Óbuda University
Kandó Kálmán Electrical Engineering Faculty
Institute of Microelectronics and Technology

Sensor laboratory, Micro- and nanotechnology

Laboratory measurement guide

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Investigation of thermal sensors

1. Measurement goal

- Examine Peltier modules
- Examine thermistors and transistors characteristics vs temperature

2. Theoretical background

There are four different types of thermal sensors that will be studied during this measurement:
- Platinum100 (Pt100)
- Termistor (NTC,PTC)
- Transistor (Si, Ge)
- Peltier thermoelectric module

The temperature of the first three will be modified using the Peltier module. The platinum resistors will be applied as a reference (being probably the most precise sensors available). Their temperature characteristic cannot be obtained (but are fairly well known in advance), but using them, the others are easily studied.

2.1. Peltier thermoelectric module

The thermoelectric effect covers the phenomenon, where temperature difference is created due to the current flow, or in the opposite case, electric current is generated by temperature difference. Three major categories are:
- Seebeck effect: Having a loop made from two different metals, current is generated if the joining points are at different temperature.
- Thomson effect: the conductor takes up or hands down heat if the electric current is flowing and there is a temperature difference between two endpoints greater than the value governed by the Joule heat.

- The Peltier effect: the situation where the junction of two different material when a current is going through its heat is transferred together with the current.

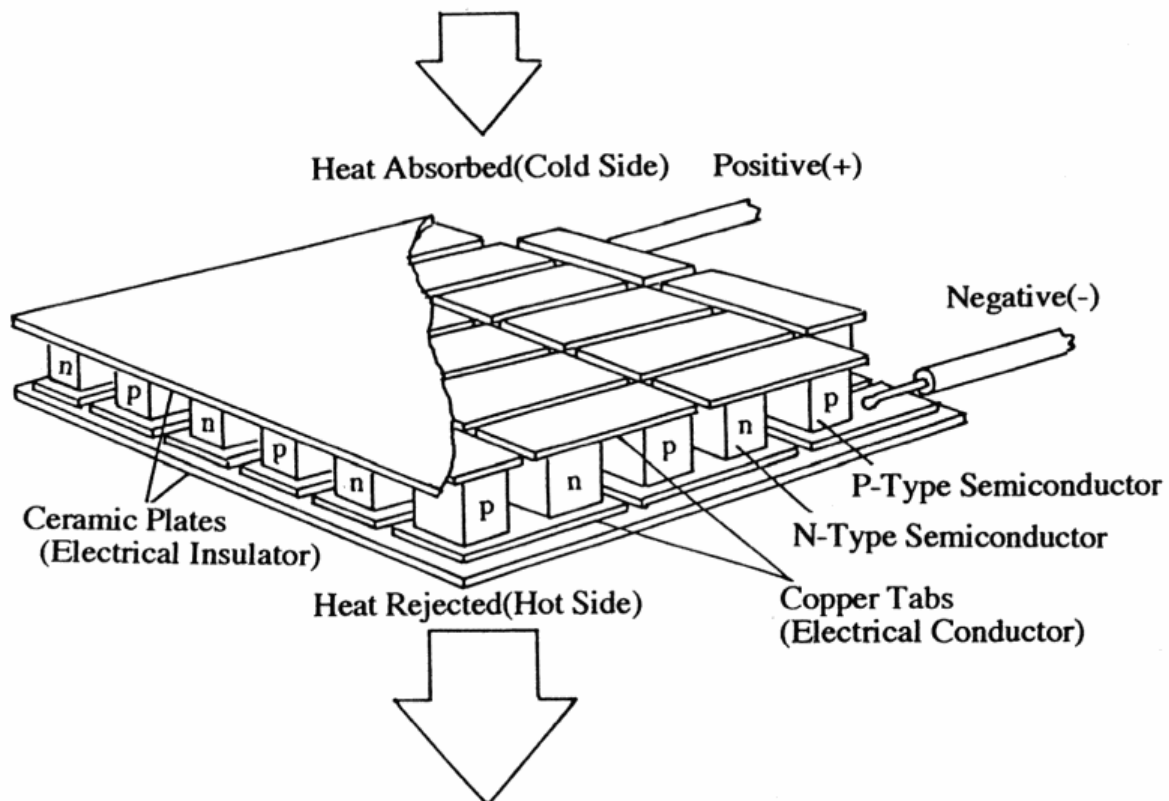Figure 1 illustrates he structure applying the Peltier effect mode of semiconductor materials.

Fig 1: The construction of the Peltier module

During the current measurement, a Peltier module is used to create temperature difference. Increasing its current the temperature difference will increase. When changing the current's direction (the polarity of the supply) the cooled/heated side will be exchanged. One side of the Peltier module is attached to the heat sink which is cooled by a ventilator. The other side is attached to a metal plate. This metal plate is mounted with the thermal sensors to be studied.

It is worth to mention, that the Peltier module can create only a given temperature difference, applying more current will cause a temperature increase at the cooled side, as well. As we reach the maximum temperature difference it is advisable to switch off the module and wait until it goes back to the room temperature. The reachable lowest temperature could be decreased if the cooled side would have better heat isolation and the heated side would have more effective outer cooling (not only a small ventilator).

Peltier modules could be used in a cascade mode, resulting higher temperature difference between the end plates. Naturally the effectiveness is below 100% every time, what it means is that the heated side is warming to a greater extent than the cooled side temperature could be lowered.

The Peltier unit could be used as a thermal generator, as well - having temperature difference between the two sides, a potential will appear its connections.

2.2. Platinum100

Platinum100 is a thermoelectric sensor, where the change of its resistance gives the temperature change. The following expression describes connection between the resistance and the sensed temperature:

$$T_R = \frac{-R_0 A + \sqrt{R_0^2 A^2 - 4R_0 B(R_0 - R_T)}}{2R_{0B}}$$

Where:

T_R is the temperature to be measured
R_T is the measurable resistance at the measured temperature
R_0 is the resistance at 0°C
A, B are constants such that:

$$A = 3.9083 \times 10^{-3} \, °C^{-1} \qquad\qquad B = -5.775 \times 10^{-7} \, °C^{-2}$$

The sensed temperature's equation is valid above 0°C and coming from this equation:

$$R_T = R_0[1 + AT + BT^2], \quad (0°C \leq T < 850°C)$$

The coefficient of the second order part is very small, that is why we can accept the temperature-resistance characteristics to be linear, but to increase our punctuality the second order part will be taken into account.

R_0 is 100 or 1000Ω in the case of most Pt resistors on the market. During this measurement we apply a 100Ω version.

The advantage of the platinum resistor is that their characteristic is very exactly known making very punctual measurement to be possible. This is the reason why it is used as a reference in the industrial life. In our case 0.01°C punctuality is achievable. Another benefit, that it is applicable in a wide temperature range, approx. -270...600 °C. The small sensitivity (0.00385 Ω/Ω/°C or 0.385 Ω/°C for a Pt100) is their disadvantage since a high accuracy measuring set-up is required to use them. Three or four-wire resistance measurement is required applying very low, constant measuring current. The response time of the bulky resistors is rather high due to their bigger heat capacitance value. (This measurement is using small size Pt resistors, their response time acceptably short.)

2.3. Thermistors

The thermistors are resistors having a high (higher than standard resistors) temperature dependent resistance. In other words, they have a high temperature coefficient. This can be negative or positive. NTC (negative thermal coefficient) thermistors decrease their resistance if temperature increases. PTC (positive thermal coefficient) thermistor increases resistance with temperature.

The material of the thermistor is semiconducting metal oxides such as MnO or NiO. There are some favorable oxide mixtures, as well, such as $TiO_2 + MnO$, $Mn_2O_3 + NiO + CoO$. The temperature dependence of the NTC thermistors is:

$$R(T) = A \cdot e^{(B/T)}$$

Where A and B are characteristic constants, T is the temperature measured in Kelvins.
Taking the logarithm of the above expression:

$$\ln R = \ln A + B/T$$

This is a linear function between the logarithm of the resistance and the reciprocal of the temperature (Fig 2).
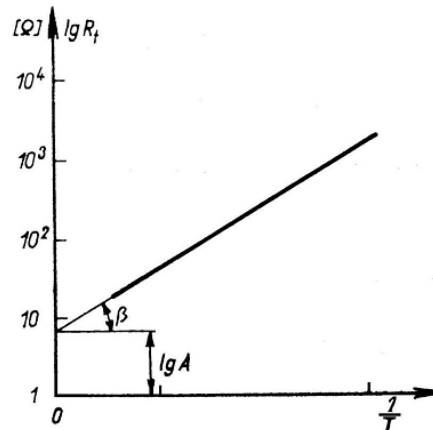

Figure 2: Logarithmic dependence of the resistance and reciprocal temperature

Applying the above graph, A and B (the material characteristic constants) could be obtained:

$$B = \ln 10 \cdot \frac{d(\lg R_t)}{d\frac{1}{T}} = \ln 10 \cdot tg\beta$$
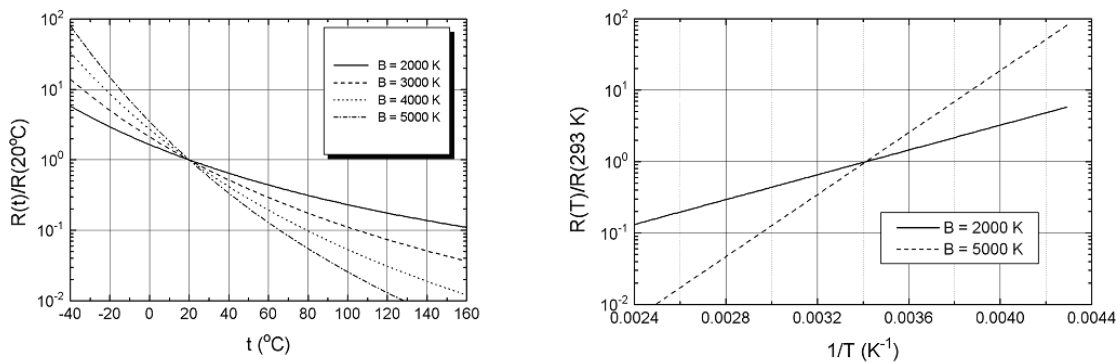
$$A = 10^{\lg A}$$

Figure 3. Characteristics of NTC thermistors

The advantage of the thermistors is their low cost and high sensitivity on a remarkable range (the NTC applied in this measurement is covering a resistance decade). The disadvantage is their nonlinear characteristics (this is especially valid for the NTCs) causing less accurate measurement than the Pt resistors.

2.4. Transistor

The increasing temperature increases the free carrier concentration in the semiconductors. This happens in the bipolar transistor, as well. Due to it, the parameters and characteristics will change, e.g., the operating point's current is growing, and the I-V characteristics will be shifted.
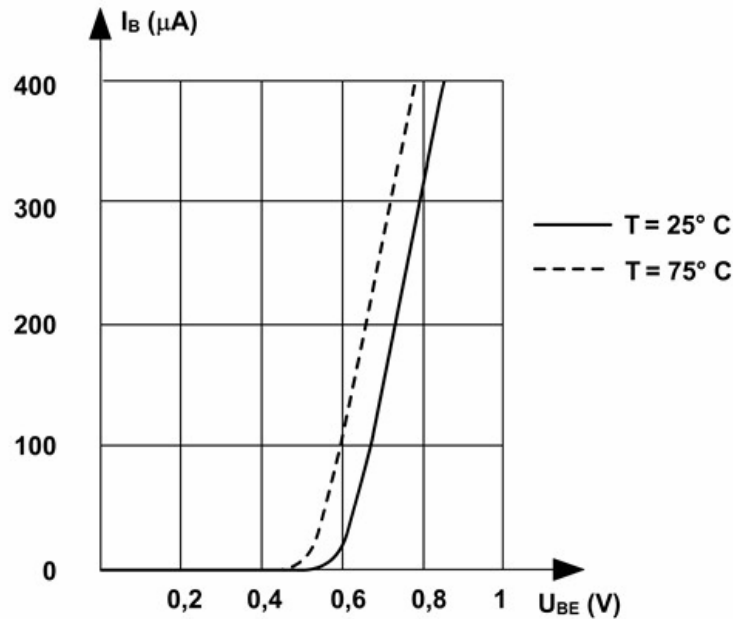
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Figure 4. temperature dependence of the input characteristics of a transistor

The temperature increase is led to the increased base- and emitter current and to the left direction shift of the characteristics. The thermal coefficient (in the part where meaningful current is flowing) is

$$TC=\Delta U_{BE}/\Delta T \approx -2mV/°C$$

Due to the above-mentioned processes, the devices containing p-n junction is applicable as a temperature sensor. This is applied mostly in the IC technologies, where the integration of Pt resistor or any thermistor brings too many difficulties. Note that the above diagram does not refer to JFET or MOSFET types.

3. Measurement setup

3.1. The software

In the measurement the cDAQ (DAQ stands for data acquisition) measurement system developed by the National Instrument is applied. At first this system should be switched on. Starting the measurement, the connection to the computer and the proper power supply should be checked. If they are ok, the computer will recognize the cDAQ system and will be ready to go. It is important, to switch on the cDAQ before the logging program starts.

To run the software, click on the *termosensor.vi* icon. This software was created using the LabView environment. In the program, find *Measurement start* button on left side. Press this to start measuring the two Pt100 sensors and two thermistors measurement. Press the *Measurement stop* button to stop measuring.

In each measurement cycle, the software saves all the measured samples. In this test setup two Pt100 resistors, one NTC and one PTC thermistor is measured. (One of the Pt100 is mounted to the upper side of the Peltier module; another is attached to the bottom side. The NTC, PTC and the transistors are mounted onto the upper side, see Fig 5.)

The last 100 samples are shown on the different tabs, and the whole test run is depicted in separate tabs, as well. Clicking on the *Save* button the results will be saved into a CSV (comma separated values) file. This can be processed by any spreadsheet program, like

Excel, Numbers, etc. The csv file contains records in which the first value is the upper Pt100, second is the lower Pt100, third is the NTC, and fourth is the PTC. Make sure to setup the proper regional setting of the CSV file by the switch in the program (HUN or ENG).

The data logger uses a constant sampling rate, so the x axes corresponds to the time. The sampling time could be determined measuring e.g. the time of 100 samples.

As it was mentioned earlier, the Pt100 sensors are the most accurate ones, that is why they are used as a reference. The software is giving the temperature in Celsius, applying the previously given expression. This may not be totally accurate in an absolute sense (it is not compensated for the cable resistance), but the difference should be small, and the relative temperature measurements are not affected by it.
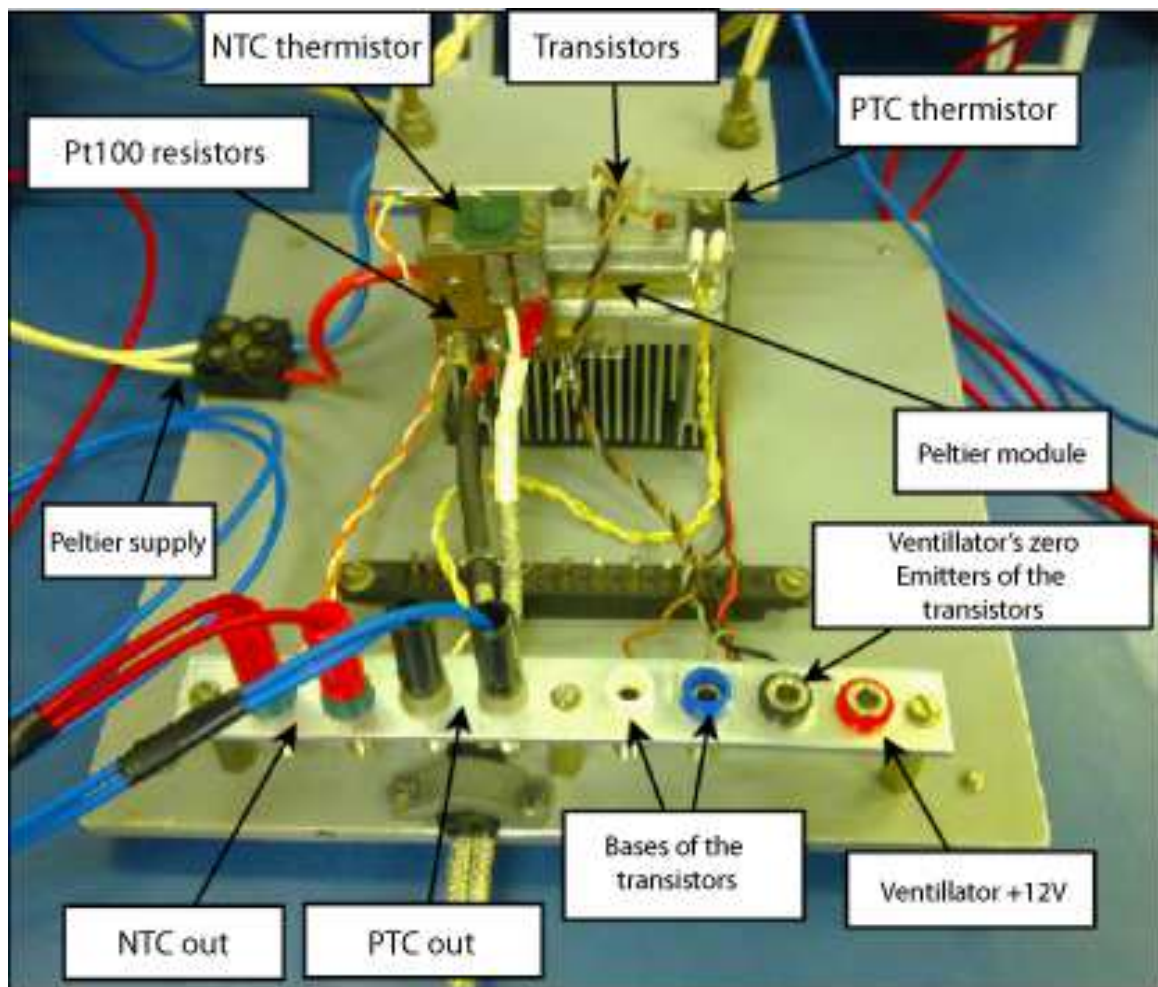
3.2. Hardware

Figure 5. The test setup

The Peltier module is cooling one side and heating the other. If the red banana plug is plugged into the positive connection then the upper side will be cooled. In the case of the opposite connection the upper side will be heated. The bottom side of the Peltier module is attached to the heat sink equipped with a ventilator (fan). The ventilator requires 12 V supply.

In both sides is mounted with a Pt1000 sensor. At the bottom side we have an NTC, a PTC thermistor, a Si, and a Ge transistor. The ground of the ventilator is joined to the emitters of the transistors. This is the common ground.

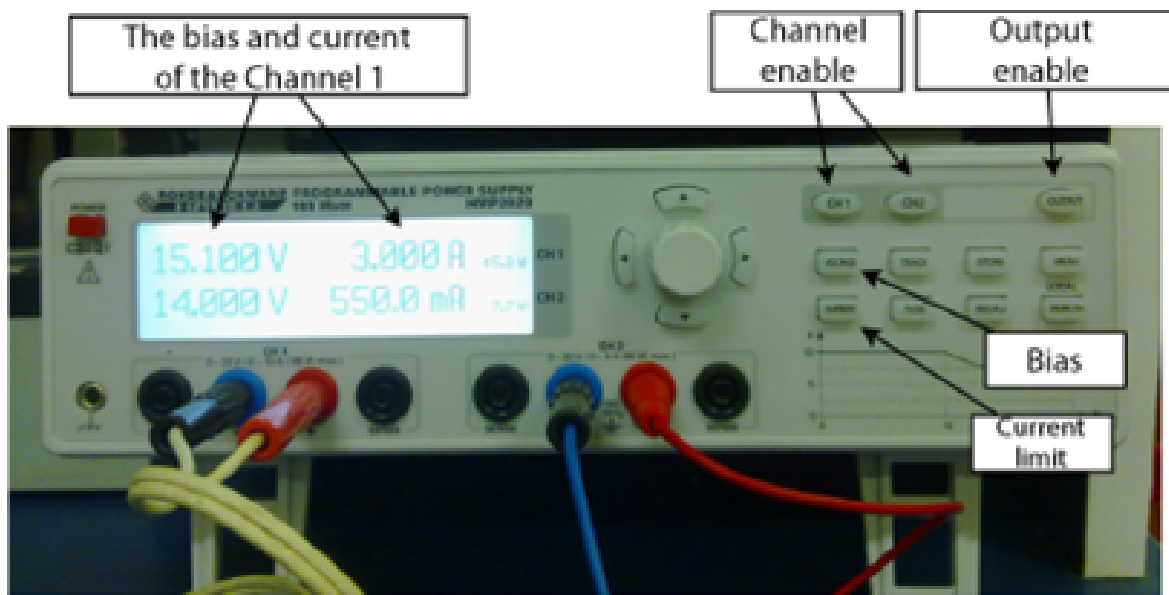## 3.3.   Application of the Power Supply

Figure 6: HMP2020 Power Supply

The left part (Channel 1) of the Hameg HMP2020 double power supply is applied to feed the Peltier unit. The right side (Channel 2) is for the ventilator. The Peltier module is driven by current, for that we have to set 15 V. The current limit should be max 2A (the teacher may give updates). Each channel can be enabled separately. The supply will appear on the output only if it is enabled with the "Output enable". The switched-on status is shown with the light is on in the buttons. Ch1, Ch2 buttons has a green light in voltage generator mode, while it has a red light in current source generator.

To adjust the voltage value, press the *Voltage* button followed by button of the desired channel. One digit on the display will blink white on black. This digit could be adjusted by the up and down arrows or using the knob. The left and right arrow is to navigate between the digits. To set the current limit, the *Current* button should be pressed, the process after that is the same.

The output color code is: positive – red, negative – blue. The display is able to show the output power, as well.

4. Measurement tasks

4.1. Peltier module

4.1.1. At room temperature, the sensitivity of the Pt100 sensors could be checked. Touch for a short time by hand the metal plate the temperature reading of the Pt100s will clearly change. Since these sensors have small sizes, they have a small heat capacitance resulting fast response.

4.1.2. Set 15V voltage and 2A current limit for the Peltier module. Connect the red banana plug to the positive pole, in this way the top plate will be cooled. Switch on the ventilator using 12V supply.

4.1.3. Measure the bottom and upper plate's temperature-time diagram. On the first tab of the program the last 100 readings of the platinum sensors are shown, together with the actual data at the left side. See the nonlinearity of the curves.

4.1.4. Find the smallest temperature that the upper plate can reach. Measure the bottom plate's temperature, as well. Study the process, as the upper plate starts to heat up (after reaching the bottom temperature). A short while after reaching this point, switch off the current of the Peltier module to let the plates reach room temperature again.
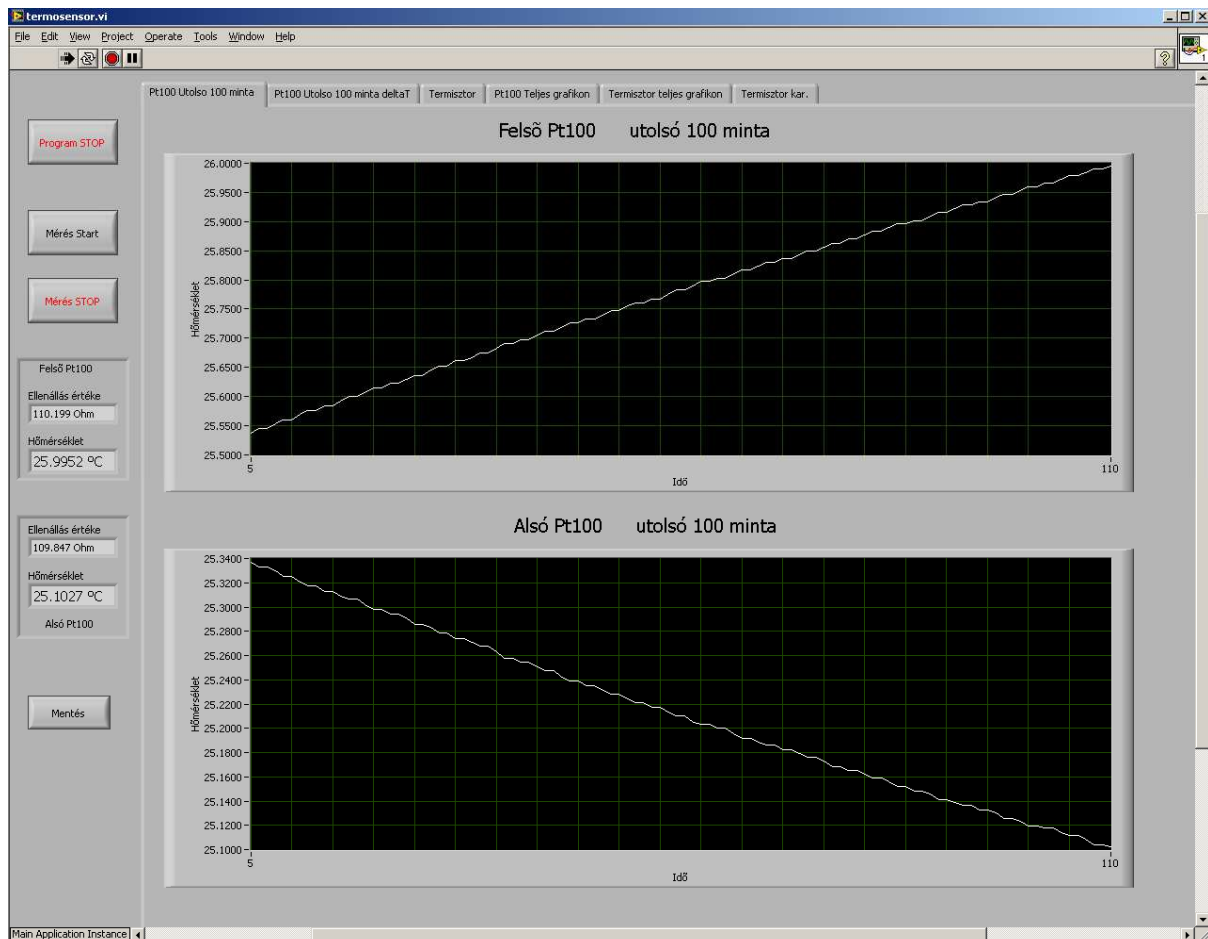

Figure 7. First tab of the software: Pt100, last 100 sample

4.1.5. Change the cables of the Peltier module from the power supply to the voltmeter. Measure the voltage of the Peltier module using the voltmeter, in the same time, the temperature difference between the two planes could be obtained from the 2nd tab of the

program. In this case the module is working like a thermocouple producing voltage due to the temperature difference. Record the values in several points while the module is cooling back to the room temperature and graph the data. Calculate the temperature-voltage ratio.
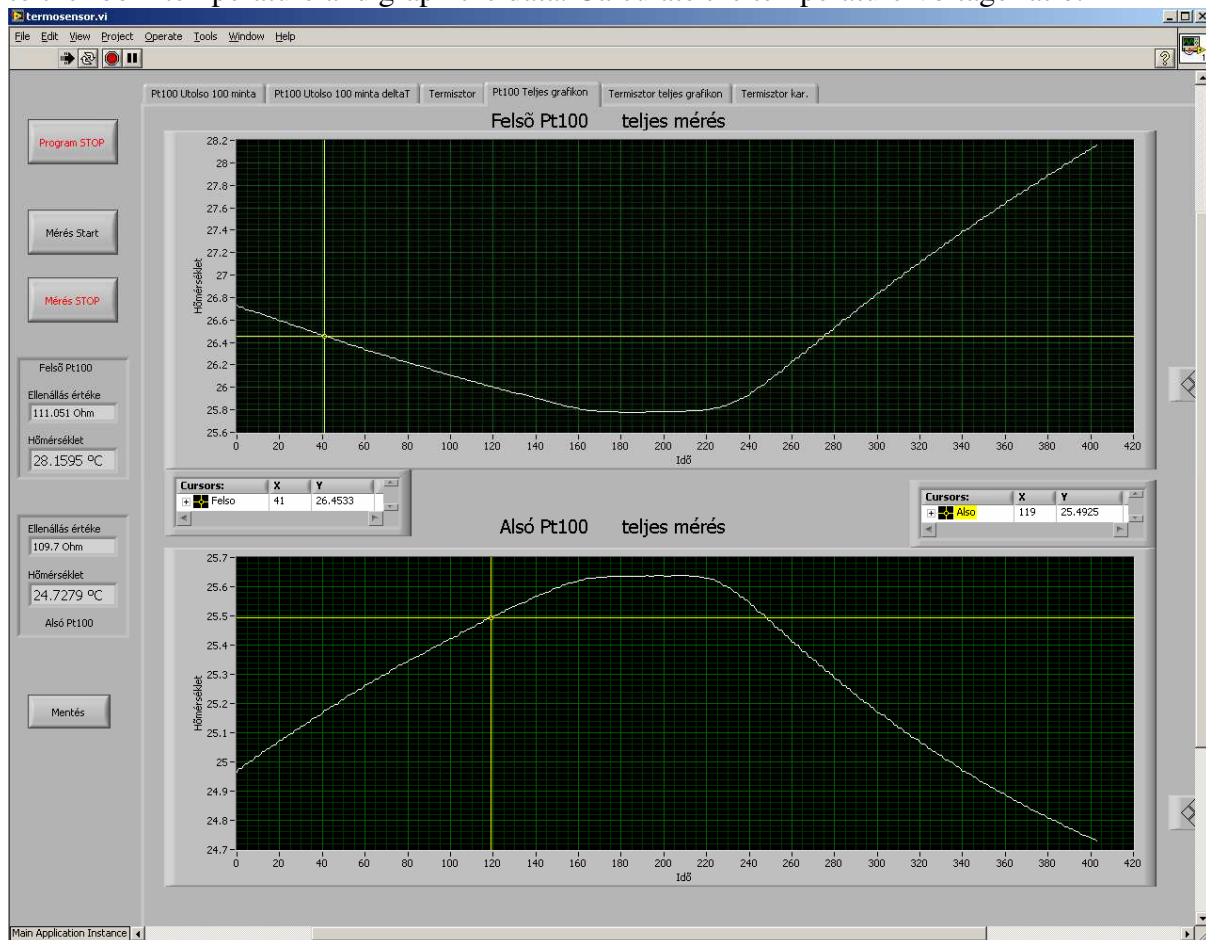

Figure 8: Software 4th tab: Pt100, whole graph

4.1.6. After stopping the measurement, clicking onto the 4th tab, the whole measured graph can be seen. There are cursors to measure separate data. (Do not click onto the *program stop* until the end of the lab session.) The graph of the measurement can be reconstructed using the CSV file using any spreadsheet program.

4.2. Thermistors

Each thermistor is mounted onto the upper plate. The data logger system is able to measure a maximum 10.5kΩ resistance. This is the resistance of the NTC thermistor at 27°C. It means that we are able to measure the NTC only above 27°C. The resistance of the PTC is about 1kΩ so it can be measured in the whole temperature range.

4.2.1. Connect the Peltier module for heating on the upper plate (red banana plug goes to the negative pole!). At the 3rd tab, the last 100 points of the temperature and of the thermistors resistances can be observed. After finishing the measurement cycle the 6th tab contains the temperature-resistance characteristics of the thermistors.
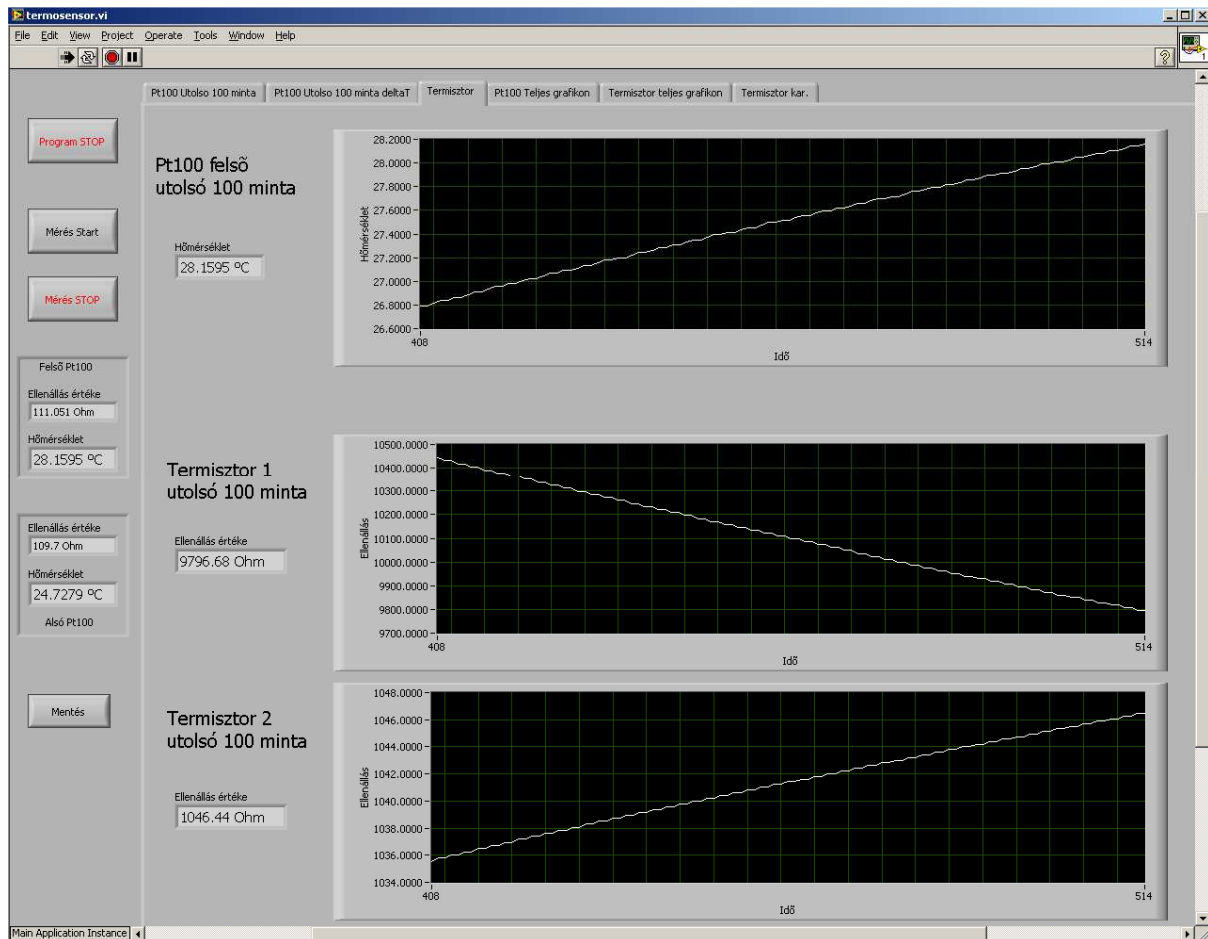
Figure 9: Software, 3rd tab: last 100 sample of thermistors measuerement

4.2.2. Obtain the characteristics of the thermistors. At first, heat up the upper plane, then connect the Peltier module in opposite to cool down until it reaches room temperature. At certain temperatures (e.g., 30°C, 40°C, etc.) the resistance values have to be recorded manually during the heating and the cooling regime, as well. Is there any difference? Why?
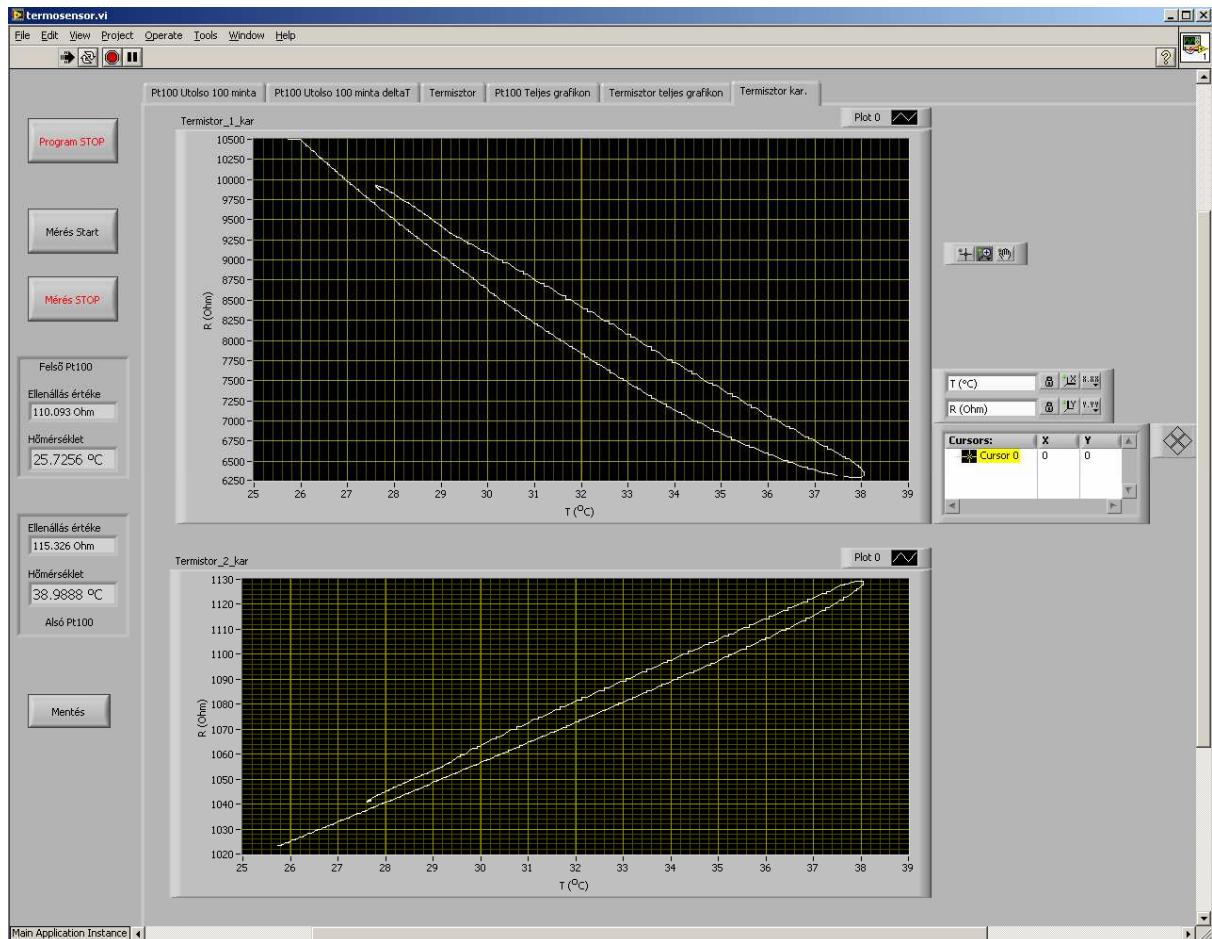
Figure 10: Software, 6ᵗʰ tab: the full thermistor characteristics with its hysteresis

4.2.3. The obtained hysteresis could be decreased if the thermistors are heated more slowly. In this way they have more time to adjust themselves to the actual temperature and the value measured by Pt100 will be a closer estimate of the thermistor temperature. Repeat the previous measurement applying only 500mA and check the hysteresis in this situation.

4.3. Transistor

4.3.1. Set up a 2A current for the Peltier module and connect the red banana plug to the negative pole. In this way the upper plate will be heated.

4.3.2. The base-emitter voltage of the transistors can be measured by the Hameg multimeter on diode mode. The emitters are on a common point together with the ventilator negative pole. (see Fig. 5) The bases have separate connections. Applying two multimeters in diode regime the forward voltages can be measured simultaneously.

4.3.3. Obtain the temperature–forward voltage curves for both transistors. The program measures the temperature; take a reading in every 5 degrees approximately! Do the graph (temperature–forward voltage). Calculate the ΔU/ΔT values. Compare it to the theory. Is there any difference between the two transistor's behaviors?

5. Equipments to be used

Peltier module, 2 pc Pt100, PTC thermistor, NTC thermistor, Ge transistor, Si transistor
2 pc digital multimeter (Hameg HM8012)
1 pc Hameg double power supply
NI cDAQ : NI 9172 frame, NI 9217 and NI 9219 modules
PC, LabView software

6. Entry test question

1. What does the Peltier module if a current is going through it?
2. What are the types of thermistors and what characterize its temperature dependence?
3. What are pros and cons of a platinum thermoresistor?
4. What is the temperature dependence of the transistor characteristics?

7. Measurement protocol

To prepare the report in Excell or Numbers is strongly recommended!

Each measuring group is asked to give in one report. The report should be submitted in pdf format and not more than 5 pages, through e-mail latest after two weeks of the measurement performed.

The file name must contain the surname of the authors and the short title of the exercise, e.g., "pap_kovacs_thermo.pdf"

The protocol must contain:

1. The title of the measurement

2. The names of the colleagues performing the task.

3. The date and location of the measurement.

4. A declaration stating that the task is performed by the enumerated colleagues.

5. The list of applied equipment with types and identification numbers.

6. The tabulated list of the measured values (it is feasible), the calculated values, and the requested graphs.

7. In the case of calculations, the applied formulas.

8. Short discussion of the results for each measurement task.

PLEASE do not copy previous protocols. Identical protocols will be refused.

To transport the measured and recorded data PLEASE use the internet connection instead of connecting any USB device.