EXPERIMENT #2 DC CIRCUITS AND SIGNAL TRANSFER ECE212H1F

OBJECTIVES:

- To review measurements of DC voltage, DC current, and resistance, using a digital multimeter, DMM.
- To study conditions necessary for an optimal signal transfer, specifically conditions for the optimal voltage transfer, optimal current transfer, and optimal power transfer, for various ratios of source and load resistance.
- To design and test a thermistor-based temperature sensor.

GENERAL COMMENTS:

- Review methods of DC voltage measurement, DC current measurement and resistance measurement using a digital multimeter, DMM.

  Reference: *Laboratory Equipment Instruction Manual (posted on Quercus with Lab 1 materials)*
- Recall that a signal has to be adjusted to a required value before it is connected to a protoboard.
- Wherever applicable, indicate values of internal resistances and ranges of the equipment used in the measurement.

Results computed in the preparation assignment of each part of the experiment serve as a prerequisite for the experimental part. Transfer all computed data in tables and graphs to your lab-book. All plots must be pasted or stapled into the lab book. **Marks will be deducted for failing to comply, and for missing or poor documentation.**

TABLE OF CONTENTS:

REQUIRED READING:

Chapters 2-4 of the course textbook (Alexander & Sadiku, 6th edition)

INTRODUCTION:

(A) DC CIRCUITS

The purpose of this experiment is to study signal transfer in electric circuits. When two electric devices are interconnected, for example when the output of a sensor (source) is applied to the input of an amplifier (load), an information-carrying signal (either voltage or current) supplied by the source might be affected.

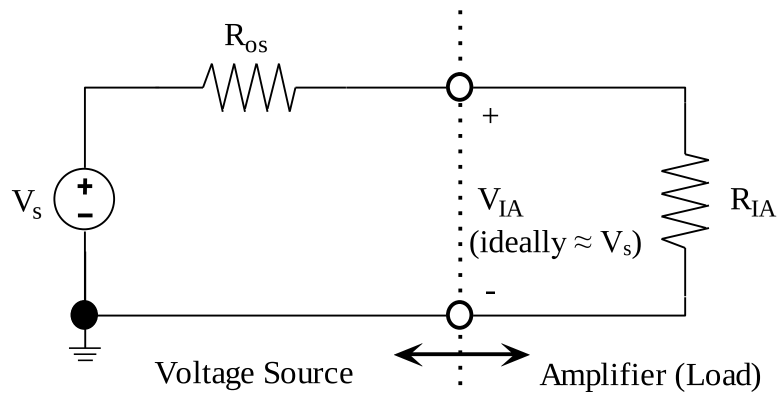


Fig. 1

If the information-carrying signal is a *voltage* as in Fig. 1, ideally the source voltage should appear across the input terminals of the amplifier, i.e. $V_s \approx V_{IA}$ as R_{OS} approaches 0Ω.

Similarly, if the information–carrying signal is a *current*, as in Fig. 2, ideally all current supplied by the current source should flow into the input of the amplifier, i.e. ideally $I_S \approx I_{IA}$ as R_{OS} approaches ∞.

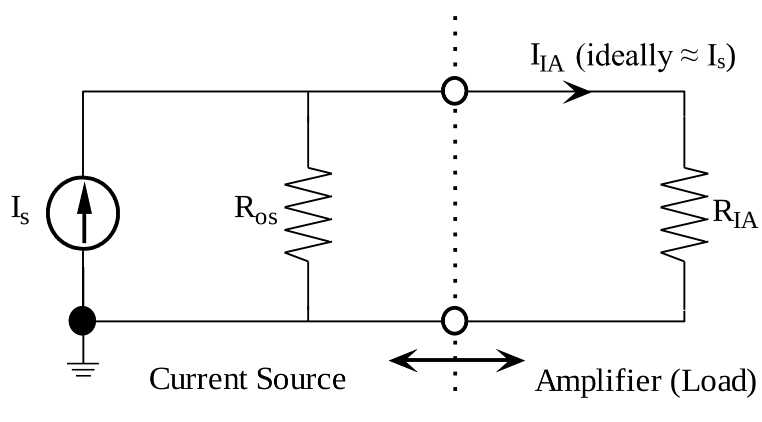


Fig. 2

For a non-ideal source, i.e. for a finite R_{OS} for either a voltage source or a current source, a fraction of the power is dissipated inside the source. If a transfer of *power* is of interest, this fraction should be as small as possible.

Since practical devices have finite values of input and output resistances, ideal conditions of signal transfer are never met. There will always be an error, i.e. a loss of information, or power, however small, whenever a signal is transferred form one stage to another.

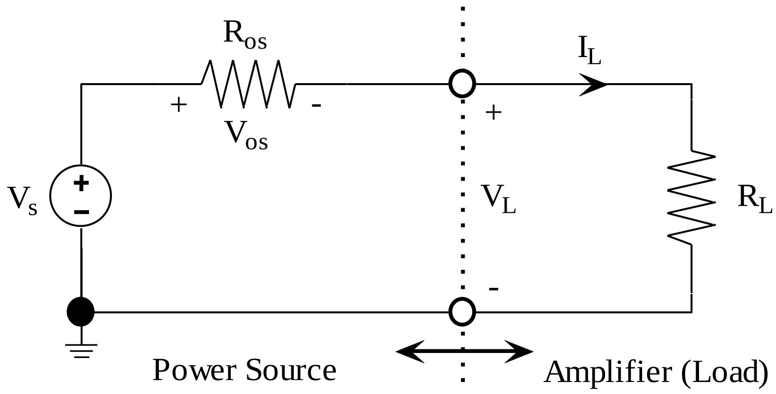


Fig. 3

With reference to Fig. 1, to ensure that the transfer of *voltage* to the load is as high as possible, the load resistance has to be much larger than the source resistance, i.e. $R_{IA} \gg R_{OS}$. Similarly, with reference to Fig. 2, to ensure that the transfer of *current* to the load is as high as possible, the load resistance has to be much smaller than the source resistance, i.e. $R_{IA} \ll R_{OS}$.

A parameter that quantitatively measures an error caused by a loss of signal transfer is referred to as the loading error. With reference to Fig. 1, the absolute loading error for voltage signals, V_{LE}, is defined as:

$$V_{LE} = V_S \frac{R_{OS}}{R_{OS} + R_{IA}} [V]$$

The loading error is often expressed as the relative error, abbreviated as ε[%], it is defined as:

$$\varepsilon[\%] = \frac{V_{LE}}{V_S} \times 100[\%]$$

In the above equations, the absolute loading error, V_{LE}, represents the fraction of the information-carrying voltage V_S, that has been "lost" across the output resistance of the source, R_{OS}. In the ideal case the loading error, V_{LE}, is equal to zero.

Similarly, with reference to Fig, 2, the absolute loading error for current signals, I_{LE}, can be written as:

$$I_{LE} = I_S \frac{R_{IA}}{R_{OS} + R_{IA}} [A]$$

In this case the absolute loading error, I_{LE}, represents the fraction of the information-carrying current I_S, that has been "lost" through the output resistance of the source, R_{OS}. The associated relative error becomes:

$$\varepsilon[\%] = \frac{I_{LE}}{I_S} \times 100[\%]$$

Finally, if maximum *power* transfer is required, then the load resistance should be made equal to the source resistance (i.e., $R_{IA} = R_{OS}$).

(B) THERMISTOR

A thermistor is a device with a temperature-dependent resistance. The transfer characteristic of the thermistor you will use in the design, i.e. the resistance of the thermistor versus the temperature, is described by the expression

$$R = 2200 \times \exp\left(3900\left(\frac{1}{T} - \frac{1}{298}\right)\right) \left[\mathrm{W}\right] \left(\mathrm{T\ in}\left[\mathrm{K}\right]\right),$$

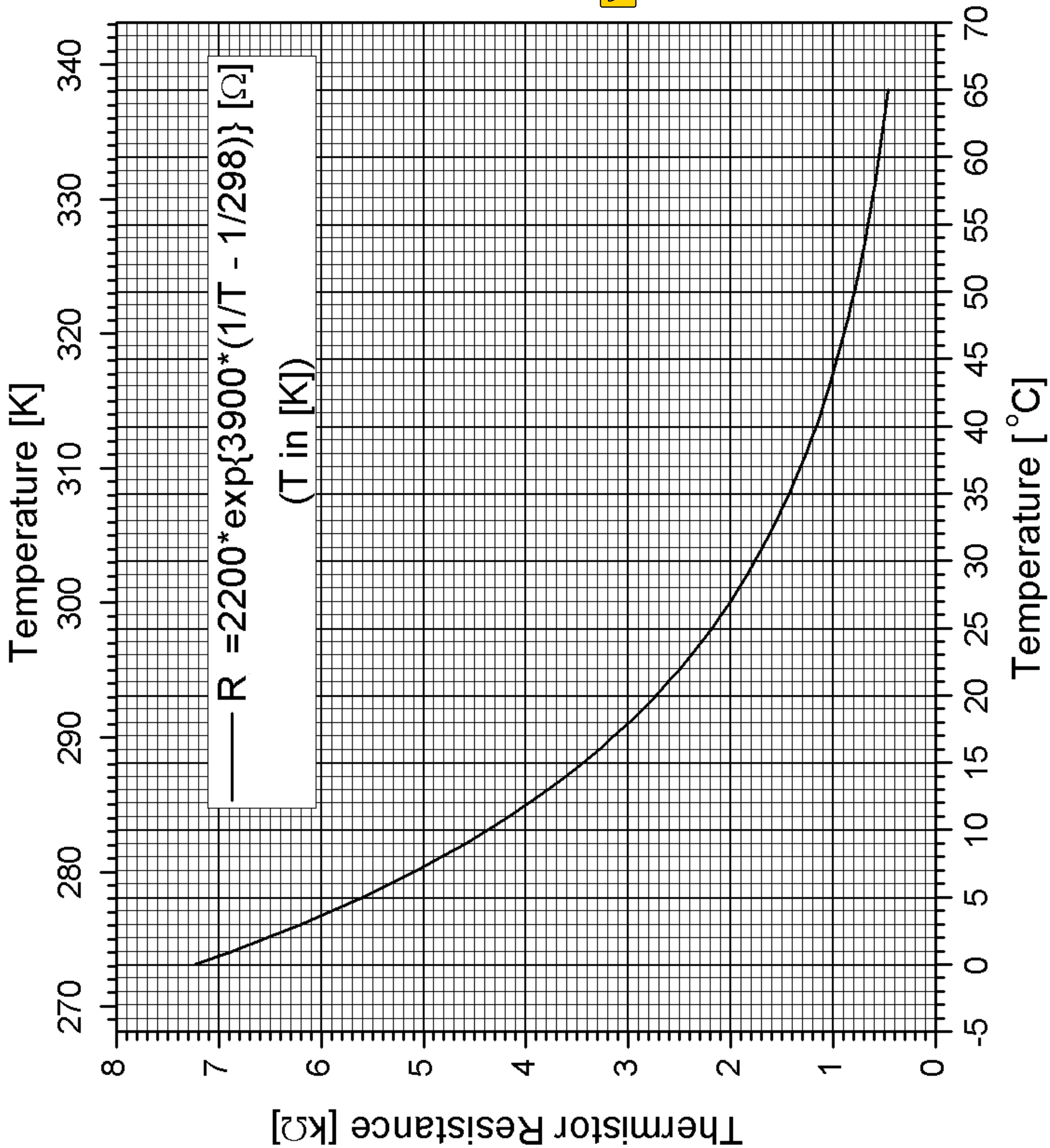
shown in Graph 1 on the next page (0° C = 273.15 K).

Note that the relationship between the resistance and the temperature is nonlinear and that the resistance of the thermistor decreases as the temperature T increases. This relationship will be used to design a temperature sensor.

EQUIPMENT

- DC power supply
- 2 digital multimeters (DMM)
- Protoboard
- Components: 510 Ω, 2.7 kΩ, 5.1 kΩ, 10 kΩ, 12 kΩ (2), 16 kΩ, 22 kΩ, 51 kΩ, 100 kΩ, and150 kΩ resistors
- Thermistor (purple leads)
- 100 Ω resistor for resistive heater (white leads)

Graph 1



Temperature [K]
270
280
290
300
310
320
330
340
R =2200*exp{3900*(1/T - 1/298)} [Ω]
(T in [K])
Thermistor Resistance [kΩ]
0
1
2
3
4
5
6
7
8
Temperature [°C]
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

EXPERIMENT

2.1.1 Thevenin and Norton equivalent Circuits

Preparation:

- When a 10 kΩ resistor is connected across the output terminal of an unknown source the voltage drop across the resistor and the current it draws are measured to be 5.455 V and 0.545 mA, respectively. When the 10 kΩ resistor is replaced by a 15 kΩ resistor, voltage and current change to 6.667 V and 0.444 mA. Find the Thevenin and Norton equivalents of the unknown source.
- Consider the circuit in Fig. 4. Find the Thevenin and Norton equivalents of the source (to the left of terminal A and B) of the circuit. Enter computed values of the equivalent circuit parameters, V_T, R_T, I_N, and R_N to Fig. 5a and Fig. 5b, respectively.
- Calculate the load voltage V_L and the load current I_L for load resistances R_L of 10 kΩ and 22 kΩ.

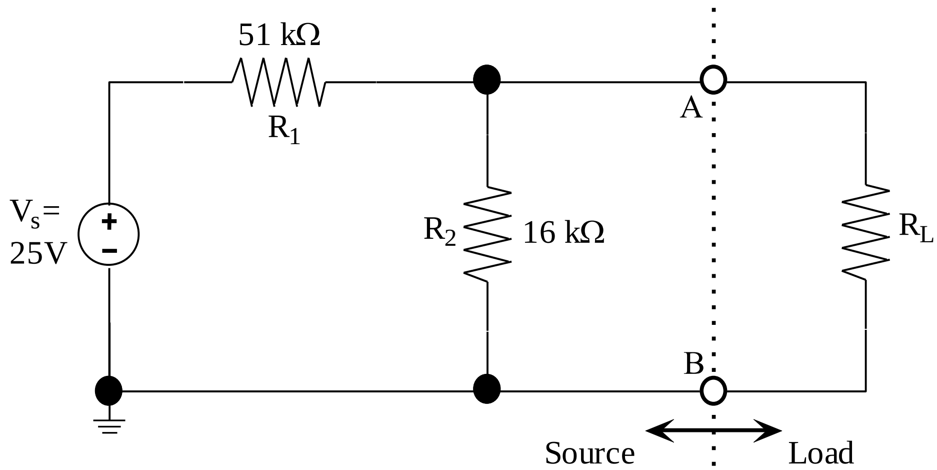


Fig. 4

Experiment:

- Set up the circuit in Fig. 4 on the protoboard and measure the load voltage and current, V_L and I_L for a load R_L=10 kΩ and compare your results with the expected values from your preparation.
- Repeat the previous step for a load resistance R_L=22 kΩ.
- Use your measured results from the previous two steps to determine the Thevenin and Norton equivalent of the source. Compare them with your preparation.
- Confirm by measurement the value of the equivalent resistance R_T of the circuit shown in Fig. 4.
  - ✓ Remove resistor R_L and measure the Thevenin voltage, V_T, and the Norton current, I_N. Use the measured values to calculate the Thevenin (or Norton) resistance R_T. Compare this value for R_T to the one calculated in the preparatory assignment.
  - ✓ Disconnect the resistors from the source, replace the source by a short circuit, and measure R_T using the DMM. Compare this value to the one obtained above.

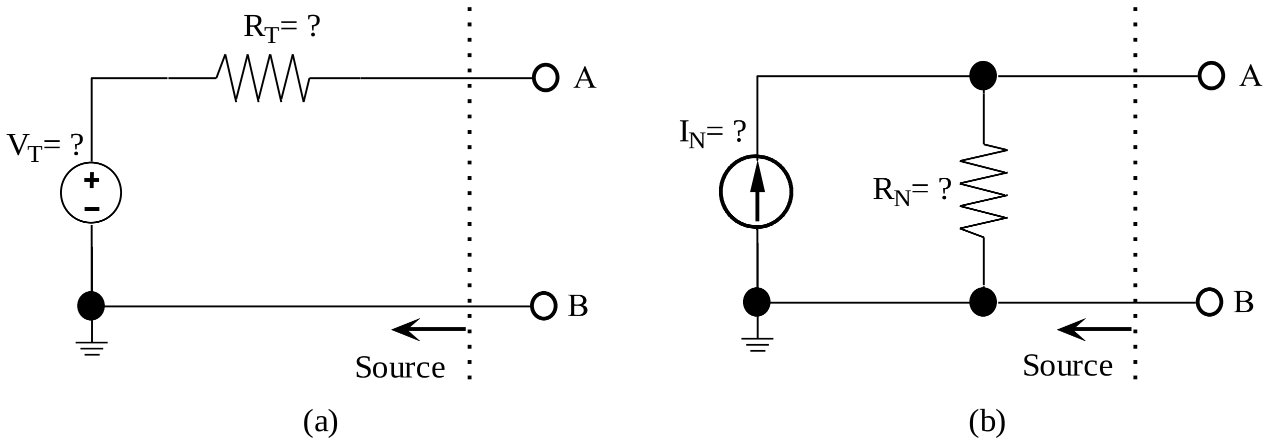


Fig. 5

2.1.2 Signal Transfer

Consider the circuit in Fig. 6 with the source voltage V_T=12 V and internal resistance R_T=12 kΩ.

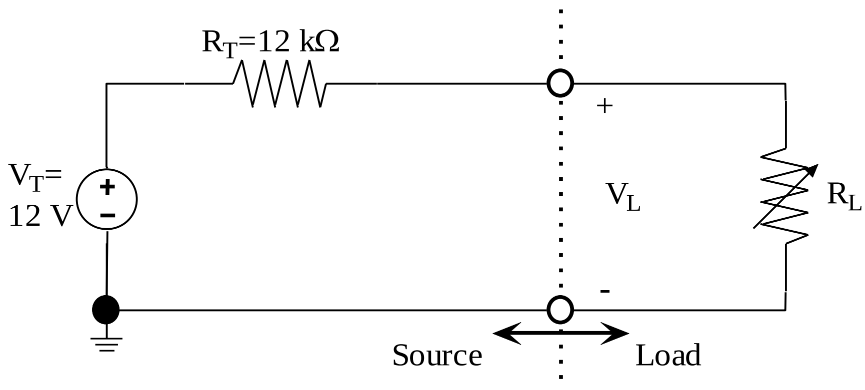


Fig. 6

Preparation

- Apply varying load resistances R_L, as indicated in Table 1, and compute voltages across the loads and associated loading errors. Enter all computed values into Table 1. Plot the output voltage V_L versus the variable load R_L in Graph 2. Note the discontinuity of the R_L scale in the graph.
- Draw the Norton equivalent of the circuit in Fig. 6. Apply load resistances R_L, as indicated in Table 2 and compute the currents into the loads and the associated loading errors. Enter all computed values into Table 2 and plot the load current I_L versus the variable load R_L in Graph 3. Note the discontinuity of the R_L scale in the graph.
- Use the values of V_L and I_L calculated in the previous two steps and compute the power P_L transferred into the varying load resistances. Enter the computed values into Table 3 and plot the power transferred, P_L, versus the variable load R_L, in Graph 4. Note the discontinuity of the R_L scale in the graph.

Experiment

- Confirm by measurement a voltage transferred, a current transferred, and a power transferred for each load value R_L as indicated in Tables 1, 2, and 3, respectively.
  - ✓ Build the circuit as shown in Fig 6 and keep the source voltage V_T constant at 12V and vary the load resistance R_L as indicated in Table 1.
  - ✓ For each value of the load resistance measure the voltage V_L across and the current I_L through the load resistor.
  - ✓ Enter the measured values for V_L and I_L into Tables 1 and 2 respectively.
  - ✓ Compute all remaining parameters so that Table 1 (indicating voltage transfer), Table 2 (indicating current transfer), and Table 3 (indicating power transfer) are completed
- Use the experimental data from Table 1 and add a plot of the measured voltage transferred V_L versus the load resistance R_L to Graph 2. Compare the theoretically expected and the experimentally obtained graphs.
- What has to be a value of the load resistance R_L relative to the source resistance R_T if the voltage loading error is to be lower than 10%?
- Use the experimental data from Table 2 and add a plot of the current into the load, I_L, versus the load resistance, R_L, to Graph 3. Compare the theoretically expected and the experimentally obtained graphs.
- Use the Norton equivalent circuit and find a value of the load resistance R_L relative to the value of the source resistance R_T (R_N), so that the current loading error is lower than 10%.
- Use the experimental data from Table 3 and add a plot of the power transferred into the load P_L versus the load resistance R_L to Graph 4. Compare the theoretically expected and the experimentally obtained graphs.
- What has to be a value of the load resistance R_L relative to a value of the source resistance R_T for maximum power transfer?

Table 1

	Theoretical (Preparation)			Experimental (Measurement)	
	Voltage transferred into R_L.	Voltage lost across R_T.	Loading error in percents	Voltage transferred into R_L	Voltage lost across R_T
R_L [Ω]	V_L [V]	ΔV [V]	ε [%]	V_L [V]	ΔV [V]
510					
2.7k					
5.1k					
12k					
22k					
51k					
150k					

Graph 2

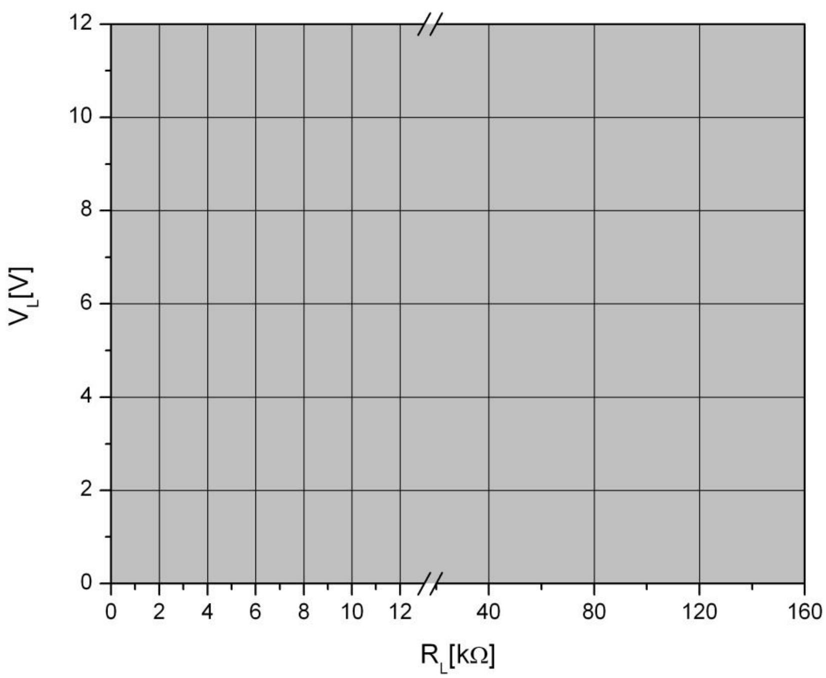
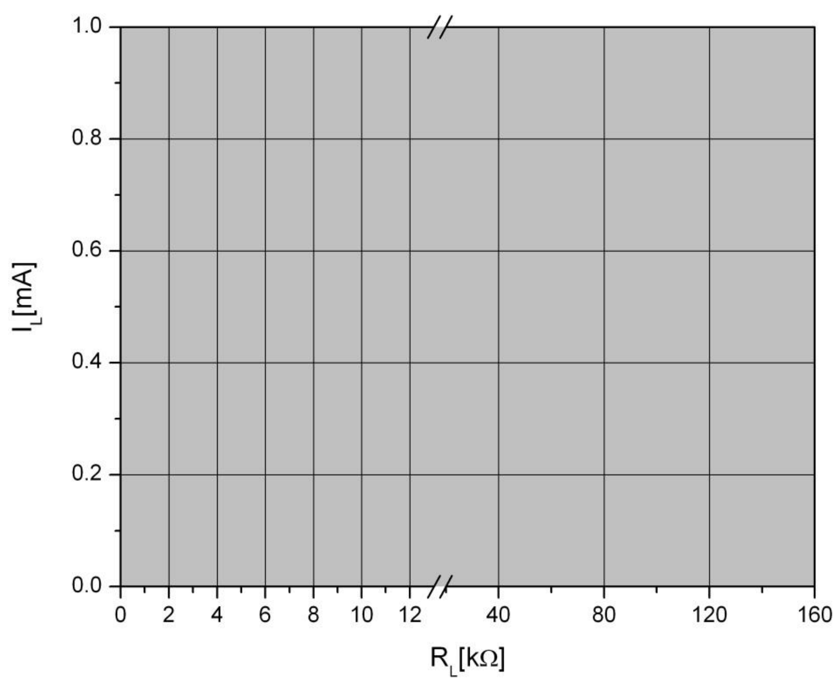


Table 2

	Theoretical (Preparation)			Experimental (Measurement)	
	Current transferred into R_L.	Current lost in R_N	Loading error in percents	Current trough load R_L	Current lost[1] $\Delta I = I_N - I_L$
R_L [Ω]	I_L [mA]	ΔI [mA]	ε [%]	I_L [mA]	ΔI [mA]
510					
2.7k					
5.1k					
12k					
22k					
51k					
150k					

Graph 3

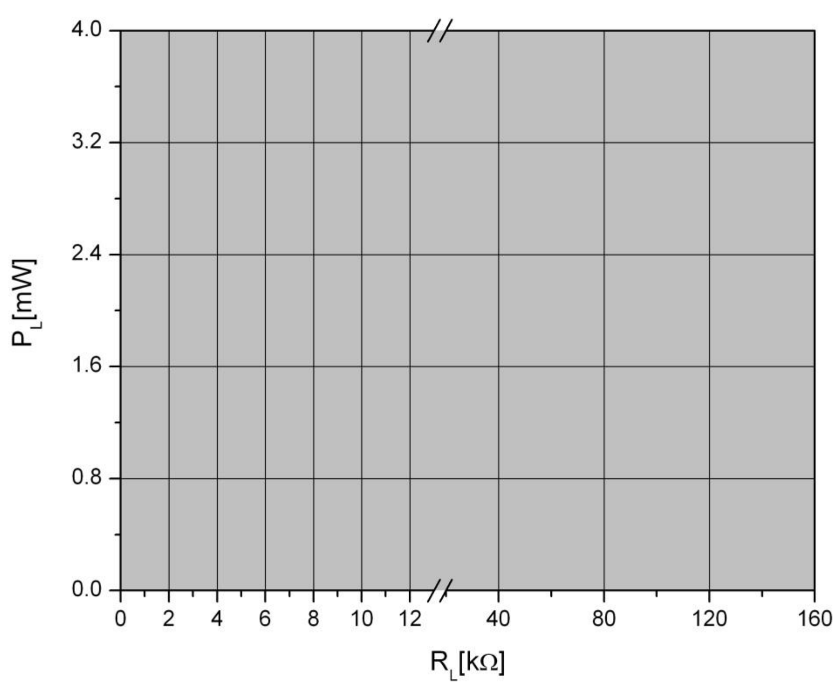


[1] In this context $\Delta I = I_N - I_L$ is the difference between the equivalent Norton current I_N (of the circuit in Fig. 6) and the current I_L into the load.

Table 3

	Theoretical (Preparation)			Experimental (Computed)	
	Power supplied by source $P_T=V_T*I_L$	Power transferred into R_L	Percentage of the source power transferred into R_L	Power supplied by source $P_T=V_T*I_L$	Power transferred into R_L
R_L [Ω]	P_T [mW]	P_L [mW]	P_L/P_T [%]	P_T [mW]	P_L [mW]
510					
2.7k					
5.1k					
12k					
22k					
51k					
150k					

Graph 4



2.2 Temperature Sensor

In this part of the experiment you will design a temperature sensor that measures ambient temperature in the range from 0° to 50°.

The requirement is that the sensor provides an output voltage which varies as a function of the temperature sensed.

Design procedure and implementation:

One possibility to design a temperature sensor is to let a DC constant current flow through the thermistor and measure the output voltage across the thermistor, as indicated in Fig. 7. As the temperature (T in [K]) varies, the thermistor resistance, R_{temp}, varies according to the equation (see Graph 1):

$R_{temp} = 2200 * exp\ (3900\ (1/T-1/298))\ [\Omega]$, with T in [K].

Thus the output voltage, V_{temp}, is a measure of the temperature.

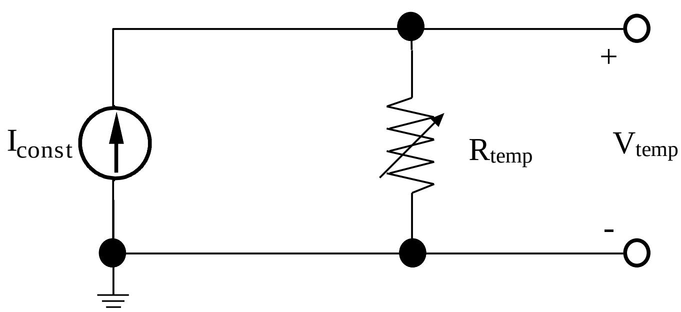


Fig. 7

There is no DC current source readily available in the laboratory. However, a DC current source can be approximated by using a DC voltage source in series with a high-value resistance, R_o, so that $R_o \gg R_{th}$, as indicated in Fig. 8.

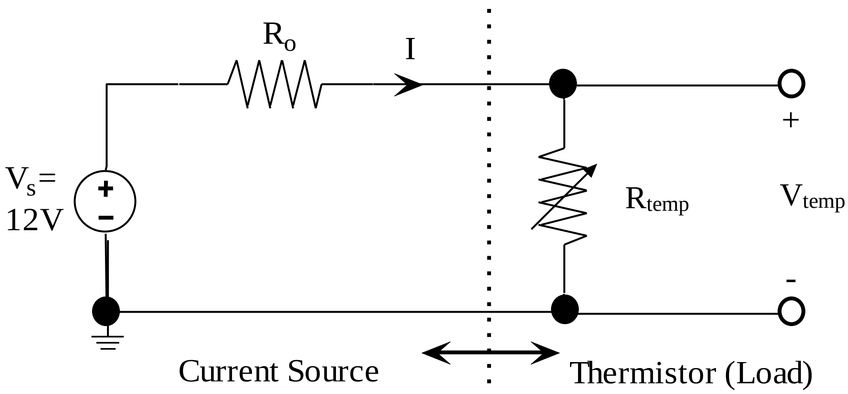


Fig. 8

There are two constraints specified for the temperature sensor.

First, a value of the DC current, I, through the thermistor should not change more than ±5% about its nominal value, I_{nom} (measured at 25°C), over the temperature range (0° to 50° C).

Second, to prevent self-heating of the thermistor (resulting in additional error) the maximum power dissipated in the thermistor must not exceed 0.75 mW over the temperature range specified.

To simplify the design procedure a value of the DC voltage and a recommended nominal value of the current I_{nom} = I_{nom} (25° C) are given: The DC voltage is equal to +12V and I_{nom} (25° C) should be approximately 100μA.

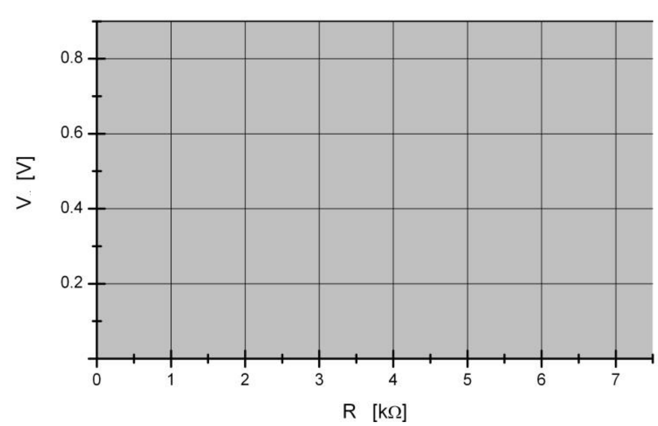
Preparation:

Design the temperature sensor for the range of 0° to 50° C.

- Determine the thermistor resistances for the temperatures given in the table below and enter the R_{temp} values in the table.
- Determine a value of the current-source internal resistance R_o, such that both conditions, i.e. accuracy constraints and maximum power dissipation, as specified above, are satisfied over the entire temperature range of measurement. In your computations consider values of R_{temp} corresponding to the two extreme temperature conditions and initially assume the nominal current to be exactly 100 μA.
- After you have determined an appropriate value for R_o, calculate a corresponding output voltage V_{th} and a corresponding current, I, for each value of R_{temp} specified in the table below. Enter the data into the table and plot V_{temp} versus R_{temp} in Graph 5. Complete the table and use the tabulated data to verify that the accuracy constraints are met. The nominal current is the current computed for 25º C.
- If you measure a thermistor voltage of 0.4 V with the sensor you have designed, what is the corresponding temperature?

As determined	Temp. [° C]	R_{temp} [Ω]	V_{temp} [V]	I [mA]	I-I_{nom} [μA]	(I-I_{nom})/I_{nom} [%]
R_o=	0					
	7					
	14					
I=I_{nom} →	**25**					
	50					

<u>Graph 5</u> Plot of V_{temp} vs. R_{temp}



Experiment:

Test the thermistor-based temperature sensor you have designed by measuring four different temperatures.

- Set up the circuit of the temperature sensor you have designed, for R_o use a combination of some of the available resistors. Use Graph 1, the thermistor resistance R_{temp} versus temperature T, and Graph 5, the output voltage V_{temp} versus resistance R_{temp} to determine:
  - ✓ Ambient temperature in the laboratory.
  - ✓ Temperature of your fingertips.
  - ✓ Temperature in the vicinity of a resistive heater.

  ⚠ **The current in the heater circuit will be 80 mA! Turn off its power source before touching any part of the circuit!**
  - ✓ To make the heater, **set up a separate circuit** by connecting the "heater", which has a resistance of 100 Ω, across a DC power supply set to 8V. Set the METER SELECTION switch on the DC power supply to monitor the current. Adjust the current so that it does not exceed 80 mA or so that the power dissipated in the heater does not exceed 640 mW!
  - ✓ Turn of the 8V DC power source and bring the "heater" to a close proximity of the thermistor (do not touch!),
  - ✓ Turn the 8V power source back on and allow for the voltage reading to stabilize before measuring V_{temp}. How long did it take for the output voltage V_{temp} to stabilize? Explain the phenomenon.
- Enter the measured values of V_{temp} in Table 5. Use the appropriate graphs and determine the associated temperatures. Complete the table.
- What has to be the input resistance of a voltmeter that measures the output voltage V_{temp} to ensure that the loading error (caused by the voltmeter) is smaller than 1% of the reading, over the temperature range?
- Suggest a practical application for the above temperature sensor.

Table 1

Measured Values	Conditions		
	Ambient room temperature	Temperature of your fingertips	Temperature in the vicinity of heater
V_{temp} [V]			
Estimated Temperature [°C]			