I DESCRIPTION OF THE EQUIPMENT

On the table you have the basic unit of the FACET (Fault Assisted Circuits for Electronics Training) system. This contains:

- power supplies
- a 32 relay matrix which switch, in order to select the excitation / measurement signal, at different nodes from the studied circuit.
- A/D and D/A convertors
- serial interface for computer.

From the manufacturer's, LAB-VOLT®, point of view the computer takes into account each student (or group of students) and leads him step by step in completing the work. Periodicaly testing occurs and sometimes progression to the next step is halted unless the correct answers is provided. At the end of the work a mark is automaticaly generated. Due to the fact that the computers found in the lab require updating, at the moment, work proceeds without the computer-manual.

The main unit houses specialised boards for different lab works (in this case TRANSDUCER FUNDAMENTALS). Obviously the computer has the corresponding programs.

The board connect to the main unit through a ZIF connector with 130 contacts.

ZIF (Zero Insertion Force) is a connector with variable geometry which opens its „jaws" at insertion and after positioning they clamp down by activating a rotating button.

This way we eliminate friction between the board and the connector and thus remove any type of use damage.

The board contains circuits for measuring various transducers clearly marked off and denoted as in the figure.

In the N-E corner of the board there are two auxiliary circuits :

- INSTRUMENTATION AMPLIFIER, with selectable ×1, ×10, ×100, ×1000 fixed gains through the DIP switches DIP (Dual In Line Plastic). Move the groove to the selected gain.

ATTENTION!

Position a single groove in the UP direction

- The reference source generates a series of fixed voltages which are stable, these being necessary in the functioning of some of the circuits found on the board but also for the ADC found on a supplementary board with microcontrollers which connects to J1.

This circuit does not directly interfere with the progression of the lab work.

In the N-W corner of the board the circuits which contain the transducers for measuring temperature are placed.

The transducers themselves are mounted inside a central, thermaly isolated chamber. The insulation is done by a plastic transparent lid. Inside the chamber 8 resters of 8,2Ω 0,5W are mounted which, under the control of an ON-OFF regulator, dissipate enough power in order to heat the chamber until pre-established temperatures : 35°C, 40°C, 45°C, 50°C selectable by placing a jumper.

The position COND - unused now - coresponds to computer controled functioning.

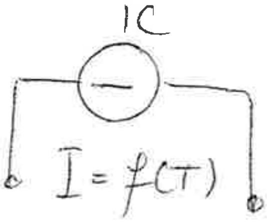
On the board we can find mini-terminals which can be connected to measuring pins where, through crocodile clamps, we can connect measuring equipment. At the same mini-terminals we can connect wires for completing circuits. For certain connections we use riders and the terminals which corespond to these type of connections are marked by a dotted line.

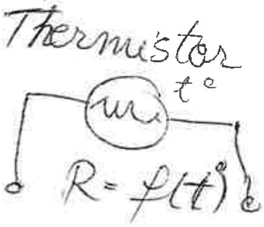
II LAB WORK PROCEEDINGS

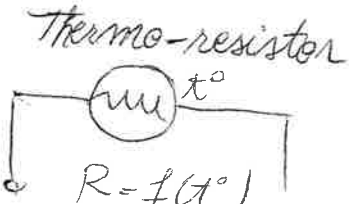
II 1. Temperature measurement

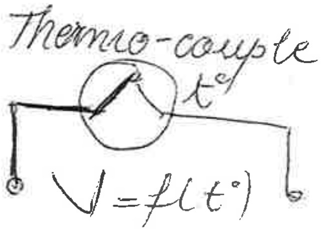
II 1.1. Introduction

We will study four transducers for temperature measurement and the the coresponding measuring circuits. For all four the input measure is temperature but the output measure differs.









One of the four, namely IC, was chosen as reference transducer and connected to the the temperature control circuit of the thermostatic enclosure.

The choice is argumented by:

- liniarity and stability of the transfer characteristics
- simple calibration
- low overtemperature at connection in the circuit due to the most favorable ratio between ~~diss~~ dissipated power and thermal resistance of the encapsulation.

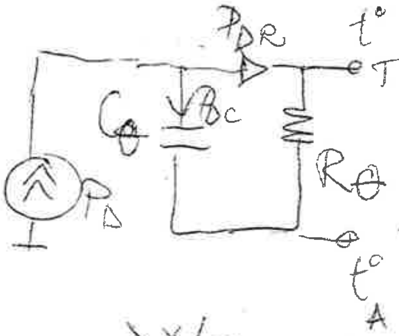
In conclusion, in this lab work ic is the means of measuring which is considered a fair standard from a metrological point of view.

Eventual measuring errors obtained by means of different transducers reffer to measurements done with this standard.

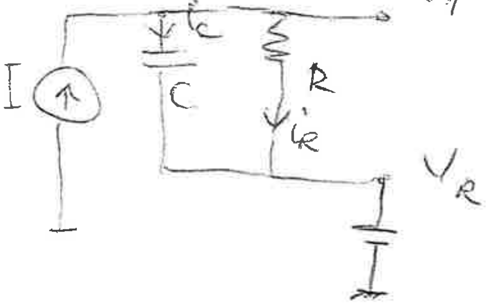
Posible measuring errors of the transducer can not be highlighted unless comparisons with other certified transducers is performed.

The thermal processes can be modeled in the ~~easy~~ easiest way by a simple equivalent thermal circuit.

We accept the following analogies:



THERMAL	ELECTRICAL
P_Δ [W]	I [A]
Δt° [°C]	ΔV [V]
$W_\Theta = \int P_\Delta dt$ [J]	$Q = \int I dt$ [C]
$W_\Theta = m\rho \cdot \Delta t^\circ = C_\Theta \cdot \Delta t^\circ$ [J]	$Q = C \cdot \Delta V$ [C]



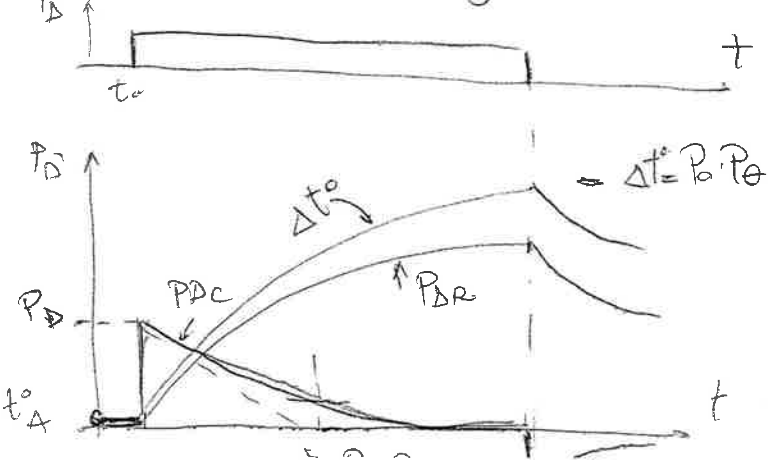
m – mass of the object which takes the dissipated power [kg]

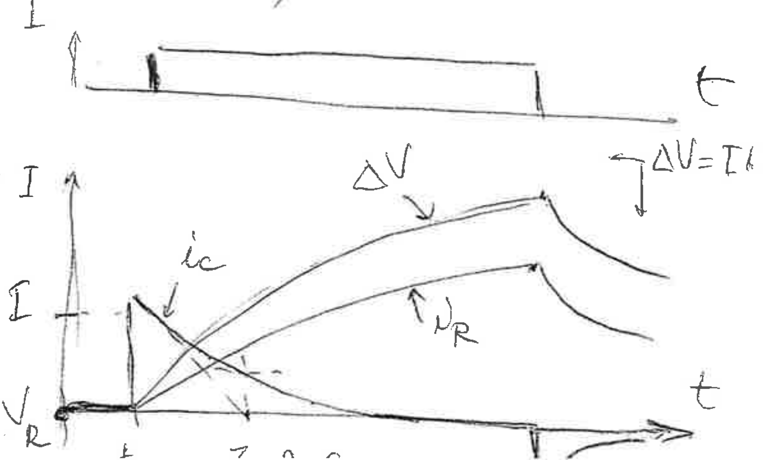
ρ – specific heat of the object [J/°C · kg]

C_Θ – thermal capacity of the heated object [J/Δt°]

If we admit that in the permanent regime the ambient temperature t°_A, and the reference voltage V_A respectively, are constant and maintain constant regardless of P_Δ and I respectivel and $P_\Delta = 0$, $I = 0$ then $t^\circ_T = t^\circ_A$ and $V_1 = V_R$

If at the moment to we apply step jumps P_Δ, I, the values discassed will vary thus:





The segments of the variation curve have one of the following forms:

$y(t) = Y_0 \cdot e^{-t/\tau}$ or $y(t) = Y_0 (1 - e^{-t/\tau})$

For any of the curves the line tangent to the curve at t_0 intersects the permanent regime after a period of time equal to τ. The value measured at this moment is equal to the magnitude of the jump lowered by e times.

Because for thermal processes the time constants are large (hundreds of seconds) we need to wait up to until the temperature stabilises in the thermostat.

II. 1.2. Temperature transducers integrated in silicon

The transducer which is utilised is of the IPTAT [Current (I) Proportional to Absolute Temperature] type, whose functioning is based on the thermal voltage $V_T = \frac{KT}{q}$ in silicon. This voltage, directly proportional with temperature in its absolute form T[K], produces a current which is directy proportional. In the case of transducer AD 592 (Analog Devices) the nominal sensitivity is $S_N = \frac{1\mu A}{K}$. The real sensitivity may differ depending on the errors specified in the data sheet.

A circuit similar to this one is found in problem No. 27 BSAD on www.messnet.pub.to. There also exist integrated transducers VPTAT (Voltage Proportional to Absolute Temperature)

The measuring circuit for voltage with AD 592 is drawn in the figure (Fig 1). The circuit contains a resistor sensor $R_S = 1k\Omega$ between the test terminals TP_1, TP_2 between which a voltage of $1\mu A/_K \cdot 10^3 \Omega = 1mV/K$ can be measured

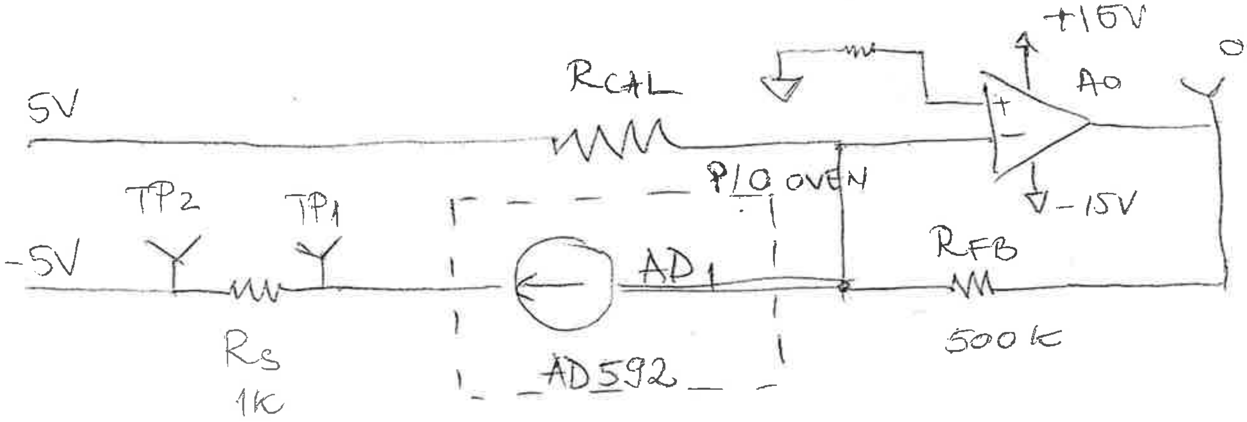


FIG 1.

Because the output measure of the transducer is a current and the usual output is a voltage, the measuring circuit is a converter through transimpedance built from AO and the feedback resister of 500 kΩ.

Thus $V_{OUT} = \frac{1\mu A}{K} \cdot 500\,k\Omega = 0.5V/K$. We neglected the current through R_{CAL}. From selecting R_{CAL} we correct the errors of the AD592 from the circuit. R_{CAL} is chosen so that $V_{OUT}(38°C) = 0$

- Check that there are no connections on the circuit board mounted on the main unit, including the DIL jumper from the IC TRANSDUCER section
- Start the main unit through the swich found on the right side. Start is confirmed by the lighting of the two red LEDs. Through this the measuring circuits are powered.
- Measure the voltage through AD592, „at cold", by measuring the voltage between TP_1 (+Multmeter) and TP_2 (-Multimeter) with the multimeter on V_{DC} and $V_{MĂS} > 200mV$ and compute and remember $I_T = \frac{V_{MĂS}}{1k\Omega} = ...\ \mu A$

  Measure and remember V_{OUT} „at cold".
- The ambient temperature can be measured with a termometer with mercury. Denote $t_A^{o} = ...\ °C$
- Considering AD592 without errors, compute R_{CAL}.

- Add the jumper DIL on the position 35°C and the white two-post connector ("rider") at "OVEN ENABLE". Through this we set the thermostat for 35°C and the circulation of the heating current is allowed. The red LES "OVEN ON" will turn on when heating is turned on. We wait for the temperature to stabilize until the LED turns off and then for another 3-4 ON-OFF cycles. "Cold" measurements are repeated and the tables below are filled:

TEMP(°C)	TRANSDUCER CURRENT[mA]
35	
40	
45	
50	

TAB 1

TEMP (°C)	OUTPUT VOLTAGE(V) (mV)
35	
40	
45	
50	

TAB 2

In both situations VDC is measured but attention!, for I_T we measure 295 ÷ 325 mV and V_{OUT} is −2500 ÷ 10000 mV. Switch the sensitivity accordingly.

- Move the jumper at 40°C and wait for 3-4 ON-OFF cycles then complete the table.
- Repeat the instructions above and move the DIL jumper to 45°C and 50°C
- Are the values in table 2 within reasonable error ranges? We remind you that the measuring circuit was designed for a sensitivity at $V_{OUT} = \frac{0.5V}{°C}$ and $V_{OUT}(30°C) = 0$. If you answered yes! then pass to the next step. Remember that

$$\boxed{V_{OUT} = (t° - 30°C) \cdot \frac{0,5V}{1°C}}$$

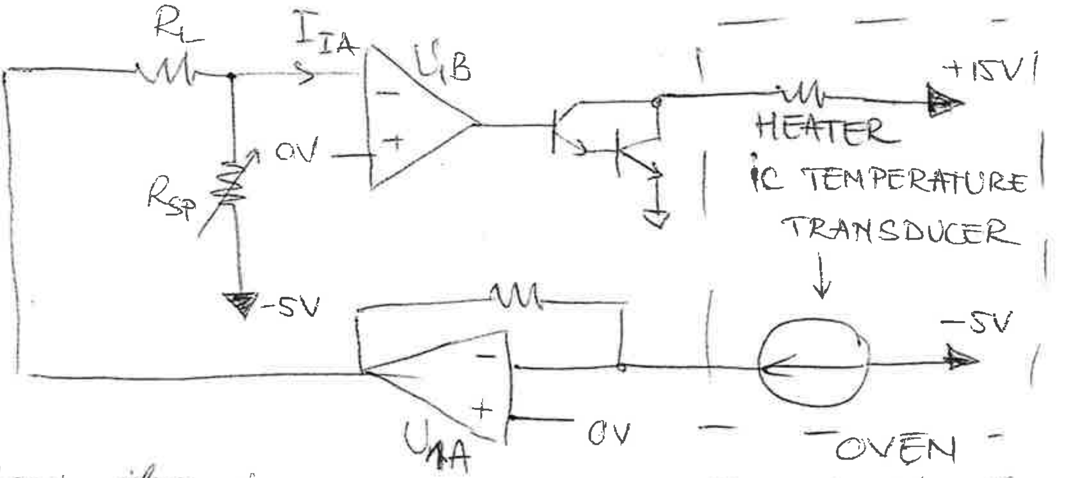
Through monitorising this voltage we have a current information about the temperature inside the thermostat enclosure.

- Connect the multimeter set at V_{DC}/10V at V_{OUT}. The measured voltage should be ≃10V. Move the jumper at 35°C and start a stopwatch. The temperature will fall from 50°C to 35°C, so with 15°C. After the passage of a time constant the variation will appear until $\frac{15°C}{e} \simeq 5,5°C$ above the reference value (35°C) meaning 40,5°C. To this temperature corresponds a voltage of 5,25V.

Watching on the multimeter the passing through this value we stop the timekeeper and we determine τ - the thermal constant of the thermostat enclosure.

II. 1.3. The study of an ON-OFF temperature regulator

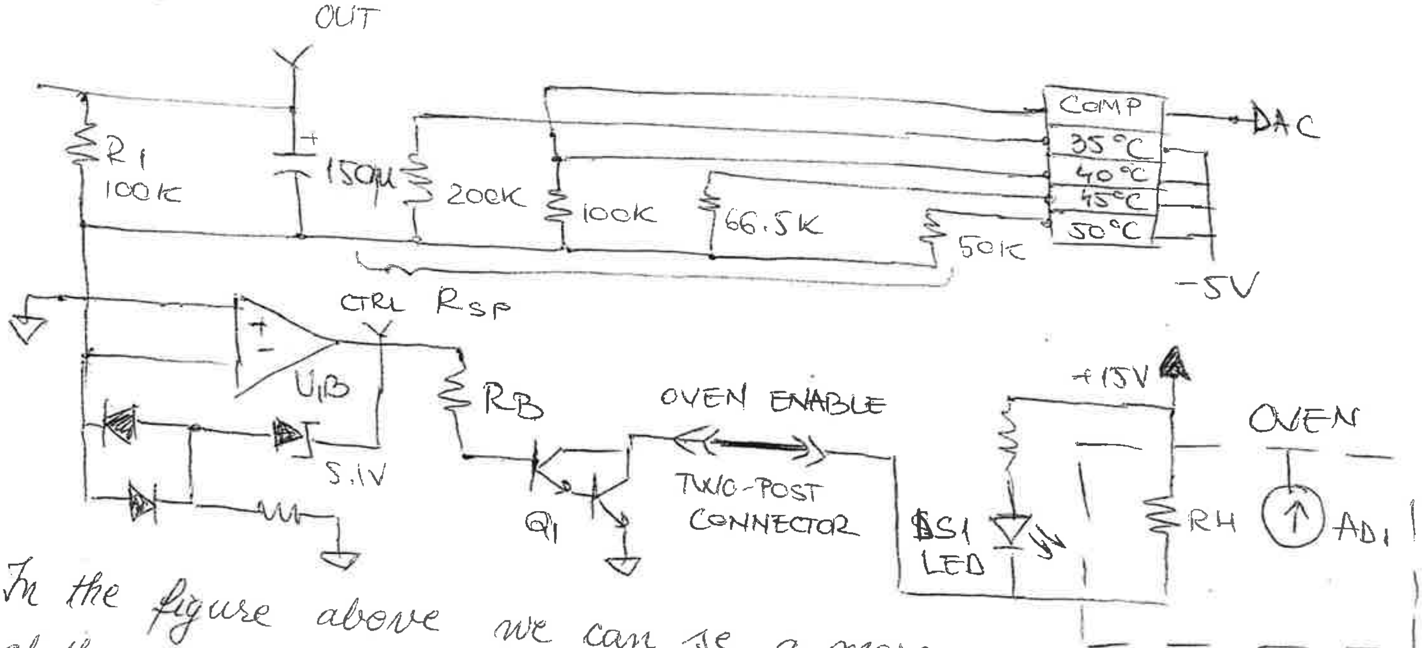
This regulator is necessary for temperature control inside the thermostat enclosure starting from the input measure of the transducer AD592 of IPTAT type.



The basic idea is measuring the voltage inside the enclosure through the IPTAT and U_1A, which generates a voltage V_{OUT} dependent on the temperature of the enclosure, and comparing it ~~to~~ at the input of the comparator U_1B: $V_{OUT}/R_L + \frac{-5V}{R_{SP}} = I_{IA}$

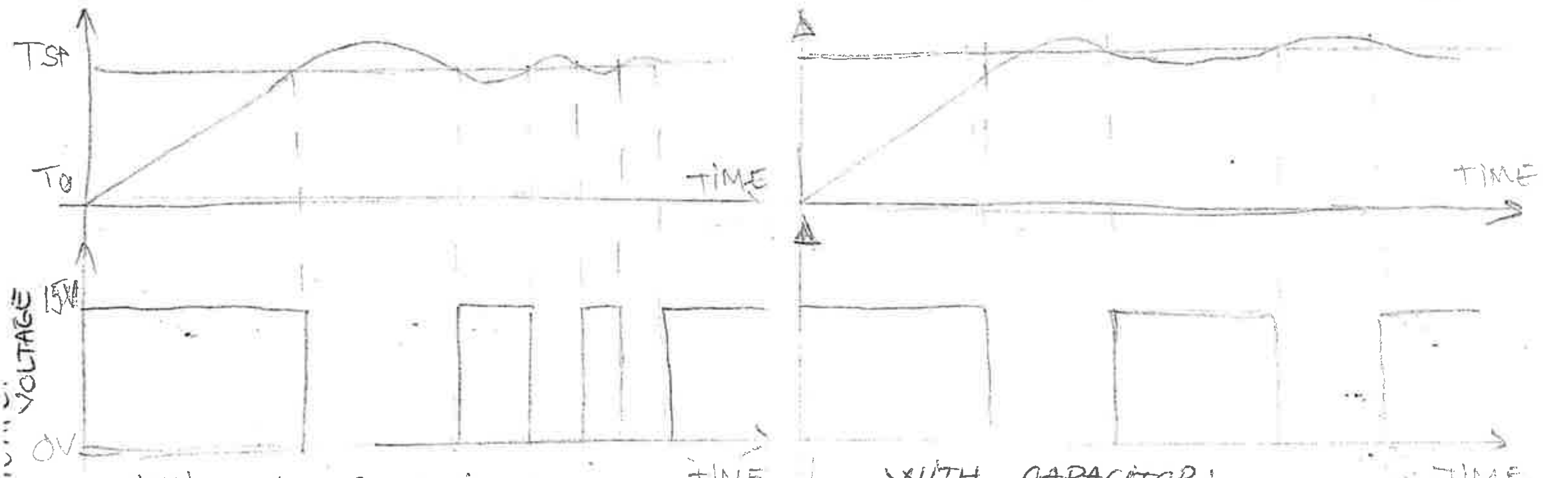
Variations of I_{IA} of approximately 1nA determine (due to the very large gain of U_{1B}) the tilting of U_{B1}'s output between + V and finaly opening the compound Darlington transistor which allows the heating current to flow through the native resistor HEATER. At predominance of the negative term on the inverting (–) terminal of U_{1B} the Darlington stage opens and the enclosure ~~opens~~ heats up and V_{OUT} increases.

When the heating makes the positive term predominant then the Darlingtone is blocked.



In the figure above we can se a more precise representation of the comparator. We can see that the resistor R_B limits the current in the base of Q_1, the rectifier and Zener diodes which limit the voltage at the CTRL terminal at +5.7V and -1.2V, the positioning of the Two-post connector "OVEN ENABLE" and the "OVEN ON" LED. The R_{SP} resistors are detailed for different values of the enclosure temperature

The most important element, from a quality p.o.v., is the 150µF capacitor. This, parallel to the R_1 resistor accentuate the effect of the fast variations of V_{OUT} (temperature) and has as effect the compensation of the thermal inertia of the enclosure.



WITHOUT CAPACITOR:
SWITCHES AT SET POINT

WITH CAPACITOR:
SWITCHES BEFORE SET POINT

In the figure we have represented the time variation of voltage pulses on the heating resistors and the temperature variation of the enclosure with and without capacitor. We can observe that in the presence of the capacitor the heat switching is anticipated and the variations around the set points is smaller.

- Move the DIL jumper at 50° and wait for the temperature inside the enclosure to stabilize. Connect the oscilloscope at 2V/div and 5s/div at the "CTRL" terminal and the multimeter on 10V at V_{OUT}.

From viewing on the oscilloscope we estimate the fill factor of the impulses from CTRL with regards to the 1.2V level $k_u \simeq 0.5V$ - we will determine the exact value $k_u = \ldots$

We observe the variation of V_{OUT} and determine the temperature variation Δt°. Remember:

$k_u = ----$ $\qquad \Delta t^{c} = ---$

Due to the mean power dissipated being $\tilde{P}_D = \frac{V^2}{R_{th}} \cdot k_u$

$$\tilde{P}_D = \frac{(15V)^2}{65.6\Omega} k_u$$

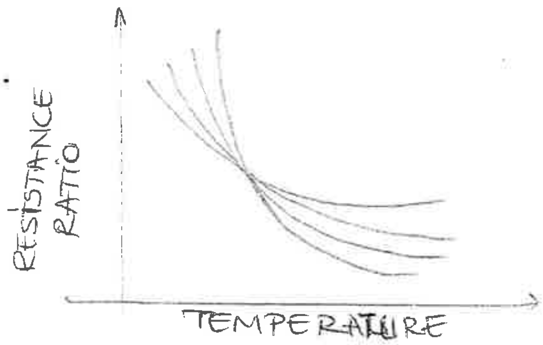
From here we compute $R_{\theta} = \frac{\Delta t^{c}}{\tilde{P}_D}$

Now we can compute the thermal capacity of the enclosure:

$C_\theta = \frac{\tau}{R_\theta}$. For τ see pg 8

II.1.4. Measuring temperature with a thermistor

The thermistor is a resistive transducer with a non-linear variation of resistance with temperature



$$\frac{R_T}{R_o} = e^{B\left(\frac{1}{T} - \frac{1}{T_o}\right)}$$

$$R_T = R_o \cdot e^{B\left(\frac{1}{T} - \frac{1}{T_o}\right)}$$

R_o - thermistor resistance at $t° = 25°$ or $T_o = 298\,K$

B - a material constant with the dimension [K]

°C	RESISTANCE RATIO	TEMPERATURE COEFICIENT	RESISTANCE DEVIATION
0	3.2650	5.1	1.5
5	2.5391	5.0	1.2
10	1.9898	4.8	0.8
15	1.5710	4.6	0.5
20	1.2491	4.5	0.2
25	1.000	4.4	0.0
30	0.8057	4.3	0.4
35	0.6531	4.2	0.7
40	0.5327	4.0	1.0
45	0.4369	3.9	1.3
50	0.3603	3.8	1.5

$R25°C = 10k\Omega \pm 10\%$

RT = R25°C x resistance ratio at T°

TAB 3

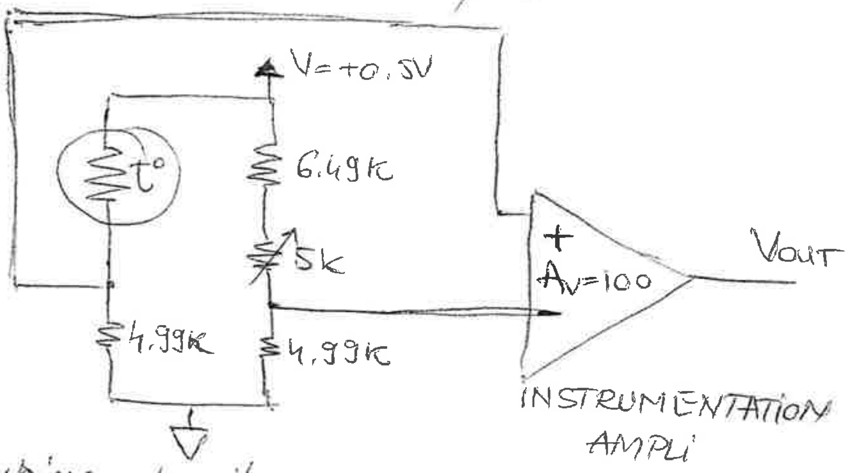
In TAB 3 are presented the data of the thermistor from the lab work, from the graphical representation but also from the table it is obvious that this transducer is non-linear. The thermistors have a high sensitivity (especialy at low temperatures) and a reasonable linearity for small temperature intervals such as in the lab work.

- Modify the temperature from the enclosure, measure the thermistor resistance with the multimeter on kΩ directly at the terminals and fill in the table:

TEMPERATURE [°C]	RESISTANCE [kΩ]
35	
40	
45	
50	

TAB.4

Compare with the data from TAB 3.



The measuring circuit is represented by a Wheatstone bridge and an instrumentation amplifier with $A_V=100$. The calibration is done for 0V at $t°=30°C$ through the variable resistor of 5kΩ. Knowing the thermistor resistance from TAB 3 what is the value of the resistance so that the bridge is balanced?

The circuit is designed for a global sensitivity of $S=0.5/°C$

For closing the circuit we need two two-post connectors linked at T_h terminations.

II. 1.5. Measuring with platinum thermoresistor

The platinum thermoresistance (RTD) are very stable transducers with a quasi-linear transfer characteristic. At least in the current temperature range the characteristic's non-linearities can be neglected.

TEMP(°C)	RESISTANEE(KΩ)
0	1.000
5	1.020
10	1.039
15	1.058
20	1.077
25	1.096
30	1.116
35	1.135
40	1.154
45	1.173
50	1.193

$\alpha = 0{,}00385$

$R0°C = 1{,}000\ K\Omega$

$R_T = R0°C \times (1+\alpha T)$

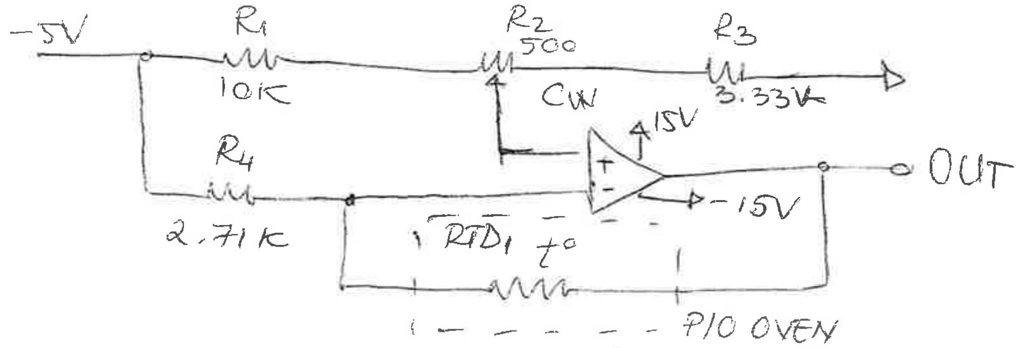
The excelent liniarity is obvious from TAB 5.

TEMP(°C)	REZ(KΩ)
35	
40	
45	
50	

TAB 6

- Connect the multimeter on KΩ directly at the terminals RTD, modify the enclosure temperature and fill in the TAB 6.

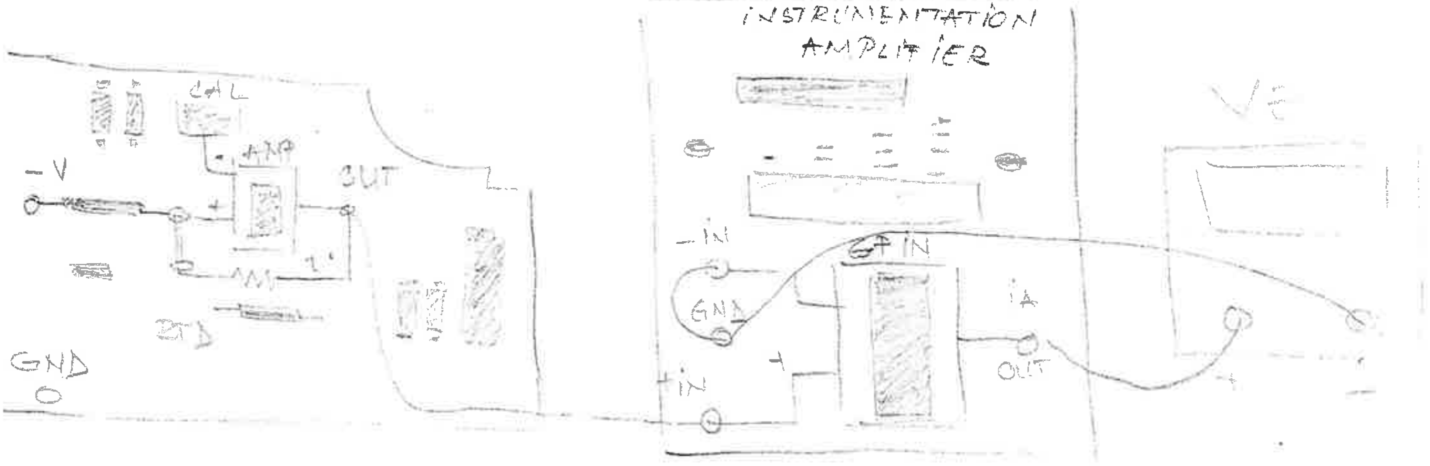
The basic measuring circuit is an active bridge with the thermoresistor connected in the negative feedback loop.



P14

The circuit is designed for Vout = 0 V at 30 °c and for a sensitivity of 5 mV/°c

In order to reach a global sensitivity of 0,5 V/°c as the cases discussed before we connect, as seen in the figure below, the instrumentation amplifier with AV = 100.



Vout → +iN
-iN → -VE
OUT → +VE