temperature Coefficient) of which resistance increases with temperature. NTC thermistor characteristics are shown in Figure 4 and by Equ. (4).

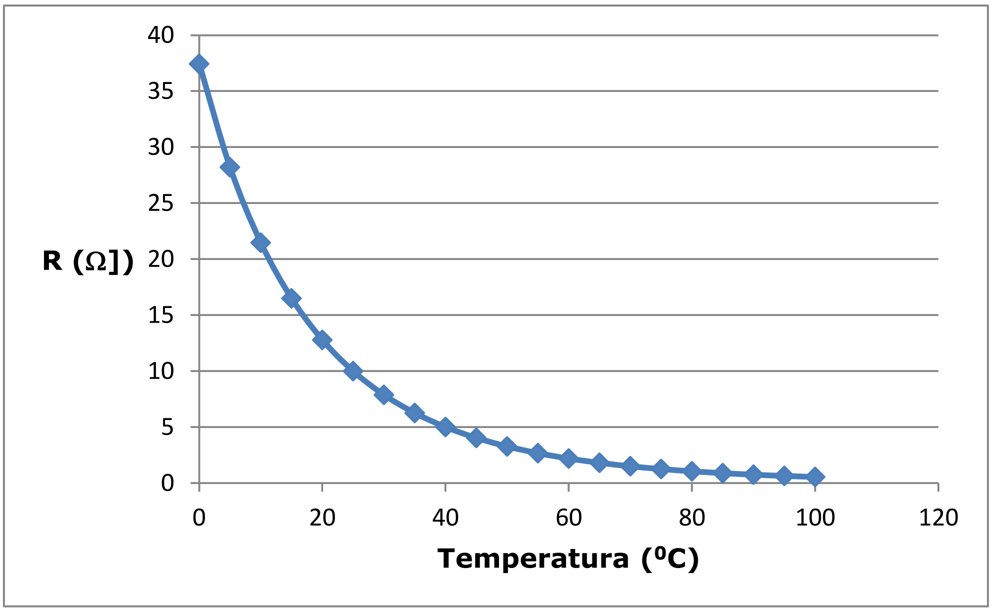


Fig. 2. Resistance vs. temperature at the range 0^0C – 100^0C for NTC of R_{ref} = 10 kΩ , T_{ref}=25^0C,

The relation between resistance of NTC thermistor vs. temperature in K (Kevin) is given by formula (4).

$$R_{NTC}\left[k\Omega\right]=R_{ref}\exp\left(B\left|\frac{1}{T}-\frac{1}{T_{ref}}\right|\right)\left[k\Omega\right]\tag{4}$$

Where, the manufacturer declare values of coefficients:

R_{ref} = 10 kΩ

B= 4300 +/- 3 %
T_{ref} .= 298,15 K

The simplest method to measure temperature by means of thermistor sensor is to measure the voltage drop across thermistor while constant FC current flow though sensor. Figure 3 shows such circuitry

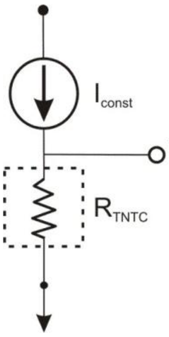


Fig.3. Diagram of the circuitry used to measure temperature in which constant current flow through R_{NTC} sensor.

Applying Ohm law, the résistance is equal:

$$R_{NTC} = V/I_{const} \tag{5}$$

Determination of the temperature thermistor is made by converting the equation (4) in which the temperature T is expressed in degrees of K. The relation is as follows:

$$T_{NTC}\left[{}^{0}C\right] = \frac{1}{\frac{1}{B}\ln\left(\frac{R_{NTC}}{R_{t=25^{0}C}}\right) + \frac{1}{T_{ref}\left[K\right]}} - 273{,}15 \quad \left[{}^{0}C\right] \tag{6}$$

Where following data are provided by thermistor manufacturer:

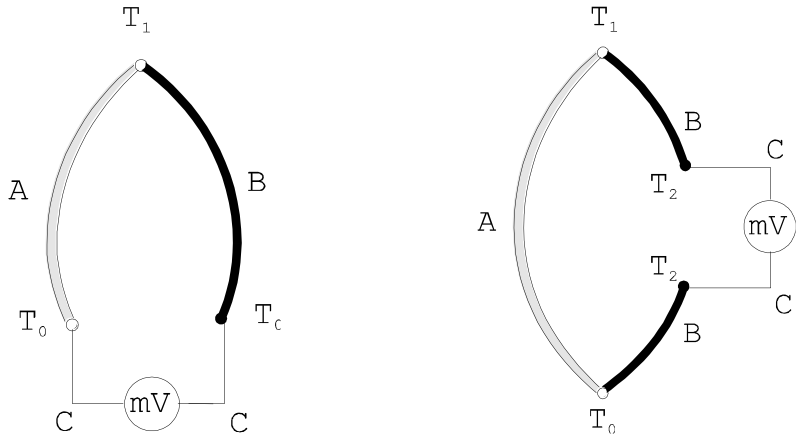
B=4300

T_{ref} [K]= 298,15 K

R_0=10 KΩ

Thermocouple thermometer

This phenomenon stands that the voltage drop arise along the length of the conductor if along conductor is a temperature gradient. If two dissimilar metals form a close circuit by joining them at their ends, and if these joints are subjected to different temperatures then the potential difference proportional to temperature difference arises. That potential difference might be measured by means of milli-voltmeter connected to circuitry as presented in Fig.4



(a) (b)

Fig.4. Mili-voltmeter used to indicate potential raised in a circuitry.
A and B metal conductors; C – wires also metal conductors used to connect voltmeter.

One junction is placed in medium at temperature T1 while the other (second junction) is subjected to temperature of known value T0, so called reference temperature

Such a reference temperature T0, can be of any known value, but a natural reference can be a temperature of a triple point of water is the temperature and pressure at which coexists the three phases (gas, liquid, and ice). This is a temperature of 0,010C.

From technical point of view, such reference source in not easy to be handled.

In order to facilitate measurements the electronic reference temperature sources had been developed, which refers to the international standard temperature scale.

Very often in the package of such electronic device the linearization of thermocouple sensors is included.

Figure 5 shows a schematic diagram of Integrated circuit and sensor (Iron-Chromel type) serving as thermometer with a voltage output. The output voltage is proportional to temperature in which sensor is immersed. Sensitivity in this case is: 10mV/^{0}C.

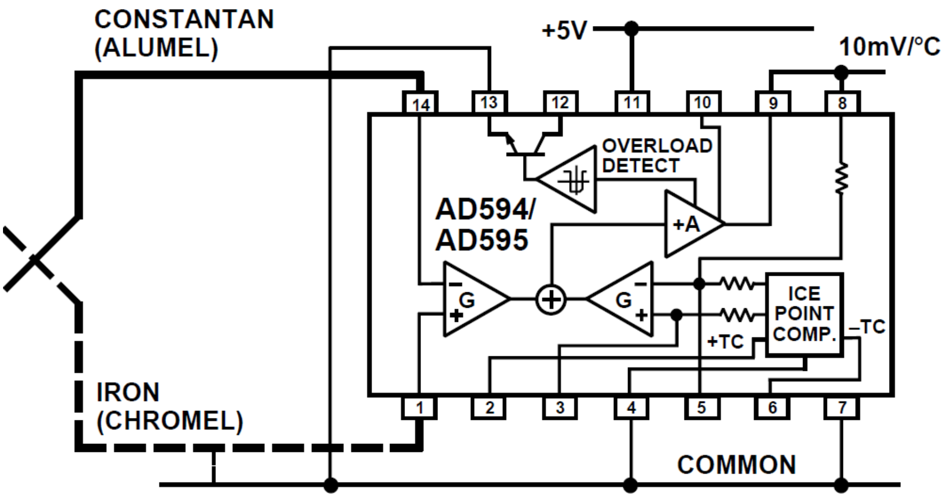


Fig. 5. Reference temperature and linearization included in AD 595 chip.

Thermocouple temperature sensors are internationally standardized. Table 2 summarizes the selected types of sensors, which are marked (capital letters): B, E, J, KN, R, S, indicating the type of materials of which sensors are formed.

Table. 2. Parameters of thermocouples according to standard: PN-EN 60584-1

Thermocouple	Type	STE mV/°C	Max. measured temp.-	Max working temp.	Colour of positive electrode	Colour of negative electrode
NiCr-NiAl	K	0,041	1200 ^{0}C	1370 ^{0}C	Green	White
NiCr-CuNi	E	0,068	900 ^{0}C	1000 ^{0}C	violet	White
Fe-CuNi	J	0,054	750 ^{0}C	1200 ^{0}C	black	white
NiCrSi-NiSi	N	0,038	1200 ^{0}C	1300 ^{0}C	pink	White
Pt30Rh-Pt6Rh	B	0,01	1700 ^{0}C	1820 ^{0}C	grey	white
Cu-CuNi	T	0,054	350 ^{0}C	400 ^{0}C	Brown	White
Pt13Rh-Pt	R	0,01	1600 ^{0}C	1760 ^{0}C	Orange	White
Pt10Rh-Pt	S	0,01	1600 ^{0}C	1540 ^{0}C	Orange	White

NOTE: Maximum measured temperature - for which tolerance is specified; maximum working temperature determines the temperature limit set by the standard in terms of maximum voltage at the output.

Type K (chromel {90% nickel and 10% chromium}—alumel {95% nickel, 2% manganese, 2% aluminium and 1% silicon})
Type E (chromel–constantan)
Type J (iron–constantan)
Type N (Nicrosil–Nisil) (nickel-chromium-silicon/nickel-silicon)
Type B thermocouples use a platinum–rhodium alloy for each conductor. One conductor contains 30% rhodium while the other conductor contains 6% rhodium.
Type T (copper – constantan)
Type R thermocouples use a platinum–rhodium alloy containing 13% rhodium for one conductor and pure platinum for the other conductor.

Type S thermocouples are constructed using one wire of 90% Platinum and 10% Rhodium (the positive or "+" wire) and a second wire of 100% platinum (the negative or "-" wire).

The dependence of thermoelectric power (STE) as a function of temperature thermocouples is shown in Figure 6 with a zero reference temperature.

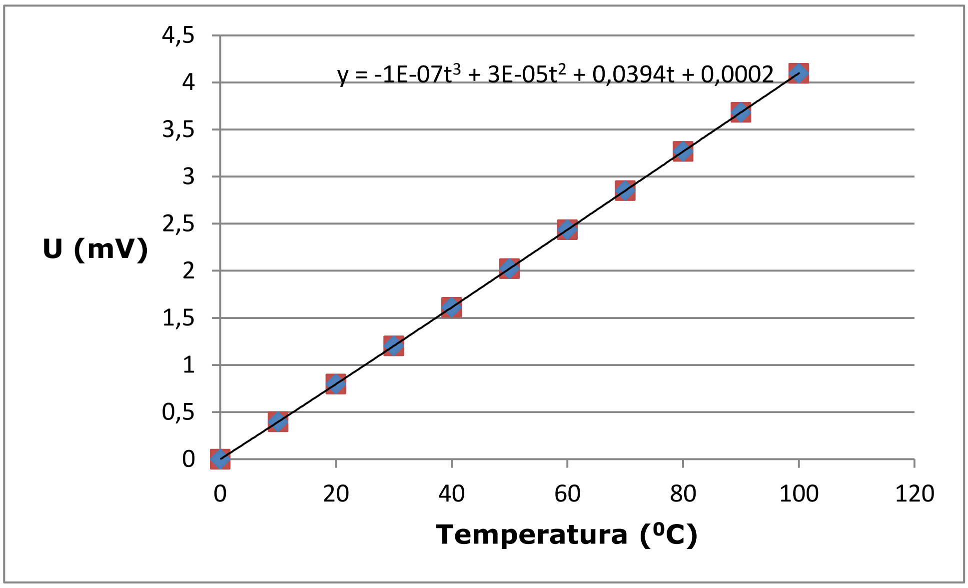


Fig. 6. STE vs. temperature at the range 0^0C – 100^0C for thermocouple „K”.

PN-EN-60584-2 defines three classes and the value of thermoelectric power as a function of temperature for different types of thermocouples.

In the case of the AD595 chip linearization and cold junction compensation thermocouple type K, states fixed processing sensitivity to 10 mV/0C.

Integrated temperature transducers with semiconductor pn sensor

Semiconductor temperature sensor (LM335) uses the phenomenon of change in voltage pn junction under the influence of temperature

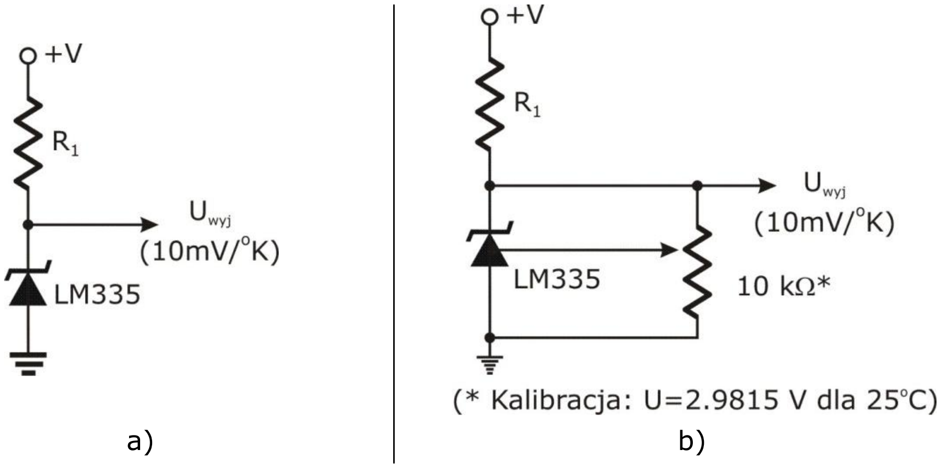
In order to increase the accuracy it is advisable to perform a one-point adjustment (calibration) at T_0=298 K (25 ^{0}C) by adjusting the output voltage U_{WYTo}= 2,9815 V (Fig. 7b) with a slide potentiometer. After LM 335 sensor calibration is correct relationship:

$$U_{wyjT} = U_{wyjT_0} \frac{T}{T_0} [V] \tag{7}$$

where: T – measured temperature, UWYT – voltage output

LM335 system does not require external calibration with the requirements of accuracy: +/-0.4 ^{o}C at room temperature (25^{o}C) and + / - 0.8 ° C change in temperature from 0 °C to +100 °C.

Dependence of the output voltage with respect to temperature is linear 10mV/°C, characteristics will be tested in the practical exercises.



a) b)

Fig. 7. A temperature sensor LM 333 - IC system without calibration b) with calibration

Properties of the semiconductor integrated circuit sensor LM-335

- Temperature range 40-1000C
    - Directly calibrated in Kelvin.
    - Power consumption 400 uA to 5 mA
    - Easy calibration (one point)
    - Low cost

EXPERIMENT:

The exercise shall be carried out by determining the static characteristics of selected sensors making measurements for fixed values over the temperature range 20-60°C (for example, at 20°C, 25°C, …. 55°C, 60°C), the results are compared with the specification / standards, and performed the sensors measure the temperature during cooling thermostat module.

TASK 1:

Acquisition of data from four temperature sensors using the USB4711 measurement card, which is connected to the output signal conditioners according to the circuit diagram shown in Figure 8 Acquisition applications facilitates USB7411 card. The built-in PID controlled thermostatic Pelier cell keeping the temperature at the required values declared at programming - software level.

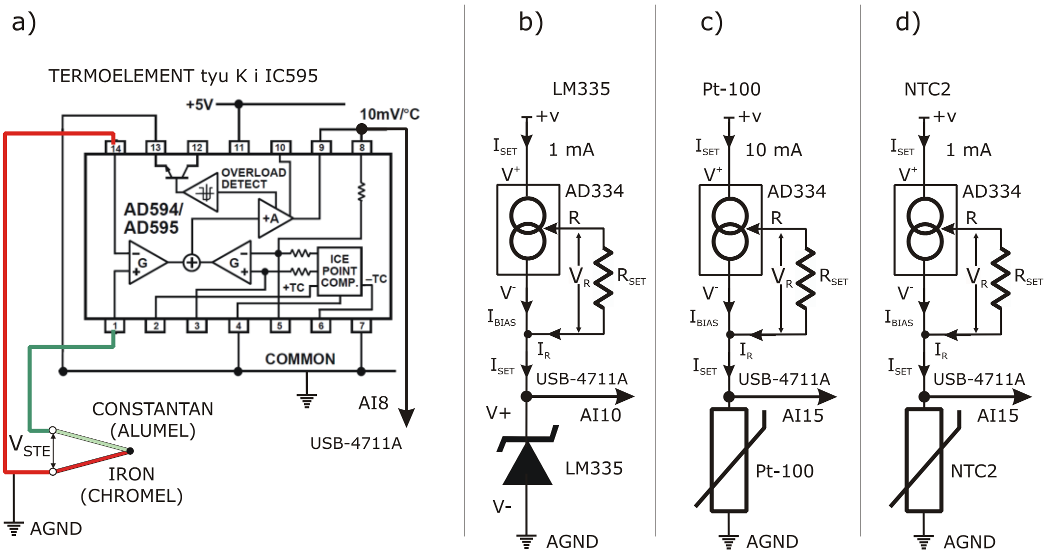


Fig. 8. Figure 8 Schematic diagram of the sensors and signal conditioners for data acquisition via a measurement card USB4711A

a) measuring system of the type K thermocouple and an integrated circuit to signal linearization and cold junction compensation thermocouple (output signal of 10 mV / °C)

b) measuring system with sensor semiconductor pn integrated on a chip LM 355, whose output is directly proportional to absolute temperature (expressed in degrees K). relationship between the output voltage and the absolute temperature 10mV / K

c) measuring system of RTD Pt-100 with DC power. Voltage on the sensor Pt-100 shall strengthen the signal conditioner and then is send to the ADC USB Card 4711

d) measuring system with semiconductor sensor NTC 1 on AC power, the voltage drop across the sensor is subject to strengthen the signal conditioner and then is delivered to the ADC USB Card 4711

Procedure

1. Wire power supply (channel 4 set to 6V voltage, current up to 3A) to thermostatic module.
   NOTE: Voltage over 6 volts might damage the Peltie cell.
2. Start the data acquisition by clicking “start” button of front panel of virtual control system which control USB-47-11A DAC module.
3. Collect data for about 5 minutes. This is the first point, which refers to room temperature of thermostatic module.
4. Then switch the thermostatic chamber to "heat" , by pressing virtual button. Also switch on the power supply output (button of power supply).
5. Then set up sequentially temperatures from room temperature up to 60 deg (every 5^{o}C), and collect data. PID will control constant temperature of the thermostat module.
6. Then, switch the polarity of the power supply and set up virtual button of temperature control to -100^{o}C
7. Record collected data as a text file (*. Txt) for further processing.

Data measurement handling

For each stable state a fixed temperature pints of the range: 25 ° C or room temperature to 60 ° C, based on recorded data calculate the mean values of outputs of each sensors

Due to the thermal inertia of the object make averaging cover stable (quasi stable) results.

Table 1 Results of measurements after averaging (quasi static conditions)

Sensor Type	Thermo couple „K”		p-n LM 335		RTD PT-100			Thermistor NTC		
Temp	V_{Kwy}	TC_K	V_{LM}	TC_{LM}	V_{PT}	R_{PT}	TC_{Pt}	V_{NTC}	R_{NTC}	TC_{NTC}
^{0}C	V	T	V	^{0}C	V	Ω	^{0}C	V	k Ω	^{0}C
25,0										
30,0										
35,0										
40,0										
45,0										
50,0										
55,0										
60,0										

Table 2 Cooling process - output Voltage, resistance vs. time

Sensor Type	Thermo couple „K"		p-n LM 335		RTD PT-100			Thermistor NTC		
Time	V_{Kwy}	TC_K	V_{LM}	TC_{LM}	V_{PT}	R_{PT}	TC_{Pt}	V_{NTC}	R_{NTC}	TC_{NTC}
s	V	T	V	^{0}C	V	Ω	^{0}C	V	k Ω	^{0}C
0										
0,5										
1,0										
1,5										
…										
…										
…										
…										

a) Determination of the temperature of thermocouple "K" of the transducer AD595:

$$T_K\left[{}^0C\right]=U_{wyK}\left[V\right]\cdot\frac{1}{0,01\frac{V}{{}^0C}}\quad\left[{}^0C\right]$$

Sensitivity constant of the transducer AD595 with thermocouple type "K" is 10 m/°C

b) temperature for the LM335 transducer (pn - junction) is given by:

$$T_{LM}\left[{}^0C\right]=\left\{U_{wyLM}\left[V\right]-2,7315V\right\}\cdot\frac{1}{0,01\frac{V}{{}^0C}}\quad\left[{}^0C\right]$$

sensitivity is 10 mV/°C

c) Resistance of Pt-100 is given by:

$$R_{Pt}\left[\Omega\right]=U_{wyPt}\left[V\right]\cdot\frac{1}{0,03954\frac{V}{\Omega}}\quad\left[\Omega\right]$$

sensitivity is 0,03954 V/°C

Temperature for Pt-100 is given by

$$T_{Pt}\left[{}^0C\right]=\frac{-AR_0+\sqrt{\left(-AR_0\right)^2-4BR_0\left(R_0-R_{Pt}\right)}}{2BR_0}\left[{}^0C\right]$$

R_0 – resistance at t=0° C and R_0=100 Ω (standard resistance)

$A=3,9083*10^{-3}\ {}^oC^{-1}$

$B=-5,775*10^{-7}\ {}^oC^{-2}$

d) Resistance of **NTC 10 k** Ω is given by:

$$R_{NTC}\left[\Omega\right]=U_{wyNTC}\left[V\right]\cdot\frac{1}{0,1911\frac{V}{\Omega}}\quad\left[\Omega\right]$$

Sensitivity of NTC with amplifier is 0,37 mV/☐

Temperature for NTC 10 k Ω

$$T_{NTC}\left[{}^{0}C\right]=\frac{1}{\frac{1}{B}\ln\left(\frac{R_{NTC}}{R_{t=25^{0}C}}\right)+\frac{1}{T_{ref}\left[K\right]}}-273{,}15\quad\left[{}^{0}C\right]$$

B=4300

T_{ref} [K]= 273,15 [^{0}C]+ 25 [^{0}C]

R_0=10 KΩ

The following characterises in the form should be included:

T_K- $f(T_{Pt})$

T_{LM}- $f(T_{Pt})$

T_{NTC}- $f(T_{Pt})$

and

R_{NTC}- $f(T_{Pt})$

R_{Pt}- $f(T_{Pt})$

TASK 2:

Assuming Pt-100 platinum sensor as reference for other sensors, (temperature) determine differences of other sensors

a) Type K thermocouple $\Delta_K = T_K - T_{Pt}$ $\Delta_K = f\left(T_{Pt}\right)$

b) LM 335 pn type junction $\Delta_{LM} = T_{LM} - T_{Pt}$ $\Delta_{LM} = f\left(T_{Pt}\right)$

c) NTC 10k thermistor $\Delta_{NTC} = T_{NTC} - T_{Pt}$ $\Delta_{NTC} = f\left(T_{Pt}\right)$

Results should be presented in one graph

TASK 3

Plot the temperature characteristics of the sensor and determine the time constants of sensors assuming a dynamic model as:

$$T(t)=(T_1-T_2)*e^{\frac{-t}{\tau}}$$

T_1 – initial temperature (just at the moment when cooling starts)

T_2 – final temperature at steady state

Plot the following characterises:

$T_K = f(t);\quad T_{LM} = f(t);\quad T_{Pt} = f(t);\quad T_{NTC} = f(t);$

Technical University of Lodz
Department of Semiconductor and Optoelectronics Devices

WWW.DSOD.PL

ELECTRONIC MEASUREMENT LAB.

EXPERIMENT No:	
TITLE:	

Laboratory Group		***Telecommunication and Computer Science***	

no.	***Name and Surname***	***Student ID***
1		
2		
3		
4		

Lecturer:	
Date of experiment:	
Date of report presentation:	
Mark:	
Remarks:	